Training materials on Copper BLM: Implementation

US Environmental Protection Agency
Office of Science and Technology
Standards and Health Protection Division
1200 Pennsylvania Avenue, N.W. (MC 4305T)
Washington, D.C. 20460

1. Implementation

1.1 What options are available to states and tribes for adopting and implementing the updated national recommended criteria statement?

States and tribes have flexibility in implementing the updated copper criteria. States and tribes can implement the BLM-based criteria as a performance-based approach and may choose either incremental or statewide implementation depending on their needs and resources. For many states and tribes, EPA regards incremental implementation as the most feasible and efficient means of implementing the updated criteria.

For states and tribes choosing to implement the BLM-based criteria using an incremental approach, EPA recommends moving as quickly as possible to adopt the BLM methodology into State or tribal water quality standards (while retaining the hardness criteria) to utilize the latest available science to develop site-specific copper criteria on a targeted basis. This approach should result in more appropriate criteria more quickly for waters where the hardness-based copper criteria may be potentially over-protective, such as waters with high DOC, or potentially under-protective, such as waters with low pH. Under this approach, the hardness-based criterion remains in State (or tribal) water quality standards and applies to all waters except for those where site-specific criteria are derived using the BLM.

States choosing to use the BLM on a targeted basis may consider adding a paragraph to their water quality standards noting that site-specific criteria for copper may be developed on a case-by-case basis using the approach described in EPA's *Aquatic Life Ambient Freshwater Quality Criteria – Copper 2007 Revision* (EPA-822-R-07-001). Or, states may choose to include a footnote indicating that if a site-specific criterion is generated using the BLM, the BLM-derived value becomes the site-specific copper criterion (see 40 CFR §131.36(b)(2) for an example). EPA recommends that states and tribes maintain an updated listing of the water bodies for which the BLM has been used as the basis for a site-specific freshwater copper criterion.

This incremental or targeted approach would provide states and tribes with the flexibility to use the BLM on a limited basis where it will have the most impact. Once developed for particular water segments, BLM-based criteria would provide the basis for permitting and assessment decisions.

In situations where states or tribes choose not to use the BLM, the state (or tribe) may continue to use the WER method as a means of developing site-specific criteria. Done this way, there would be two ways to develop site-specific criteria: 1) using the hardness-based criteria with a WER, and 2) using the BLM on a targeted basis. The permitting authority may consider requiring individual dischargers to collect the monitoring data in order to use the BLM, which EPA expects in most cases would be less expensive to obtain than site-specific toxicology data to develop a WER.

An alternative implementation approach would be where states or tribes choose to adopt the national criteria recommendation (the BLM) as the statewide standard. States and tribes can develop numeric results up front when adopting the revised criteria or later when developing permits or conducting assessments. Under this approach, the BLM-based criteria would replace the hardness-based criteria for copper. This approach allows states and tribes to use the latest available science to apply a copper criterion to each site that would best reflect predicted effects on aquatic life based on the behavior of copper in the receiving stream. States and tribes can incorporate BLM input parameters into their statewide monitoring programs to ensure that data are available to use the BLM. The additional monitoring data may later prove to be useful if and when the BLM is developed and calibrated for other metals, such as zinc and silver.

This statewide implementation option could likely result in increased costs to state monitoring programs, because some of the BLM input parameters (particularly DOC) are not routinely monitored. In addition, selecting this option may obligate the state or tribe to use the BLM, even for waters where the hardness-based criteria may be adequate.

1.2 Have any states or tribes used the BLM to calculate site-specific copper criteria?

Yes. Colorado has used the BLM as an alternative means to develop site-specific WER for several effluent dominated stream segments. The Colorado Water Quality Division developed informal guidance regarding use of the BLM. This informal guidance suggests the following:

- Water quality samples should be taken above and below wastewater treatment facilities. The downstream sample should be taken where the effluent has fully mixed with the receiving water. More than one sampling site is recommended for stream segments longer than five miles.
- Water quality samples should be taken below each National Pollutant Discharge Elimination System (NPDES) permit discharge for stream segments with more than one NPDES permit.
- Water quality data should adequately describe seasonal attributes of a stream.
- At least one year of water quality data is recommended, with a minimum of 24 sampling events.

The suggestions outlined in Colorado’s informal guidance should not be construed as EPA’s recommendations for how to use the BLM; rather, the guidelines are presented here as an illustrative example of how one State has used the BLM.

Additionally, Massachusetts Department of Environmental Protection (MA DEP) evaluated the applicability of the BLM to develop site-specific copper criteria in the Taunton River watershed. Water quality samples were collected at 13 sites (10 in stream locations and three publicly-owned treatment works (POTWs) discharge points) in the watershed; samples were taken in the spring (to capture average to high flow conditions) and the summer (to capture low flow conditions). Samples were taken both upstream and downstream of three POTWs discharging to the Taunton River and its tributaries.

1.3 How does the BLM compare to the WER method in terms of cost?

In general, EPA expects the water chemistry data required by the BLM to be less expensive than WER toxicity testing on a per site basis. States routinely monitor for some of the BLM input parameters; therefore, the need for a state or tribe to initiate monitoring for all 10 input parameters to use the BLM represents a worst-case scenario. States and tribes may choose to work with direct dischargers to collect monitoring data for the BLM. Parameter estimation techniques may also eventually reduce the implementation costs.

It is difficult to do a direct cost comparison of the BLM and WER method because the cost of data collection and analysis will vary depending on the location and site-specific conditions of the site. Currently, dischargers typically pay for WER testing, while the costs of using the BLM may be borne by the discharger or the state (or tribe), depending on how states (and tribes) choose to implement the updated criteria.

Costs associated with implementing the BLM include those for field work (including sample collection containers and technician-hours in the field) and laboratory services (including analytical services and other lab charges, such as sample handling and disposal and reporting forms). EPA estimates that the total cost for one set of 10 input parameters is approximately $325. Depending on the number of data sets collected, BLM-related costs may range from $325 (the cost of an “instantaneous criterion”) to $1300 (the cost of one sampling event per season, for a total of four) or more per site. There could be additional costs that vary depending on the location and complexity of the site, including study design to define the site, statistical evaluation of the sampling scheme, and transportation.

Costs associated with the Streamlined WER method to develop a site-specific criterion include the costs of two (or more) sampling events (with a representative sample of upstream water and effluent taken for each sampling event), side-by-side toxicity tests for laboratory and site water with one test species; and other measurements (including hardness, pH, alkalinity, total suspended solids (TSS), and DOC for both the site water and the laboratory water). EPA estimates the cost of the Streamlined WER method (two samples and one test species) to be approximately $10,000.

Costs associated with the 1994 Interim WER method (the “non-streamlined” method) are likely to be higher, given that the Interim WER method recommends three sampling events for one species, and one sampling event with a second species (for a total of four WER tests). EPA estimates the cost of using the1994 Interim WER method at a relatively simple site to be on the order of $20,000. Some more complex applications of the WER method have costs over $100,000.

1.4 Will existing site-specific freshwater copper criteria derived using the WER method need to be revised using the BLM?

A state or tribe may choose to retain the WER-adjusted hardness criterion or use the BLM on a targeted basis to develop site-specific criteria. EPA developed different BLM implementation options for states and tribes to consider (see Question 1.1).

1.5 If the BLM results in a different criterion than a state currently has, will a use attainability analysis (UAA) be needed to change a use?

A UAA would not be required if application of the BLM for copper resulted in different criteria, assuming that the state or tribe would not be revising the underlying designated use. In that circumstance, a UAA would not be necessary regardless of whether application of the BLM results in a more or less stringent copper criterion. On the other hand, if the designated use would be revised to a different aquatic life use subcategory, and a less stringent criterion for copper (or any other parameter) would also be adopted, a UAA would need to be prepared pursuant to 40 CFR 131.10(j)(2).

National Recommended Water Quality Criteria - Organoleptic Effects

Related Information

- Human Health Criteria Table
- Aquatic Life Criteria Table

EPA's compilation of national recommended water quality criteria is presented as a summary table containing recommended water quality criteria for the protection of aquatic life and human health in surface water for approximately 150 pollutants. These criteria are published pursuant to Section 304(a) of the Clean Water Act (CWA) and provide guidance for states and tribes to use to establish water quality standards and ultimately provide a basis for controlling discharges or releases of pollutants.

Organoleptic Effects (e.g., taste and odor)

Pollutant	CAS Number	Organoleptic Effect Criteria (µg/L)
Acenaphthene	83329	20
Color	—	NP
Iron	7439896	300
Monochlorobenzene	108907	20
Tainting Substance	—	NP
3-Chlorophenol	—	0.1

Pollutant	**CAS Number**	**Organoleptic Effect Criteria (µg/L)**
4-Chlorophenol	106489	0.1
2,3-Dichlorophenol	—	0.04
2,5-Dichlorophenol	—	0.5
2,6-Dichlorophenol	—	0.2
3,4-Dichlorophenol	—	0.3
2,4,5-Trichlorophenol	95954	1
2,4,6-Trichlorophenol	88062	2
2,3,4,6-Tetrachlorophenol	—	1
2-Methyl-4-Chlorophenol	—	1800
3-Methyl-4-Chlorophenol	59507	3000
3-Methyl-6-Chlorophenol	—	20
2-Chlorophenol	95578	0.1
Copper	7440508	1000
2,4-Dichlorophenol	120832	0.3
2,4-Dimethylphenol	105679	400
Hexachlorocyclopentadiene	77474	1
Manganese	7439965	
Nitrobenzene	98953	30
Pentachlorophenol	87865	30

Pollutant	**CAS Number**	**Organoleptic Effect Criteria (µg/L)**
Phenol	108952	300
Zinc	7440666	5000

These criteria are based on organoleptic (taste and odor) effects. Because of variations in chemical nomenclature systems, this listing of pollutants does not duplicate the listing in Appendix A of 40 CFR Part 423 (PDF) (9 pp, 222 K, About PDF)

Source: Quality Criteria for Water, 1986 ("Gold Book")

LAST UPDATED ON JANUARY 9, 2020

From: Roybal, Jonathan, SRCA
To: Fullam, Jennifer, NMENV
Subject: RE: 20.6.4 NMAC formatting question
Date: Monday, July 27, 2020 9:32:11 AM
Attachments: image001.png

A dash and colon essentially are used for the same function, so having a dash after a colon is redundant. The correct way would be the colon followed by 2 spaces just like your example on 2.6.4.206.

Fom: Fullam, Jennifer, NMENV <Jennifer.Fullam@state.nm.us>
Sent: Monday, July 27, 2020 8:23 AM
To: Roybal, Jonathan, SRCA <Jonathan.Roybal@state.nm.us>
Subject: 20.6.4 NMAC formatting question

Good morning Jonathan,

I have a quick formatting question (hope it is quick).
We noticed that some sections under our water quality standards (20.6.4 NMAC) have a dash following the colon but some sections do not (example highlighted below).
Do you know the reasoning for these dashes?
Which format is correct, and should we correct those that do not follow this format (whichever one is correct).

Thanks.

20.6.4.205 PECOS RIVER BASIN: - Brantley reservoir.

A. Designated uses: irrigation storage, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.205 NMAC - Rp 20 NMAC 6.1.2205, 10/12/2000; A, 5/23/2005; A, 12/1/2010]

20.6.4.206 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its tributaries downstream of Bonney canyon and perennial reaches of the Rio Felix.

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

Jennifer Fullam
Standards, Planning & Reporting Team Leader
Surface Water Quality Bureau
New Mexico Environment Department
1190 S. St. Francis Dr.
Santa Fe, NM 87505
Phone: 505.827.2637
jennifer.fullam@state.nm.us

"Innovation, Science, Collaboration, Compliance"

From: Roybal, Jonathan, SRCA
To: Fullam, Jennifer, NMENV
Subject: RE: Question on amendment notation
Date: Tuesday, February 2, 2021 2:44:15 PM
Attachments: image001.png

Hi Jennifer,

The specific change highlighted in the provided Sections does not require an amendment nor the history notes to reflect the change. This is simply style and format and has no substantive change, so what we can do is add a line to your amendment that states the change throughout the rule (i.e., "Minor corrections for style and format to remove dash were made throughout the entire rule.").

From: Fullam, Jennifer, NMENV <Jennifer.Fullam@state.nm.us>
Sent: Tuesday, February 2, 2021 1:46 PM
To: Roybal, Jonathan, SRCA <Jonathan.Roybal@state.nm.us>
Subject: Question on amendment notation

Good afternoon Jonathan,

As you know we are working on our Triennial Review of *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC). There are a few sections that are proposed to only have grammatical amendments (removal of a "-"). Would this type of change require a notation at the end of the section with the date of the amendment?

Below is an example of one of the proposed amendments we are considering:

20.6.4.107 RIO GRANDE BASIN: [-] The Jemez river from the Jemez pueblo boundary upstream to Soda dam near the town of Jemez Springs and perennial reaches of Vallecito creek.

A. Designated uses: *coldwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat; and public water supply on Vallecito creek.*

B. Criteria: *The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F).*

[20.6.4.107 NMAC - Rp 20 NMAC 6.1.2105.5, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, XX/XX/XXXX]

Clarification from Records on how this needs to be documented would be great.

Thanks.

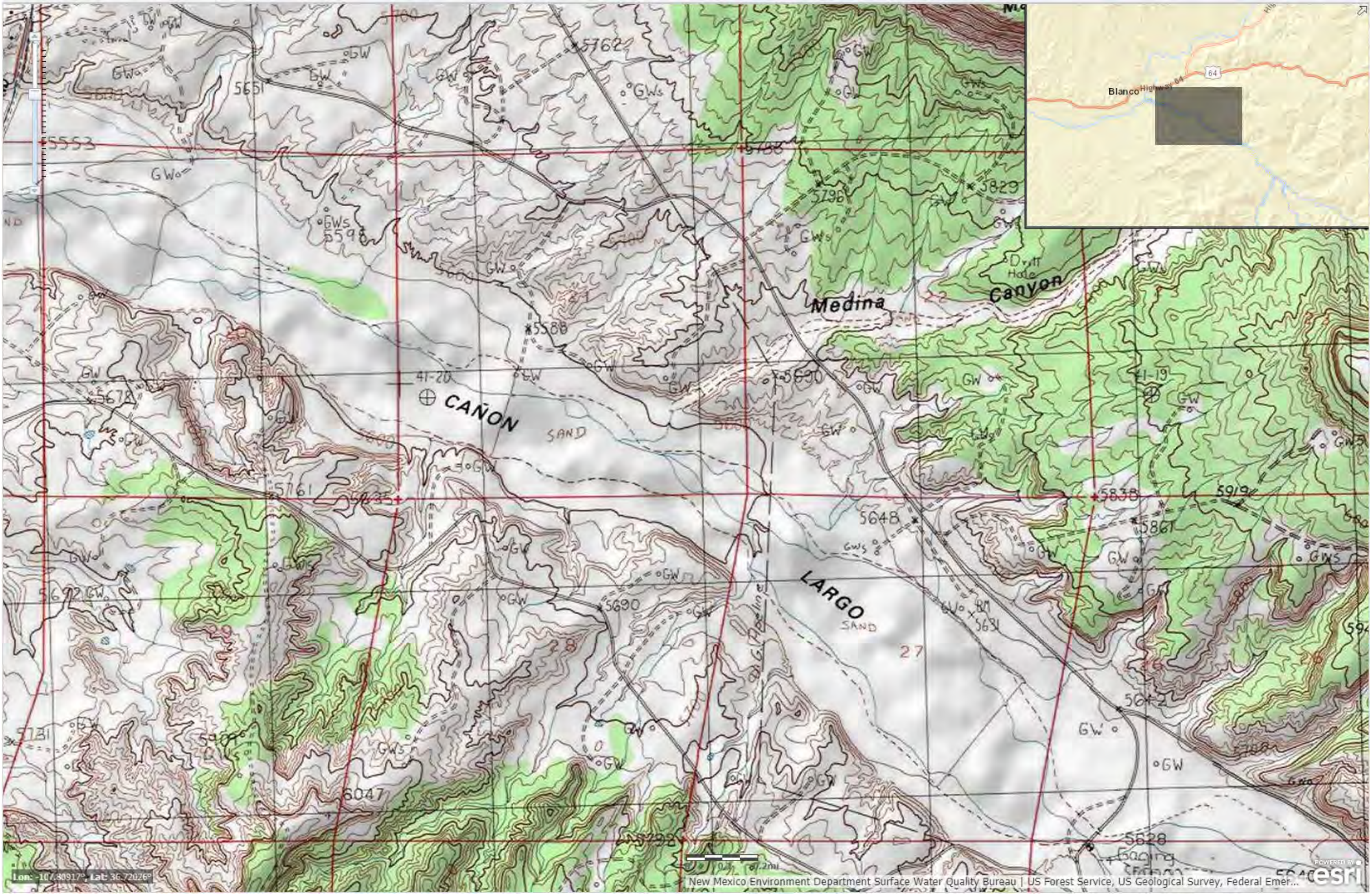
Jennifer Fullam
Standards, Planning & Reporting Team Leader
Surface Water Quality Bureau
New Mexico Environment Department
1190 S. St. Francis Dr.

Santa Fe, NM 87505
*Phone: 505.946.8954
jennifer.fullam@state.nm.us

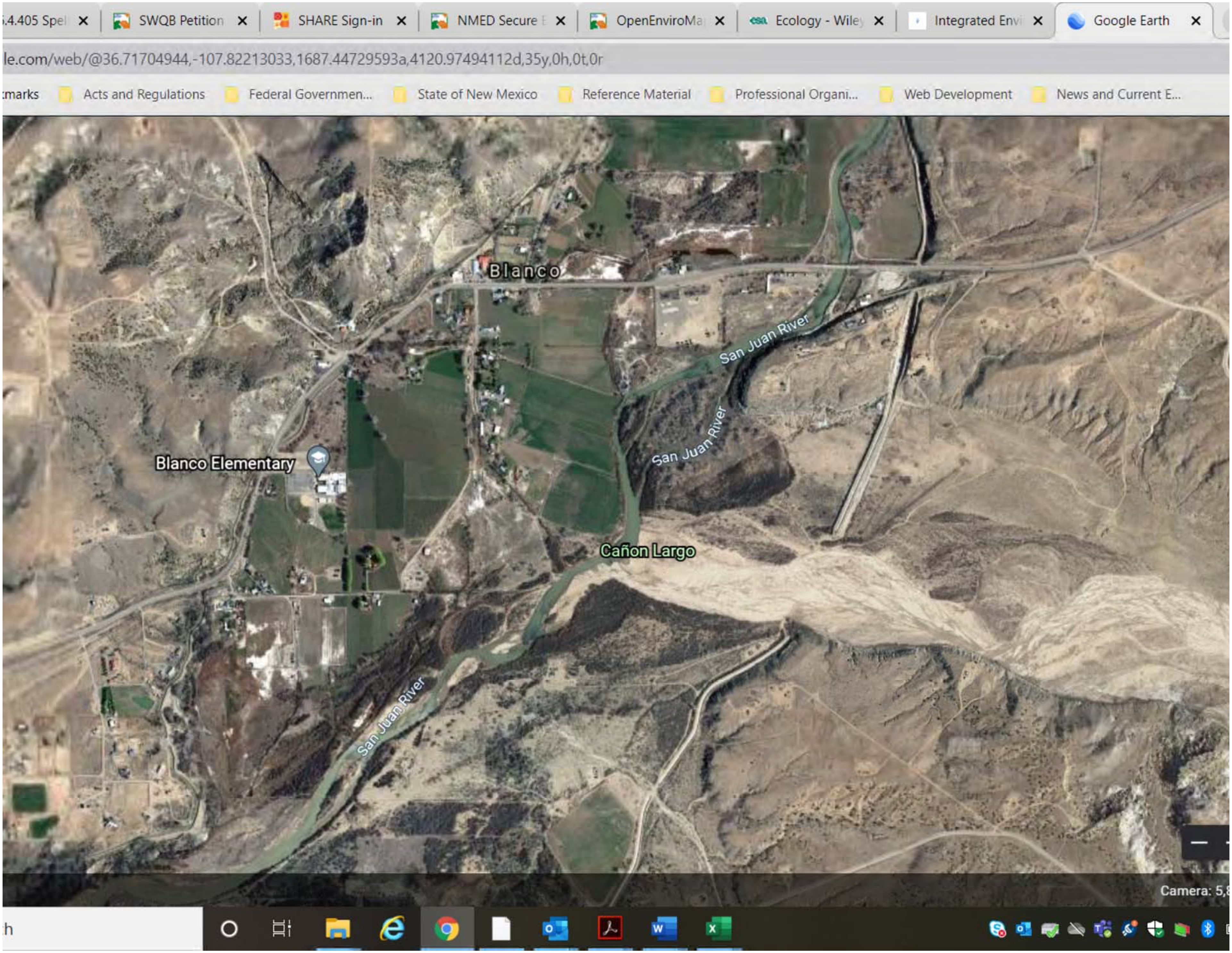
****PLEASE NOTE NEW PHONE NUMBER***

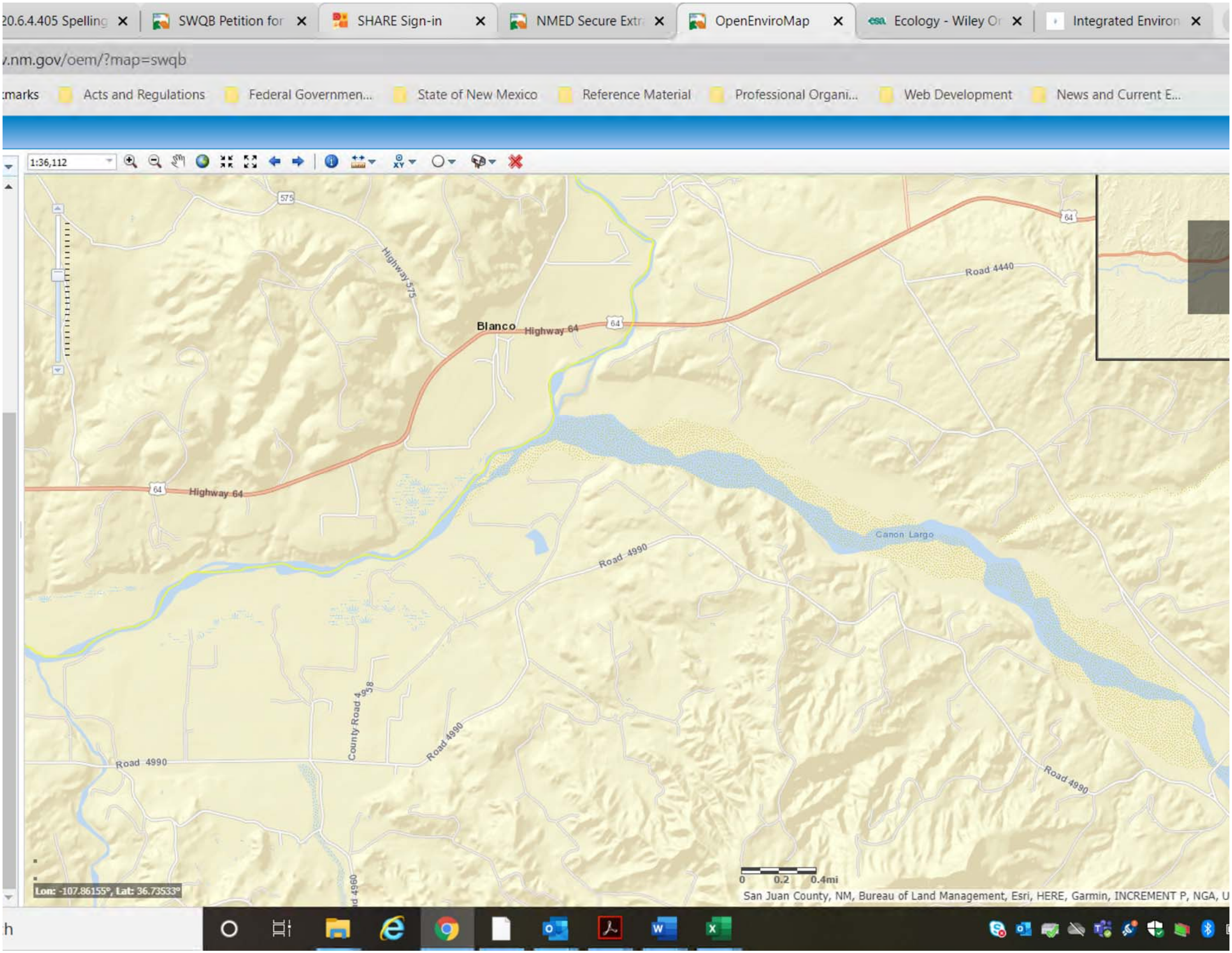
"Innovation, Science, Collaboration, Compliance"

NMED's Map Canon Largo 2021



New Mexico Environment Department Surface Water Quality Bureau | US Forest Service, US Geological Survey, Federal Emer...


.4.405 Spel
SWQB Petition
SHARE Sign-in
NMED Secure
OpenEnviroMa
Ecology - Wiley
Integrated Envi
Google Earth
le.com/web/@36.71704944,-107.82213033,1687.44729593a,4120.97494112d,35y,0h,0t,0r
marks
Acts and Regulations
Federal Governmen...
State of New Mexico
Reference Material
Professional Organi...
Web Development
News and Current E...
Blanco
San Juan River
San Juan River
San Juan River
Blanco Elementary
Cañon Largo
San Juan River
Camera: 5,



20.6.4.405 Spelling
SWQB Petition for
SHARE Sign-in
NMED Secure Extr
OpenEnviroMap
Ecology - Wiley Or
Integrated Environ
.nm.gov/oem/?map=swqb
marks
Acts and Regulations
Federal Governmen...
State of New Mexico
Reference Material
Professional Organi...
Web Development
News and Current E...
1:36,112
575
Highway 575
Blanco
Highway 64
64
Road 4440
Highway 64
Canon Largo
Road 4990
County Road 4958
Road 4990
Road 4990
Road 4990
4960
0 0.2 0.4mi
Lon: -107.86155°, Lat: 36.73533°
San Juan County, NM, Bureau of Land Management, Esri, HERE, Garmin, INCREMENT P, NGA, U

NMED
New
Mexico
Environment
Department

Existing Use Analysis of Recreational Uses for Classified Waters 20.6.4.101-20.6.4.899 NMAC

Prepared by:
Surface Water Quality Bureau

May 3, 2021

This Page Intentionally Left Blank

Table of Contents

I. Introduction

The objective of the Clean Water Act ("CWA") is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. One of the goals established under the CWA to achieve this objective, is to ensure, wherever attainable water quality provides for the protection and propagation of fish, shellfish and wildlife (aquatic life) and provides for the ability to recreate in and on the water. The CWA implements the measures necessary to achieve this goal through 40 Code of Federal Regulations ("C.F.R."), which, in part, requires states to uphold these goals through the adoption of surface Water Quality Standards ("WQS"). In accordance with 40 C.F.R. § 131.6, these WQS contain, at a minimum, the designated uses for waterbodies, the surface water quality criteria to protect those uses, and an antidegradation policy to ensure the water quality is maintained. The State of New Mexico has codified its WQS under *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC) but recognizes that water quality protection is ongoing and protections for waters may change over time. The most common type of amendments to water quality protections are those associated with the established designated uses.

There are three general conditions to which a designated use may be amended:

1. In accordance with 40 C.F.R. § 131.10(g) and 20.6.4.15 NMAC, if a designated use, that is not an existing use, is not attainable due to one of the six factors identified under 40 C.F.R. 131.10(g) it may be removed through a Use Attainability Analysis ("UAA"). The UAA must be conducted to demonstrate that the proposed designated use is not less stringent than the existing use, determine the factor preventing the attainment of the current use, and provide evidence supporting the highest attainable use; or
2. In accordance with 40 C.F.R. § 131.10(i), the state reviews and revises applicable WQS to reflect the uses actually attained should those be more stringent than the current designated uses; or
3. In accordance with 40 C.F.R. § 131.20, the state reviews applicable WQS to which there is new (not considered before) information that has become available. If such new information indicates that more stringent uses specified in Section 101(a)(2) of the [Clean Water] Act are attainable, the state revises its standards accordingly during the Triennial Review.

As discussed in this Existing Use Analysis ("EUA"), there is reasonable evidence that existing uses may be more stringent than the current designated use. Therefore, in accordance with 40 C.F.R. § 131.10(i) and 40 C.F.R. § 131.20, this EUA will assess the appropriate recreational uses for classified waters in 20.6.4.101-20.6.4.899 NMAC that have a designated recreational secondary contact use to determine if the recreational primary contact use is attainable.

This EUA includes the following sections: the State's regulatory authority and procedures to amend a WQS, the waters and designated uses being evaluated under this analysis, an evaluation of how the State's antidegradation policy relates to designated use amendments, an evaluation of threatened and endangered species that may be impacted by amending the designated use, general site conditions, data that were used to establish existing (and attainable) uses, and whether a more stringent designated use specified in Section 101(a)(2) of the CWA is attainable.

Throughout the document some of the referenced regulatory citations have been provided in boxed text to aid with referencing.

II. Regulatory Authority and Framework

A. Authority

The goals and objectives of the CWA, as established in Section 101(a), are to restore and maintain the chemical, physical and biological integrity of the Nations waters; and wherever attainable, to protect for the propagation of fish, shellfish and wildlife, and provide for recreation in and on the water. The CWA requires states to adopt WQS under 40 C.F.R. § 131.4 to achieve these goals and objectives.

> ***CWA § 101(a)***
>
> *The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. In order to achieve this objective, it is hereby declared that, consistent with the provisions of this Act—*
>
> *(2) it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983;*

> **40 C.F.R. § 131.4**
>
> ***(a)*** *States (as defined in § 131.3) are responsible for reviewing, establishing, and revising water quality standards. As recognized by section 510 of the Clean Water Act, States may develop water quality standards more stringent than required by this regulation. Consistent with section 101(g) and 518(a) of the Clean Water Act, water quality standards shall not be construed to supersede or abrogate rights to quantities of water.*

The basic authority for water quality management in New Mexico is provided through the Water Quality Act (NMSA 1978, §§ 74-6-1 to 74-6-17). This law establishes the Water Quality Control Commission ("WQCC") and specifies its duties and powers. The WQCC is the State's water pollution control agency for all purposes of the federal Clean Water Act (NMSA 1978, § 74-6-3(E)). Under Section 74-6-4(D), the Water Quality Act requires the WQCC to adopt WQS based on credible scientific data and reliable evidence. New Mexico's *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC) establish surface WQS that consist of designated uses for surface waters of the State, the water quality criteria necessary to protect the designated uses, and an antidegradation policy.

> ***74-6-4 NMSA 1978 Duties and powers of commission.***
>
> *The commission:*
>
> *D. shall adopt water quality standards for surface and ground waters of the state based on credible scientific data and other evidence appropriate under the Water Quality Act. The standards shall include narrative standards and, as appropriate, the designated uses of the waters and the water quality criteria necessary to protect such uses. The standards shall at a minimum protect the public health or welfare, enhance the quality of water and serve the purposes of the Water Quality Act. In making standards, the commission shall give weight it deems appropriate to all facts and circumstances, including the use and value of the water for water supplies, propagation of fish and wildlife, recreational purposes and agricultural, industrial and other purposes;*

The WQCC has the authority to delegate responsibility for administering its regulations to constituent agencies to assure adequate coverage and prevent duplication of effort (NMSA 1978, § 74-6-3(F)). As such, the New Mexico Environment Department ("NMED") is the primary constituent agency responsible for administering and enforcing all programs implemented by the state under the CWA. The WQCC must approve and adopt amendments to the State's WQS prior to NMED filing the amendments with State Records and Archives. Amendments become effective for State purposes under the Water Quality Act thirty days after filing with State Records (NMSA 1978, § 74-6-6(E)) or after publication in the New Mexico Register (NMSA 1978, § 14-4-5)), whichever comes later. In accordance with 40 C.F.R. 131.20, within thirty days of the final state action to adopt and certify the revised WQS, the State must submit the amendments and any supporting documentation to the U.S. Environmental Protection Agency ("EPA") for review and approval under the CWA.

> ***40 C.F.R. § 131.20*** *State review and revision of water quality standards.*
> ***(c) Submittal to EPA.*** *The State shall submit the results of the review, any supporting analysis for the use attainability analysis, the methodologies used for site-specific criteria development, any general policies applicable to water quality standards and any revisions of the standards to the Regional Administrator for review and approval, within 30 days of the final State action to adopt and certify the revised standard, or if no revisions are made as a result of the review, within 30 days of the completion of the review.*

B. Background for an Existing Use Analysis

Water quality standards must contain three key elements that are intricate to their regulatory function. These include establishing designated uses, criteria to protect for those uses and an antidegradation policy. These requirements uphold the objective of the CWA (Section 101 of the CWA) to "restore and maintain the chemical, physical and biological integrity of the Nation's waters."

> ***40 C.F.R. § 131.3 Definitions***
> ***(b) Criteria*** *are elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use.*
>
> ***(f) Designated uses*** *are those uses specified in water quality standards for each water body or segment whether or not they are being attained.*
>
> ***40 C.F.R. § 131.12 Antidegradation policy and implementation methods.***
> ***(a)*** *The State shall develop and adopt a statewide antidegradation policy…*

According to 40 C.F.R. § 131.3(e), the definition of existing uses "are those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards." A designated use may not be less stringent than an existing use.

> ***40 C.F.R. § 131.3 Definitions***
> ***(e) Existing uses*** *are those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards.*

> ***40 C.F.R. § 131.10 Designation of uses.***
> ***(i)*** *Where existing water quality standards specify designated uses less than those which are presently being attained, the State shall revise its standards to reflect the uses actually being attained.*

40 C.F.R. § 131.20 State review and revision of water quality standards.
(a) **State review.** *The* State *shall from time to time, but at least once every 3 years, hold public hearings for the purpose of reviewing applicable* water quality standards*... The* State *shall also re-examine any waterbody segment with* water quality standards *that do not include the uses specified in section 101(a)(2) of* the Act *every 3 years to determine if any new information has become available. If such new information indicates that the uses specified in section 101(a)(2) of* the Act *are attainable, the* State *shall revise its standards accordingly…*

If the designated use has criteria less stringent than the existing use, the State must amend the WQS to reflect the use actually attained. Unlike the requirements for removing or lowering a designated use under 40 C.F.R. § 131.10(g), a Use Attainability Analysis ("UAA") is not required for revising standards to reflect an existing use that is also the highest attainable use. However, in the State of New Mexico designated uses are codified under rule (20.6.4 NMAC) and the State must undertake a rulemaking process to amend the WQS. NMED must provide supporting evidence that demonstrates compliance with regulatory elements to petition the WQCC and provide EPA the reasoning to establish a more stringent designated use. An EUA standardizes the elements necessary for a WQS designated use amendment. Although neither federal nor State law or rule define the term "EUA", 40 C.F.R. § 131.10(i) and 20.6.4.10(B) NMAC establish the requirement to amend uses to be at least as stringent as existing uses.

40 C.F.R. ***§ 131.10 Designation of uses***
(g) *States may designate a use, or remove a use that is not an existing use, if the State conducts a use attainability analysis as specified in paragraph (j) of this section that demonstrates attaining the use is not feasible because of one of the six factors in this paragraph. If a State adopts a new or revised water quality standard based on a required use attainability analysis, the State shall also adopt the highest attainable use, as defined in § 131.3(m).*

40 C.F.R. § 131.3 Definitions
(m) *Highest attainable use is the modified aquatic life, wildlife, or recreation use that is both closest to the uses specified in section 101(a)(2) of the Act and attainable, based on the evaluation of the factor(s) in 40 C.F.R. § 131.10(g) that preclude(s) attainment of the use and any other information or analyses that were used to evaluate attainability. There is no required highest attainable use where the State demonstrates the relevant use specified in section 101(a)(2) of the Act and sub-categories of such a use are not attainable.*

Therefore, this analysis intends to provide the supporting evidence needed to determine if a designated use change is warranted based on existing uses.

III. Analysis Framework

A. Reasoning for Analysis

There are two subcategories for designated recreational uses in 20.6.4 NMAC: primary contact and secondary contact as defined under 20.6.4.7(P)(5) NMAC and 20.6.4.7(S)(1) NMAC, respectively. The numeric criteria for primary and secondary contact recreational uses are established in 20.6.4.900(D) NMAC and 20.6.4.900(E) NMAC, respectively. Both primary and secondary contact have criteria for *Escherichia coli* (*E. coli*) and, in addition, primary contact has a numeric pH criterion. *E. coli,* expressed in colony forming units ("cfu") or most probable number ("MPN") per 100 milliliters ("mL"), is used as an indicator for measuring levels of fecal contamination in surface waters, which has been demonstrated to pose serious health risks to humans, if ingested (USEPA 2012).

20.6.4.7 NMAC. Definitions
(P)(5) "Primary contact" *means any recreational or other water use in which there is prolonged and intimate human contact with the water, such as swimming and water skiing, involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard. Primary contact also means any use of surface waters of the state for cultural, religious or ceremonial purposes in which there is intimate human contact with the water, including but not limited to ingestion or immersion, that could pose a significant health hazard.*

20.6.4.7 NMAC. Definitions
(S)(1) "Secondary contact" *means any recreational or other water use in which human contact with the water may occur and in which the probability of ingesting appreciable quantities of water is minimal, such as fishing, wading, commercial and recreational boating and any limited seasonal contact.*

20.6.4.900 NMAC
D. Primary contact: *The monthly geometric mean of E. coli bacteria of 126 cfu/100 mL or MPN/100 ml and single sample of 410 cfu/100 mL or MPN/100 mL and pH within the range of 6.6 to 9.0 apply to this use. The results for E. coli may be reported as either colony forming units (CFU) or the most probable number (MPN) depending on the analytical method used.*
E. Secondary contact: *The monthly geometric mean of E. coli bacteria of 548 cfu/100 mL or MPN/100 mL and single sample of 2507 cfu/100 mL or MPN/100 mL apply to this use. The results for E. coli may be reported as either colony forming units (CFU) or the most probable number (MPN), depending on the analytical method used.*

There are several classified waterbodies in 20.6.4.101-20.6.4.899 NMAC that have a designated secondary contact recreational use and there is empirical evidence that the existing recreational use for these waters is more stringent than the designated use.

A previous petition to amend these designated uses was filed on June 25, 2014 by the Surface Water Quality Bureau ("SWQB") during the last triennial review of WQS, docket number WQCC 14-05(R). As part of that petition, SWQB proposed that the secondary contact designated uses in 20.6.4 NMAC Sections 103, 116, 124, 204, 206, 207, 213, 219, and 308 be changed to primary contact designated uses reasoning that the primary contact was likely attainable (WQCC 2014).

On December 12, 2014, a notice of intent to present technical testimony was filed by the San Juan Water Commission ("SJWC"). In this filing, SJWC provided direct technical testimony stating:

> "…NMED does not offer any data, documentation, or evidence that primary contact *is* occurring and *is* attainable. NMED's artfully crafted language is an attempt to create yet another rebuttable presumption-a presumption that primary contact is an attainable use-and avoid the obligation to provide actual data and other evidence supporting the designated use upgrade. NMED is merely 'presuming' that primary contact is an attainable use, and the same 'Basis for Change' language is used for the following eight stream segments: 20.6.4.116, 20.6.4.124, 20.6.4.204 20.6.4.206, 20.6.4.207, 20.6.4.213, 20.6.4.219, and 20.6.4.308 NMAC. No information specific to each individual stream segment is provided…NMED presents no 'new information' supporting its

> proposal, despite its recognition in its Basis for Change that standards should be revised based on 'new information.'
> ... The WQCC should not adopt more stringent water quality standards absent information and data proving a use is attainable. SJWC therefore recommends that the WQCC not adopt NMED's proposed revisions for upgrading recreational use on the aforementioned nine waterbody segments."(WQCC, 2014(b))."

During the hearing in October 2015, the Commission heard oral testimony on the matter, to which NMED presented field observations, website reviews and expert testimony as evidence to support primary contact recreation was occurring.

On April 16, 2016, the San Juan Water Commission ("SJWC") submitted a letter to the WQCC on its exceptions to the Hearing Officer's proposed statement of reasons and final order. SJWC gave the following statement:

> "…opposing NMED's proposal to upgrade the recreational designated use for nine water body segments from secondary contact to primary contact on the ground NMED has failed to provide sufficient credible scientific or other evidence to meet the regulatory requirements for upgrading the designated use…" (WQCC 2016)."

On January 10, 2017, the WQCC provided its final order towards the petition to amend designated secondary contact use to primary contact which stated:

> "The upgrade from secondary contact to primary contact suggested by the Department in Sections 20.6.4.103, .116, .124, .204, .206, .207, .213, .219, and .308 is rejected by the Commission. The Commission instead accepts the reasoning proposed by the San Juan Water Commission to maintain secondary contact for the nine enumerated segments." (WQCC 2017)."

Given the historical context of the proposed amendment, it is the intent of this EUA to provide a more comprehensive analysis and documentation that demonstrates the appropriate designated use.

B. Waterbodies Evaluated

NMED evaluated the nine classified standards segments under 20.6.4 NMAC with secondary contact designated uses (noted above) to determine if there was enough information and data to move forward with review and analysis as part of this EUA. NMED determined that several classified segments did not have adequate information and data to proceed with an evaluation under the premise of this EUA. Appendix A of this EUA provides the reasoning for excluding those sections. However, NMED did find that five segments did have enough information to proceed as part of this EUA. The segments that were investigated for this EUA are listed in Table III-1 (emphasis added).

Table III-1. *Sections of 20.6.4 NMAC being evaluated under this EUA.*

20.6.4.103 RIO GRANDE BASIN - The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties, excluding waters on tribal lands.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, <u>secondary contact</u> and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

C. Remarks: flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.

[20.6.4.103 NMAC - Rp 20 NMAC 6.1.2103, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.116 RIO GRANDE BASIN: The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 31°C (87.8°F) or less.

[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.204 PECOS RIVER BASIN: - The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.204 NMAC - Rp 20 NMAC 6.1.2204, 10-12-00; A, 05-23-05; A, 12-01-10]

[**NOTE:** The segment covered by this section was divided effective 05-23-05. The standards for Avalon Reservoir are under 20.6.4.219 NMAC.]

20.6.4.206 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its tributaries downstream of Bonney canyon and perennial reaches of the Rio Felix.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.207 PECOS RIVER BASIN: - The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.

A. Designated Uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 8,000 mg/L or less, sulfate 2,500 mg/L or less and chloride 4,000 mg/L or less.
[20.6.4.207 NMAC - Rp 20 NMAC 6.1.2207, 10-12-00; A, 05-23-05; A, 12-01-10]

Figure III-1 is a map of New Mexico with the locations of the waterbodies (bold lines) for the referenced sections above. Appendix C contains more detailed maps.

Figure III-1. ***Waterbodies with secondary recreational contact use being analyzed under this EUA.***

IV. Antidegradation Evaluation

A. Regulatory Background

In accordance with 40 C.F.R. 131.12, states are required to develop and adopt a statewide antidegradation policy, which includes protection for various levels of water quality. In addition, states are required to develop methods for implementing the antidegradation policy. New Mexico's antidegradation policy, codified under 20.6.4.8 NMAC, defines three tiers of protection against degradation. These include protections for existing uses ("Tier 1"), protections for high quality waters that exceed levels necessary to support aquatic life, wildlife and recreational uses ("Tier 2"), and protections for waters designated as Outstanding National Resource Waters ("Tier 3"). Antidegradation implementation activities listed in 20.6.4.8(B) NMAC are supplemented by detailed antidegradation review procedures developed under the State's Water Quality Management Plan/Continuing Planning Process (WQMP/CPP), whichis approved by both the WQCC and EPA.

40 C.F.R. § 131.12 Antidegradation policy and implementation methods.
(a) The State shall develop and adopt a statewide antidegradation policy.

20.6.4.8 NMAC – Antidegradation Policy and Implementation Plan
A. Antidegradation Policy: This antidegradation policy applies to all surface waters of the state.
(1) Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected in all surface waters of the state.
(2) Where the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure water quality adequate to protect existing uses fully. Further, the state shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable BMPs for nonpoint source control. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.
(3) No degradation shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A.

20.6.4.8 NMAC – Antidegradation Policy and Implementation Plan
B. Implementation Plan: The department, acting under authority delegated by the commission, implements the water quality standards, including the antidegradation policy, by describing specific methods and procedures in the continuing planning process and by establishing and maintaining controls on the discharge of pollutants to surface waters of the state. The steps summarized in the following paragraphs, which may not all be applicable in every water pollution control action, list the implementation activities of the department. These implementation activities are supplemented by detailed antidegradation review procedures developed under the state's continuing planning process.

In order to determine if any proposed amendments would conflict with the state's antidegradation policy, NMED evaluated information regarding any designated ONRWs and existing uses, as discussed below.

B. Outstanding National Resource Waters

An ONRW is a designation granted by the WQCC for waters that have been determined to have a particular benefit to the State. These designated waters are listed under 20.6.4.9(D) NMAC and are protected from degradation in accordance with 20.6.4.8(A)(3) NMAC.

NMAC 20.6.4.8 ANTIDEGRADATION POLICY AND IMPLEMENTATION PLAN:
(A)(3) *No degradation shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A.*

According to 20.6.4.9(D) NMAC, Las Animas creek in the Aldo Leopold wilderness is the only identified ONRW listed on any of the classified waters in this analysis. Las Animas creek is classified under 20.6.4.103 NMAC as it is a perennial reach of a tributary to the Rio Grande (Caballo reservoir being considered part of the Rio Grande as it pertains to this tributary) in Sierra county. It should be noted that the majority of Las Animas creek is not within the Aldo Leopold wilderness area and therefore not part of the ONRW designation.

Table IV-1. *Identified ONRWs within analysis area (emphasis added).*

- **Waterbody:**
  Las Animas Creek (perennial parts Animas Gulch to headwaters) AU ID: NM-2103.A_50
- **WQS:**
  20.6.4.103 NMAC. RIO GRANDE BASIN: - The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties, excluding waters on tribal lands.
- **ONRW:**
  20.6.4.9(D)(3)(a)(i) NMAC Waters classified as ONRWs:
  (i) in the Aldo Leopold wilderness: Byers Run, Circle Seven creek, Flower canyon, Holden Prong, Indian canyon, Las Animas creek, Mud Spring canyon, North Fork Palomas creek, North Seco creek, Pretty canyon, Sids Prong, South Animas canyon, Victorio Park canyon, Water canyon;

Since, through this EUA, NMED proposes to amend the recreational contact designated use to a more stringent use, it is found that the proposed amendment would not negatively impact nor degrade water quality in the segment of Las Animas Creek that is designated as an ONRW .

C. Existing Use

According to 40 C.F.R. § 131.3(e) and 20.6.4.7(E)(3) NMAC, the definition of "existing uses" are those uses actually attained in the waterbody on or after November 28, 1975, whether or not they are designated uses and whether or not they are currently attained. If the designated use is less stringent than the existing use, the State must amend the WQS to reflect the use actually attained. Also, according to 40 C.F.R. § 131.10, a state can't remove a designated use if it is an existing use.

40 C.F.R. § 131.10 Designation of uses.
(i) *Where existing water quality standards specify designated uses less than those which are presently being attained, the State shall revise its standards to reflect the uses actually being attained.*

In this EUA, NMED evaluated the existing recreational contact uses of the five classified segments. The goal of this EUA is to evaluate and amend, where justified, the designated use to a more stringent existing use. Since the proposed amendment is to adopt a more stringent use, NMED determined that the proposed amendment will not negatively impact nor degrade water quality in waterbodies that were evaluated in this EUA.

V. Threatened and Endangered Species Review

A. Regulatory Background

In accordance with Section 7(a)(2) of the Endangered Species Act ("ESA"), EPA shall consult with the U.S. Fish and Wildlife Service to ensure that any action authorized by the EPA is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of habitat of such species. If there is reason to believe that a threatened or endangered species can be affected or jeopardized by the implementation of a WQS change, then the federal agencies, through ESA consultation, must ensure that the appropriate actions are implemented (ESA 2019). In order to assist EPA with the evaluation of this EUA, NMED includes a preliminary screening of listed threatened and endangered species within the geographical areas being analyzed for potential designated use changes.

> ***Section 7(a) of the ESA***
> ***FEDERAL AGENCY ACTIONS AND CONSULTATIONS***
> ***(1)*** *The Secretary shall review other programs administered by him and utilize such programs in furtherance of the purposes of this Act. All other Federal agencies shall, in consultation with and with the assistance of the Secretary, utilize their authorities in furtherance of the purposes of this Act by carrying out programs for the conservation of endangered species and threatened species listed pursuant to section 4 of this Act.*
> ***(2)*** *Each Federal agency shall, in consultation with and with the assistance of the Secretary, insure that any action authorized, funded, or carried out by such agency (hereinafter in this section referred to as an agency action) is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined by the Secretary, after consultation as appropriate with affected States, to be critical, unless such agency has been granted an exemption for such action by the Committee pursuant to subsection (h) of this section. In fulfilling the requirements of this paragraph each agency shall use the best scientific and commercial data available.*

B. Evaluation of Endangered and Threatened Species

This EUA includes a review of U.S. Fish and Wildlife Service's Information for Planning and Consultation (IPaC) project planning tool (https://ecos.fws.gov/ipac/) to determine the geographical locations of the listed waterbodies in this EUA and whether they overlap with listed species or critical habitat, as detailed below.

The geographical area proximal to the main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties (20.6.4.103 NMAC):

1. Federally listed threatened species:
    - *a.* Mexican Spotted Owl (*Strix occidentalis lucida*)
    - *b.* Yellow-billed Cuckoo (*Coccyzus americanus*)
    - *c.* Narrow-headed Gartersnake (*Thamnophis rufipunctatus*)
    - *d.* Chiricahua Leopard Frog (*Rana chiricahuensis*)
    - *e.* Gila Trout (*Oncorhynchus gilae)*

    - *f.* Pecos Sunflower *(Helianthus paradoxus)*
2. Federally listed endangered species:
    - *a.* Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
    - *b.* Rio Grande Silvery Minnow (*Hybognathus amarus*)
    - *c.* Todsen's Pennyroyal (*Hedeoma todsenii*)
    - *d.* New Mexico Meadow Jumping Mouse *(Zapus hudsonius luteus)*
    - *e.* Least Tern *(Sterna antillarum),* Piping Plover *(Charadrius melodus)*
    - *f.* Alamosa Spring Snail *(Tryonia alamosae)*
    - *g.* Chupadera Springsnail *(Pyrgulopsis chupaderae)*
    - *h.* Socorro Spring Snail *(Pyrgulopsis neomexicana)*
    - *i.* Socorro Isopod *(Thermosphaeroma thermophilus)*
3. Area within federally delineated critical habitat for the following species:
    - a. Yellow-billed Cuckoo (*Coccyzus americanus*)
    - b. Rio Grande Silvery Minnow*(Hybognathus amarus)*
    - c. Southwestern Willow Flycatcher (*Empidonax traillii extimus*)

The geographical area proximal to the Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito (20.6.4.116 NMAC):

1. Federally listed threatened species:
    - a. Canada Lynx (*Lynx canadensis*)
    - b. Mexican Spotted Owl *(Strix occidentalis lucida)*
    - c. Yellow-billed Cuckoo *(Coccyzus americanus*)
2. Federally listed endangered species:
    - a. New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
    - b. Least Tern (*Sterna antillarum)*
    - c. Southwestern Willow Flycatcher *(Empidonax traillii extimus)*
    - d. Jemez Mountains Salamander (*Plethodon neomexicanus*)
3. Area within federally delineated critical habitat for the following species:
    - a. No critical habitats in this location

The geographical area proximal to the main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam (20.6.4.204 NMAC):

1. Federally listed threatened species:
    - a. Mexican Spotted Owl *(Strix occidentalis lucida)*
    - b. Piping Plover *(Charadrius melodus)*
    - c. Pecos Bluntnose Shiner *(Notropis simus pecosensis)*
    - d. Gypsum Wild-buckwheat *(Eriogonum gypsophilum)*
    - e. Kuenzler Hedgehog Cactus *(Echinocereus fendleri var. kuenzleri)*
2. Federally listed endangered species:
    - a. Least Tern (*Sterna antillarum)*
    - b. Southwestern Willow Flycatcher *(Empidonax traillii extimus)*
    - c. Pecos Gambusia *(Gambusia nobilis)*
    - d. Texas Hornshell *(Popenaias popeii)*
    - e. Sneed Pincushion Cactus *(Coryphantha sneedii var. sneedii)*

3. Area within federally delineated critical habitat for the following species:
    a. No critical habitats in this location

The geographical area proximal to the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its tributaries downstream of Bonney canyon and perennial reaches of the Rio Felix (20.6.4.206 NMAC):

1. Federally listed threatened species:
    a. Mexican Spotted Owl (Strix occidentalis lucida)
    b. Piping Plover (Charadrius melodus)
    c. Yellow-billed Cuckoo (Coccyzus americanus)
    d. Pecos Bluntnose Shiner (Notropis simus pecosensis)
    e. Gypsum Wild-buckwheat (Eriogonum gypsophilum)
    f. Kuenzler Hedgehog Cactus (Echinocereus fendleri var. kuenzleri)
    g. Lee Pincushion Cactus (Coryphantha sneedii var. leei)
    h. Pecos (=puzzle, =paradox) Sunflower (Helianthus paradoxus)
    i. Sacramento Mountains Thistle (Cirsium vinaceum)
2. Federally listed endangered species:
    a. New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus)*
    b. Least Tern (*Sterna antillarum)*
    c. Southwestern Willow Flycatcher *(Empidonax traillii extimus)*
    d. Pecos Gambusia *(Gambusia nobilis)*
    e. Texas Hornshell *(Popenaias popeii)*
    f. Koster's Springsnail *(Juturnia kosteri)*
    g. Pecos Assiminea Snail *(Assiminea pecos)*
    h. Roswell Spring snail (*Pyrgulopsis roswellensis)*
    i. Noel's Amphipod (*Gammarus desperatus)*
    j. Sacramento Prickly Poppy (*Argemone pleiacantha ssp. Pinnatisecta*)
    k. Sneed Pincushion Cactus (*Coryphantha sneedii var. sneedii*)
    l. Todsen's Pennyroyal (*Hedeoma todsenii*).
3. Area within federally delineated critical habitat for the following species:
    a. Koster's springsnail (*Juturnia kosteri*)
    b. Mexican Spotted Owl *(Strix occidentalis lucida)*
    c. New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus)*
    d. Noel's Amphipod (*Gammarus desperatus*)
    e. Pecos (=puzzle, =paradox) Sunflower (Helianthus paradoxus)
    f. Pecos Assiminea Snail *(Assiminea pecos)*
    g. Pecos Bluntnose (*Shiner Notropis simus pecosensis*)
    h. Roswell Springsnail (*Pyrgulopsis roswellensis*).

The geographical area proximal to the main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam (20.6.4.207 NMAC):

1. Federally listed threatened species:
    a. Piping Plover *(Charadrius melodus)*
    b. Pecos Bluntnose Shiner *(Notropis simus pecosensis)*
    c. Kuenzler Hedgehog Cactus *(Echinocereus fendleri var. kuenzleri)*

   - d. Pecos Sunflower *(Helianthus paradoxus).*
2. Federally listed endangered species:
   - a. Least Tern *(Sterna antillarum)*
   - b. Pecos Gambusia *(Gambusia nobilis)*
   - c. Koster's Springsnail *(Juturnia kosteri)*
   - d. Pecos Assiminea Snail *(Assiminea pecos)*
   - e. Roswell Spring snail *(Pyrgulopsis roswellensis)*
   - f. Noel's Amphipod *(Gammarus desperatus).*
3. Area within federally delineated critical habitat for the following species:
   - a. Wright's Marsh Thistle *(Cirsium wrightii).*

Appendix C of this EUA contains section maps depicting the waterbody segments, the IPaC geographical area delineations, and a description of how the area was defined.

NMED maintains that any proposed amendments to change secondary contact to primary contact will not jeopardize the continued existence of any threatened and endangered species, nor result in the destruction or adverse modification of critical habitat because the proposed amendment is to a more stringent designated use. This increased protection would presumably not negatively affect nor degrade species habitat but would provide enhanced water quality to the waterbodies and possibly further protect those species that are dependent on them.

VI. Site Conditions

When conducting a designated use analysis, site-specific conditions can be used to inform the decision and justify the proposed amendment. As part of this analysis, NMED reviewed site conditions to assist in the determination of the existing use and appropriate designated use.

A. Geographic Locations

The areas being considered under this EUA are located in several areas within New Mexico. They have been described in more detail as follows:

1. In south-central New Mexico, the main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam in Sierra, Socorro and Torrance county; and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties (20.6.4.103 NMAC) .
2. In north-central New Mexico, the Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito (20.6.4.116 NMAC) in Rio Arriba County.
3. In southeastern New Mexico, the main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Sumner dam (20.6.4.204 NMAC), the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme) (20.6.4.206 NMAC) and the main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam (20.6.4.207) in the counties of DeBaca, Chaves, and Eddy.
4. In southeastern New Mexico, the perennial reaches of tributaries to the Pecos River including the Rio Peñasco downstream from state highway 24 near Dunken, the Rio Hondo and its tributaries downstream of Bonney canyon and the Rio Felix (20.6.4.206 NMAC) in Eddy and Chaves counties.

B. Physiographic and Ecological Conditions

The physiographic and ecological conditions to which these waters are found is broad and extensive, with drastic changes in elevation, geology, ecosystems and weather conditions.

New Mexico's arid and semiarid landscape make surface water a limited resource. The dry conditions in New Mexico greatly influence the hydrological conditions of the State's watersheds, making ephemeral and intermittent streams extremely common. Ecoregions are areas where ecosystems are generally similar and are identified by analyzing the patterns and composition of various biotic and abiotic factors. EPA has several resolutions of ecoregional mapping. EPA's Level III Ecoregions of North America classify the Southwestern states as predominantly dry, desert, or semiarid where annual losses of water through evaporation at the earth's surface exceed annual water gains from precipitation (USEPA 2006).

Waterbodies listed in 20.6.4.116 NMAC are located in the northern part of new Mexico with characteristic Level III Ecoregions labeled as the "Southern Rockies" and the "Arizona/New Mexico Plateau" (USEPA 2006). Characteristics of the Arizona/New Mexico Plateau represent a large transitional zone where drier shrublands transition into higher relief tablelands. Mountainous areas include the Southern Rockies composed of steep, rugged mountains with high elevations. Grass, shrubs, and juniper-oak woodlands dominate at lower elevations and conifer forests consisting of Douglas fir, ponderosa pine, and aspen dominate at higher elevations (USEPA 2006).

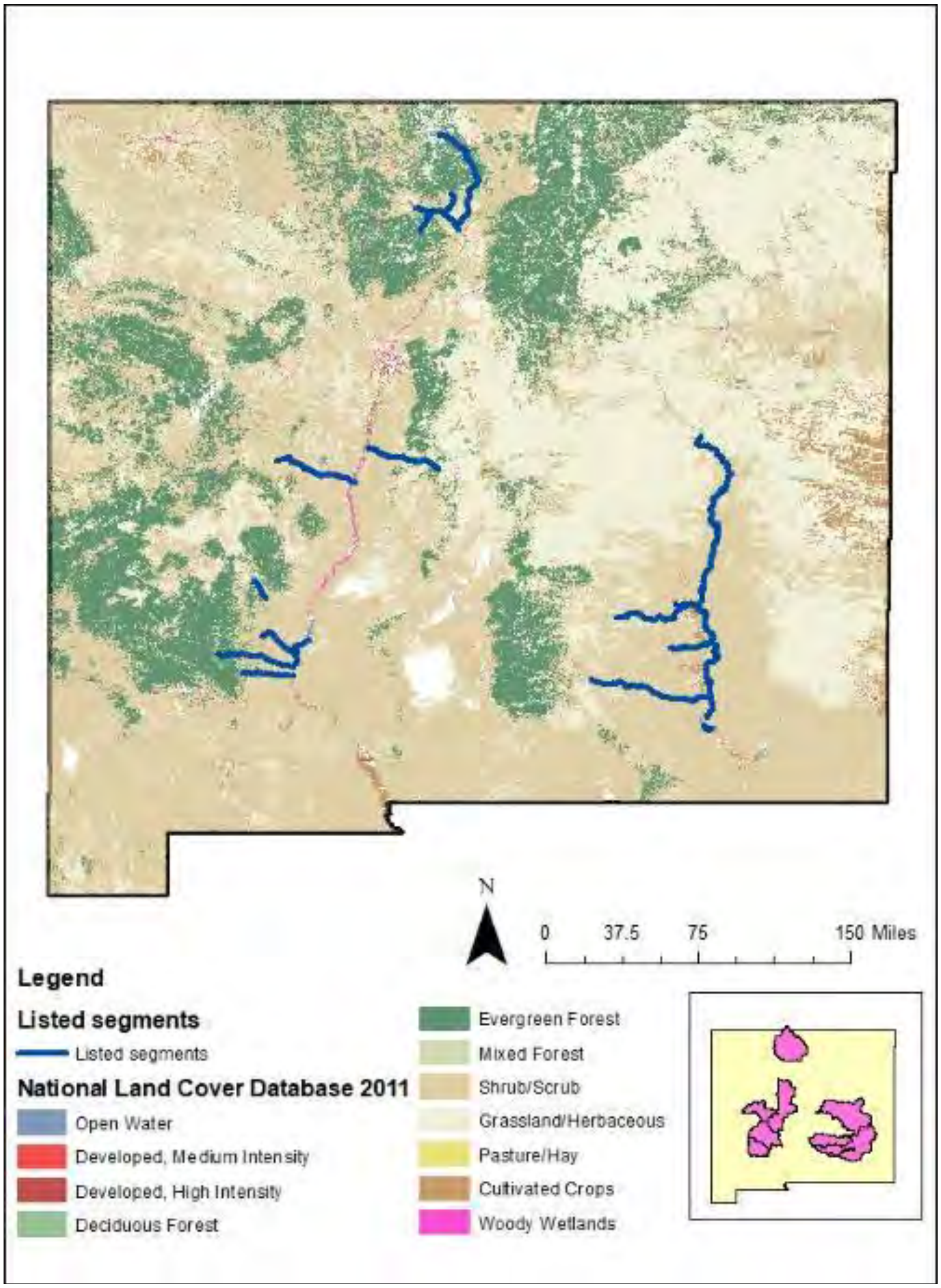
The remaining waterbodies listed in 20.6.4.103, 20.6.4.204, 20.6.4.206, and 20.6.4.207 NMAC are in the southeastern region of New Mexico. This area is mainly characterized under the Level III Ecoregions labeled as the "Chihuahuan Desert," "Southwestern Tablelands," "Arizona/New Mexico Plateau" and the "Arizona/New Mexico Mountains" (USEPA 2006). The Chihuahuan Desert is characterized by desert grasslands and arid shrubland (USEPA 2006). The Southwestern Tablelands contain canyons, mesas and badlands with characterized sub-humid grassland and semiarid range land composed of grama-buffalo grass and juniper-scrub oak-midgrass savanna on escarpment bluffs (USEPA 2006). The Arizona/New Mexico Plateau is a large transitional area between drier shrublands and higher relief wooded areas, such as sagebrush ecosystems that provide refuge for species such as Gunnison prairie dogs, owls, weasels, badgers, and a variety of snakes (USEPA 2006). The Arizona/New Mexico Mountains are lower elevation mountains (as compared to other mountainous ecoregions) with vegetation indicative of drier and warmer environments, such as chaparral, pinyon-juniper, and oak woodlands. Higher elevations are mostly ponderosa pine forests with spruce and Douglas fir limited to the highest elevations (USEPA 2006).

Any site conditions that would affect designated use attainment would also affect the existing use. Therefore, NMED finds that the physiographic and ecological conditions to which these waterbodies are located would not restrict a WQS amendment to a more stringent recreational designated use.

C. Land Use, Ownership and History

There are numerous anthropogenic disturbances that could affect water quality in the segments being evaluated. The waterbodies under this EUA could have anthropogenic disturbances that include: agriculture, camping, hiking, hydrologic modification (divserions, ponds), livestock grazing, land clearing, mining, off-road vehicle use, roads and road construction, timber harvesting, vegetation conversion, and urbanization. Even though anthropogenic disturbances can affect water quality, this EUA focuses on existing use data – the level of water quality that has been actually attained in the waterbody on or after November 28, 1975. Therefore, NMED determined that the general site conditions (e.g., physiographic and ecological conditions, land use, ownership) do not provide direct evidence to support or refute the proposed amendments. The geospatial locations and associated land cover (USGS 2011) of the waterbodies under review are mapped in Figure VI-1.

Figure VI-1. Standard sections listed (blue) depicting the spatial and land cover variability.



D. National Pollutant Discharge Elimination System and Stormwater General Permit

As part of this EUA, SWQB conducted a review of EPA's National Pollutant Discharge Elimination System ("NPDES") permits and Stormwater General Permits associated with the waterbody segments under review. The review's purpose was to identify permits associated with the waterbody segments under review and identify those permits that could be affected by a change in the recreational designated use. The review located five relevant permits. Four of them currently have *E.coli* effluent discharge limits that are greater than the primary contact numeric criteria. All the NPDES permits identified are municipal wastewater treatment plants, which are summarized in Table VI.1.

Table VI-1. *Permits associated to the referenced waterbodies and standard sections with their pertinent discharge limits and whether the current permit values are higher than the E.coli criteria for primary contact.*

Wastewater Treatment Plant Name	Permit #	Permit Expiration Date	Associated WQS Receiving Water	AU ID	*E. coli* Effluent Limits (cfu/100 mL)		Design Flow (MGD*)	Effluent Limits > Primary Contact Criteria ?
					single sample	geometric mean		
City of Truth Or Consequences	NM0020681	9/30/2021	20.6.4.103 Rio Grande	NM-2103.A_00	2507	548	1.06	YES
Abiquiu	NM0024830	8/31/2022	20.6.4.116 Rio Chama	NM-2113_00	88	47	0.04	NO
City of Roswell	NM0020311	12/31/2024	20.6.4.206 Rio Hondo	NM-2208_26	2507	548	7.00	YES
City of Artesia	NM0022268	12/31/2024	20.6.4.206 Pecos River	NM-2206.A_02	2507	548	2.60	YES
Village of Fort Sumner	NM0023477	4/30/2023	20.6.4.207 Pecos River	NM-2207_02	2507	548	0.21	YES

* Millions of Gallons perDay (MGD)

Primary contact criteria: monthly geometric mean of 126 cfu/100 mL and single sample of 410 cfu/100 mL.

Secondary contact criteria: monthly geometric mean of 548 cfu/100 mL and single sample of 2507 cfu/100 mL.

Even though point source discharges can affect water quality, they do not provide direct evidence to support or refute an existing use analysis.

E. Urban Areas

SWQB reviewed the U.S. Census Bureau's Master Address File/Topologically Integrated Geographic Encoding and Referencing ("MAF/TIGER") Database ("MTDB") TIGER/Line shapefile to determine if the areas of study are under an Urban Area designation. Table VI.2 lists the urban areas that either contain a referenced segment or are proximal.

Table VI-2. *Waterbodies identified to traverse through designated urban clusters.*

Urban Cluster name	AU name	WQS Reference
Espanola	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	20.6.4.116
Truth or Consequences	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	20.6.4.103

Urban Cluster name	AU name	WQS Reference
Roswell	Rio Hondo (Perennial prt North Spring R to Bonney Cyn) North Spring River (Rio Hondo to headwaters)	20.6.4.206
Artesia	Pecos River (Rio Penasco to Eagle Creek)	20.6.4.206

Even though urban areas can affect water quality, this document focuses on existing use data. The identified urban areas do not provide direct evidence to support or refute an existing use analysis.

VII. Existing Use Evaluation

A. Designated Use and Criteria Evaluated

The EPA recreational criteria guidelines have undergone several historical iterations. The EPA 1986 recreational criteria guidelines included different "use intensity" bacteria criteria levels based on how waterbodies were being utilized by recreational users (USEPA 1986). In 2010, EPA was directed to revise recreational use criteria based on the latest research and science. By 2012, the new EPA recreational criterion was released. The 2012 guidance was grounded on protecting primary contact users from exposure to harmful levels of pathogens based on the latest science regarding the magnitude of bacterial indicators and their estimated illness rates (USEPA 2012). NMAC's recreational designated use primary contact numeric criteria is based on the EPA's recommended *E. coli* criteria.

Both primary and secondary contact recreational uses have *E. coli* criteria, expressed as cfu or MPN per 100 mL. Either cfu or MPN may be used for purposes of evaluation of recreational uses, as described in 20.6.4.900 (D) and 20.6.4.900 (E) NMAC.

According to 20.6.4.900(D) NMAC, to attain primary contact criteria, the pH must be within a range of 6.6 to 9.0 and *E. coli* must not exceed the monthly geometric mean criteron of 126 cfu/100 mL or exceed the single sample criterion of 410 cfu/100 mL. According to 20.6.4.900(E) NMAC, to attain secondary contact *E. coli* must not exceed the geometric mean criterion of 548 cfu/100 mL or exceed the single sample criterion of 2507 cfu/100 mL.

Available *E. coli* data for waterbodies with a secondary contact designation were evaluated to determine the waterbodies' existing uses and whether a change to the designated use is warranted.

B. Data Used for Evaluation

In order to determine the existing recreational use designation for the waterbodies under evaluation a historical data search was conducted. A search for historical data older than 2009 was conducted by querying validated SWQB datasets in archived folders on the Department's shared server. Any data collected since 2010 were acquired through the SWQB's Surface water Quality Information Database ("SQUID").

Archived and SQUID *E.coli* and pH data were collated for the waterbody segments under review (20.6.4.103, 20.6.4.116, 20.6.4.204, 20.6.4.206 and 20.6.4.207 NMAC). Each standards segment may contain one or several Assessment Units ("AU"), or stream reaches. AUs are designed to represent waters with assumed homogeneous water quality (WERF 2007). Each AU contains at least one sampling station that is associated with both an AU identification ("ID") and a sampling station ID. Accordingly, a waterbody segment as described under NMAC, may have one or more AUs with one or more sampling stations. The data review resulted in a total of 30 AUs representing the five sections under analysis. All relevant water quality data were retrieved (20.6.4.103, 20.6.4.116, 20.6.4.204, 20.6.4.206 and 20.6.4.207 NMAC) and can be found in Appendix B.

SWQB collects water quality data pursuant to the most recent, EPA-approved *Quality Assurance Project Plan for Water Quality Management Programs* ("QAPP") and Standard Operating Procedures ("SOPs"), which are incorporated into the QAPP by reference. In addition, SWQB has a Quality Management Plan ("QMP") that is updated annually and describes SWQB's quality system for planning, implementing, documenting, and assessing the effectiveness of activities supporting environmental data operations. Accordingly, relevant and applicable *E. coli* and pH data collected by SWQB are defensible and appropriate for purposes of this EUA:

- SOP Field Sampling Plan Development and Execution (SWQB 2011, 2012, 2015 and 2019).
- SOP Sonde Calibration and Maintenance (SWQB 2011, 2012, 2013, 2014, 2016 and 2018).
- SOP Sonde Deployment (SWQB 2011, 2012, 2013, 2014, 2015 and 2018).
- SOP Bacteriological Sampling and Analysis (SWQB 2011, 2013, 2015, 2016 and 2018)
- SOP Long-term Deployment Datalogger Data QA and SQUID Upload Instructions (SWQB 2012, 2020)
- SOP Data Verification and Validation Procedures (SWQB 2011 and 2016).

SWQB does not monitor or gather information on recreational use demonstrating full immersion, such as swimming and wading. However, visitor brochures and recreational websites encourage popular recreational activities, such as swimming, kayaking and wading, in waters related to the five classified segments evaluated as part of this EUA. Several sections, including the Rio Grande between Elephant Butte and Caballo Reservoirs, the Rio Chama between Abiquiu Reservoir and the Rio Grande, and the Rio Ojo Caliente, are noted in guides to river rafting in New Mexico. Furthermore, as stated in direct written testimony of SWQB, entered into the pleadings log as part of the last triennial review (WQCC Docket 14-05(R)), evidence of these uses has not only been encouraged, but has also been recorded.

C. Methods and initial evaluation

Historical datasets were acquired for each water segment, and parsed to contain only the waterbodies under review with their associated *E. coli* and pH data. Any waterbodies that did not contain both pH and *E. coli* data were excluded from the analysis and are not included in the proposed recreational use amendment. The listings of each waterbody with its associated WQS, AU ID, name of the AU and whether or not pH and *E.coli* data were available for each waterbody is summarized under Table VII-1.

Table VII-1. *Summary of perennial Assessment Units (AU) with corresponding E.coli and pH data.*

WQS	AU ID	AU NAME	pH and *E. coli* data available?
20.6.4.103	NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	Yes
20.6.4.103	NM-2103.A_10	Rio Salado (Rio Grande to Alamo Navajo boundary)	Yes
20.6.4.103	NM-2103.A_20	Percha Creek (Perennial parts Wicks Gulch to Middle Percha Creek)	Yes
20.6.4.103	NM-2103.A_21	Percha Creek (Perennial prt Caballo Rsvr to Wicks Gulch)	Yes*

WQS	AU ID	AU NAME	pH and *E. coli* data available?
20.6.4.103	NM-2103.A_30	Alamosa Creek (Perennial reaches above Monticello diversion)	Yes
20.6.4.103	NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	Yes
20.6.4.103	NM-2103.A_50	Las Animas Ck (perennial part Animas Gulch to headwaters)	Yes
20.6.4.103	NM-2103.A_51	Las Animas Ck (perennial part Rio Grande to Animas Gulch)	Yes
20.6.4.103	NM-2103.A_60	Palomas Creek (perennial portion Rio Grande to headwaters)	Yes
20.6.4.103	NM-2103.A_61	South Fork Palomas Ck (Palomas Ck to headwaters)	Yes
20.6.4.103	No AU IDs	Other perennial reaches of tribs to the Rio Grande in Sierra & Socorro Co.	No data
20.6.4.116	NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	Yes
20.6.4.116	NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	Yes
20.6.4.116	NM-2113_11	Rio Ojo Caliente (Rio Chama to Arroyo El Rito)	Yes*
20.6.4.116	NM-2113_30	Rio Tusas (Perennial prt Rio Vallecitos to headwaters)	Yes
20.6.4.116	NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	Yes
20.6.4.116	NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	Yes
20.6.4.204	NM-2204.A_00	Pecos River (Avalon Reservoir to Brantley Reservoir)	Yes
20.6.4.206	NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	Yes
20.6.4.206	NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	Yes
20.6.4.206	NM-2206.A_02	Pecos River (Rio Penasco to Eagle Creek)	Yes
20.6.4.206	NM-2206.A_03	Pecos River (Eagle Creek to Rio Felix)	Yes
20.6.4.206	NM-2206.A_10	Rio Penasco (Perennial part Pecos River to HWY 24)	Yes
20.6.4.206	NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	Yes
20.6.4.206	NM-2206.A_30	Rio Felix (Perennial reaches Pecos River to headwaters)	No Data
20.6.4.206	NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	Yes
20.6.4.206	NM-2208_25	Rio Hondo (Perennial prt North Spring R to Bonney Cyn)	Yes*
20.6.4.206	NM-2208_26	Rio Hondo (Perennial part Pecos River to North Spring River)	Yes
20.6.4.206	No AU ID	Other perennial reaches of tribs to the Rio Hondo d/s of Bonney canyon	No Data
20.6.4.207	NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	Yes
20.6.4.207	NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	Yes
20.6.4.207	NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	Yes
20.6.4.207	NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	Yes

**There is no E. coli data for this particular AU, however data from another AU/sample station within the waterbody segment will be used.*

NMED evaluated the dataset to determine which of the waterbodies meet the primary contact pH range of 6.6 to 9.0. Any waterbodies that did not meet the appropriate pH range were excluded from the analysis and were not included in the proposed recreational use designation change.

NMED also analyzed the *E. coli* data. For this analysis, the single grab criterion was utilized since the number of samples necessary to calculate a monthly geometric mean were not available. NMED compared the dataset to the primary contact single sample *E. coli* criterion of 410 cfu/100mL to evaluate the existing use. If the waterbody segment contained at least one *E. coli* sample result equal to or less than 410 cfu/mL, then NMED determined that the waterbody's existing use to be at least primary contact. This determination is based on the existing use definitions in 20.6.4.7(E)(3) NMAC and 40 CFR § 131.3, which state that an existing use is a use that has actually been attained by a surface water. Therefore, if a segment under review achieves the primary contact criterion, then the waterbody should be able to support primary contact recreation. Alternatively, if the *E. coli* single sample results for a waterbody segment are all greater than 410 cfu/100 mL, then NMED determined that the waterbody's existing use is appropriately designated under secondary contact.

D. Findings

The findings confirmed that existing use data for the waterbody segments evaluated under this EUA were available except for three instances, shown in Table VII-1 as "No Data." For these waterbodies, an existing use dataset was not available, and the designated recreational use will not be amended at this time. Due to lack of data, waterbodies eliminated from the existing use analysis and proposed amendments include:

1. Rio Felix (20.6.4.206 NMAC)
2. Perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon with the exception of North Spring river, which does have data. (20.6.4.206 NMAC)
3. Perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties with the following exceptions: Rio Salado, Percha Creek, Alamosa Creek, Abo Arroyo, Las Animas Creek and Palomas Creek (20.6.4.103 NMAC), all of which had data.

For the primary contact existing use analysis, all of the remaining waterbodies (including the exceptions noted above) had a pH range within 6.6 to 9.0 and one or more *E. coli* samples that fell well below the 410 cfu/100 mL single sample criterion. Table VII-2 is a summary of findings, which confirms that the listed AUs have existing water quality that achieves the pH and *E. coli* criteria for primary contact. Table VII-2 also identifies the number of samples that fell at or below 410 cfu/mL versus the total number of *E. coli* samples collected in that AU, the minimum *E. coli* value achieved in the AU, and the percent exceedances for *E. coli*. It should be noted that exceedances are not an indication that the primary contact recreation use is not attainable. The data clearly show that water quality in these AUs attain and in most instances are better than the *E. coli* criterion designated to protect primary contact recreation. Pursuant to 40 C.F.R. § 131, states are required to revise their WQS when: (1) new information indicates that the uses specified in CWA § 101(a)(2) are attainable, and (2) existing water quality standards specify designated uses less than those which are presently being attained.

Table VII-2. *Summary of Assessment Unit ("AU") as it pertains to attaining primary contact.*

WQS Segment	AU ID	pH range within 6.6 to 9.0?	# samples ≤ 410 cfu/100 mL over total # samples within AU	Minimum *E. coli* sample value (cfu/100 mL)	Primary contact criteria attained?	% above 410 cfu/ 100 mL
20.6.4.103	NM-2103.A_00	YES	24/24	1	YES	0%
20.6.4.103	NM-2103.A_10	YES	3/4	23	YES	25%

WQS Segment	AU ID	pH range within 6.6 to 9.0?	# samples ≤ 410 cfu/100 mL over total # samples within AU	Minimum *E. coli* sample value (cfu/100 mL)	Primary contact criteria attained?	% above 410 cfu/ 100 mL
20.6.4.103	NM-2103.A_20	YES	4/4	1	YES	0%
20.6.4.103	NM-2103.A_30	YES	4/4	6	YES	0%
20.6.4.103	NM-2103.A_40	YES	5/7	6	YES	29%
20.6.4.103	NM-2103.A_50	YES	3/3	18	YES	0%
20.6.4.103	NM-2103.A_51	YES	4/5	45	YES	20%
20.6.4.103	NM-2103.A_60	YES	4/4	10	YES	0%
20.6.4.116	NM-2113_00	YES	12/13	1	YES	8%
20.6.4.116	NM-2113_10	YES	5/6	15	YES	17%
20.6.4.116	NM-2113_30	YES	3/4	67	YES	25%
20.6.4.116	NM-2113_40	YES	5/7	55	YES	29%
20.6.4.116	NM-2113_50	YES	5/6	13	YES	17%
20.6.4.204	NM-2204.A_00	YES	6/7	9	YES	14%
20.6.4.206	NM-2206.A_00	YES	13/16	1	YES	19%
20.6.4.206	NM-2206.A_01	YES	6/7	2	YES	14%
20.6.4.206	NM-2206.A_02	YES	3/3	1	YES	0%
20.6.4.206	NM-2206.A_03	YES	2/2	1	YES	0%
20.6.4.206	NM-2206.A_10	YES	5/5	1	YES	0%
20.6.4.206	NM-2206.A_20	YES	6/8	2	YES	25%
20.6.4.206	NM-2206.A_40	YES	8/9	23	YES	11%
20.6.4.206	NM-2208_26	YES	13/16	3	YES	19%
20.6.4.207	NM-2207_00	YES	6/7	3	YES	14%
20.6.4.207	NM-2207_01	YES	5/7	6	YES	29%
20.6.4.207	NM-2207_02	YES	15/22	3	YES	32%
20.6.4.207	NM-2207_03	YES	10/10	1	YES	0%

VIII. Conclusions

In accordance with 40 C.F.R. § 131.10(i), the state must review and revises applicable WQS to reflect the uses actually being attained should those be more stringent than the current designated uses. Designated uses must be amended to be no less stringent than the existing use, and if there is evidence supporting a more stringent existing use then it shall be applied to the new designated use.

NMED conducted an EUA to determine if the existing recreational use for waters classified in 20.6.4.103, 20.6.4.116, 20.6.4.204, 20.6.4.206 and 20.6.4.207 NMAC were more stringent than their current secondary contact designated use. Accordingly, SWQB collated applicable pH and *E. coli* data for the WQS segments being evaluated.

Before the EUA was initiated, an antidegradation evaluation was conducted. As a result of this antidegradation evaluation, NMED found that Las Animas creek in the Aldo Leopold wilderness is designated as an ONRW; however, the proposed amendment is not expected to degrade water quality in the portion of Las Animas Creek that is designated as an ONRW because the proposed designated use (primary contact) is more stringent than the current use (secondary contact).

In addition, an evaluation of threatened and endangered species was conducted. Any proposed amendments to change secondary contact to primary contact would be more stringent and presumed to not negatively affect or degrade habitat, yet would provide enhanced protections to the waterbodies and those species that are dependent on them.

For the EUA, each of the five WQS segments had to contain at least one sampling event that had both pH and *E. coli* values in order to be analyzed and recommended for a designated use change. All segments fulfilled this requirement, with the exclusion of the following waters that did not have available data to evaluate under this EUA:

1. 20.6.4.103 NMAC: Perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties with the following exceptions: Rio Salado, Percha Creek, Alamosa Creek, Abo Arroyo, Las Animas Creek and Palomas Creek, all of which had available data.
2. 20.6.4.206 NMAC: Rio Felix.
3. 20.6.4.206 NMAC: Perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon with the exception of North Spring river, which does have data.

These exclusions did not undergo any further analysis and are recommended to remain under secondary contact designated use and are reflected as such in the proposed changes under Section IX. All of the remaining waterbodies contained the appropriate data and were further reviewed for pH and *E.coli* criteria numeric values.

SWQB determined that for the appropriate waterbodies all pH data values ranged from 6.6 to 9.0, thus meeting the criterion for primary contact. In addition, all available *E. coli* data contained more than one sample event that fell at or below 410 cfu/100 mL, thus meeting the single sample criterion for primary contact. These findings assert that the select listed waterbodies attain the criteria for primary contact recreational use.

This EUA provides evidence that primary contact is an existing use for most of the waterbodies evaluated. In accordance with 40 C.F.R. § 131.10(i) and 40 C.F.R. § 131.20, SWQB recommends amending the recreational designated uses identified in 20.6.4.103, 20.6.4.116, 20.6.4.204, 20.6.4.206 and 20.6.4.207 NMAC to be no less stringent than the existing recreational use, which attains the fishable/swimmable goals of the CWA. The proposed recreational designated use changes are summarized in Table VIII-1. No changes are proposed for other designated uses (aquatic life, irrigation, livestock watering, wildlife habitat) as a result of this EUA.

Table VIII-1. *Proposed recreational designated use amendments for five WQS segments evaluated as part of this EUA.*

WQS	CURRENT recreational designated use	PROPOSED recreational designated use based on existing use
20.6.4.103	secondary	primary*
20.6.4.116	secondary	primary
20.6.4.204	secondary	primary
20.6.4.206	secondary	primary*
20.6.4.207	secondary	primary

*With the exclusions identified in Section VII, Paragraph D of this EUA.
No changes are proposed for other designated uses (aquatic life, irrigation, livestock watering, wildlife habitat) as a result of this EUA

IX. Amended Water Quality Standards Proposed Language

Based on this EUA, SWQB recommends the following amendments to NMAC as follows:

20.6.4.103 RIO GRANDE BASIN: [~~The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and p~~]Perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties not specifically identified under other sections of 20.6.4 NMAC, excluding waters on tribal lands.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, secondary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[~~**C. Remarks:** flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.~~]

[20.6.4.103 NMAC - Rp 20 NMAC 6.1.2103, 10-12-00; A, 05-23-05; A, 12-01-10]

[NOTE: This segment was divided effective XX/XX/XXXX. The standards for the main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas creek, perennial reaches of Rio Salado, perennial reaches of Percha creek, perennial reaches of Alamosa creek, and perennial reaches of Abo arroyo are under 20.6.4.112 NMAC.]

20.6.4.112 [~~[RESERVED]~~] RIO GRANDE BASIN: The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam, perennial reaches of Palomas creek, perennial reaches of Rio Salado, perennial reaches of Percha creek, perennial reaches of Alamosa creek, and perennial reaches of Abo arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, primary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

C. Remarks: flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.

[20.6.4.112 NMAC - Rp 20 NMAC 6.1.2109, 10/12/2000; A, 5/23/2005; Repealed, 12/1/2010; A, XX/XX/XXXX]

20.6.4.116 RIO GRANDE BASIN: The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.
A. Designated Uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and [~~secondary~~]primary contact.
B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 31°C (87.8°F) or less.
[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, XX/XX/XXXX]

20.6.4.204 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.
A. Designated Uses: irrigation, livestock watering, wildlife habitat, [~~secondary~~]primary contact and warmwater aquatic life.
B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.204 NMAC - Rp 20 NMAC 6.1.2204, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, XX/XX/XXXX]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for Avalon Reservoir are under 20.6.4.219 NMAC.]

20.6.4.206 PECOS RIVER BASIN: [~~The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its~~]Perennial reaches of the Rio Felix and perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon, excluding North Spring river[~~ and perennial reaches of the Rio Felix~~].
A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.
B. Criteria:
(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.
[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10/12/2010; A, 5/23/2005; A, 12/1/2010; A, 3/2/2017; A, XX/XX/XXXX]
[**NOTE:** This segment was divided effective XX/XX/XXXX. The standards for the main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, and perennial reaches of the Rio Hondo are under 20.6.4.231 NMAC.]

20.6.4.207 PECOS RIVER BASIN: The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.
A. Designated Uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and [~~secondary~~]primary contact.

B. Criteria:
(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
(2) At all flows above 50 cfs: TDS 8,000 mg/L or less, sulfate 2,500 mg/L or less and chloride 4,000 mg/L or less.
[20.6.4.207 NMAC - Rp 20 NMAC 6.1.2207, 10/12/2000; A, 5/23/2005; A, 12/1/2010; A, XX/XX/XXXX]

20.6.4.231 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of North Spring river and perennial reaches of the Rio Hondo downstream of Bonney canyon.

A. Designated uses: irrigation, livestock watering, wildlife habitat, primary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[N, XX/XX/XXXX]

X. References

40 Code of Federal Regulations (C.F.R) §131.10 (2019).

Endangered Species Act (ESA), 16 U.S. Code (USC) § 7 (2019).

Federal Water Pollution Control Act (Clean Water Act) 33 U.S.C. 1251 et seq.

Linenfelser, B. (2007). Evaluating waterbody assessment and listing processes: Integration of monitoring and evaluative techniques. Water Environment Research Foundation (WERF). Alexandria, VA. 94 p.

New Mexico Administrative Code (NMAC). 2018. State of New Mexico Standards for Interstate and Intrastate Surface Waters. New Mexico Water Quality Control Commission (WQCC). As amended through September 12, 2018 (20.6.4 NMAC).

New Mexico Environment Department/Surface Water Quality Bureau (NMED/SWQB). 2019. Comprehensive Assessment and Listing Methodology (CALM): Procedures for Assessing water quality standards attainment for the state of New Mexico CWA § 303(d) /§ 305(b) Integrated Report. https://www.env.nm.gov/wp-content/uploads/2017/03/PUBLIC-DRAFT-Main-CALM-190626.pdf

NMED/SWQB. 2019. Standard Operating Procedure (SOP) 2.1 for Field Sampling Plan Development and Execution. https://www.env.nm.gov/wp-content/uploads/sites/25/2017/06/2.1-Field-Sampling-Plans-20190122-Signed.pdf

NMED/SWQB. 2015. SOP 2.1 for Field Sampling Plan Development and Execution.

NMED/SWQB. 2012. SOP 2.1 for Field Sampling Plan Development and Execution.

NMED/SWQB. 2011. SOP 2.1 for Field Sampling Plan Development and Execution.

NMED/SWQB. 2019. SOP 6.1 for Sonde Calibration and Maintenance. https://www.env.nm.gov/surface-water-quality/wp-content/uploads/sites/25/2017/06/6.1-SOP-Sonde-Calibration-and-Maintenance-20210205-approved.pdf

NMED/SWQB. 2016. SOP 6.1 for Sonde Calibration and Maintenance.

NMED/SWQB. 2014. SOP 6.1 for Sonde Calibration and Maintenance.

NMED/SWQB. 2013. SOP 6.1 for Sonde Calibration and Maintenance.

NMED/SWQB. 2012. SOP 6.1 for Sonde Calibration and Maintenance.

NMED/SWQB. 2011. SOP 6.1 for Sonde Calibration and Maintenance.

NMED/SWQB. 2018. SOP 6.2 Sonde Deployment.

https://www.env.nm.gov/wp-content/uploads/sites/25/2017/06/SOP-6-2-Sonde-Deployment-20180718.pdf
NMED/SWQB. 2015. SOP 6.2 Sonde Deployment.

NMED/SWQB. 2014. SOP 6.2 Sonde Deployment.

NMED/SWQB. 2013. SOP 6.2 Sonde Deployment.

NMED/SWQB. 2012. SOP 6.2 Sonde Deployment.

NMED/SWQB. 2011. SOP 6.2 Sonde Deployment.

NMED/SWQB. 2016. SOP 9.1 Bacteriological Sampling and Analysis.

NMED/SWQB. 2013. SOP 9.1 Bacteriological Sampling and Analysis.

NMED/SWQB. 2011. SOP 9.1 Bacteriological Sampling and Analysis.

NMED/SWQB. 2020. SOP 6.4 Long-term Deployment Datalogger Data QA and SQUID Upload Instructions

NMED/SWQB. 2012. SOP 6.4 Long-term Deployment Datalogger Data QA and SQUID Upload Instructions

NMED/SWQB. 2016. SOP 15.0 Data Verification and Validation Procedures.

NMED/SWQB. 2011. SOP 15.0 Data Verification and Validation Procedures.

United States Environmental Protection Agency (USEPA) . 2012. Recreational Water Quality Criteria; Office of Water. Washington, D.C., USA. EPA-OW-2011-0466.

USEPA. 2006. Level III ecoregions of the continental United States (revision of Omernik, 1987): *Corvallis, Oregon, E.P.A. – National Health and Environmental Effects Research Laboratory*, Map M-1, various scales.

USEPA. 1986. EPA's Ambient Water Quality Criteria for Bacteria – 1986. U.S. Environmental Protection Agency: Washington, DC. EPA440/5-84-002.

U.S. Fish and Wildlife Service (USFWS). IPaC Information for Planning and Consultation, 2019. Web. August 17, 2020. Accessed at: https://ecos.fws.gov/ipac/

U.S. Geological Survey (USGS) Earth Resources Observation and Science Center. (2011) The National Land Cover Database. (accessed June 1, 2020 through New Mexico Environment Department Office of Information Technology).

Water Quality Control Commission (WQCC). 2014. WQCC 14-05(R) In the Matter of Proposed Amendments to Standards for Interstate and Intrastate Surface Waters, 20.6.4. NMAC New Mexico Environment Department, Surface Water Quality Bureau's Petition to Amend the Surface Water Quality Standards (20.6.4 NMAC) and Request for Hearing.

WQCC. 2014 (b). WQCC 14-05(R) San Juan Water Commission's Notice of Intent to Present Technical Testimony.

WQCC. 2016. WQCC 14-05(R) In the Matter of the Triennial Review of Standards for Interstate and Intrastate Surface Waters, 20.6.4. NMAC San Juan Water Commission's Exceptions to the Hearing Officer Proposed Statement of Reasons and Final Order and Request that Either the Hearing Officer Issue a Revised Report Setting Forth the Positions of all Triennial Review Participants of the WQCC Strike the Report.

WQCC. 2017. WQCC 14-05(R) In the Matter of Proposed Amendments to Standards for Interstate and Intrastate Surface Waters, 20.6.4. NMAC Statement of Reasons and Final Oder.

Appendix A

Sections omitted from Existing Use Analysis

The following listings were listings were “secondary contact” language was identified. After the listings there is a description of the exclusion’s rationale.

20.6.4.103 RIO GRANDE BASIN - The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties, excluding waters on tribal lands.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life, secondary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

C. Remarks: flow in this reach of the Rio Grande main stem is dependent upon release from Elephant Butte dam.

[20.6.4.103 NMAC - Rp 20 NMAC 6.1.2103, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.116 RIO GRANDE BASIN: The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 31°C (87.8°F) or less.

[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.124 RIO GRANDE BASIN: Perennial reaches of Sulphur creek from its confluence with Redondo creek upstream to its headwaters.

A. Designated Uses: limited aquatic life, wildlife habitat, livestock watering and secondary contact.

B. Criteria: the use-specific criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: pH within the range of 2.0 to 9.0, maximum temperature 30ºC (86ºF), and the chronic aquatic life criteria of Subsections I and J of 20.6.4.900 NMAC.

[20.6.4.124 NMAC - N, 05-23-05; A, 12-01-10]

20.6.4.126 RIO GRANDE BASIN: - Perennial portions of Cañon de Valle from Los Alamos national laboratory (LANL) stream gage E256 upstream to Burning Ground spring, Sandia canyon from Sigma canyon upstream to LANL NPDES outfall 001, Pajarito canyon from Arroyo de La Delfe upstream into Starmers gulch and Starmers spring and Water canyon from Area-A canyon upstream to State Route 501.

A. Designated uses: coldwater aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.126 NMAC - N, 05-23-05; A, 12-01-10]

20.6.4.128 RIO GRANDE BASIN: - Ephemeral and intermittent portions of watercourses within lands managed by U.S. department of energy (DOE) within LANL, including but not limited to: Mortandad canyon, Cañada del Buey, Ancho canyon, Chaquehui canyon, Indio canyon, Fence canyon, Potrillo canyon and portions of Cañon de Valle, Los Alamos canyon, Sandia canyon, Pajarito canyon and Water canyon not specifically identified in 20.6.4.126 NMAC. (Surface waters within lands scheduled for transfer from DOE to tribal, state or local authorities are specifically excluded.)

A. Designated uses: livestock watering, wildlife habitat, limited aquatic life and secondary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: the acute total ammonia criteria set forth in Subsection K of 20.6.4.900 NMAC (salmonids absent). 20.6.4 NMAC 28

[20.6.4.128 NMAC - N, 05-23-05; A, 12-01-10]

20.6.4.204 PECOS RIVER BASIN: - The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

[20.6.4.204 NMAC - Rp 20 NMAC 6.1.2204, 10-12-00; A, 05-23-05; A, 12-01-10]

[**NOTE:** The segment covered by this section was divided effective 05-23-05. The standards for Avalon Reservoir are under 20.6.4.219 NMAC.]

20.6.4.206 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its tributaries downstream of Bonney canyon and perennial reaches of the Rio Felix.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.207 PECOS RIVER BASIN: - The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.

A. Designated Uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and secondary contact.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 8,000 mg/L or less, sulfate 2,500 mg/L or less and chloride 4,000 mg/L or less.

[20.6.4.207 NMAC - Rp 20 NMAC 6.1.2207, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.213 PECOS RIVER BASIN - McAllister lake.

A. Designated Uses: coldwater aquatic life, secondary contact, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 25°C (77°F) or less.

[20.6.4.213 NMAC - Rp 20 NMAC 6.1.2211.3, 10-12-00; A, 05-23-05; A, 12-01-10

20.6.4.219 PECOS RIVER BASIN - Avalon reservoir.

A. Designated Uses: irrigation storage, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses. [20.6.4.219 NMAC - N, 05-23-05; A, 12-01-10
20.6.4.308 CANADIAN RIVER BASIN - Charette lakes. **A. Designated Uses:** coldwater aquatic life, warmwater aquatic life, <u>secondary contact</u>, livestock watering and wildlife habitat. **B. Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses. [20.6.4.308 NMAC - Rp 20 NMAC 6.1.2305.5, 10-12-00; A, 05-23-05; A, 12-01-10

There are lakes and reservoirs that contain a secondary contact designation (section 20.6.4.213, 20.6.4.219, and 20.6.4.308) but SWQB does not have existing use data for these sections to conduct the proposed analysis. It is recommended that these be look at in a separate analysis document to properly determine the change in designation.

Section 20.6.4.124 contains site specific criteria where the pH range is outside the range of the pH range of 6.6 to 9.0, therefore this analysis study is not appropriate for this designated use change. It is recommended that these be look at in a separate analysis document to properly determine the change in designation.

Sections 20.6.4.126 and 20.6.4.128, contain a secondary contact designation but they will be investigated under a separate UAA, as appropriate.

The section review concludes that 20.6.4.103, 20.6.4.116, 20.6.4.204, 20.6.4.206 and 20.6.4.207 are appropriate to review for recreational criteria existing use.

Appendix B

Data sets for *E.coli* and pH from sampling stations relevant to 20.6.4.103 NMAC, 20.6.4.116 NMAC, 20.6.4.204 NMAC, 20.6.4.206 NMAC and 20.6.4.207 NMAC

20.6.4.103 RIO GRANDE BASIN - The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties, excluding waters on tribal lands.

AUs that are part of section 20.6.4.103:

AU ID	AU NAME	WQS
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	20.6.4.103
NM-2103.A_10	Rio Salado (Rio Grande to Alamo Navajo boundary)	20.6.4.103
NM-2103.A_20	Percha Ck (Perennial parts Wicks Gulch to Middle Percha Creek)	20.6.4.103
NM-2103.A_21*	Percha Ck (Perennial part Caballo Rsvr to Wicks Gulch)	20.6.4.103
NM-2103.A_30	Alamosa Creek (Perennial reaches above Monticello diversion)	20.6.4.103
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	20.6.4.103
NM-2103.A_50	Las Animas Ck (perennial part Animas Gulch to headwaters)	20.6.4.103
NM-2103.A_51	Las Animas Ck (perennial part Rio Grande to Animas Gulch)	20.6.4.103
NM-2103.A_60	Palomas Creek (perennial portion Rio Grande to headwaters)	20.6.4.103

*There is no *E. coli* data for NM-2103_21, however upper stream data from NM-2103.A_20 will represent the segment.

E. coli and pH data set for WQS 20.6.4.103:

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand184.1	4/20/2004	20	8.04
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand184.1	5/5/2004	90	NA
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand184.1	6/7/2004	20	NA
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand184.1	7/28/2004	550	NA
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand184.1	8/2/2004	10	NA
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand184.1	9/20/2004	30	NA
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand184.1	11/8/2004	125	NA
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand196.6	3/12/2019	24	7.2
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand196.6	6/18/2019	21	7.3
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand196.6	7/30/2019	15	6.8
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	2/21/2012	16	8.0
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	4/26/2011	22	8.4
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	6/15/2011	4	8.4
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	6/15/2011	15	8.4
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	6/15/2011	8	8.3
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	8/17/2011	74	7.8
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	11/9/2011	25	8.2
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	12/7/2011	18	7.9
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	4/9/2012	16	8.2

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	5/16/2019	8	8.3
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	9/10/2019	22	7.3
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand205.4	10/16/2019	10	8.4
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	4/26/2011	1	8.4
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	6/15/2011	3	8.3
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	8/17/2011	7	7.8
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	11/9/2011	19	8.2
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	4/9/2012	1	8.2
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	5/15/2019	3	8.5
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	6/5/2014	6	8.0
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	5/12/2014	1	8.1
NM-2103.A_00	Rio Grande (Caballo Reservoir to Elephant Butte Reservoir)	41RGrand217.5	10/21/2014	39	8.0
NM-2103.A_10	Rio Salado (Rio Grande to Alamo Navajo bnd)	38RSalad030.0	7/15/2014	1986	7.9
NM-2103.A_10	Rio Salado (Rio Grande to Alamo Navajo bnd)	38RSalad030.0	6/11/2014	326	8.3
NM-2103.A_10	Rio Salado (Rio Grande to Alamo Navajo bnd)	38RSalad030.0	4/29/2014	23	7.9
NM-2103.A_10	Rio Salado (Rio Grande to Alamo Navajo bnd)	38RSalad030.0	10/7/2014	46	8.1
NM-2103.A_20	Percha Ck (Perennial prt Wicks Gulch to Middle Percha Ck)	41Percha025.3	8/16/2011	4	8.0
NM-2103.A_20	Percha Ck (Perennial prt Wicks Gulch to Middle Percha Ck)	41Percha025.3	4/25/2011	5	7.8
NM-2103.A_20	Percha Ck (Perennial prt Wicks Gulch to Middle Percha Ck)	41Percha025.3	11/8/2011	3	7.8
NM-2103.A_20	Percha Ck (Perennial prt Wicks Gulch to Middle Percha Ck)	41Percha025.3	6/18/2019	1	7.6
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	6/24/2004	20	8.2
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	8/2/2004	2300	7.8
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	9/20/2004	100	NA
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	10/19/2004	35	8.1
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	4/25/2011	9	8.5
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	4/25/2011	6	8.5
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	8/16/2011	15	8.0
NM-2103.A_30	Alamosa Creek (Perennial reaches abv Monticello diversion)	40Alamos058.5	11/9/2011	88	8.2
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	9/28/2005	7.3	7.4
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	7/16/2014	1120	8.0
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	6/11/2014	45	8.1
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	3/19/2014	6	8.2
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	4/30/2014	49	7.9
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	5/12/2014	272	7.2
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	9/2/2014	1414	8.0
NM-2103.A_40	Abo Arroyo (Rio Grande to headwaters)	32AboArr037.7	8/12/2014	65	7.8

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2103.A_50	Las Animas Ck (perennial prt Animas Gulch to headwaters)	41LAnima029.3	4/26/2011	18	7.5
NM-2103.A_50	Las Animas Ck (perennial prt Animas Gulch to headwaters)	41LAnima029.3	8/17/2011	44	7.5
NM-2103.A_50	Las Animas Ck (perennial prt Animas Gulch to headwaters)	41LAnima029.3	11/8/2011	23	7.6
NM-2103.A_51	Las Animas Ck (perennial prt R Grande to Animas Gulch)	41LAnima009.0	3/12/2019	81	8.2
NM-2103.A_51	Las Animas Ck (perennial prt R Grande to Animas Gulch)	41LAnima009.0	6/18/2019	727	8.5
NM-2103.A_51	Las Animas Ck (perennial prt R Grande to Animas Gulch)	41LAnima018.6	4/26/2011	51	7.4
NM-2103.A_51	Las Animas Ck (perennial prt R Grande to Animas Gulch)	41LAnima018.6	8/17/2011	196	7.3
NM-2103.A_51	Las Animas Ck (perennial prt R Grande to Animas Gulch)	41LAnima018.6	11/8/2011	45	7.6
NM-2103.A_60	Palomas Creek (perennial portion R Grande to N and S Forks)	41Paloma036.7	8/16/2004	15750	NA
NM-2103.A_60	Palomas Creek (perennial portion R Grande to N and S Forks)	41Paloma036.7	9/20/2004	10	NA
NM-2103.A_60	Palomas Creek (perennial portion R Grande to N and S Forks)	41SPalom000.1	4/26/2011	30	8.0
NM-2103.A_60	Palomas Creek (perennial portion R Grande to N and S Forks)	41SPalom000.1	8/17/2011	110	7.9
NM-2103.A_60	Palomas Creek (perennial portion R Grande to N and S Forks)	41SPalom000.1	11/8/2011	16	7.8
NM-2103.A_60	Palomas Creek (perennial portion R Grande to N and S Forks)	41SPalom019.1	4/25/2011	10	7.8

20.6.4.116 RIO GRANDE BASIN: The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.

A. Designated Uses: irrigation, livestock watering, wildlife habitat, coldwater aquatic life, warmwater aquatic life and secondary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 31°C (87.8°F) or less.

[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10-12-00; A, 05-23-05; A, 12-01-10]

AUs that are part of section 20.6.4.116:

AU ID	AU NAME	WQS
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	20.6.4.116
NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	20.6.4.116
NM-2113_11*	Rio Ojo Caliente (Rio Chama to Arroyo El Rito)*	20.6.4.116
NM-2113_30	Rio Tusas (Perennial prt Rio Vallecitos to headwaters)	20.6.4.116
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	20.6.4.116
NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	20.6.4.116

* AU was not assessed but segment does have data points either upstream or downstream that where utilized as per segment.

E. coli and pH data set for WQS 20.6.4.116:

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama050.4	8/28/2012	1	8.0
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	NM0024830	8/23/2012	1	8.0
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	NM0024830	9/13/2012	6	7.4
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	NM0024830	11/1/2012	11	7.5
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	5/22/2012	16	8.2
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	7/26/2012	23	8.9
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	10/31/2012	23	8.4
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	8/15/2012	25	8.4
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	6/28/2012	28	8.7
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	4/26/2012	29	8.2
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	NM0024830	9/27/2012	53	no value
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	9/18/2012	61	8.3
NM-2113_00	Rio Chama (Ohkay Owingeh to Abiquiu Dam)	29RChama038.3	9/13/2012	921	8.4
NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	29ROjoCa026.1	5/31/2012	15	8.5
NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	29ROjoCa026.1	11/1/2012	36	8.4
NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	29ROjoCa026.1	6/27/2012	50	8.3
NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	29ROjoCa026.1	4/26/2012	57	8.1
NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	29ROjoCa026.1	8/15/2012	60	8.0
NM-2113_10	Rio Ojo Caliente (Arroyo El Rito to Rio Vallecitos)	29ROjoCa026.1	9/13/2012	980	8.4
NM-2113_30	Rio Tusas (Perennial prt Rio Vallecitos to headwaters)	29RTusas001.9	8/15/2012	67	8.6
NM-2113_30	Rio Tusas (Perennial prt Rio Vallecitos to headwaters)	29RTusas001.0	5/22/2012	93	7.7
NM-2113_30	Rio Tusas (Perennial prt Rio Vallecitos to headwaters)	29RTusas001.0	6/27/2012	153	8.2
NM-2113_30	Rio Tusas (Perennial prt Rio Vallecitos to headwaters)	29RTusas001.0	4/26/2012	488	8.2
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	29ElRito008.6	4/26/2012	55	8.2
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	29ElRito008.6	5/22/2012	91	8.0
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	29ElRito008.6	6/27/2012	153	7.8
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	29ElRito008.6	7/26/2012	261	7.9
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	29ElRito008.6	11/1/2012	345	7.5
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	29ElRito008.6	8/15/2012	411	7.4
NM-2113_40	El Rito Creek (Perennial reaches below HWY 554)	29ElRito008.6	9/13/2012	770	8.2
NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	29Abiqui001.8	4/24/2012	13	7.8
NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	29Abiqui001.8	5/29/2012	17	8.0
NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	29Abiqui001.8	10/31/2012	29	8.1
NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	29Abiqui001.8	6/28/2012	115	8.2
NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	29Abiqui001.8	8/15/2012	727	8.3
NM-2113_50	Abiquiu Creek (Rio Chama to headwaters)	29Abiqui001.8	7/24/2012	1120	8.5

20.6.4.204 PECOS RIVER BASIN: - The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.
A. Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.
B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.204 NMAC - Rp 20 NMAC 6.1.2204, 10-12-00; A, 05-23-05; A, 12-01-10]
[**NOTE:** The segment covered by this section was divided effective 05-23-05. The standards for Avalon Reservoir are under 20.6.4.219 NMAC.]

AUs that are part of section 20.6.4.204:

AU ID	AU NAME	WQS
NM-2204.A_00	Pecos River (Avalon Reservoir to Brantley Reservoir)	20.6.4.204

E. coli and pH data set for WQS 20.6.4.204:

AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2204.A_00	60PecosR123.1	7/9/2013	8.5	7.59
NM-2204.A_00	60PecosR123.1	3/27/2013	12	8.27
NM-2204.A_00	60PecosR123.1	9/25/2013	13.4	7.35
NM-2204.A_00	60PecosR123.1	2/20/2013	14.6	no data
NM-2204.A_00	60PecosR123.1	6/5/2013	17.3	8.01
NM-2204.A_00	60PecosR123.1	4/30/2013	38.9	7.57
NM-2204.A_00	60PecosR123.1	8/13/2013	770.1	8.15
NM-2204.A_00	60PecosR123.1	11/13/2013	no data	8.22
NM-2204.A_00	60PecosR123.1	4/16/2015	no data	8.08

20.6.4.206 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its tributaries downstream of Bonney canyon and perennial reaches of the Rio Felix.
A. Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.
B. Criteria:
(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.
[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10-12-00; A, 05-23-05; A, 12-01-10]

AUs that are part of section 20.6.4.206:

AU ID	AU NAME	WQS
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	20.6.4.206
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	20.6.4.206
NM-2206.A_02	Pecos River (Rio Penasco to Eagle Creek)	20.6.4.206
NM-2206.A_03	Pecos River (Eagle Creek to Rio Felix)	20.6.4.206
NM-2206.A_10	Rio Penasco (Perennial part Pecos River to HWY 24)	20.6.4.206
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	20.6.4.206
NM-2206.A_30	Rio Felix (Perennial reaches Pecos River to headwaters)	20.6.4.206
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	20.6.4.206
NM-2208_25	Rio Hondo (Perennial part North Spring River to Bonney Canyon)	20.6.4.206
NM-2208_26	Rio Hondo (Perennial part Pecos River to North Spring River)	20.6.4.206

E. coli and pH data set for WQS 20.6.4.206:

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	2/20/2013	1	no data
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	4/29/2013	1	7.9
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	7/9/2013	12	8.0
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	4/29/2013	13	7.8
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	7/9/2013	19	8.1
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	10/30/2013	25	7.7
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	2/20/2013	29	no data
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	10/31/2013	37	7.9
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	9/25/2013	119	7.4
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	9/26/2013	214	8.0
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	3/19/2013	228	7.8
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	3/19/2013	248	7.9
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	8/13/2013	365	7.9
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR239.9	6/4/2013	548	7.7
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	6/5/2013	980	7.9
NM-2206.A_00	Pecos River (Rio Felix to Rio Hondo)	56PecosR262.6	8/13/2013	1553	8.1
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	60PecosR134.3	4/29/2013	2	7.8
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	60PecosR134.3	3/26/2013	7	8.4
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	60PecosR134.3	2/20/2013	10	no data
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	60PecosR134.3	7/10/2013	48	7.9
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	60PecosR134.3	9/25/2013	61	7.4
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	60PecosR134.3	6/6/2013	129	8.4

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2206.A_01	Pecos River (Brantley Reservoir to Rio Penasco)	60PecosR134.3	8/13/2013	770	7.8
NM-2206.A_02	Pecos River (Rio Penasco to Eagle Creek)	56PecosR169.0	1/23/2013	1	8.2
NM-2206.A_02	Pecos River (Rio Penasco to Eagle Creek)	56PecosR169.0	2/20/2013	3	no data
NM-2206.A_02	Pecos River (Rio Penasco to Eagle Creek)	56PecosR169.0	12/17/2013	3	7.9
NM-2206.A_03	Pecos River (Eagle Creek to Rio Felix)	56PecosR176.2	12/17/2013	1	7.6
NM-2206.A_03	Pecos River (Eagle Creek to Rio Felix)	56PecosR176.2	1/23/2013	3	6.7
NM-2206.A_10	Rio Penasco (Perennial prt Pecos River to HWY 24)	59RPenas090.0	4/5/2012	1	8.4
NM-2206.A_10	Rio Penasco (Perennial prt Pecos River to HWY 24)	59RPenas090.0	10/10/2012	7	8.1
NM-2206.A_10	Rio Penasco (Perennial prt Pecos River to HWY 24)	59RPenas090.0	5/10/2012	19	8.4
NM-2206.A_10	Rio Penasco (Perennial prt Pecos River to HWY 24)	59RPenas090.0	8/8/2012	96	8.4
NM-2206.A_10	Rio Penasco (Perennial prt Pecos River to HWY 24)	59RPenas090.0	7/26/2012	140	8.4
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	2/20/2013	2	no data
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	4/29/2013	2	7.8
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	7/9/2013	19	8.1
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	10/31/2013	30	7.1
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	9/26/2013	137	8.0
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	3/19/2013	185	8.0
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	8/14/2013	488	8.5
NM-2206.A_20	Pecos River (Rio Hondo to Salt Creek)	56PecosR273.0	6/5/2013	1553	7.3
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin002.0	2/21/2013	23	no data
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin003.4	2/21/2013	36	no data
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin003.4	7/9/2013	52	7.6
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin002.0	7/9/2013	60	8.0
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin002.0	6/5/2013	118	7.8
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin002.0	9/26/2013	155	8.0
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin003.4	4/29/2013	172	8.1
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin003.4	6/5/2013	186	7.7
NM-2206.A_40	North Spring River (Rio Hondo to headwaters)	57NSprin002.0	4/29/2013	1733	7.6
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo000.5	4/29/2013	3	7.5
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo000.5	6/5/2013	14	6.9
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo011.5	1/23/2013	16	7.4
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo004.3	10/31/2013	17	7.7
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo000.5	10/31/2013	36	7.6
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo011.5	12/17/2013	37	7.6
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo004.3	6/5/2013	50	7.2
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	NM0020311	1/23/2013	69	7.5

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo010.6	12/17/2013	87	7.6
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo010.6	1/23/2013	96	7.5
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo000.5	7/9/2013	162	7.5
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo000.5	9/26/2013	167	7.5
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo000.5	2/20/2013	461	no data
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo000.5	8/14/2013	517	7.7
NM-2208_26	Rio Hondo (Perennial prt Pecos R to North Spring R)	57RHondo004.3	8/14/2013	649	8.1
NM-2208_30	Rio Hondo (Perennial prt Pecos R to North Spring R)	NM0020315	12/17/2013	90	no data

20.6.4.207 PECOS RIVER BASIN: - The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.
A. Designated Uses: irrigation, marginal warmwater aquatic life, livestock watering, wildlife habitat and secondary contact.
B. Criteria:
(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
(2) At all flows above 50 cfs: TDS 8,000 mg/L or less, sulfate 2,500 mg/L or less and chloride 4,000 mg/L or less.
[20.6.4.207 NMAC - Rp 20 NMAC 6.1.2207, 10-12-00; A, 05-23-05; A, 12-01-10]

AUs that are part of section 20.6.4.207:

AU ID	AU NAME	WQS
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	20.6.4.207
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	20.6.4.207
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	20.6.4.207
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	20.6.4.207

E. coli and pH data set for WQS 20.6.4.207:

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	52PecosR305.0	4/29/2013	3	8.1
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	52PecosR305.0	2/21/2013	6	no data
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	52PecosR305.0	10/31/2013	9	7.7
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	52PecosR305.0	7/9/2013	20	8.1
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	52PecosR305.0	9/26/2013	96	7.8
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	52PecosR305.0	3/19/2013	118	8.0
NM-2207_00	Pecos River (Salt Creek to Crockett Draw)	52PecosR305.0	8/14/2013	613	8.6
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	52PecosR343.0	10/16/2013	6	8.3

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	52PecosR343.0	4/24/2013	8	7.9
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	52PecosR343.0	2/21/2013	13	no data
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	52PecosR343.0	9/10/2013	17	7.4
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	52PecosR343.0	8/7/2013	23	7.9
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	52PecosR343.0	3/15/2013	1120	7.5
NM-2207_01	Pecos River (Crockett Draw to Yeso Creek)	52PecosR343.0	5/28/2013	1553	8.2
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	4/24/2013	3	7.8
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.8	2/21/2013	3	no data
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	2/21/2013	5	no data
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	5/28/2013	6	8.0
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.8	5/28/2013	6	7.9
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	8/7/2013	8	8.0
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.8	4/24/2013	9	7.7
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	8/7/2013	17	8.0
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	3/15/2013	20	7.5
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	8/7/2013	74	8.0
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	9/10/2013	75	7.3
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	2/21/2013	127	no data
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.8	8/7/2013	157	8.0
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.8	10/8/2013	365	7.8
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	10/8/2013	387	7.9
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	7/2/2013	411	7.7
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.7	9/10/2013	411	7.5
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	52PecosR447.8	9/10/2013	727	7.3
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	7/2/2013	866	7.5
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	10/8/2013	866	7.7
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	5/28/2013	1120	7.6
NM-2207_02	Pecos River (Yeso Creek to Truchas Creek)	NM0023477	4/24/2013	1414	7.4
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	3/15/2013	1	7.8
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	4/24/2013	1	8.0
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	8/6/2019	1	8.0
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	8/7/2013	2	8.2
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	9/10/2013	2	7.7
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	10/9/2019	2	8.2
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	10/8/2013	5	8.1
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	5/28/2013	7	8.2

AU ID	AU NAME	STATION_ID	DATE	*E. coli* cfu/100 mL	pH
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	7/2/2013	11	8.0
NM-2207_03	Pecos River (Truchas Creek to Sumner Reservoir)	52PecosR485.0	2/21/2013	15	no data

Appendix C

US Fish and Wildlife Service Environmental Conservation Online System Information for Planning and Consultation (IPaC) geographical area delineations for species evaluation.

C-1. 20.6.4.103 RIO GRANDE BASIN

The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam and perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties, excluding waters on tribal lands.

IPaC delineation description and image of IPaC delineations for section 20.6.4.103

“The main stem of the Rio Grande from the headwaters of Caballo reservoir upstream to Elephant Butte dam”:

Rio Grande- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; Caballo Reservoir to Elephant Butte dam.

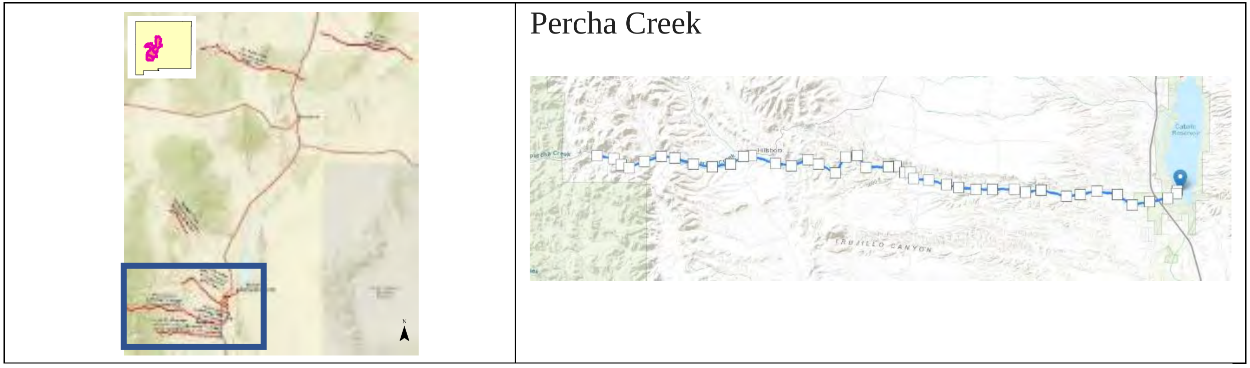
Figure C-1.1. Delineation maps for: Rio Grande

	Rio Grande 

“perennial reaches of tributaries to the Rio Grande in Sierra and Socorro counties” :

Percha Creek- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; the confluence of South Percha Creek to Percha Creek to Caballo Reservoir.

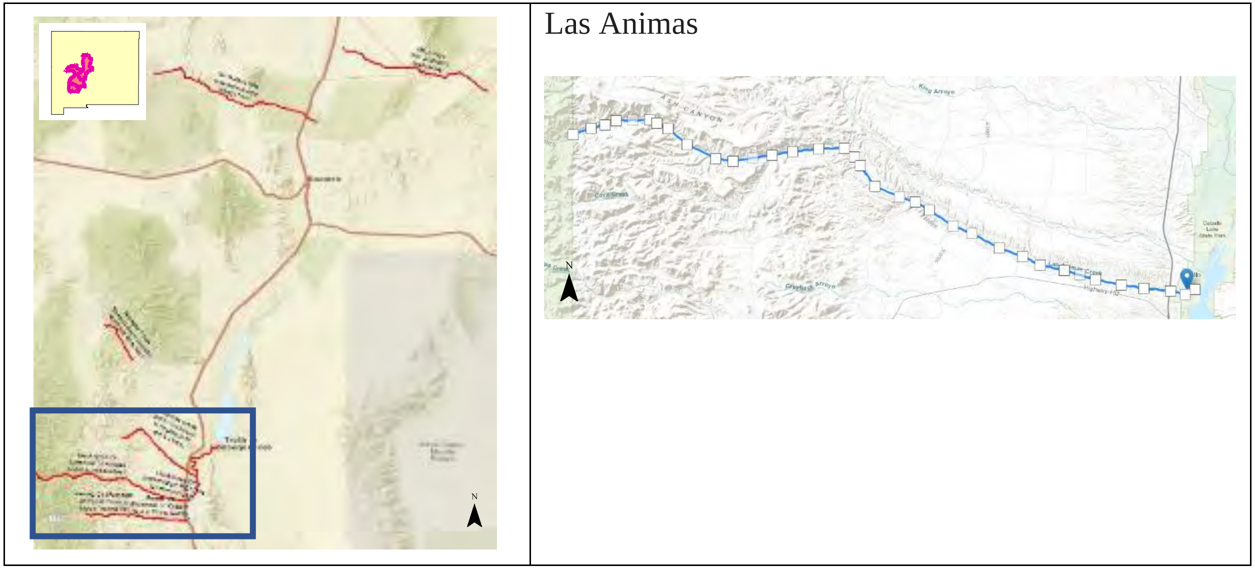
Figure C-1.2. Delineation maps for: Percha Creek



Percha Creek

Las Animas- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; Las Animas headwaters to Caballo Reservoir.

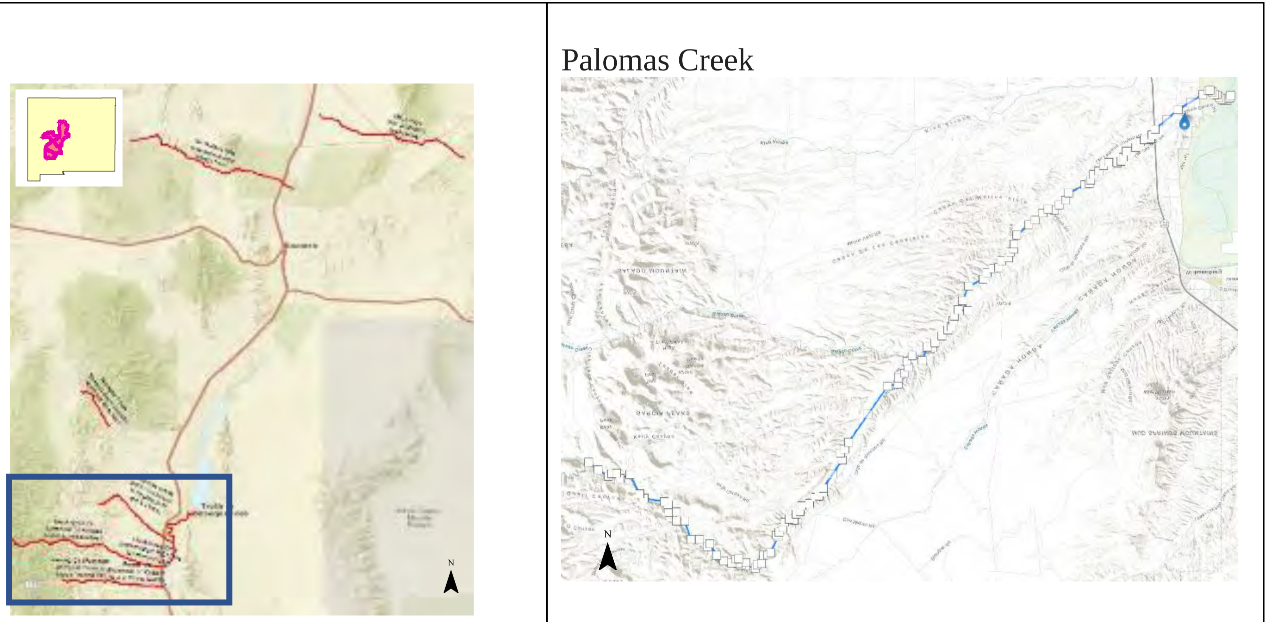
Figure C-1.3. Delineation maps for: Las Animas



Las Animas

Las Palomas- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; the confluence of North and Southfork downstream along Las Palomas to the Rio Grande.

Figure C-1.4. Delineation maps for: Palomas Creek.

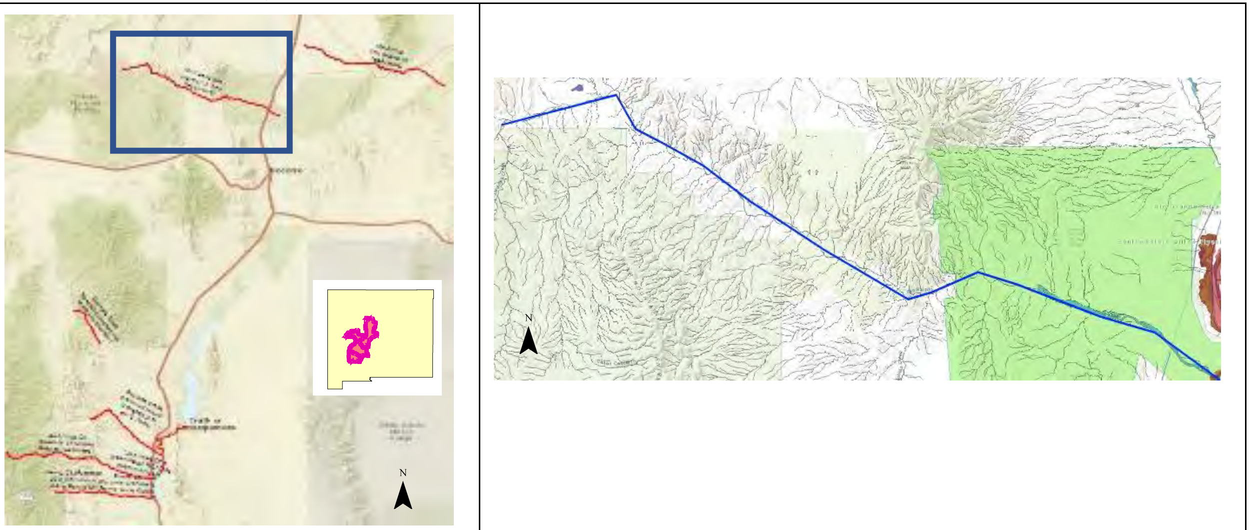

Palomas Creek

Alamosa Creek- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; where Forest Road meets State road 52 to Monticello diversion.

Figure C-1.5. Delineation maps for: Alamosa Creek.

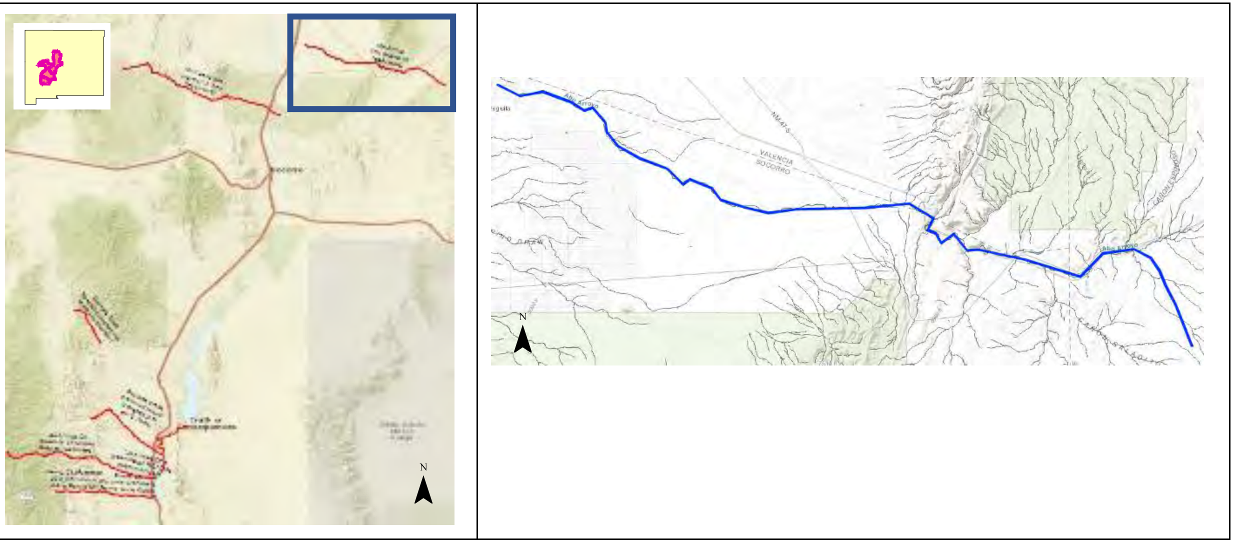
Rio Salado- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; Alamo Navajo boundary along Rio Salado to Rio Grande.

Figure C-1.6. Delineation maps for: Rio Salado



Abo Arroyo- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; from Abo headwaters to the Rio Grande.

Figure C-1.7. Delineation maps for: Abo Arroyo



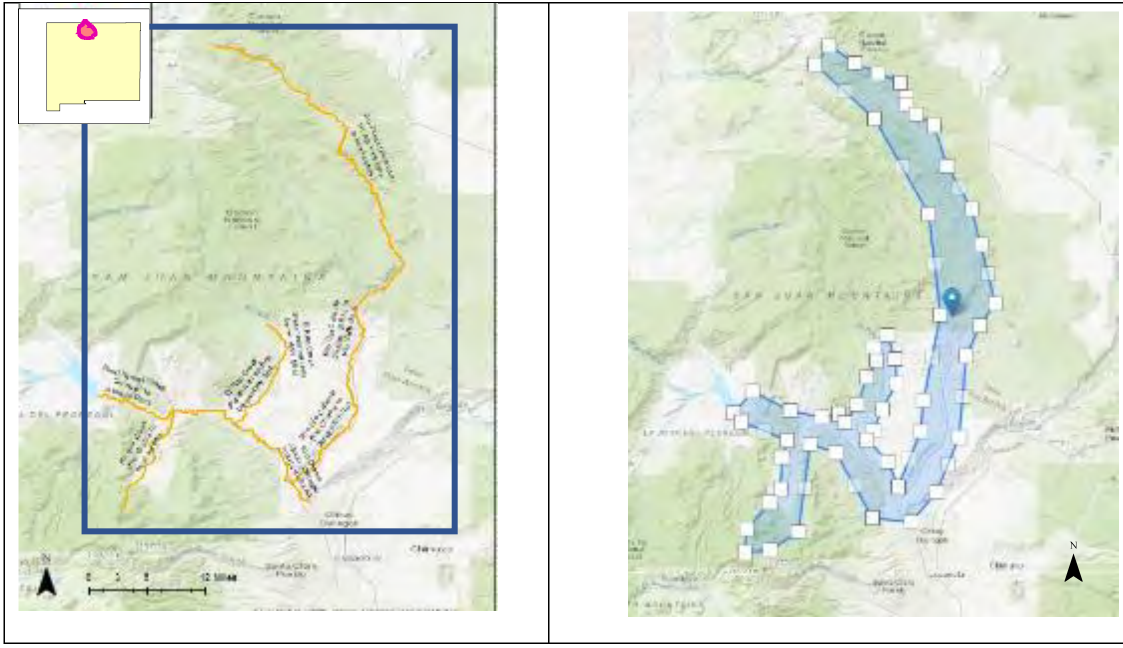
C-2. 20.6.4.116 RIO GRANDE BASIN

The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek and perennial reaches of El Rito creek downstream of the town of El Rito.

IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.116

Abo Arroyo- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; from Abo headwaters to the Rio Grande.

Figure C-2.1. Delineation maps for: Rio Tusas, Rio Ojo Caliente, El Rito Creek, Rio Chama, Abiquiu Creek.



C-3. 20.6.4.204 PECOS RIVER BASIN

The main stem of the Pecos river from the headwaters of Avalon reservoir upstream to Brantley dam.

IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.204

Abo Arroyo- To determine if any species of concern are within the study area, a line with a 200 ft buffer zone was manually drawn from; Brantley Lake, along the Pecos River to Lake Avalon.

Figure C-3.1. Delineation maps for: Pecos River (Avalon reservoir upstream to Brantley dam)

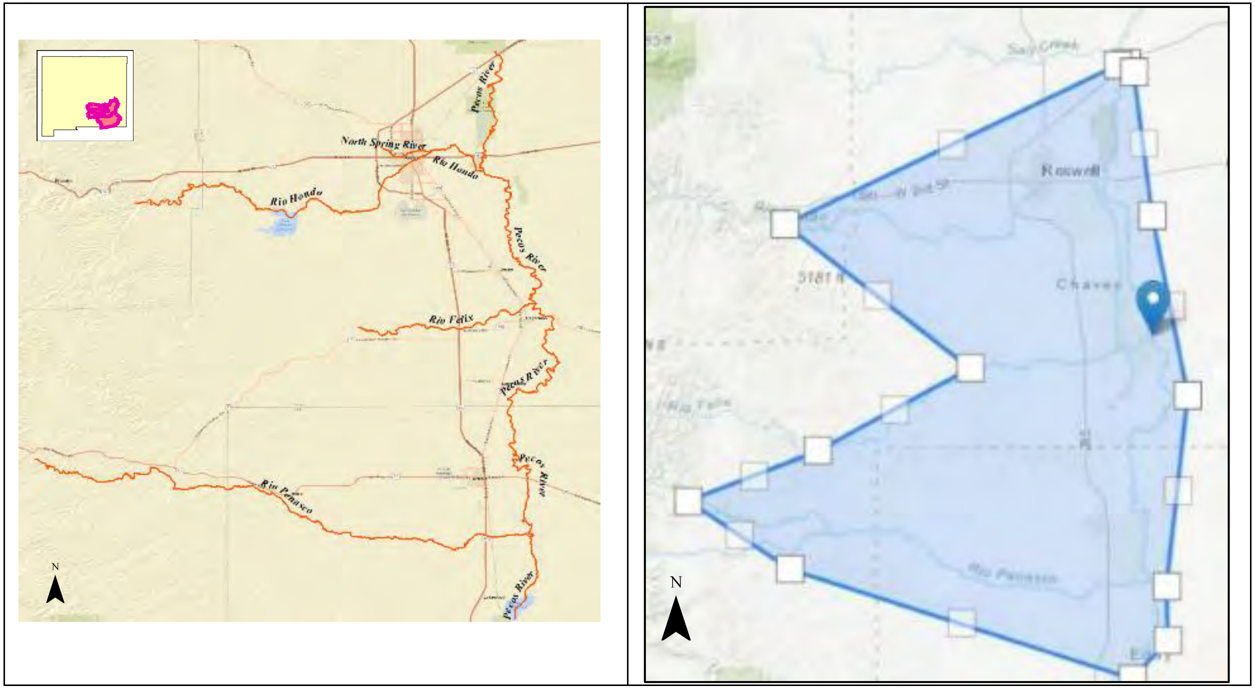
C-4. 20.6.4.206 PECOS RIVER BASIN

The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its tributaries downstream of Bonney canyon and perennial reaches of the Rio Felix.

IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.206

To determine if any species of concern are within the study area, a polygon was manually drawn from; Pecos river at Salt Creek southwest to Rio Hondo at Bonney Canyon, then southeast to Rio Felix at Old Y O Crossing Road off Sagebrush Valley Road, then southwest to Rio Penasco at Rio Penasco Road at Dunken Route, then southeast to Pecos river at Brantley Reservoir, then north along the Pecos River up to Salt Creek.

Figure C-4.1. Delineation maps for: Pecos River, North Spring River, Rio Hondo, Rio Felix, Rio Penasco.



C-5. 20.6.4.207 PECOS RIVER BASIN

The main stem of the Pecos river from Salt creek (near Acme) upstream to Sumner dam.

IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.207

To determine if any species of concern are within the study area, a line with a 500 ft buffer zone was manually drawn from; Sumner Reservoir downstream along the Pecos River to confluence with Salt Creek.

Figure C-5.1. Delineation maps for: Pecos River

From: Becker, Kathryn, NMENV
To: Fullam, Jennifer, NMENV
Subject: FW: Proposed amendments to the State"s Standards for Interstate and Intrastate Surface Waters
Date: Thursday, April 15, 2021 12:58:35 PM
Attachments: image002.png

From: Becker, Kathryn, NMENV
Sent: Friday, January 29, 2021 12:18 AM
To: Aranda, Diana, NMENV <Diana.Aranda@state.nm.us>
Subject: FW: Proposed amendments to the State's Standards for Interstate and Intrastate Surface Waters

For your records, as requested.

From: Becker, Kathryn, NMENV
Sent: Thursday, January 28, 2021 2:24 PM
To: Adam Duran <aduran@pojoaque.org>; Alan Hatch <alan.hatch@santaana-nsn.gov>; Cameron Martinez <cmartinez@taospueblo.com>; Cordell TeCube <cltecube@yahoo.com>; Cynthia Naha <cnaha@kewa-nsn.us>; Dino Chavarria <dinoc@santaclarapueblo.org>; DMartinez <dmartinez@poamail.org>; Erin Martinez <eymartinez@sanipueblo.org>; Evaristo A. Cruz <ecruz@ydsp-nsn.gov>; Franklin Martinez <fmartinez@puebloofacoma.org>; Glenn Tortalita <GTortalita@ziapueblo.org>; Gregory Jojola <gjojola@lagunapueblo-nsn.gov>; Jacob Pecos <jacob_pecos@pueblodecochiti.org>; Jennifer Heminokeky <jennifer.heminokeky@fortsillapache-nsn.gov>; Jesse Young <jyoung@ziapueblo.org>; Karmen Badoni <karmen@enipc.org>; Keith Manwell <kcmanwell@yahoo.com>; Larry Phillips, Jr. <larry.phillips@ohkay.org>; Manuel Vigil <mvigil@taospueblo.com>; Margaret Chavez <mchavez@enipc.org>; Naomi Archuleta <naomi.archuleta@ohkay.org>; Paul Clark <paul.clarke@jemezpueblo.org>; Pauline Electric Warrior <electricwarriorpk@yahoo.com>; Pinu'u Sout <pstout@sfpueblo.com>; Pueblo of Picuris Env. Admin <administrativeassistantppe@picurispueblo.org>; Pueblo of Picuris Environment <environment@picurispueblo.org>; Ramona Montoya <ramona.montoya@isletapueblo.com>; Raymond Martinez <rmartinez@sanipueblo.org>; Ruben Lucero <ruben.lucero@isletapueblo.com>; Ryan Swazo-Hinds <rswazohinds@pueblooftesuque.org>; Shannon Tenorio <administrator@picurispueblo.org>; Ronnie Ben <ronnieben@navajo-nsn.gov>; Greg Kaufman <gkaufman@sandiapueblo.nsn.us>; Sophie Stauffer <sstauffer@pueblooftesuque.org>; Steve Rydeen <srydeen@nambepueblo.org>; Steven Etter <setter@lagunapueblo-nsn.gov>; Tammy Belone <tammy.belone@jemezpueblo.org>; Tammy Parker <tammy.parker@ashiwi.org>; Thora Padilla <thora@mescalerodrmp.org>; Valinda Shirley <valinda.shirley@navajo-nsn.gov>; Victoria Atencio <victoria.atencio@santaana-nsn.gov>; Wayne Yazzie <lt.governor@picurispueblo.org>
Subject: Proposed amendments to the State's Standards for Interstate and Intrastate Surface Waters

Good afternoon,

Previously I sent out information and notice for involvement in the NM Environment Department's Triennial Review, and now NMED is considering amendments for you to consider. In particular,

NMED Exhibit 57

NMED is proposing an amendment to increase stringency for recreational protections by changing water quality standards from secondary contact to primary contact on a couple of tributaries that cross into tribal waters. Below is a summary of the amendments and the point of contact, Jennifer Fullam. Please do not hesitate to reach out to her with any questions about this proposed amendment.
Best,

Kathryn S. Becker
Assistant General Counsel
Tribal Liaison
New Mexico Environment Department
Office of General Counsel
P.O. Box 5469
Santa Fe, NM 87502-5469
Phone: 505-827-2054
kathryn.becker@state.nm.us
www.env.nm.gov

The New Mexico Environment Department's ("NMED" or "Department") Surface Water Quality Bureau ("SWQB") is currently proposing changes to the designated recreational use in several waterbodies including the Rio Salado and the Rio Chama as part of the Triennial Review of the State's *Standards for Interstate and Intrastate Surface Waters*, 20.6.4 New Mexico Administrative Code ("NMAC"). The proposed amendment would change the designated recreational use from secondary contact to primary contact, which would change the *E.coli* single sample criterion from 2507 cfu/100 mL to 410 cfu/100 mL and the *E.coli* monthly geometric mean criterion from 548 cfu/100 mL to 126 cfu/100 mL. If the proposed amendment is approved by the Water Quality Control Commission ("WQCC") as part of the upcoming Triennial Review, the applicable *E.coli* bacteria criteria would be more stringent than it currently is under the State's Standards 20.6.4 NMAC.

The State recognizes Section 518(e)(2) of the Clean Water Act that provides the U.S. Environmental Protection Agency ("EPA") authority "to treat an Indian tribe as a State" for the purposes of management and protection of water resources. The State further recognizes EPA's approval of tribal water quality standards for purposes of the Clean Water Act and is therefore soliciting input from potentially affected tribes on these proposed amendments for the waterbodies which cross over state and tribal jurisdictional boundaries.

The Department would like to extend an invitation to answer any questions you may have regarding the proposed amendments. If interested, please contact Diana Aranda, Environmental Scientist Specialist-Advanced, by phone at (505) 946-8666 or by email at Diana.Aranda@state.nm.us. Please keep in mind that due to the restrictions currently in place by the Governor's Executive Orders and various emergency public health orders designed to protect the public and prevent the spread of the Novel Coronavirus Disease – 2019 (COVID-19), all communication at this time will take place remotely.

Your interest in this process is greatly appreciated and we look forward to discussing any comments or questions you may have.

Thank you.

Jennifer Fullam
Standards, Planning & Reporting Team Leader
Surface Water Quality Bureau
New Mexico Environment Department
1190 S. St. Francis Dr.
Santa Fe, NM 87505
*Phone: 505.946.8954
jennifer.fullam@state.nm.us

****PLEASE NOTE NEW PHONE NUMBER***

“Innovation, Science, Collaboration, Compliance”

From: Becker, Kathryn, NMENV
To: Fullam, Jennifer, NMENV
Subject: FW: Proposed amendments to the State"s Standards for Interstate and Intrastate Surface Waters
Date: Thursday, April 15, 2021 12:58:25 PM
Attachments: image002.png

From: Becker, Kathryn, NMENV
Sent: Friday, January 29, 2021 12:18 AM
To: Aranda, Diana, NMENV <Diana.Aranda@state.nm.us>
Subject: FW: Proposed amendments to the State's Standards for Interstate and Intrastate Surface Waters

Part 2, because two addresses had to be corrected. For your records, as requested.

From: Becker, Kathryn, NMENV
Sent: Thursday, January 28, 2021 3:13 PM
To: Greg Kaufman <gkaufman@sandiapueblo.nsn.us>; Franklin Martinez (fmartinez@poamail.org) <fmartinez@poamail.org>
Subject: Proposed amendments to the State's Standards for Interstate and Intrastate Surface Waters

Good afternoon,

Previously I sent out information and notice for involvement in the NM Environment Department's Triennial Review, and now NMED is considering amendments for you to consider. In particular, NMED is proposing an amendment to increase stringency for recreational protections by changing water quality standards from secondary contact to primary contact on a couple of tributaries that cross into tribal waters. Below is a summary of the amendments and the point of contact, Jennifer Fullam. Please do not hesitate to reach out to her with any questions about this proposed amendment.
Best,

Kathryn S. Becker
Assistant General Counsel
Tribal Liaison
New Mexico Environment Department
Office of General Counsel
P.O. Box 5469
Santa Fe, NM 87502-5469
Phone: 505-827-2054
kathryn.becker@state.nm.us
www.env.nm.gov

The New Mexico Environment Department's ("NMED" or "Department") Surface Water Quality Bureau ("SWQB") is currently proposing changes to the designated recreational use in several waterbodies including the Rio Salado and the Rio Chama as part of the Triennial Review of the State's *Standards for Interstate and Intrastate Surface Waters*, 20.6.4 New Mexico Administrative Code ("NMAC"). The proposed amendment would change the designated recreational use from secondary contact to primary contact, which would change the *E.coli* single sample criterion from 2507 cfu/100 mL to 410 cfu/100 mL and the *E.coli* monthly geometric mean criterion from 548 cfu/100 mL to 126 cfu/100 mL. If the proposed amendment is approved by the Water Quality Control Commission ("WQCC") as part of the upcoming Triennial Review, the applicable *E.coli* bacteria criteria would be more stringent than it currently is under the State's Standards 20.6.4 NMAC.

The State recognizes Section 518(e)(2) of the Clean Water Act that provides the U.S. Environmental Protection Agency ("EPA") authority "to treat an Indian tribe as a State" for the purposes of management and protection of water resources. The State further recognizes EPA's approval of tribal water quality standards for purposes of the Clean Water Act and is therefore soliciting input from potentially affected tribes on these proposed amendments for the waterbodies which cross over state and tribal jurisdictional boundaries.

The Department would like to extend an invitation to answer any questions you may have regarding the proposed amendments. If interested, please contact Diana Aranda, Environmental Scientist Specialist-Advanced, by phone at (505) 946-8666 or by email at Diana.Aranda@state.nm.us. Please keep in mind that due to the restrictions currently in place by the Governor's Executive Orders and various emergency public health orders designed to protect the public and prevent the spread of the Novel Coronavirus Disease – 2019 (COVID-19), all communication at this time will take place remotely.

Your interest in this process is greatly appreciated and we look forward to discussing any comments or questions you may have.

Thank you.

Jennifer Fullam
Standards, Planning & Reporting Team Leader
Surface Water Quality Bureau
New Mexico Environment Department
1190 S. St. Francis Dr.
Santa Fe, NM 87505
*Phone: 505.946.8954
jennifer.fullam@state.nm.us

****PLEASE NOTE NEW PHONE NUMBER***

"Innovation, Science, Collaboration, Compliance"

From: Fullam, Jennifer, NMENV
To: Aranda, Diana, NMENV
Bcc: "phernandez@artesianm.gov"; "jcox@artesianm.gov"; "fscityhallmayor@plateautel.net"; "fswwtp37@yahoo.com"; "mmadrid@torcnm.org"; "jcole@torcnm.org"; "a.valadez@roswell-nm.gov"; Cooney, Barbara, NMENV; Holcomb, Sarah, NMENV; LucasKamat, Susan, NMENV; Lemon, Shelly, NMENV; Barrios, Kristopher, NMENV; Verheul, John, NMENV; Maxfield, Annie, NMENV
Subject: Stakeholder Outreach Regarding Proposed Amendments to Recreational Uses for Water Quality Standards
Date: Wednesday, January 20, 2021 2:48:00 PM
Attachments: image002.png

Good afternoon,

The New Mexico Environment Department's ("NMED" or "Department") Surface Water Quality Bureau ("SWQB") is currently proposing changes to the designated recreational use in several waterbodies, as part of the Triennial Review of the State's *Standards for Interstate and Intrastate Surface Waters*, 20.6.4 New Mexico Administrative Code ("NMAC"). The proposed amendment would change the designated recreational use from secondary contact to primary contact, which would change the *E.coli* single sample criterion from 2,507 cfu/100 mL to 410 cfu/100 mL and the *E.coli* monthly geometric mean criterion from 548 cfu/100 mL to 126 cfu/100 mL. If the proposed amendment is approved by the Water Quality Control Commission ("WQCC") as part of the upcoming Triennial Review, the applicable *E.coli* bacteria criteria would be more stringent than it currently is under the State's Standards 20.6.4 NMAC.

You have been identified as a stakeholder because your facility discharges to one of the waterbodies under consideration for amendment and therefore may be directly affected by this action. The Department would like to extend an invitation to answer any questions you may have regarding the proposed amendments. If interested, please contact Diana Aranda, Environmental Scientist Specialist-Advanced, by phone at (505) 946-8666 or by email at Diana.Aranda@state.nm.us. Please keep in mind that due to the restrictions currently in place by the Governor's Executive Orders and various emergency public health orders designed to protect the public and prevent the spread of the Novel Coronavirus Disease – 2019 (COVID-19), all communication at this time will take place remotely.

Your interest in this process is greatly appreciated and we look forward to discussing any comments or questions you may have.

Thank you.

Jennifer Fullam
Standards, Planning & Reporting Team Leader
Surface Water Quality Bureau
New Mexico Environment Department
1190 S. St. Francis Dr.
Santa Fe, NM 87505
*Phone: 505.946.8954
jennifer.fullam@state.nm.us

PLEASE NOTE NEW PHONE NUMBER

“Innovation, Science, Collaboration, Compliance”

USE ATTAINABILITY ANALYSIS

for

Select Non-Perennial Reaches in Classified Waters 20.6.4.101-20.6.4.899 NMAC

Prepared by:
Surface Water Quality Bureau

May 3, 2021

Left intentionally blank

Table of Contents

I. Introduction

The objective of the Clean Water Act ("CWA") is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. One of the goals established under the CWA to achieve this objective, is to ensure, wherever attainable, water quality provides for the protection and propagation of fish, shellfish and wildlife (aquatic life), and for the ability to recreate in and on the water (known as "fishable/swimmable" goals). The CWA implements the measures necessary to achieve these goals through Title 40 Chapter I Subchapter D of the Code of Federal Regulations ("C.F.R."), which, in part, requires states to uphold these goals through the adoption of surface Water Quality Standards ("WQS"). In accordance with 40 C.F.R. § 131.6, these WQS contain, at a minimum, the designated uses for waterbodies, the surface water quality criteria that protect for those uses, and an antidegradation policy to ensure the water quality is maintained. The State of New Mexico has codified its WQS under *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC) but recognizes that water quality protection is ongoing and protections for waters may change over time. The most common type of amendments to water quality protections are those associated with establishing or amending designated uses.

There are three general conditions to which a designated use may be amended.

A. In accordance with 40 C.F.R. § 131.10(g) and 20.6.4.15 NMAC, if a designated use, that is not an existing use, is not attainable due to one of the six factors identified under 40 C.F.R. § 131.10(g) it may be removed through a Use Attainability Analysis ("UAA"). The UAA must be conducted to demonstrate that the proposed designated use is not less stringent than the existing use, determine the factor preventing the attainment of the current use, and provide evidence supporting the highest attainable use; or

B. In accordance with 40 C.F.R. § 131.10(i), the state reviews and revises applicable WQS to reflect the uses actually attained should those be more stringent than the current designated uses; or

C. In accordance with 40 C.F.R. § 131.20, the state reviews applicable WQS to which there is new (not considered before) information that has become available. If such new information indicates that more stringent uses specified in Section 101(a)(2) of the CWA are attainable, the state revises its standards accordingly during the Triennial Review.

The Department is evaluating the removal of designated uses for non-perennial tributaries identified in select sections of classified waters under 20.6.4.101-899 NMAC. This amendment requires a UAA. As such, this UAA includes a discussion of the State's authority and the regulatory procedures to amend a WQS, an antidegradation evaluation, identification of threatened and endangered species associated to the amended waters, a site assessment for the waterbodies under revision, a demonstration that the current designated use is not attainable based on one of the factors identified under 40 C.F.R. § 131.10(g), and a demonstration of the highest attainable use.

Throughout the document some of the referenced regulatory citations have been provided in boxed text to aid with referencing.

II. Use Attainability Analysis and its Regulatory Process.

A. Authority

In accordance with Section 101(a) of CWA, the objective of the Act is to restore and maintain the chemical, physical and biological integrity of the Nations waters. As provided in Section 101(a)(2) of the CWA the national goal for water quality, wherever attainable, is to provide for the protection and propagation of fish, shellfish, wildlife, and provides for recreation in and on the water. Pursuant to 40 C.F.R. § 131.4, states are required to adopt WQS to achieve these goals and objectives.

CWA § 101(a)
The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. In order to achieve this objective, it is hereby declared that, consistent with the provisions of this Act—

> *(2) it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983*

40 C.F.R. § 131.4
(a) *States (as defined in § 131.3) are responsible for reviewing, establishing, and revising water quality standards. As recognized by section 510 of the Clean Water Act, States may develop water quality standards more stringent than required by this regulation. Consistent with section 101(g) and 518(a) of the Clean Water Act, water quality standards shall not be construed to supersede or abrogate rights to quantities of water.*

The basic authority for water quality management in New Mexico is provided through the Water Quality Act (NMSA 1978, §§ 74-6-1 to 74-6-17). This law establishes the Water Quality Control Commission ("WQCC") and specifies its duties and powers. The WQCC is the state water pollution control agency for all purposes of the federal CWA (NMSA 1978, § 74-6-3(E)). Under Section 74-6-4(D), the Water Quality Act requires the WQCC to adopt WQS based on credible scientific data and reliable evidence. New Mexico's *Standards for Interstate and Intrastate Surface Waters* (20.6.4 NMAC) establish surface WQS that consist of designated uses for surface waters of the State, the water quality criteria necessary to protect the designated uses, and an antidegradation policy. The State of New Mexico WQS are established to protect the public health or welfare, enhance the quality of water, and are consistent with and serve the purposes of the New Mexico Water Quality Act and the federal CWA (33 U.S.C. § 1251). In accordance with 40 C.F.R. § 131.20, the State is required to review and revise its WQS regularly to ensure that they align with the federal regulations.

74-6-4 NMSA 1978 Duties and powers of commission.
The commission:
D. shall adopt water quality standards for surface and ground waters of the state based on credible scientific data and other evidence appropriate under the Water Quality Act. The standards shall include narrative standards and, as appropriate, the designated uses of the waters and the water quality criteria necessary to protect such uses. The standards shall at a minimum protect the public health or welfare, enhance the quality of water and serve the purposes of the Water Quality Act. In making standards, the commission shall give weight it deems appropriate to all facts and circumstances, including the use and value of the water for water supplies, propagation of fish and wildlife, recreational purposes and agricultural, industrial and other purposes;

40 C.F.R. § 131.20 *State review and revision of water quality standards.*
(c) Submittal to EPA. *The State shall submit the results of the review, any supporting analysis for the use attainability analysis, the methodologies used for site-specific criteria development, any general policies applicable to water quality standards and any revisions of the standards to the Regional Administrator for review and approval, within 30 days of the final State action to adopt and certify the revised standard, or if no revisions are made as a result of the review, within 30 days of the completion of the review.*

The WQCC has the authority to delegate responsibility for administering its regulations to constituent agencies to assure adequate coverage and prevent duplication of effort (NMSA 1978, § 74-6-3(F)). As such, the New Mexico Environment Department ("NMED") is the primary constituent agency responsible for administering and enforcing all programs implemented by the state under the CWA. The NMED Surface Water Quality Bureau ("SWQB") is responsible for evaluating and proposing amendments to the State's WQS in 20.6.4 NMAC. However, the WQCC approves and adopts amendments to the State's WQS prior to SWQB filing the amendments with State Records and Archives. Amendments become effective for State purposes under the Water Quality Act thirty days after filing with State Records (NMSA 1978, § 74-6-6(E)) or after publication in the New Mexico Register (NMSA 1978, § 14-4-5)), whichever comes later. In accordance with 40 C.F.R. 131.20, within thirty days of the final state action to adopt and certify the revised WQS, the State must submit the amendments and any supporting documentation to the U.S. Environmental Protection Agency ("EPA") for review and approval under the CWA.

B. Use Attainability Analysis

In accordance with 20.6.4.15(A) NMAC and 40 C.F.R. § 131.10(g), a UAA is required any time the criteria for a proposed designated use are less stringent than the criteria for the current designated use. A UAA is also required if a waterbody is to be classified for the first time without an aquatic life or recreational designated use or if the designated use is being proposed to be removed in its entirety.

A UAA is a scientific study used to determine the factors affecting the attainment of a designated use. There are three primary elements to a UAA. First, the proposed change in the designated use must be determined to have equal or more stringent criteria than the existing use. An existing use is defined under 20.6.4.7(E)(3) NMAC, as those uses actually attained in a surface water of the state on or after November 28, 1975, whether or not it is a designated use. The existing use may or may not be the current water quality of any given waterbody. The designated use, whether current or proposed, shall not be less stringent than the existing use. Second, pending the findings from evaluating the existing use, a UAA must then demonstrate that a designated use is not attainable due to one of the factors identified under 40 C.F.R. § 131.10(g). Third, once the demonstration that the designated use is not attainable, the highest attainable use must be determined. Defining the highest attainable use requires evaluation of existing uses, biotic and abiotic conditions, anthropogenic influences and consideration for various types of protected status delegations.

This UAA will expand on each of these elements in detail for select sections of classified waters under 20.6.4.101-899 NMAC.

40 C.F.R. § 131.10 Designation of uses.
(a) *Each State must specify appropriate water uses to be achieved and protected. The classification of the waters of the State must take into consideration the use and value of water for public water supplies, protection and propagation of fish, shellfish and wildlife, recreation in and on the water, agricultural, industrial, and other purposes including navigation. If adopting new or revised designated uses other than the uses specified in section 101(a)(2) of the Act, or removing designated uses, States must submit documentation justifying how their consideration of the use and value of water for those uses listed in this paragraph appropriately supports the State's action. A use attainability analysis may be used to satisfy this requirement. In no case shall a State adopt waste transport or waste assimilation as a designated use for any waters of the United States.*

20.6.4.15 NMAC Use Attainability Analysis:
A. *A use attainability analysis is a scientific study conducted for the purpose of assessing the factors affecting the attainment of a use. Whenever a use attainability analysis is conducted, it shall be subject to the requirements and limitations set forth in 40 C.F.R. § 131, Water Quality Standards; specifically, Subsections 131.3(g),131.10(g), 131.10(h) and 131.10(j) shall be applicable.*

III. Designated Uses Being Evaluated

A. Reasoning for a Designated Use Evaluation

As part of the Triennial Review, docketed matter WQCC 03-05(R), the WQCC adopted designated uses for unclassified, non-perennial waters through the creation of a new section, 20.6.4.98 NMAC. As part of this amendment and as established in the WQCC's statement of reasons (WQCC 2005), most of the unnamed, classified non-perennial waters were amended to unclassified waters with designated uses identified in 20.6.4.98 NMAC by adding the following language to the classified WQS sections in 20.6.4.101 through 899 NMAC, "perennial reaches of tributaries to…". The creation of 20.6.4.98 NMAC along with the additional language for classified WQS sections provided clarification regarding the designated protections for unnamed non-perennial waters. The administrative record and WQCC provide further explanation regarding this amendment in the transcript of proceedings (WQCC 2004) and the Statement of Reason for Amendment of Standards (WQCC 2005). Appendix A and Appendix B of this UAA provide blackline excerpts of the adopted language from the Statement of Reason (WQCC 2005).

Upon review of classified waters within 20.6.4.101 through 899 NMAC, it was found that some sections were not amended in accordance with the WQCC-03-05(R) ruling, and still contained language that applied perennial designated uses to non-perennial waterbodies. Therefore, it is the intent of this UAA to evaluate the appropriate designated uses for non-perennial tributaries to those sections that did not undergo the amendments as described above.

B. Waterbodies Being Evaluated

This UAA review identified the following classified WQS sections that still contain language regarding non-perennial waterbodies. This UAA focuses on the non-perennial portions in the following sections (emphasis added by underlining):

20.6.4.108 RIO GRANDE BASIN: - Perennial reaches of the Jemez river and all its tributaries above Soda dam near the town of Jemez Springs, except San Gregorio lake and Sulphur creek above its confluence with Redondo creek, and perennial reaches of the Guadalupe river and all its tributaries.

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (800 µS/cm or less on Sulphur creek); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and pH within the range of 2.0 to 8.8 on Sulphur creek.

[20.6.4.108 NMAC – Rp 20 NMAC 6.1.2106, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]

[NOTE: The segment covered by this section was divided effective 05-23-05. The standards for the additional segment are under 20.6.4.124 NMAC. The standards for San Gregorio lake are in 20.6.4.134 NMAC, effective 07-10-12]

20.6.4.115 RIO GRANDE BASIN: - The perennial reaches of Rio Vallecitos and its tributaries except Hopewell lake, and perennial reaches of Rio del Oso and perennial reaches of El Rito creek above the town of El Rito.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact; public water supply on the Rio Vallecitos and El Rito creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.115 NMAC - Rp–20 NMAC 6.1.2112, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]

[**NOTE:** The standards for Hopewell lake are in 20.6.4.134 NMAC, effective 07-10-12]

20.6.4.206 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo and its tributaries downstream of Bonney canyon and perennial reaches of the Rio Felix.

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less.

[20.6.4.206 NMAC - Rp–20 NMAC 6.1.2206, 10-12-2000; A, 05-23-2005; A, 12-01-2010; A, 03-02-2017]

20.6.4.208 PECOS RIVER BASIN: - Perennial reaches of the Rio Peñasco and its tributaries above state highway 24 near Dunken, perennial reaches of the Rio Bonito downstream from state highway 48 (near Angus), the Rio Ruidoso downstream of the U.S. highway 70 bridge near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

A. Designated uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 30°C (86°F) or less, and phosphorus (unfiltered sample) less than 0.1 mg/L.

[20.6.4.208 NMAC - Rp–20 NMAC 6.1.2208, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.209 PECOS RIVER BASIN: - Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito and its tributaries upstream of state highway 48 (near Angus) excluding Bonito lake, and perennial reaches of the Rio Ruidoso and its tributaries upstream of the U.S. highway 70 bridge near Seeping Springs lakes, above and below the Mescalero Apache boundary.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the

Rio Ruidoso; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.209 NMAC - Rp–20 NMAC 6.1.2209, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]
[**NOTE:** The standards for Bonito lake are in 20.6.4.223 NMAC, effective 07-10-12]

20.6.4.215 PECOS RIVER BASIN: - Perennial reaches of the Gallinas river and all its tributaries upstream of the diversion for the Las Vegas municipal reservoir, perennial reaches of Tecolote creek upstream of Blue creek, and all perennial tributaries of Tecolote creek.

A. Designated uses: domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, industrial water supply and primary contact; and public water supply on the Gallinas river.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less (450 µS/cm or less in Wright Canyon creek); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.215 NMAC - Rp–20 NMAC 6.1.2212, 10-12-00; A, 05-23-05; A, 12-01-10; A, 02-13-2018]
[**NOTE:** This segment was divided effective 02-13-2018. The standards for Tecolote creek from I-25 to Blue creek are under 20.6.4.230 NMAC.]

20.6.4.220 PECOS RIVER BASIN: - Perennial reaches of the Gallinas river and its tributaries from its mouth upstream to the diversion for the Las Vegas municipal reservoir, except Pecos Arroyo.

A. Designated uses: irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.
[20.6.4.220 NMAC - N,–05-23-05; A, 12-01-10]

20.6.4.307 CANADIAN RIVER BASIN: - Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except lakes identified in 20.6.4.313 NMAC, perennial reaches of Ocate creek and its tributaries downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. Designated uses: marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.307 NMAC - Rp–20 NMAC 6.1.2305.3, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]

20.6.4.309 CANADIAN RIVER BASIN: - The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek and its tributaries, the Cimarron river and its perennial tributaries above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek and its tributaries above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate,

A. **Designated uses:** domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron and on perennial reaches of Rayado creek and its tributaries.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.309 NMAC – Rp 20 NMAC 6.1.2306, 10-12-00; A, 7-19-01; A, 05-23-05; A, 12-01-10; A, 07-10-12]

[**NOTE:** The segment covered by this section was divided effective 05-23-05. The standards for the additional segment are under 20.6.4.310 NMAC. The standards for Shuree ponds are in 20.6.4.314 NMAC and the standards for Eagle Nest lake are in 20.6.4.315 NMAC, effective 07-10-12]

C. Designated Uses Being Evaluated

This UAA evaluated the designated uses for each of the non-perennial waterbodies identified in Table III-1, including aquatic life and recreational uses, which are protected under the CWA. Other New Mexico-specific designated uses such as livestock watering, wildlife habitat, domestic water supply and irrigation were also evaluated as part of this UAA.

Table III-1. *Selected sections non-perennial portions and their current designated uses.*

WQS	Tributary of	Contact Use	Aquatic Life Use	Domestic water supply	Fish culture and water supply	Irrigation and irrigation storage	Livestock watering	Wildlife habitat
20.6.4.108	Non-perennial tributaries to the Jemez River above Soda dam	primary contact	high quality coldwater	domestic water supply	fish culture	irrigation	livestock watering	wildlife habitat
20.6.4.108	Non-perennial tributaries to the Guadalupe River	primary contact	high quality coldwater	domestic water supply	fish culture	irrigation	livestock watering	wildlife habitat
20.6.4.115	Non-perennial tributaries to the Rio Vallecitos	primary contact	high quality coldwater	domestic water supply	public water supply	irrigation	livestock watering	wildlife habitat
20.6.4.206	Non-perennial tributaries to the Rio Hondo downstream of Bonney Canyon	secondary contact	warmwater	not applicable	not applicable	irrigation	livestock watering	wildlife habitat
20.6.4.208	Non-perennial tributaries to the Rio Peñasco above state highway 24 near Dunken	primary contact	coldwater	not applicable	fish culture	irrigation	livestock watering	wildlife habitat
20.6.4.209	Non-perennial tributaries to the Rio Bonito upstream of state highway 48 (near Angus)	primary contact	high quality coldwater	domestic water supply	public water supply	irrigation	livestock watering	wildlife habitat
20.6.4.209	Non-perennial tributaries to the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes, above and below the Mescalero Apache boundary	primary contact	high quality coldwater	domestic water supply	public water supply	not applicable	livestock watering	wildlife habitat
20.6.4.215	Non-perennial tributaries to the Gallinas River upstream of the diversion for the Las Vegas municipal reservoir	primary contact	high quality coldwater	domestic water supply	public water supply, industrial water supply	irrigation	livestock watering	wildlife habitat
20.6.4.220	Non-perennial tributaries to the Gallinas River from its mouth upstream to the diversion for the Las Vegas municipal reservoir	primary contact	marginal coldwater	not applicable	not applicable	irrigation	livestock watering	wildlife habitat
20.6.4.307	Non-perennial tributaries to the Ocate Creek downstream of Ocate	primary contact	marginal coldwater, warmwater	not applicable	not applicable	irrigation	livestock watering	wildlife habitat
20.6.4.309	Non-perennial tributaries to the Coyote Creek	primary contact	high quality coldwater	domestic water supply	public water supply	irrigation	livestock watering	wildlife habitat
20.6.4.309	Non-perennial tributaries to the Rayado Creek above Miami lake diversion	primary contact	high quality coldwater	domestic water supply	public water supply	irrigation	livestock watering	wildlife habitat

IV. Antidegradation and Existing Use

In accordance with 40 C.F.R. § 131.12, states must develop and adopt a statewide antidegradation policy, which shall include protection for various levels of water quality. In addition, states must develop methods for implementing the antidegradation policy. New Mexico's antidegradation policy, codified under 20.6.4.8 NMAC, defines three tiers of protection against degradation. These include protections for existing uses ("Tier 1"), protections for high quality waters that exceed levels necessary to support aquatic life, wildlife and recreational uses ("Tier 2"), and protections for waters designated as Outstanding National Resource Waters ("Tier 3"). The antidegradation policy also requires an evaluation of downstream waters to ensure their protections are also sustained, should a designated use amendment be supported.

> ***40 C.F.R. § 131.12 Antidegradation policy and implementation methods.***
> ***(a)*** *The State shall develop and adopt a statewide antidegradation policy.*

> ***20.6.4.8 NMAC – Antidegradation Policy and Implementation Plan***
> ***A. Antidegradation Policy:*** *This antidegradation policy applies to all surface waters of the state.*
> ***(1)*** *Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected in all surface waters of the state.*
> ***(2)*** *Where the quality of a surface water of the state exceeds levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water, that quality shall be maintained and protected unless the commission finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic and social development in the area in which the water is located. In allowing such degradation or lower water quality, the state shall assure water quality adequate to protect existing uses fully. Further, the state shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable BMPs for nonpoint source control. Additionally, the state shall encourage the use of watershed planning as a further means to protect surface waters of the state.*
> ***(3)*** *No degradation shall be allowed in waters designated by the commission as outstanding national resource waters (ONRWs), except as provided in Subparagraphs (a) through (e) of this paragraph and in Paragraph (4) of this Subsection A.*

To determine if the proposed amendments would conflict with the state's antidegradation policy, NMED evaluated information regarding designated ONRWs and existing uses, as discussed below.

A. Outstanding National Resource Waters.

An ONRW is a designation granted by the WQCC for waters that have been determined to have a particular benefit to the State. These designated waters are listed under 20.6.4.9(D) NMAC and are protected from degradation under 20.6.4.8(3) NMAC. In order to evaluate changes to a designated use, it must be determined whether the waterbody has been designated as an ONRW.

For this UAA, a review was conducted for any ONRWs that are associated with the non-perennial waters being evaluated. According to 20.6.4.9 NMAC, none of the non-perennial portions being evaluated for this UAA are listed as an ONRW and no designated ONRWs are downstream of the non-perennial waters in this UAA. Therefore, NMED concluded that no ONRWs will be affected by the outcomes of this UAA.

B. Determination of existing use.

According to 40 C.F.R. § 131.3(e), the definition of existing uses "are those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards." A designated use may not be less stringent than an existing use. The State's WQS under 20.6.4.7(E)(3) NMAC have a similar definition, which states that an existing use is "a use actually attained in a surface water of the state on or after November 28, 1975, whether or not it is a designated use." In accordance with 40 C.F.R. § 131.10, a designated use must be at least as stringent as the existing use and, in accordance with 40 C.F.R. § 131.20, if new information indicates that an aquatic life or recreational use is attainable, such as the information used to determine an existing use, the state shall revise its standards accordingly. Further, in accordance with 20.6.4.15(A)(2) NMAC, a designated use cannot be removed if it is an existing use. Therefore, as part of this UAA, the existing uses must first be established to determine if a designated use may be removed and provide a baseline for establishing the highest attainable use.

> ***40 C.F.R. § 131.10 Designation of uses.***
> ***(i)*** *Where existing* water quality standards *specify* designated uses *less than those which are presently being attained, the* State *shall revise its standards to reflect the uses actually being attained.*

> ***40 C.F.R. § 131.20 State review and revision of water quality standards.***
> ***(a)*** **State review.** *…If such new information indicates that the uses specified in section 101(a)(2) of* the Act *are attainable, the* State *shall revise its standards accordingly…*

> ***20.6.4.15 NMAC. USE Attainability Analysis.***
> *A. A use attainability analysis is a scientific study conducted for the purpose of assessing the factors affecting the attainment of a use…*
> *(1) The commission may remove a designated use specified in Section 101(a)(2) of the federal Clean Water Act or adopt subcategories of a Section 101(a)(2) use requiring less stringent criteria only if a use attainability analysis demonstrates that attaining the use is not feasible because of a factor listed in 40 C.F.R. § 131.10(g)…*
> *(2) A designated use cannot be removed if it is an existing use unless a use requiring more stringent criteria is designated.*

To determine the existing uses for the non-perennial waters being evaluated under this UAA, a data search was conducted through SWQB's Surface Water Quality Information Database ("SQUID"). There were no applicable data in SQUID for the non-perennial tributaries referenced above and consequently existing uses were not able to be established at the time this UAA was developed. Therefore, NMED determined that removal of a designated use would not result in the lowering of an existing use.

V. Endangered and Threatened Species Review

A. Regulatory background.

In accordance with Section 7(a)(2) of the Endangered Species Act ("ESA"), EPA shall use the best scientific and commercial data available to consult with the US. Fish and Wildlife Service to ensure that any action authorized by the EPA is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of habitat of such species. If there is reason EPA believes that an endangered or a threatened species can be affected or jeopardized by the implementation of a WQS change, then the Federal agencies, through ESA consultation, shall ensure that the appropriate actions are implemented (ESA 2019). In order to assist EPA with the evaluation the UAA includes a preliminary screening of listed threatened and endangered species within the geographical areas being analyzed for potential designated use changes.

B. Evaluation of Endangered and Threatened Species.

This UAA includes a review of U.S. Fish and Wildlife Service's Information for Planning and Consultation (IPaC) project planning tool (https://ecos.fws.gov/ipac/) to determine if the geographical locations of the listed waterbodies in this UAA overlap with listed species or critical habitat (when applicable).

According to the IPaC planning tool, threatened and endangered species for the geographical areas associated with the above referenced waterbodies are included below. Appendix C of this document contains section maps of the SWQB WQS waterbody segments, the IPaC geographical area delineations and their descriptions and their associated assessed IPaC map image.

Listed are the following species results from the assessment IPaC delineations:

The area for WQS 20.6.4.108 (see appendix C) with the following species results:

Threatened: Canada Lynx (*Lynx canadensis*)
Mexican Spotted Owl (*Strix occidentalis lucida*)
Yellow-billed Cuckoo (*Coccyzus americanus*)
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Least Tern (*Sterna antillarum*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Jemez Mountains Salamander (*Plethodon neomexicanus*)
Rio Grande Silvery Minnow (*Hybognathus amarus)*
Critical Habitat: Jemez Mountains Salamander (*Plethodon neomexicanus*)
New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*).

The area for WQS 20.6.4.115 (see appendix C) with the following species results:

Threatened: Canada Lynx (*Lynx canadensis*)
Mexican Spotted Owl (*Strix occidentalis lucida*)
Yellow-billed Cuckoo (*Coccyzus americanus*)
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Least Tern (*Sterna antillarum*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Jemez Mountains Salamander (*Plethodon neomexicanus*)
Critical Habitat: They are no critical habitats at this location.

The area for WQS 20.6.4.206 (see appendix C) with the following species results:

Threatened: Mexican Spotted Owl (*Strix occidentalis lucida*)
Piping Plover (*Charadrius melodus*)
Yellow-billed Cuckoo (*Coccyzus americanus*)
Pecos Bluntnose Shiner (*Notropis simus pecosensis*)
Gypsum Wild-buckwheat (Eriogonum gypsophilum)
Kuenzler Hedgehog Cactus (*Echinocereus fendleri var. kuenzleri*)
Lee Pincushion Cactus (Coryphantha sneedii var. leei)
Pecos (=puzzle, =paradox) Sunflower (Helianthus paradoxus)
Sacramento Mountains Thistle (Cirsium vinaceum)
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Least Tern (*Sterna antillarum*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Pecos Gambusia (*Gambusia nobilis*)
Texas Hornshell (*Popenaias popeii*)

Koster's Springsnail (*Juturnia kosteri*)
Pecos Assiminea Snail (*Assiminea pecos*)
Roswell Spring snail (*Pyrgulopsis roswellensis*)
Noel's Amphipod (*Gammarus desperatus*)
Sacramento Prickly Poppy (*Argemone pleiacantha ssp. Pinnatisecta*)
Sneed Pincushion Cactus (*Coryphantha sneedii var. sneedii*)
Todsen's Pennyroyal (*Hedeoma todsenii*).
Candidate: Penasco Least Chipmunk (*Tamias minimus atristriatus*)
Wright's Marsh Thistle (*Cirsium wrightii*)
Experimental non-essential population: Northern Aplomado Falcon (*Falco femoralis septentrionalis*)
Critical Habitat: Koster's springsnail (*Juturnia kosteri*)
Mexican Spotted Owl (*Strix occidentalis lucida*)
New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Noel's Amphipod (*Gammarus desperatus*)
Pecos (=puzzle, =paradox) Sunflower (*Helianthus paradoxus*)
Pecos Assiminea Snail (*Assiminea pecos*)
Pecos Bluntnose (*Shiner Notropis simus pecosensis*)
Roswell Springsnail (*Pyrgulopsis roswellensis*)

The area for WQS 20.6.4.208 (see appendix C) with the following species results:
Threatened: Mexican Spotted Owl *(Strix occidentalis lucida*)
Southwestern Willow Flycatcher *(Empidonax traillii extimus*)
Piping Plover (Charadrius melodus)
Pecos Bluntnose Shiner (*Notropis simus pecosensis*)
Kuenzler Hedgehog Cactus (*Echinocereus fendleri var. kuenzleri*)
Pecos (=puzzle, =paradox) Sunflower (*Helianthus paradoxus*)
Sacramento Mountains Thistle (*Cirsium vinaceum*)
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Least Tern (*Sterna antillarum*)
Pecos Gambusia (*Gambusia nobilis*)
Koster's Spring snail (*Juturnia kosteri*)
Pecos Assiminea Snail (*Assiminea pecos*)
Roswell Spring snail (*Pyrgulopsis roswellensis*)
Noel's Amphipod (*Gammarus desperatus*)
Sacramento Prickly Poppy (*Argemone pleiacantha ssp. Pinnatisecta*)
Todsen's Pennyroyal (*Hedeoma todsenii*)
Experimental non-essential population: Northern Aplomado Falcon *(Falco femoralis septentrionalis*)
Candidate: Wright's Marsh Thistle (*Cirsium wrightii*)
Penasco Least Chipmunk (*Tamias minimus atristriatus*)
Critical Habitat: Mexican Spotted Owl (*Strix occidentalis lucida*)
New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)

The area for WQS 20.6.4.209 (see appendix C) with the following species results:
Threatened: Mexican Spotted Owl (*Strix occidentalis lucida*)
Yellow-billed Cuckoo (*Coccyzus americanus*)
Kuenzler Hedgehog Cactus (*Echinocereus fendleri var. kuenzleri*)
Sacramento Mountains Thistle (*Cirsium vinaceum*)
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Least Tern (*Sterna antillarum*)

Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Sacramento Prickly Poppy (*Argemone pleiacantha ssp. Pinnatisecta*)
Todsen's Pennyroyal (*Hedeoma todsenii*)
Experimental non-essential population: Northern Aplomado Falcon (*Falco femoralis septentrionalis*)
Candidate: Penasco Least Chipmunk (*Tamias minimus atristriatus*)
Wright's Marsh Thistle (*Cirsium wrightii*)
Critical Habitat: Mexican Spotted Owl (*Strix occidentalis lucida*).

<u>The area for WQS 20.6.4.215 (see appendix C) with the following species results:</u>
Threatened: Mexican Spotted Owl (*Strix occidentalis lucida*)
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Holy Ghost Ipomopsis (*Ipomopsis sancti-spiritus*)
Critical Habitat: Mexican Spotted Owl (*Strix occidentalis lucida*)

The area for WQS 20.6.4.220 (see appendix C) with the following species results:
Threatened: Mexican Spotted Owl (*Strix occidentalis lucida*)
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Holy Ghost Ipomopsis (*Ipomopsis sancti-spiritus*)
Critical Habitat: No Critical habitats in this area.

The area for WQS 20.6.4.307 (see appendix C) with the following species results:
Threatened: Canada Lynx (*Lynx canadensis*)
Mexican Spotted Owl (*Strix occidentalis lucida*).
Endangered: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Holy Ghost (*IpomopsisIpomopsis sancti-spiritus*)
Critical Habitat: Mexican Spotted Owl (*Strix occidentalis lucida*)

The area for WQS 20.6.4.309 (see appendix C) with the following species results:
Threatened: Canada Lynx (*Lynx canadensis*)
Mexican Spotted Owl (*Strix occidentalis lucida*)
Piping PloverCHCharadrius melodus
Yellow-billed Cuckoo (*Coccyzus americanus*)
Endangered: Black-footed Ferret (*Mustela nigripes*)
New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)
Critical Habitat: New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*)
Southwestern Willow Flycatcher (*Empidonax traillii extimus*)

The amendment to clarify language to “perennial reaches of tributaries to” should not jeopardize the continued existence of any threatened and endangered species nor result in the destruction or adverse modification of critical habitat. It is not believed that the amendments should jeopardize natural communities of conservation concern (e.g., emergent wetland, riverine wetland, prairie, and glade) because habitat will not be impacted. In addition, the clarification of the attainable uses should ensure appropriate protections are implemented for the waterbodies identified in this UAA.

VI. Site Conditions

The geospatial locations of the waterbodies being analyzed are depicted in Figure VI-1. The non-perennial tributaries being evaluated as part of this UAA are some of the eastern flowing tributaries in the northern Sangre de Cristo mountain range, the Jemez mountains, Cruces Basin and the tributaries flowing east from the Sacramento mountains in southern New Mexico. The areas represent a broad and extensive range of ecoregions; with drastic changes in elevation, geology, ecosystems and weather conditions.

New Mexico's arid and semiarid landscape make surface water a limited resource. The dry conditions in New Mexico greatly influence the hydrology of the State's watersheds, making ephemeral and intermittent streams extremely common, comprised of characteristic ecoregions. Ecoregions are areas where ecosystems are generally similar and are identified by analyzing the patterns and composition of various biotic and abiotic factors. EPA has several resolutions of ecoregional mapping. The EPA's Ecological Regions of North America ("EPA ecoregions") classify the Southwestern states as predominantly dry, desert, or semi-arid where annual losses of water through evaporation at the earth's surface exceed annual water gains from precipitation (USEPA 2006). NMED evaluated anthropogenic influences, as described below, that could impact the hydrology of a stream and aquatic life that depend on the persistence of flow. Further site conditions were evaluated utilizing a hydrology data set which is described in section VII-C.

A. Land use and history

There are numerous human-related disturbances throughout the regions identified in this UAA. The non-perennial tributaries being evaluated as part of this analysis are subject to anthropogenic disturbances including but not limited to land clearing, mining, timber harvesting, urbanization, agriculture, roads and road construction, livestock grazing, off-road vehicle use, camping, hiking, and vegetation conversion (Levick et al. 2008).

Even though anthropogenic disturbances can affect water quality, NMED determined that land use and history do not provide direct evidence to support or refute the proposed amendments. Non-perennial tributaries, regardless of anthropogenic influences, should be able to attain the established designated uses. Therefore, the potential anthropogenic impacts on water quality do not play a factor into this UAA which is basing the removal and replacement of designated uses on natural, low-flow conditions.

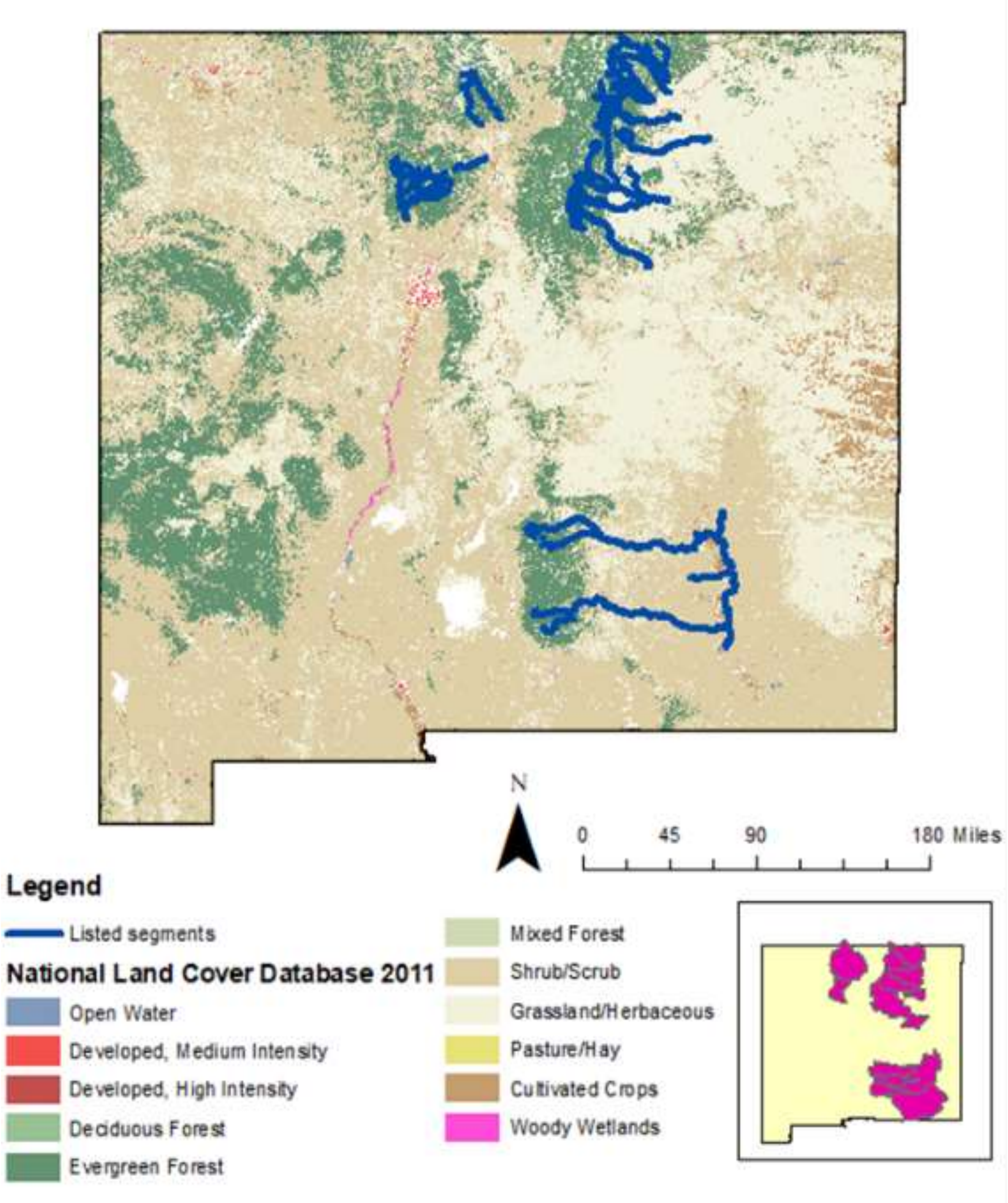
B. Dams

Other human-related disturbances that are numerous throughout the regions include impoundments, groundwater withdrawals, and channelization. These anthropogenic disturbances can create low-flow conditions, disrupt natural surface flow and sediment transport, interfere with natural geomorphic processes, alter water temperatures, and fragment the natural stream systems (Levick et al. 2008). This UAA analysis is not proposing the amendment of designated uses for reaches that have low flow due to dams, diversions or other types of hydrologic modifications.

C. Surface declarations and permits

The New Mexico Office of the State Engineer ("OSE") is the responsible agency of issuing surface water declaration and permits also known as "water rights." A water right is a legal right, issued as a permit or declaration to utilize water (19.26.2 NMAC). Some permits may involve hydrologic modifications, such as diversions. The flow regime of a stream, which is necessary for attaining water quality associated with designated uses, is impacted by surface water diversions.

Figure VI-1. ***Location of standard sections (blue) depicting the spatial and land cover variability.***



A stream with a diversion may signify that low flow is due to hydrological modifications and not due to natural causes. Therefore, if a non-perennial water under review contains a surface declaration or a permit with an associated existing designated use, then that water will retain its current designated use, at this time, because low flow could be due to anthropogenic hydrologic modifications and not natural causes.

NMED conducted an OSE surface declaration and permit review to identify if any permits exist within the non-perennial waters under review. For this assessment, permit data were obtained from the OSE's "Point of Diversions" (POD) Open Data Site. According to the data description provided by OSE: "*These data were extracted from the OSE W.A.T.E.R.S. (Water Administration Technical Engineering Resource*

System) database and geo-located (mapped). These data have varying degrees of accuracy and have not been validated. Data is current as of April 1, 2020." (OSE 2020)

For the analysis, NMED loaded OSE shapefiles into ArcMap 10.6.1 software. Next, NMED visually located on a map the OSE datapoints for active surface declarations and or surface permits (surface water only, no groundwater or spring appropriations). Also, NMED utilized the National Hydrography Dataset ("NHD"), a geospatial surface water database tool, to locate non-perennial segments (see section VII-C for more detailed information on NHD).

Through this assessment, NMED found some surface declarations and OSE permits in waters under review. These waters include Calaveras Canyon (20.6.4.108 NMAC) and Cox Canyon (20.6.4.208 NMAC), both have designated uses for irrigation and fish culture and water supply. Table VI-1 provides a list of the sections and their designated uses and a summary of the active OSE diversions found for surface waters on non-perennial waterbodies identified using NHD maps.

Table VI-1. *Summary of surface water diversions for non-perennial tributaries.*

	Designated Use			
WQS	**Domestic water supply**	**Fish culture and water supply**	**Irrigation**	**Livestock watering**
20.6.4.108	NA*	Calaveras Canyon	NA*	NA*
20.6.4.115	NA*	NA*	NA*	NA*
20.6.4.206	not a designated use	not a Designated use	NA*	NA*
20.6.4.208	not a designated use	NA*	Cox Canyon	NA*
20.6.4.209	NA*	NA*	NA*	NA*
20.6.4.215	NA*	NA*	not a designated use	NA*
20.6.4.220	not a designated use	not a designated use	NA*	NA*
20.6.4.307	not a designated use	not a designated use	NA*	NA*
20.6.4.309	NA*	NA*	NA*	NA*

NA= No locations identified under criteria described in Section VI-C.*

D. National Pollutant Discharge Elimination System and Stormwater General Permit.

A review of EPA's National Pollutant Discharge Elimination System ("NPDES") Individual and Stormwater General Permits associated with the non-perennial sections was conducted to determine if flows from permitted discharges could compensate the low-flow conditions.

According to SWQB records, the following non-perennial sections in this analysis have NPDES individual or Stormwater General Permits:

Table VI-2. *Summary of NPDES permits discharging to non-perennial tributaries.*

WQS	**FACILITY NAME**	**PERMIT NUMBER**	**Waterbody**
20.6.4.309	Chevron Mining Inc./Ancho Mine	NM0030180	Ancho Canyon, Brackett Canyon, Gachupin Canyon, Salyers Canyon and tributaries to the Vermejo River thence to the Canadian River

NPDES Individual Permit NM0030180, Chevron Mining, Inc., Ancho, Gachupin and Brackett Mines regulates the discharge of stormwater from active reclamation areas during precipitation events (SWQB 2019). The mine includes temporary impoundments and other measures to control sediment which restrict flow conditions (SWQB 2019). Discharges under this permit are irregular and do not provide a consistent source of water to offset the non-perennial nature of the waters being reviewed as part of this UAA.

E. Urban Areas.

SWQB reviewed the U.S. Census Bureau's Master Address File/Topologically Integrated Geographic Encoding and Referencing (MAF/TIGER) Database (MTDB) TIGER/Line shapefile to determine if any NHD delineated non-perennial tributaries are within an Urban Area designation.

According to the urban areas and SWQB segment records, the following sections have an Urban Area that contain non-perennial waterbodies, see Table VI-3.

Table VI-3. *Summary non-perennial tributaries that run through a designated urban cluster.*

WQS	Urban Cluster	Waterbodies (according to NHD)
20.6.4.206	Roswell, NM	Berrendo Creek (Intermittent), Unnamed tributary to North Spring River (Intermittent), two unnamed tributaries near Eagle Creek (intermittent)
20.6.4.209	Ruidoso, NM	4 unnamed tributaries to Rio Ruidoso (intermittent)
20.6.4.220	Las Vegas, NM	Several unnamed tributaries to Arroyo Pecos and several unnamed tributaries to Gallinas River.

Even though anthropogenic disturbances can affect water quality due to impervious surfaces, and promote desertification (Levick et al. 2008), anthropogenic storm water systems can affect water quality and should be taken into consideration when water quality changes are being evaluated. Non-perennial tributaries, regardless of anthropogenic influences, should be able to attain the established designated uses. Further, discharges from urban areas are irregular and do not provide a consistent source of water to offset the non-perennial nature of the waters being reviewed as part of this UAA.

VII. Removal of a Designated Use.

A. Authority to remove a designated use and proposed removals

According to 40 C.F.R. § 131.10, States can remove a designated use if it is not an existing use, and if the rationale for removal of a designated use falls under one of the six factors in 40 C.F.R. § 131.10(g).

> ***40 C.F.R. § 131.10 Designation of uses. (emphasis added)***
>
> ***(a)*** *Each State must specify appropriate water uses to be achieved and protected. The classification of the waters of the State must take into consideration the use and value of water for public water supplies, protection and propagation of fish, shellfish and wildlife, recreation in and on the water, agricultural, industrial, and other purposes including navigation. If adopting new or revised designated uses other than the uses specified in section 101(a)(2) of the Act, or removing designated uses, States must submit documentation justifying how their consideration of the use and value of water for those uses listed in this paragraph appropriately supports the State's action. A use attainability analysis may be used to satisfy this requirement. In no case shall a State adopt waste transport or waste assimilation as a designated use for any waters of the United States.*

> ***(g)*** *States may designate a use, or remove a use that is not an existing use, if the State conducts a use attainability analysis as specified in paragraph (j) of this section that demonstrates attaining the use is not feasible because of one of the six factors in this paragraph. If a State adopts a new or revised water quality standard based on a required use attainability analysis, the State shall also adopt the highest attainable use, as defined in § 131.3(m).*

Based on this UAA, the Department proposes to amend or remove the aquatic life, fish culture and water supply, domestic water supply, and irrigation uses, see Table VII-1. Although the recreational designated use will remain primary contact and requires no further evaluation, there is one instance where the designated recreational use is secondary contact (non-perennial tributaries to the Rio Hondo downstream of Bonney Canyon). As part of this UAA, NMED will evaluate whether its appropriate to remove the current designated uses for the waters under review including secondary contact use, which is under the aquatic life use designation.

B. Factor preventing the attainment of the current designated use.

Designated uses may be removed or amended to have less stringent criteria if a UAA can demonstrate that attaining the designated use is not feasible based on one of the six factors in 40 C.F.R. § 131.10(g). Based on reasonable evidence, the Department maintains that natural, ephemeral, intermittent or low flow conditions are preventing attainment of the current designated uses (“Factor 2”) in the non-perennial tributaries addressed by this UAA.

> ***40 C.F.R.*** § ***131.10 (g)(2)***
> *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met.*

NMED will demonstrate that Factor 2 is preventing attainment of the current designated use through two lines of evidence. The first identifies non-perennial tributaries through the use of the NHD, while the second provides the rationale and evidence to support why natural, ephemeral, intermittent or low-flow conditions prevent the attainment of each of the designated uses.

Table VII-1. *Select non-perennial waters and proposed designated uses to be removed.*

WQS	Tributary	Contact Use	Aquatic Life Use	Domestic water supply	Fish culture and water supply	Irrigation	Livestock watering	Wildlife habitat
20.6.4.108	Non-perennial tributaries to the Jemez River above Soda dam	primary contact	*high quality coldwater	*X	*X except Calaveras Canyon	*X	X	X
20.6.4.108	Non-perennial tributaries to the Guadalupe River	primary contact	*high quality coldwater	*X	*X	*X	X	X
20.6.4.115	Non-perennial tributaries to the Rio Vallecitos	primary contact	*high quality coldwater	*X	*X	*X	X	X
20.6.4.206	Non-perennial tributaries to the Rio Hondo downstream of Bonney Canyon	*secondary contact	* warmwater	Not applicable	Not applicable	*X	X	X
20.6.4.208	Non-perennial tributaries to the Rio Peñasco above state HWY 24 near Dunken	primary contact	*coldwater	Not applicable	*X except Cox Canyon	*X	X	X
20.6.4.209	Non-perennial tributaries to the Rio Bonito upstream of state HWY 48 (near Angus)	primary contact	*high quality coldwater	*X	*X	*X	X	X
20.6.4.209	Non-perennial tributaries to the Rio Ruidoso upstream of the U.S. HWY 70 bridge near Seeping Springs lakes, above and below the Mescalero Apache boundary	primary contact	*high quality coldwater	*X	*X	*X	X	X
20.6.4.215	Non-perennial tributaries to the Gallinas River upstream of the diversion for the Las Vegas municipal reservoir	primary contact	*high quality coldwater	*X	*X	*X	X	X
20.6.4.220	Non-perennial tributaries to the Gallinas River from its mouth upstream to the diversion for the Las Vegas municipal reservoir	primary contact	*marginal coldwater	Not applicable	Not applicable	*X	X	X
20.6.4.307	Non-perennial tributaries to the Ocate Creek downstream of Ocate	primary contact	*marginal coldwater; * warmwater	Not applicable	Not applicable	*X	X	X
20.6.4.309	Non-perennial tributaries to the Coyote Creek	primary contact	*high quality coldwater	*X	*X	*X	X	X
20.6.4.309	Non-perennial tributaries to the Rayado Creek above Miami lake diversion	primary contact	*high quality coldwater	*X	*X	*X	X	X

***Designated uses being evaluated as part of this UAA.**
"X" denotes the waterbody has this as a designated use

C. Establishment of non-perennial conditions through the evaluation of the National Hydrography Dataset.

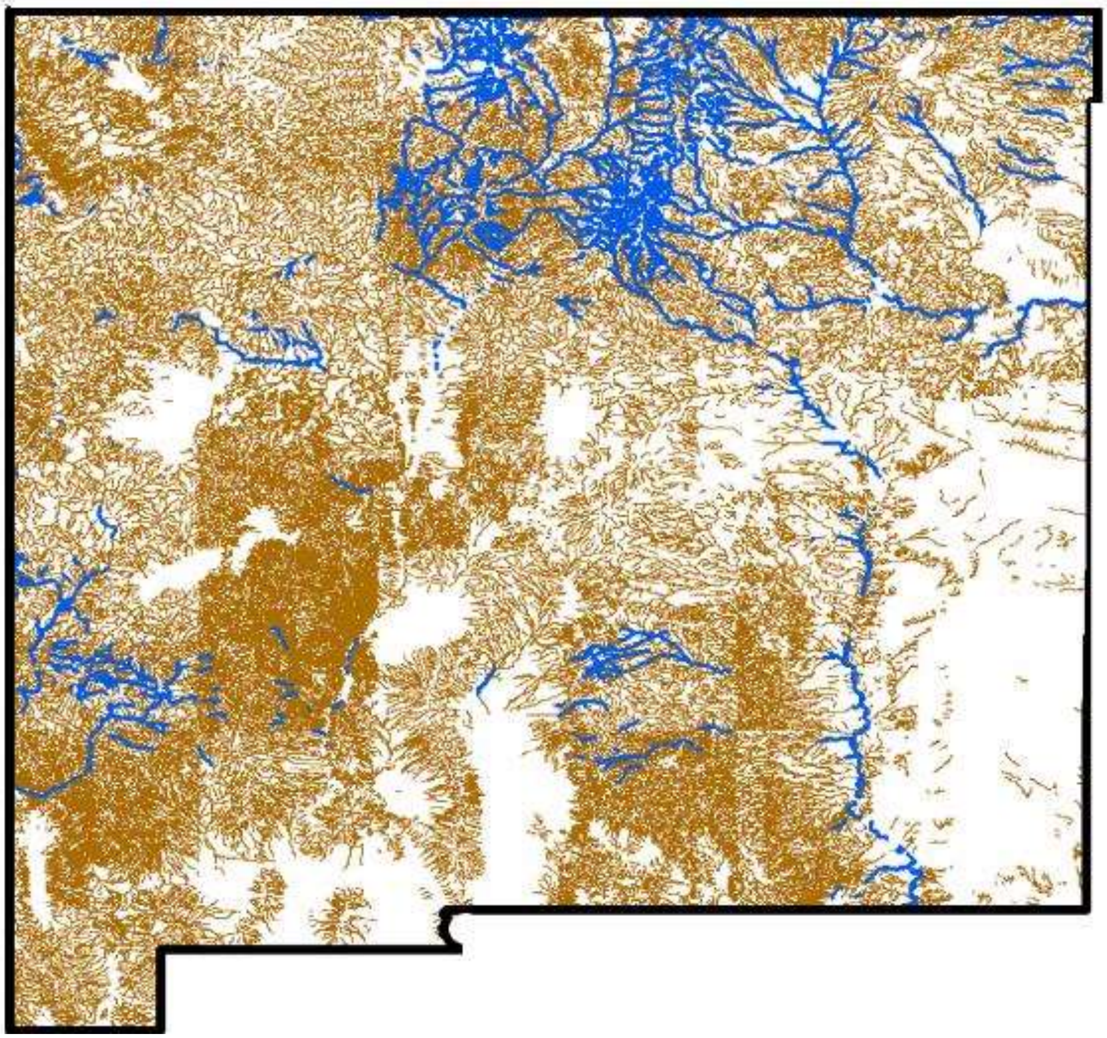
In New Mexico, non-perennial hydrological conditions are common and can occur along an entire waterbody or can be interspersed throughout any point, or many points, along the waterbody. Non-perennial tributaries are very important to the hydrologic and ecologic functions of semi-arid and arid stream systems, yet their fundamental characteristics (e.g., flashy, high-energy, seasonal, erodibility, etc.) prevent them from supporting some designated uses that are associated with perennial waters. Currently, the non-perennial tributaries described in this UAA are included in WQS sections that have designated uses for perennial waters. One way to determine the hydrological features of the waters under review is through the NHD. To establish the appropriate designated uses for these waters, SWQB evaluated the hydrological features using the NHD to determine whether natural, ephemeral, intermittent or low flow conditions may be present, preventing the attainment of the current uses for the waters under review.

The NHD is a geospatial surface water database tool developed through the collaboration of the U.S. Geological Survey ("USGS") and the EPA. The NHD was created through the compilation of many water quality databases, gaging stations, water quality monitoring sites and models that use multiple datasets to analyze upstream/downstream order classification (USGS 2006). The database delineates hydrological features such as perennial streams, intermittent streams, canals, springs, wells, gaging stations, perennial lakes, intermittent lakes, playas, ponds, and wetlands.

The NHD "*does not include stream segments less than one mile in length, combines intermittent and ephemeral streams, and is based on 1:100,000 scale topographic maps… calculates the percent of streams that are ephemeral or intermittent relative to total stream length using total kilometers of linear streams in watersheds that are totally or partially contained within each state boundary."* (Levick et al. 2008). These limitations should be taken into consideration when the NHD is implemented into a study, particularly if high resolution or ground truthing is necessary to assert hydrologic conditions. However, as it pertains to the determination of hydrologic conditions in this UAA, the NHD was used as a gross-scale geospatial reference for determining presence of non-perennial waters.

Figure 2 illustrates perennial (blue lines) and non-perennial waters (brown lines) in New Mexico. As determined through the NHD, approximately 12% of the State's surface waters are perennial, and approximately 88% are non-perennial (USGS 2018). Based on the NHD, there is evidence non-perennial waters are within the WQS sections of 20.6.4 NMAC identified in this UAA.

Figure 2. New Mexico's perennial (blue) and non-perennial (brown) waterways according to the NHD.



D. Demonstration designated uses are unattainable

As currently classified, the non-perennial waters identified in this UAA have several designated uses including those considered uses protected under Section 101(a)(2) of the CWA. The NHD analysis provides evidence that there are non-perennial tributaries within the WQS sections being evaluated under this UAA.

The flow regimes in intermittent and ephemeral waterbodies can create water quality issues that in turn "alter the scope of surface water uses" (Datry et al. 2018). Intermittent and ephemeral rivers and streams are variable environments, where climate and hydrology dynamics limit species richness. In times of drought wet conditions might not occur for several years (Datry et al., 2017). The physical, chemical and biological conditions of ephemeral and intermittent streams undergo "extraordinary diel variability… in water temperature, pH, dissolved oxygen and salinity..." (Gomez et al. 2007). Aquatic life uses have specific chemical and temperature criteria that cannot be met due to seasonal extreme ranges and "daily amplitudes of water temperature much larger than in perennial systems and more similar to air conditions" (Gomez et al. 2007). These diel and seasonal swings provide reasonable evidence to support Factor 2 for this UAA – that natural, ephemeral, intermittent or low-flow conditions prevent the attainment of high quality coldwater, coldwater, marginal coldwater, coolwater, and warmwater aquatic life. In addition, reduced riparian vegetation in non-perennial systems results in higher levels of irradiation to the waterbody surface, leading to increased maximum water temperatures (Gomez et al. 2007). Due to higher salinity levels and increased concentration of pollutants due to evaporation as well as the exceptional diel and seasonal swings, as noted above, SWQB asserts that other uses cannot be attained in these systems including domestic water supply, irrigation, fish culture, public water supply and industrial water supply. Based on reasonable evidence, the Department maintains that natural, ephemeral, intermittent or low flow conditions are preventing attainment of these designated uses.

Natural low flow conditions or the lack of persistent water associated with the non-perennial waters evaluated as part of this UAA prevents the attainment of the current designated aquatic life, domestic water supply, fish culture, public water supply, industrial water supply and irrigation uses of the non-perennial waters identified in this UAA. With the exception of Calaveras Canyon (20.6.4.108 NMAC) and Cox Canyon (20.6.4.208 NMAC), the Department finds that in accordance with 40 C.F.R. § 131.10(g)(2) the current designated uses may be amended or removed for non-perennial waters based on hydrological conditions and non-perennial characteristics.

VIII. Establishing Highest Attainable Use

Once the factor that precludes the attainment of the use has been demonstrated, 40 C.F.R. § 131.10 requires the UAA provide demonstration of the highest attainable use. The definition of highest attainable use can be found in 40 C.F.R. § 131.3(m).

40 C.F.R. § 131.3 Definitions
(m) *Highest attainable use is the modified aquatic life, wildlife, or recreation use that is both closest to the uses specified in section 101(a)(2) of the Act and attainable, based on the evaluation of the factor(s) in §131.10(g) that preclude(s) attainment of the use and any other information or analyses that were used to evaluate attainability. There is no required highest attainable use where the State demonstrates the relevant use specified in section 101(a)(2) of the Act and sub-categories of such a use are not attainable.*

For the determination of the highest attainable use, this UAA relied on the expert testimony provided by the U.S. Fish and Wildlife Service ("USFWS") as explained in the next section.

A. WQCC historical rule making analysis for highest attainable use.

In the rule making action WQCC-03-05(R), the WQCC adopted a definition for *Intermittent Waters* under 20.6.4.7(I)(2) NMAC and designated uses for intermittent waters under 20.6.4.98 NMAC. The evidence presented for this amendment was in part supported from the USFWS expert testimony. According to the WQCC-03-05(R), *Transcript of Proceedings In the Matter of the Triennial Review of Standards for Interstate and Intrastate Surface Waters, 20.6.4. NMAC* (WQCC 2004), the USFWS from the New Mexico Ecological Services Field office, gave testimony regarding the criteria to which intermittent and ephemeral waters in NM can support (WQCC 2004). Their testimony stated that intermittent waters have specialized biota that:

> *"have evolved or developed life history strategies and tactics which allow these species to withstand the physical, chemical and biological characteristics of these types of environments… species adapted to intermittency can cope with many environmental*

> *changes, such as intermittent flow, high turbidity, fluctuating temperature, variable dissolved oxygen content and salinity… pollutants can impact aquatic life in intermittent and ephemeral waters.*" (WQCC 2004).

This testimony provided evidence to establish the highest attainable use for all non-perennial waters now protected under 20.6.4.98 NMAC.

The language under 20.6.4.98 NMAC was amended in 2010 and 2017 to reflect a format change and an update for E. coli bacteria criteria but otherwise remains unamended as it pertains to the designated use for aquatic life.

20.6.4.7(I)(2) NMAC "Intermittent" when used to describe a surface water of the state means the water body contains water for extended periods only at certain times of the year, such as when it receives seasonal flow from springs or melting snow.

20.6.4.98 INTERMITTENT WATERS: All non-perennial surface waters of the state, except those ephemeral waters included under section 20.6.4.97 NMAC or classified in 20.6.4.101-899 NMAC.

A. Designated uses: livestock watering, wildlife habitat, marginal warmwater aquatic life and primary contact.

B. Criteria: the use-specific criteria in 20.6.4.900 NMAC are applicable to the designated uses, except that the following site-specific criteria apply: the monthly geometric mean of E. coli bacteria 206 cfu/100 mL or less, single sample 940 cfu/100 mL or less.

[20.6.4.98 NMAC - N, 5/23/2005; A, 12/1/2010; A, 3/2/2017]

The evidence provided for the creation of 20.6.4.98 NMAC, is the same evidence for establishing the highest attainable uses for the non-perennial tributaries listed in this UAA.

B. Highest Attainable Designated Uses.

The highest attainable aquatic life use was determined using the evidence presented by the USFWS in their testimony during the Triennial Review approved for rule making action WQCC-03-05(R), and the NHD map analysis. The WQCC-03-05(R) USFWS Triennial Review testimony provided evidence that marginal warmwater aquatic life is the highest attainable use for non-perennial (intermittent) waters. The NHD map analysis confirmed that in the listed sections being evaluated under this UAA there are non-perennial segments. Therefore, NMED asserts that marginal warmwater aquatic life use is the highest attainable use for non-perennial tributaries identified in this UAA.

The highest attainable recreational use remains the same except for those non-perennial waters classified under 20.6.4.206 NMAC, which are currently designated as secondary contact. The highest attainable (designated) recreational use for all non-perennial waters currently protected under 20.6.4.98 NMAC is primary contact. Therefore, without *E. coli* data to prove otherwise, NMED assumes the recreation use for non-perennial tributaries to the Rio Hondo downstream of Bonney Canyon can also attain primary contact.

It is also assumed that all non-perennial waters including those under this UAA can attain uses for livestock watering and wildlife habitat as identified under 20.6.4.98 NMAC.

Table VIII-1. *Selected sections non-perennial portions and highest attainable designated uses.*

Current WQS	Proposed WQS Reference	Tributary of	Contact Use	Aquatic Life Use	Livestock watering	Wildlife habitat
20.6.4.108	20.6.4.98	Non-perennial tributaries to the Jemez River above Soda dam	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.108	20.6.4.98	Non-perennial tributaries to the Guadalupe River	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.115	20.6.4.98	Non-perennial tributaries to the Rio Vallecitos	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.206	20.6.4.98	Non-perennial tributaries to the Rio Hondo downstream of Bonney Canyon	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.208	20.6.4.98	Non-perennial tributaries to the Rio Peñasco above state highway 24 near Dunken	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.209	20.6.4.98	Non-perennial tributaries to the Rio Bonito upstream of state highway 48 (near Angus)	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.209	20.6.4.98	Non-perennial tributaries to the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes, above and below the Mescalero Apache boundary	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.215	20.6.4.98	Non-perennial tributaries to the Gallinas River upstream of the diversion for the Las Vegas municipal reservoir	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.220	20.6.4.98	Non-perennial tributaries to the Gallinas River from its mouth upstream to the diversion for the Las Vegas municipal reservoir	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.307	20.6.4.98	Non-perennial tributaries to the Ocate Creek downstream of Ocate	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.309	20.6.4.98	Non-perennial tributaries to the Coyote Creek	primary contact	Marginal warmwater	livestock watering	wildlife habitat
20.6.4.309	20.6.4.98	Non-perennial tributaries to the Rayado Creek above Miami lake diversion	primary contact	Marginal warmwater	livestock watering	wildlife habitat

IX. Conclusions

A UAA is a scientific study conducted for the purpose of assessing the factors that affect attainment of a designated use. For this analysis, the Department examined low-flow, intermittent or ephemeral conditions that may prevent attainment of the designated uses for non-perennial segments associated with the WQS sections identified in this UAA.

In this UAA, NMED presents evidence demonstrating that attainment of the current designated uses for non-perennial tributaries in the referenced WQS sections is not feasible. This was based on three elements that must be supported for a change in designated use: (1) determination that the current and proposed designated uses are no less stringent than the existing use; (2) demonstration that one of the factors under 40 C.F.R. § 131.10(g) is preventing attainment of the current designated use; and (3) evidence supporting the highest attainable use.

As presented in this UAA, NMED determined that there are no available data to establish existing uses, therefore it can be concluded that removal of a designated use will not result in the lowering of an existing use. NMED identified that there are natural low-flow, intermittent or ephemeral conditions as described under 40 C.F.R. § 131.10(g)(2) that prevent attainment of the designated uses for non-perennial tributaries listed in this UAA. Evidence of these low flow conditions was ascertained through NMED's NHD analysis, which found non-perennial waters in the WQS sections evaluated in this UAA. Finally, according to the USFWS's testimony during the Triennial Review, docket number WQCC-03-05(R), the highest attainable uses are those already designated in 20.6.4.98 NMAC.

This UAA supports the removal of non-perennial reaches of tributaries from 20.6.4.108, 20.6.4.115, 20.6.4.206, 20.6.4.208, 20.6.4.209, 20.6.4.215, 20.6.4.220, 20.6.4.307, and 20.6.4.309 NMAC, and NMED recommends amending the language in these WQS sections to reflect "perennial reaches of tributaries to." The highest attainable uses for the non-perennial tributaries evaluated in this UAA (with the exceptions of Calaveras Canyon (20.6.4.108 NMAC) and Cox Canyon (20.6.4.208 NMAC)) were found to be livestock watering, wildlife habitat, marginal warmwater aquatic life and primary contact, consistent with the designated uses in 20.6.4.98 NMAC – Intermittent Waters.

The non-perennial portions of Calaveras Canyon (20.6.4.108 NMAC) and Cox Canyon (20.6.4.208 NMAC) were not evaluated as part of this UAA due to the potential influence of hydrological modifications that were beyond the scope of this UAA. The Department recognizes that non-perennial conditions associated with these waters likely prevent the attainment of the designated aquatic life use. Therefore, it is the intention of the Department to evaluate the attainability of these designated aquatic life uses independently from this UAA.

X. Amended Water Quality Standards Proposed Language

The highest attainable designated uses for non-perennial tributaries evaluated in this UAA are livestock watering, wildlife habitat, marginal warmwater aquatic life and primary contact, consistent with designated uses under 20.6.4.98 NMAC. Therefore, NMED finds that all non-perennial tributaries evaluated under this UAA should be protected under 20.6.4.98 NMAC. Reasonable evidence provided in this UAA supports clarifying language to exclude non-perennial tributaries from certain WQS sections of NMAC. NMED recommends that the following classified waters be amended to exclude non-perennial tributaries as follows:

20.6.4.108 RIO GRANDE BASIN: - Perennial reaches of the Jemez river **upstream of Soda dam near the town of Jemez Springs** **and** **[~~all its~~]perennial reaches of** **tributaries** **to the Jemez river except those not specifically identified under other sections of 20.6.4 NMAC [~~above Soda dam near the town of Jemez Springs, except San Gregorio lake and Sulphur creek above its confluence with Redondo creek~~]****, and perennial reaches of the Guadalupe river and** **perennial reaches of [~~all its~~]** **tributaries** **to the Guadalupe river, and reaches of Calaveras canyon****.**

A. Designated uses: domestic water supply, fish culture, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 400 µS/cm or less (800 µS/cm or less on Sulphur creek); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less; and pH within the range of 2.0 to 8.8 on Sulphur creek.

[20.6.4.108 NMAC - Rp 20 NMAC 6.1.2106, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]

[NOTE: The segment covered by this section was divided effective 05-23-05. The standards for the additional segment are under 20.6.4.124 NMAC. The standards for San Gregorio lake are in 20.6.4.134 NMAC, effective 07-10-12]

20.6.4.115 RIO GRANDE BASIN: - The perennial reaches of Rio Vallecitos, [~~and its~~] perennial reaches of tributaries to Rio Vallecitos except Hopewell lake, and perennial reaches of Rio del Oso and perennial reaches of El Rito creek above the town of El Rito.

A. Designated uses: domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat and primary contact; public water supply on the Rio Vallecitos and El Rito creek.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.115 NMAC - Rp 20 NMAC 6.1.2112, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]

[**NOTE:** The standards for Hopewell lake are in 20.6.4.134 NMAC, effective 07-10-12]

20.6.4.206 PECOS RIVER BASIN: The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, perennial reaches of the Rio Hondo downstream of Bonney canyon and [~~its~~] perennial reaches of tributaries to the Rio Hondo downstream of Bonney canyon and perennial reaches of the Rio Felix.

A. Designated uses: irrigation, livestock watering, wildlife habitat, secondary contact and warmwater aquatic life.

B. Criteria:

(1) The use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.

(2) At all flows above 50 cfs: TDS 14,000 mg/L or less, sulfate 3,000 mg/L or less and chloride 6,000 mg/L or less. [20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10-12-2000; A, 05-23-2005; A, 12-01-2010; A, 03-02-2017]

20.6.4.208 PECOS RIVER BASIN: [-] Perennial reaches of the Rio Peñasco above state highway 24 near Dunken, [~~and its~~]perennial reaches of tributaries to the Rio Peñasco above state highway 24 near Dunken, perennial reaches of Cox canyon, perennial reaches of the Rio Bonito downstream from state highway 48 (near Angus), the Rio Ruidoso downstream of the U.S. highway 70 bridge near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon and perennial reaches of Agua Chiquita.

A. Designated uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater aquatic life and primary contact.

B. Criteria: the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: temperature 30°C (86°F) or less, and phosphorus (unfiltered sample) less than 0.1 mg/L.

[20.6.4.208 NMAC - Rp 20 NMAC 6.1.2208, 10-12-00; A, 05-23-05; A, 12-01-10]

20.6.4.209 PECOS RIVER BASIN: [-] Perennial reaches of Eagle creek upstream of Alto dam to the Mescalero Apache boundary, perennial reaches of the Rio Bonito upstream of state highway 48 (near Angus) excluding Bonito lake, [~~and its~~] perennial reaches of tributaries to the Rio Bonito upstream of state highway 48 (near Angus)[-], [~~and~~] perennial reaches of the Rio Ruidoso upstream

of the U.S. highway 70 bridge near Seeping Springs lakes[~~,~~] above and below the Mescalero Apache boundary and [~~its~~]perennial reaches of tributaries to the Rio Ruidoso upstream of the U.S. highway 70 bridge near Seeping Springs lakes[~~,~~] above and below the Mescalero Apache boundary.

A. **Designated uses:** domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, public water supply and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 600 µS/cm or less in Eagle creek, 1,100 µS/cm or less in Bonito creek and 1,500 µS/cm or less in the Rio Ruidoso; phosphorus (unfiltered sample) less than 0.1 mg/L; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.209 NMAC - Rp 20 NMAC 6.1.2209, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]

[**NOTE:** The standards for Bonito lake are in 20.6.4.223 NMAC, effective 07-10-12]

20.6.4.215 PECOS RIVER BASIN: - Perennial reaches of the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, [~~and all its~~] perennial reaches of tributaries to the Gallinas river upstream of the diversion for the Las Vegas municipal reservoir, perennial reaches of Tecolote creek upstream of Blue creek[~~,~~] and all perennial reaches of tributaries [~~of~~]to Tecolote creek upstream of Blue creek.

A. **Designated uses:** domestic water supply, high quality coldwater aquatic life, irrigation, livestock watering, wildlife habitat, industrial water supply and primary contact; and public water supply on the Gallinas river.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 300 µS/cm or less (450 µS/cm or less in Wright Canyon creek); the monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.

[20.6.4.215 NMAC - Rp 20 NMAC 6.1.2212, 10-12-00; A, 05-23-05; A, 12-01-10; A, 02-13-2018]

[**NOTE:** This segment was divided effective 02-13-2018. The standards for Tecolote creek from I-25 to Blue creek are under 20.6.4.230 NMAC.]

20.6.4.220 PECOS RIVER BASIN: - Perennial reaches of the Gallinas river and [~~its~~] perennial reaches of tributaries to the Gallinas river from its mouth upstream to the diversion for the Las Vegas municipal reservoir, except Pecos Arroyo.

A. **Designated uses:** irrigation, livestock watering, wildlife habitat, marginal coldwater aquatic life and primary contact.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criterion applies: temperature 30°C (86°F) or less.

[20.6.4.220 NMAC - N, 05-23-05; A, 12-01-10]

20.6.4.307 CANADIAN RIVER BASIN: - Perennial reaches of the Mora river from the USGS gaging station near Shoemaker upstream to the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river downstream from the USGS gaging station at La Cueva in San Miguel and Mora counties except lakes identified in 20.6.4.313 NMAC, perennial reaches of Ocate creek downstream of Ocate, [~~and its~~]perennial reaches of tributaries to Ocate creek downstream of Ocate, and perennial reaches of Rayado creek downstream of Miami lake diversion in Colfax county.

A. **Designated uses:** marginal coldwater aquatic life, warmwater aquatic life, primary contact, irrigation, livestock watering and wildlife habitat.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses.
[20.6.4.307 NMAC - Rp 20 NMAC 6.1.2305.3, 10-12-00; A, 05-23-05; A, 12-01-10; A, 07-10-12]

20.6.4.309 CANADIAN RIVER BASIN: [-] The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora except lakes identified in 20.6.4.313 NMAC, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek, [~~and its~~]perennial reaches of tributaries to Coyote creek, the Cimarron river above state highway 21 in Cimarron, [~~and its~~]perennial reaches of tributaries to the Cimarron river above state highway 21 in Cimarron except Eagle Nest lake, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64 except north and south Shuree ponds, perennial reaches of Rayado creek above Miami lake diversion, [~~and its~~]perennial reaches of tributaries to Rayado creek above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

A. **Designated uses:** domestic water supply, irrigation, high quality coldwater aquatic life, livestock watering, wildlife habitat, and primary contact; and public water supply on the Cimarron river upstream from Cimarron, [~~and~~]on perennial reaches of Rayado creek and on perennial reaches of [~~its~~]tributaries to Rayado creek.

B. **Criteria:** the use-specific numeric criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses, except that the following segment-specific criteria apply: specific conductance 500 µS/cm or less; the monthly geometric mean of *E. coli* bacteria 126 cfu/100 mL or less, single sample 235 cfu/100 mL or less.
[20.6.4.309 NMAC - Rp 20 NMAC 6.1.2306, 10/12/2000; A, 7/19/2001; A, 5/23/2005; A, 12/1/2010; A, 7/10/2012; A, XX/XX/XXXX]
[**NOTE:** The segment covered by this section was divided effective 5/23/2005. The standards for the additional segment are under 20.6.4.310 NMAC. The standards for Shuree ponds are in 20.6.4.314 NMAC and the standards for Eagle Nest lake are in 20.6.4.315 NMAC, effective 7/10/2012]

XI. References

40 Code of Federal Regulations (C.F.R.) §131.10 (2019).

Endangered Species Act (ESA), 16 U.S. Code (USC) § 7 (2019).

Datry et al. (2017) The Biota of Intermittent Rivers and Ephemeral Streams: Fishes. In Adam Kerezsy, Keith Gido, Maria F. Magalhães, and Paul H. Skelton (Eds.) Intermittent Rivers and Ephemeral Streams: Ecology and Management, (Pages 273-298) Academic Press.

Gomez et al. (2017) Water Physicochemistry in Intermittent Rivers and Ephemeral Streams. In Adam Kerezsy, Keith Gido, Maria F. Magalhães, and Paul H. Skelton (Eds.) Intermittent Rivers and Ephemeral Streams: Ecology and Management, (Pages 109-134) Academic Press.

Levick, L., J. Fonseca, D. Goodrich, M. Hernandez, D. Semmens, J. Stromberg, R. Leidy, M. Scianni, D. P. Guertin, M. Tluczek, and W. Kepner. (2008). The ecological and hydrological significance of ephemeral and intermittent streams in the arid and semi-arid American southwest. *U.S. Environmental Protection Agency and USDA/ARS Southwest Watershed Research Center*, EPA/600/R-08/134, ARS/233046, 116 pp. https://www.epa.gov/cwa-404/ecological-and-hydrological-significance-ephemeral-and-intermittent-streams-arid-and-semi (accessed June 1, 2020).

Thibault Datry, Andrew J. Boulton, Núria Bonada, Ken Fritz, Catherine Leigh, Eric Sauquet, Klement Tockner, Bernard Hugueny, and Clifford N. Dahm. (2018). Flow intermittence and ecosystem services in rivers of the Anthropocene. Journal of Applied Ecology.

New Mexico Administrative Code (NMAC). 2021. Natural Resources and Wildlife Surface Water Administration . Office of the State Engineer. As amended through April 15, 2021 (19.26.2 NMAC).

New Mexico Administrative Code (NMAC). 2020. State of New Mexico Standards for Interstate and Intrastate Surface Waters. *New Mexico Water Quality Control Commission*. As amended through May 22, 2020 (20.6.4 NMAC).

New Mexico Environment Department/ Surface Water Quality Bureau (NMED/SWQB), 2019. Modification of Permit Condition for Ancho Mine, Permit No. NM0030180

New Mexico Office of the State Engineer. (2020) Point of Diversions Open Data Site Water Administration Technical Engineering Resource System. http://geospatialdata-ose.opendata.arcgis.com/ (accessed June 5, 2020).

State of New Mexico Water Quality Control Commission (WQCC). 03-05(R). (2004) *Transcript of Proceedings. In the Matter of the Triennial Review of Standards for Interstate and Intrastate Surface Waters, 20.6.4. NMAC.*

State of New Mexico Water Quality Control Commission (WQCC). 03-05(R). (2005). *Statement of Reason for Amendment of Standards. In the Matter of the Triennial Review of Standards for Interstate and Intrastate Surface Waters*, 20.6.4. NMAC.

U.S. Environmental Protection Agency (USEPA). (2006). Level III ecoregions of the continental United States (revision of Omernik, 1987): *Corvallis, Oregon, USEPA – National Health and Environmental Effects Research Laboratory*, Map M-1, various scales.

U.S. Geological Survey (USGS). (2018). National Hydrography Dataset (NHD) for 4-digit Hydrologic Unit - 1302 (published August 30, 2018).

U.S. Geological Survey (USGS). (2006). National Hydrography Dataset. http://nhd.usgs.gov (accessed June 1, 2020).

U.S. Fish and Wildlife Service (USFWS). (2019). IPaC Information for Planning and Consultation. https://ecos.fws.gov/ipac/ (accessed on May 26, 2020).

Appendix A

Excerpts for Classified Waters reviewed for this UAA from the *WQCC 03-05(R) Statement of Reason for Amendments of Standards* (WQCC 2005)

20.6.4.108 RIO GRANDE BASIN - [~~The~~] Perennial reaches of the Jemez river and all its tributaries above [~~state highway 4~~] Soda dam near the town of Jemez Springs, except Sulphur creek above its confluence with Redondo creek, and perennial reaches of the Guadalupe river and all its tributaries.

Designated Uses: domestic water supply, fish culture, high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat[,] and secondary contact.

[~~Standards~~]Criteria:
In any single sample: [~~conductivity shall not exceed~~]specific conductance 400 µmhos/cm or less, pH [~~shall be~~] within the range of 6.6 to 8.8[,] and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 25 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
[~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.108 NMAC - Rp 20 NMAC 6.1.2106, 10-12-00; A, XX-XX-05]
[NOTE: The segment covered by this section was. The standards for the additional segment are under 20.6.4.124 NMAC.]

> 213. The Commission adopts NMED's proposal to amend the segment description because it applies the designated uses to perennial reaches and changes the reference from "state highway 4" to "Soda dam" to use a geologic rather than a cultural feature. Currently, this segment includes all tributaries in the Jemez and Guadalupe River watersheds, instead of just perennial waters. Intermittent reaches will be covered by new Section 20.6.4.98. The Commission adopts NMED's proposal to move Sulphur Creek to a new section to reflect its unique conditions for the reasons stated in Section 20.6.4.124.
>
> 214. The Commission adopts NMED's proposal to change the bacterial criteria type and values. The proposed changes are based on EPA guidance. The segment currently has a secondary contact designated use and more stringent primary contact criteria for fecal coliform bacteria of 100/100 mL (geometric mean) and 200/100 mL (single sample). These criteria translate to E. coli criteria of 126/100 mL (geometric mean) and 235/100 mL (single sample). NMED's proposal to make similar changes in other segments is adopted for these reasons (Section 115, 119, 121, 123, 209, 215, 309, 405, 407, 503, 603, 701, 702, 801, 802, 803, and 804), and the Commission adopts those changes below on the same basis.

20.6.4.115 RIO GRANDE BASIN - The perennial reaches of Rio Vallecitos and its tributaries, and perennial reaches of Rio del Oso[,] and perennial reaches of El Rito creek above the town of El Rito.

Designated Uses: domestic water supply, irrigation, high quality coldwater [~~fishery~~]aquatic life, livestock watering, wildlife habitat[,] and secondary contact.

[~~Standards~~]Criteria:
In any single sample: [~~conductivity shall not exceed~~]specific conductance 300 ⍰mhos/cm or less, pH [~~shall be~~] within the range of 6.6 to 8.8[,]and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 10 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

[~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.115 NMAC - Rp 20 NMAC 6.1.2112, 10-12-00; A, XX-XX-05]

> 221. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the intermittent reaches are properly covered by new Section 20.6.4.98.

20.6.4.206 PECOS RIVER BASIN - The main stem of the Pecos river from the headwaters of Brantley reservoir upstream to Salt creek (near Acme), perennial reaches of the Rio Peñasco downstream from state highway 24 near Dunken, [~~any flow at the mouth of~~] perennial reaches of the Rio Hondo and its tributaries below Bonney canyon and [~~any flow from~~] perennial reaches of the Rio Felix[~~ which enters the main stem of the Pecos river~~].

Designated Uses: irrigation, livestock watering, wildlife habitat, secondary contact[,] and warmwater [~~fishery~~]aquatic life.

[~~Standards~~]Criteria:
In any single sample: pH [~~shall be~~] within the range of 6.6 to 9.0 and temperature [~~shall not exceed~~] 32.2°C (90°F) or less. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
[~~The monthly geometric mean of fecal coliform bacteria shall not exceed l,000/100 mL; no single sample shall exceed 2,000/100 mL~~]The monthly geometric mean of E. coli bacteria 548 cfu/100 mL or less; single sample 2507 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
At all flows above 50 cfs: TDS [~~shall not exceed~~] 14,000 mg/L or less, sulfate [~~shall not exceed~~] 3,000 mg/L or less[,] and chloride [~~shall not exceed~~] 6,000 mg/L or less.
[20.6.4.206 NMAC - Rp 20 NMAC 6.1.2206, 10-12-00; A, XX-XX-05]

> 251. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the nonperennial reaches are properly covered by new Section 20.6.4.98.
>
> 252. The Commission adopts NMED's proposal to identify the segment terminus at Bonney Canyon because it eliminates a possible conflict with Section 20.6.4.208.

20.6.4.208 PECOS RIVER BASIN - Perennial reaches of the Rio Peñasco and its tributaries above state highway 24 near Dunken, perennial reaches of the Rio Bonito downstream from state highway 48 (near Angus), the Rio Ruidoso downstream of the U.S. highway 70 bridge near Seeping Springs lakes, perennial reaches of the Rio Hondo upstream from Bonney canyon[,] and perennial reaches of Agua Chiquita.

Designated Uses: fish culture, irrigation, livestock watering, wildlife habitat, coldwater [~~fishery~~]aquatic life[,] and secondary contact.

[~~Standards~~]Criteria:
In any single sample: pH [~~shall be~~] within the range of 6.6 to 8.8, temperature [~~shall not exceed~~] 30°C (86°F) or less and total phosphorus (as P) [~~shall be~~] less than 0.1 mg/L. The use-specific numeric

[~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
[~~The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 mL; no single sample shall exceed 400/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 410 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.208 NMAC - Rp 20 NMAC 6.1.2208, 10-12-00; A, XX-XX-05]

> 254. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the nonperennial reaches are properly covered by new Section 20.6.4.98.

20.6.4.209 PECOS RIVER BASIN - Perennial reaches of Eagle creek above Alto reservoir, perennial reaches of the Rio Bonito and its tributaries upstream of state highway 48 (near Angus)[,] and perennial reaches of the Rio Ruidoso and its tributaries upstream of the U.S. highway 70 bridge near Seeping Springs lakes.

Designated Uses: domestic water supply, fish culture, high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat, municipal and industrial water supply[,] and secondary contact.

[~~Standards~~]Criteria:
In any single sample: [~~conductivity shall not exceed~~]specific conductance 600 µmhos/cm or less in Eagle creek, 1,100 ⍰mhos or less in Bonito creek, and 1,500 µmhos or less in the Rio Ruidoso, pH [~~shall be~~]within the range of 6.6 to 8.8, total phosphorus (as P) less than 0.1 mg/L and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 10 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
[~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.209 NMAC - Rp 20 NMAC 6.1.2209, 10-12-00; A, XX-XX-05]

> 255. The Commission adopts NMED's proposal to add a phosphorous criterion because it restores criterion that was removed inadvertently in the 1998 triennial review.
>
> 256. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the nonperennial reaches are properly covered by new Section 20.6.4.98.

20.6.4.215 PECOS RIVER BASIN - [~~The~~]Perennial reaches of the Gallinas river and all its tributaries above the diversion for the Las Vegas municipal reservoir and perennial reaches of Tecolote creek and its perennial tributaries.

Designated Uses: domestic water supply, high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat, municipal and industrial water supply[,] and secondary contact.

[~~Standards~~]Criteria:
In any single sample: [~~conductivity shall not exceed~~]specific conductance 300 µmhos/cm or less except [~~conductivity shall not exceed~~]specific conductance 450 µmhos/cm or less in Wright Canyon creek, pH

[~~shall be~~] within the range of 6.6 to 8.8[,] and temperature [~~shall not exceed~~]20°C (68°F) or less[~~, and turbidity shall not exceed 10 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
[~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.215 NMAC - Rp 20 NMAC 6.1.2212, 10-12-00; A, XX-XX-05]

> 262. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the nonperennial reaches are properly covered by new Section 20.6.4.98.

20.6.4.309 CANADIAN RIVER BASIN - The Mora river and perennial reaches of its tributaries upstream from the state highway 434 bridge in Mora, all perennial reaches of tributaries to the Mora river upstream from the USGS gaging station at La Cueva, perennial reaches of Coyote creek and its tributaries, the Cimarron river and its perennial tributaries above state highway 21 in Cimarron, all perennial reaches of tributaries to the Cimarron river north and northwest of highway 64, perennial reaches of Rayado creek and its tributaries above Miami lake diversion, Ocate creek and perennial reaches of its tributaries upstream of Ocate, perennial reaches of the Vermejo river upstream from Rail canyon and all other perennial reaches of tributaries to the Canadian river northwest and north of U.S. highway 64 in Colfax county unless included in other segments.

Designated Uses: domestic water supply, irrigation, high quality coldwater [~~fishery~~]aquatic life, livestock watering, wildlife habitat, municipal and industrial water supply[,] and secondary contact.

[~~Standards~~]Criteria:
In any single sample: [~~conductivity shall not exceed~~]specific conductance 500 µmhos/cm or less[~~ (at 25°C)~~], pH [~~shall be~~]within the range of 6.6 to 8.8[,] and temperature [~~shall not exceed~~] 20°C (68°F)[~~, and turbidity shall not exceed 25 NTU~~] or less. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.
[~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 m/L; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.309 NMAC - Rp 20 NMAC 6.1.2306, 10-12-00; A, 7-19-01; A, XX-XX-05]
[NOTE: The segment covered by this section was divided effective XX-XX-05. The standards for the additional segment are under 20.6.4.310 NMAC.]

> 284. The Commission adopts NMED's proposal to move the upper reaches of the Vermejo River to another section for the reasons described in Section 20.6.4.305.
>
> 285. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the nonperennial reaches are properly covered by new Section 20.6.4.98

Appendix B

New standard section 20.6.4.98 from the *WQCC 03-05(R) Statement of Reason for Amendments of Standards* (WQCC 2005)

20.6.4.98 INTERMITTENT WATERS - All intermittent surface waters of the state that are not included in a classified water of the state in 20.6.4.101 through 20.6.4.899 NMAC.

A. Designated Uses: livestock watering, wildlife habitat, aquatic life and secondary contact.

B. Criteria:

(1) The use-specific criteria in 20.6.4.900 NMAC.

(2) The monthly geometric mean of E. coli bacteria shall not exceed 548 cfu/100 mL, no single sample shall exceed 2507 cfu/100 mL (see Subsection B of 20.6.4.14 NMAC).

[20.6.4.98 NMAC - N, XX-XX-05]

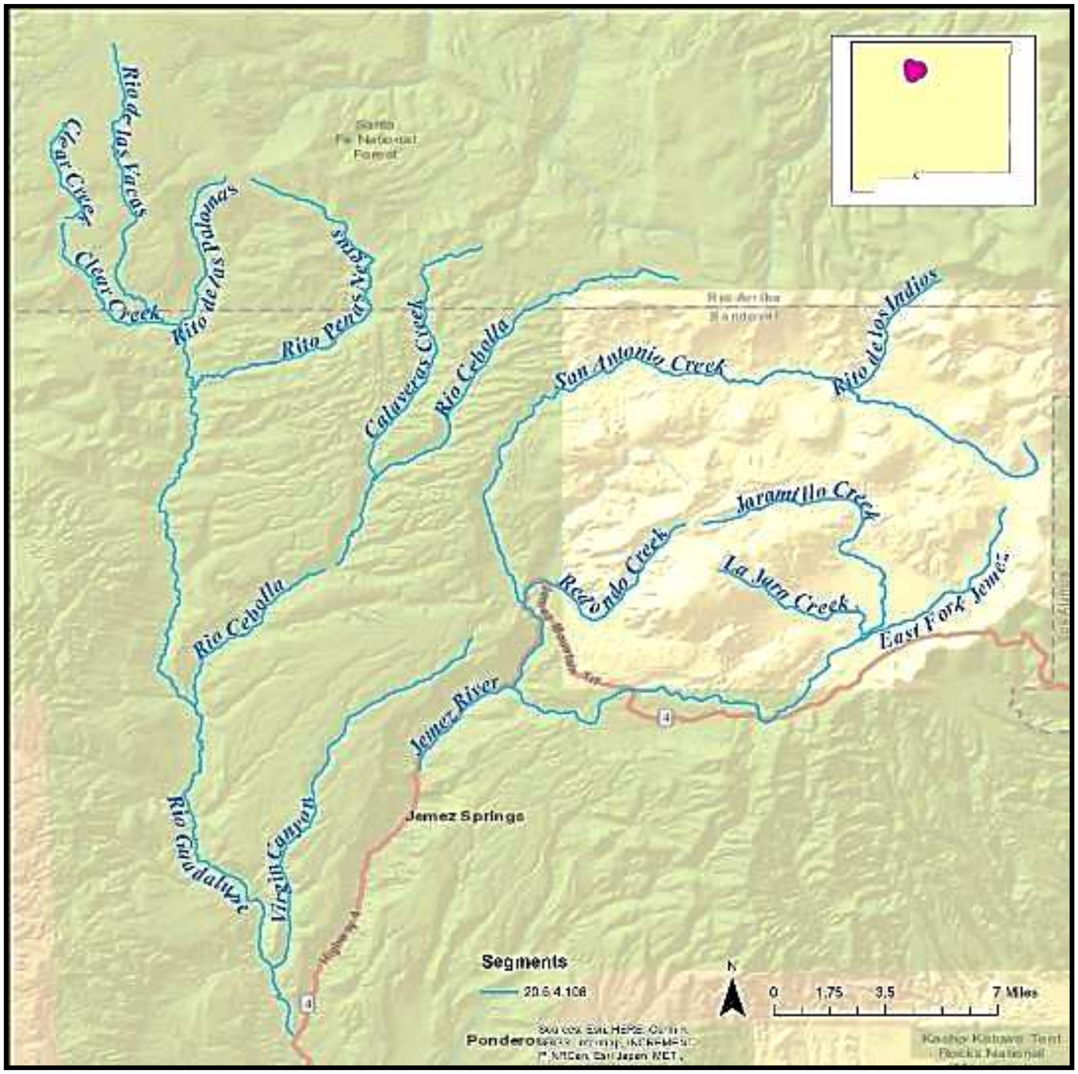
192. The Commission adopts NMED's proposal to create a provision containing default designated uses for unclassified intermittent waters to ensure that all unclassified intermittent waters are protected in compliance with the CWA. Intermittent waters have the same default uses as ephemeral waters for the same reasons stated above in paragraph 188, except that it is "aquatic life" rather than "limited aquatic life." Aquatic life in intermittent waters have a longer residence time, and there are many intermittent reaches of perennial streams. The Commission believes it is appropriate to apply chronic criteria to intermittent waters because of the potential long-term exposure of aquatic life to pollutants.

Appendix C

US Fish and Wildlife Service Environmental Conservation Online System Information for Planning and Consultation (IPaC) geographical area delineations for species evaluation.

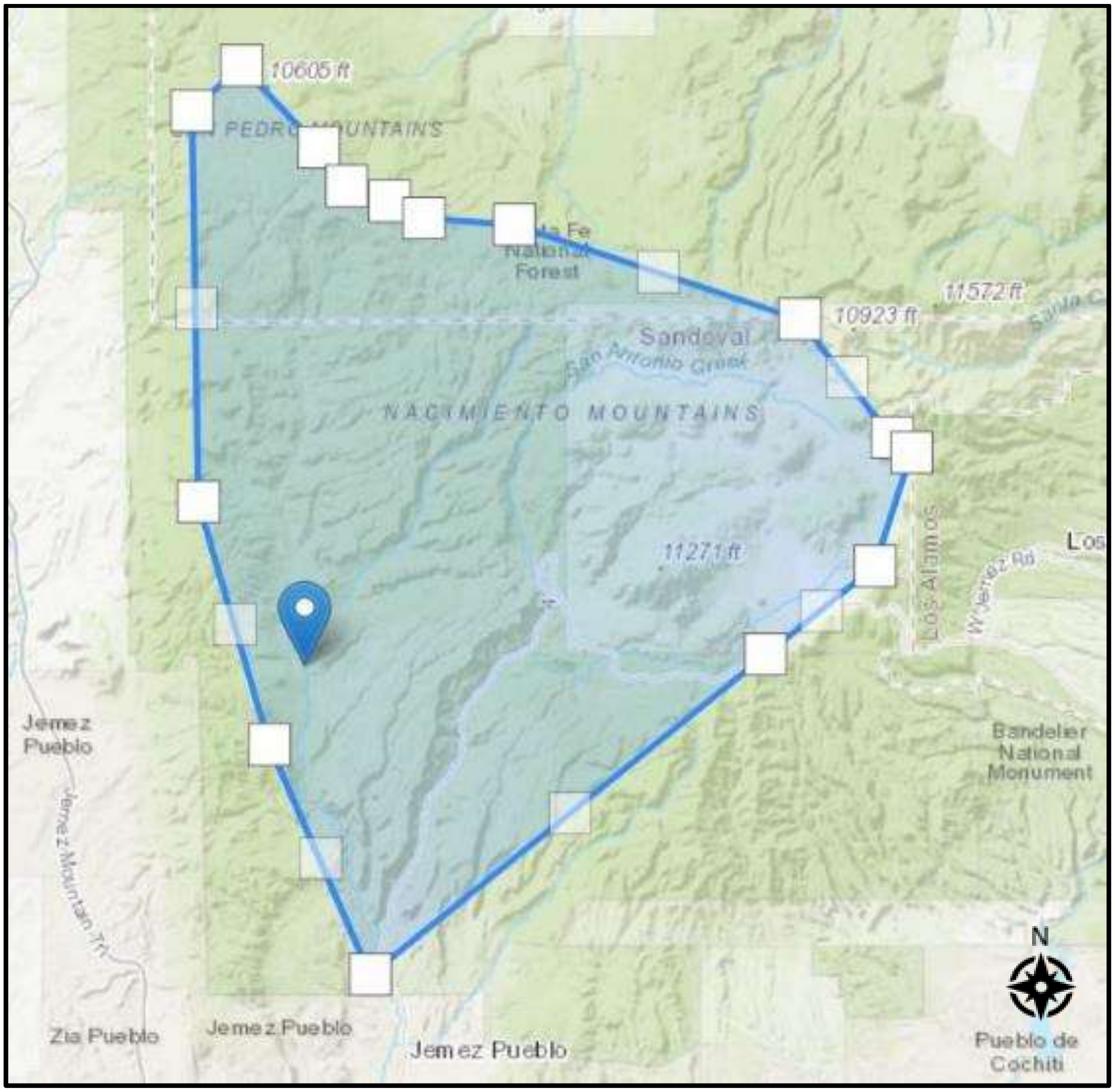
The following contains maps created by the SWQB for each of the classified waters including those non-perennial waters being reviewed under this UAA . Following each of the general SWQB area maps are descriptions of the steps taken to create the IPaC delineations used to determine threatened and endangered species within the study area. IPaC map online tool did not provide a distance scale when running an IPaC evaluation.

C-1. WQS 20.6.4.108 RIO GRANDE BASIN



<u>IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.108</u>

To determine if any species of concern are within the study area, a polygon was manually drawn; from the headwaters of Rito de los Indios to the headwaters of San Antonio Creek, then south perpendicular to State highway 4, then west to Soda Dam, then again along highway 4 to Rio Guadalupe at its confluence with Jemez River, then north along Rio Guadalupe to Clear Creek headwaters, then to Rio de las Vacas headwaters east to Rio de los Indios headwaters.

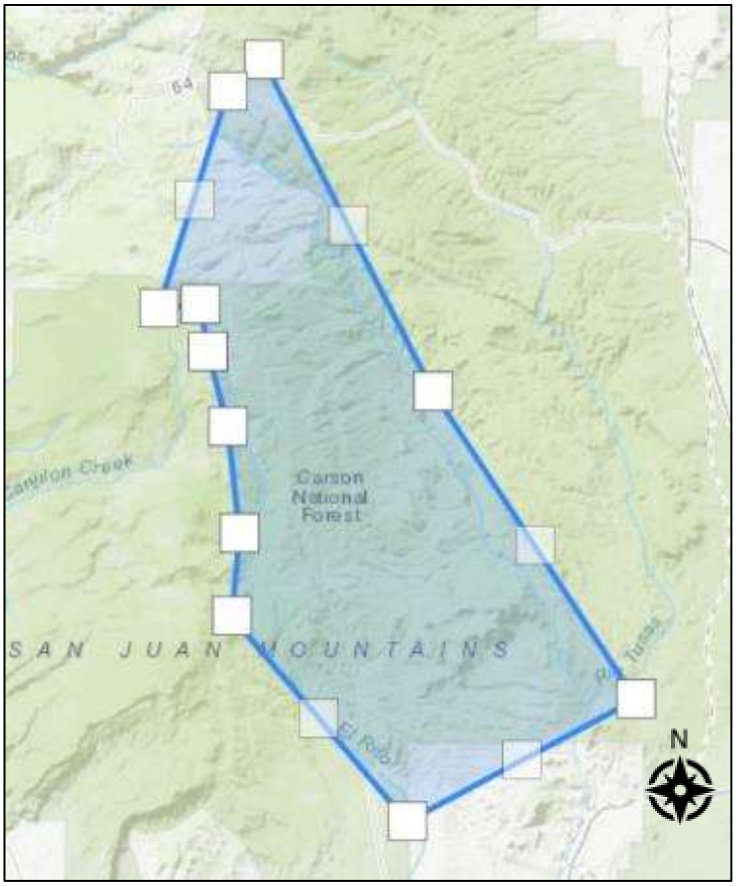

10605 ft
SAN PEDRO MOUNTAINS
Santa Fe National Forest
11572 ft
10923 ft
Sandoval
San Antonio Creek
NACIMIENTO MOUNTAINS
11271 ft
Los Alamos
W Jemez Rd
Los
Jemez Pueblo
Bandelier National Monument
Jemez Mountain Trl
Zia Pueblo
Jemez Pueblo
Jemez Pueblo
N
Pueblo de Cochiti

C-2. WQS 20.6.4.115 RIO GRANDE BASIN

<u>IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.115</u>

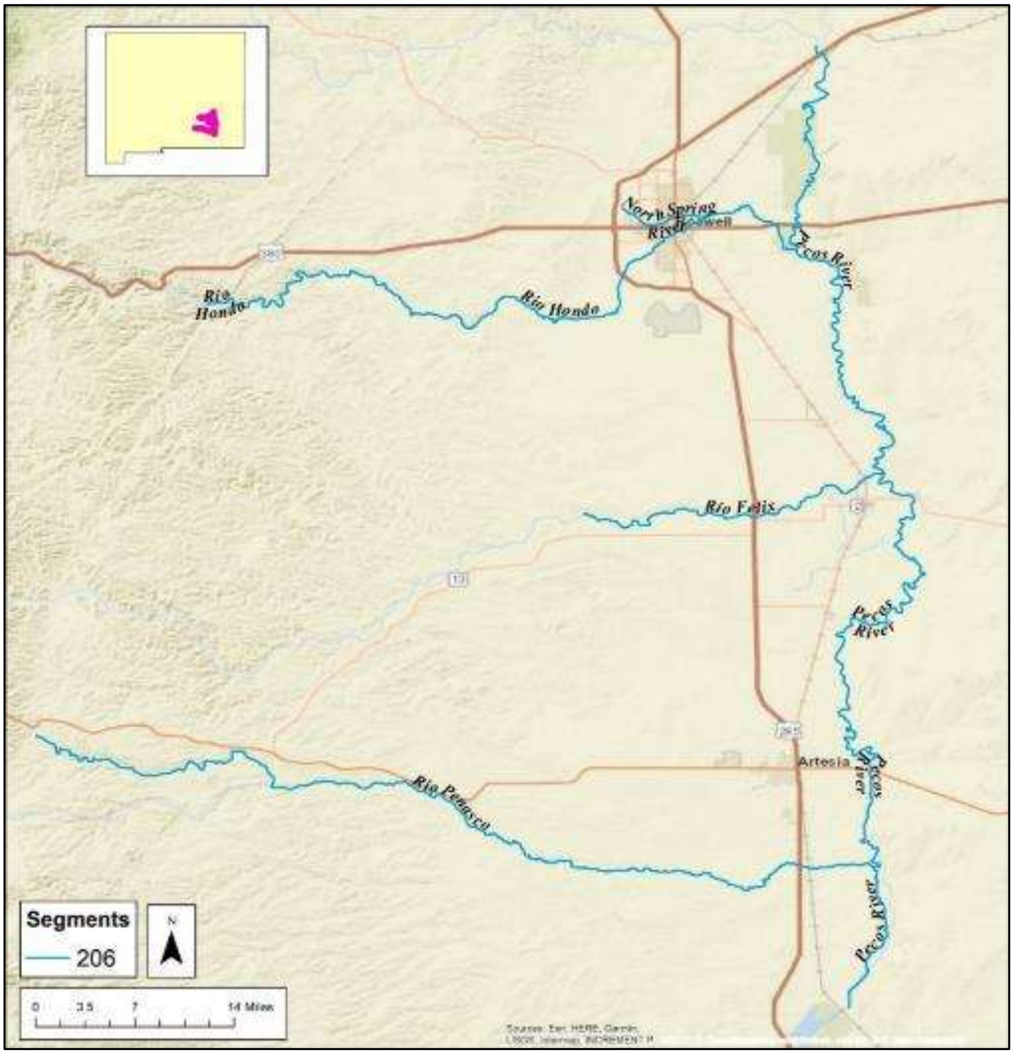
IPaC Assessment included: Placer Creek, Rio Vallecitos, Jarosa Creek and El Rito Creek.

To determine if any species of concern are within the study area, a polygon was manually drawn from; Placer Creek headwaters to Rio Vallecitos headwaters, then to Jarosa Creek headwaters, then west to El Rito headwaters, then south along El Rito all the way to State Highway 554, then northeast to the confluence of Rio Vallecitos and Rio Tusas, then north along Rio Vallecitos all the way to Placer Creek headwaters.



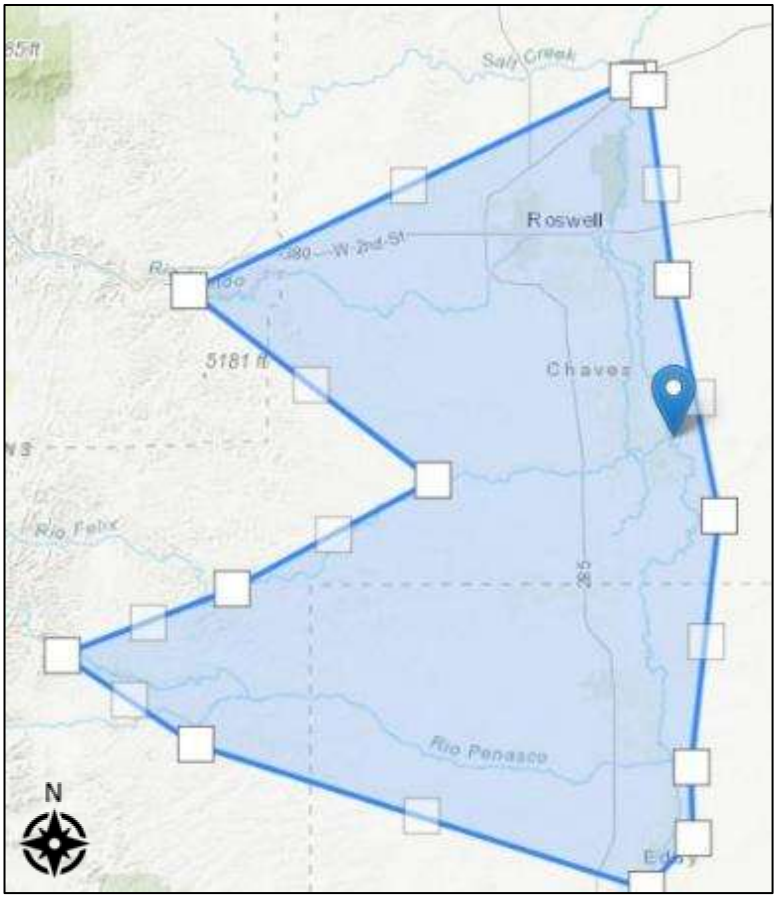
IPaC assessment for Rio del Oso.
Assessment created with a line drawing too with a 500 ft buffer. Rio del Oso starting at the Rio Chama confluence to headwaters.

C-3. WQS 20.6.4.206 PECOS RIVER BASIN



IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.206

To determine if any species of concern are within the study area, a polygon was manually drawn from; Pecos river at Salt Creek southwest to Rio Hondo at Bonney Canyon, then southeast to Rio Felix at Old Y O Crossing Road off Sagebrush Valley Road, then southwest to Rio Penasco at Rio Penasco Road at Dunken Route, then southeast to Pecos river at Brantley Reservoir, then north along the Pecos River up to Salt Creek.

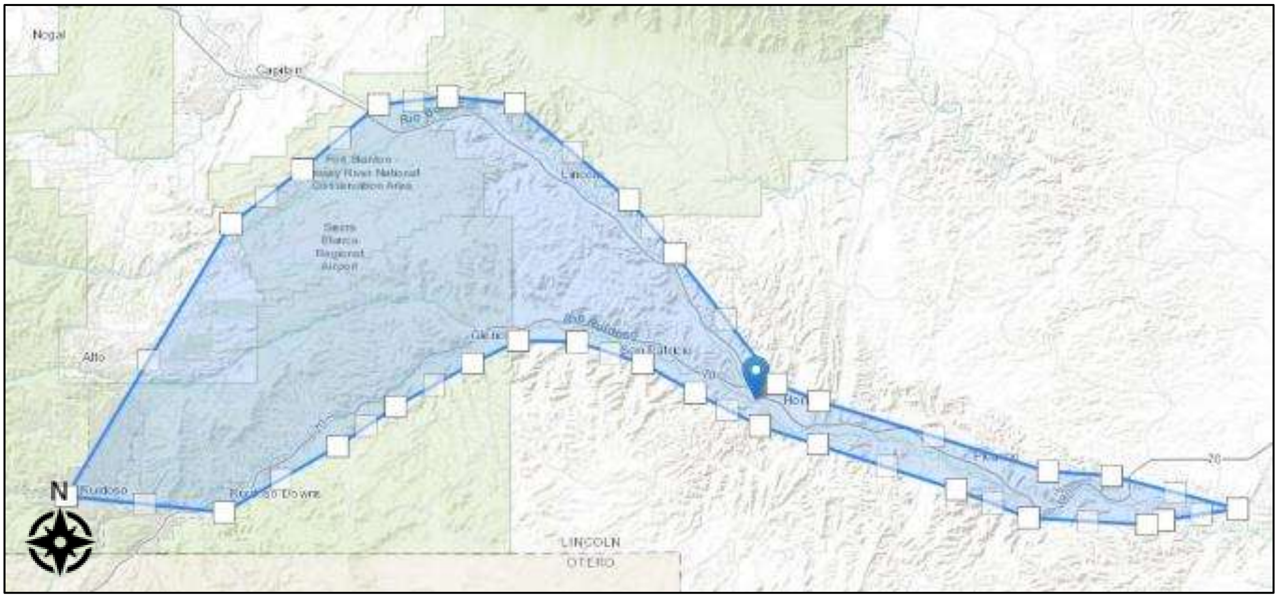

Salt Creek
Roswell
380 W 2nd St
Rio Hondo
5181 ft
Chaves
Rio Felix
285
Rio Penasco
Eddy
N

C-4. WQS 20.6.4.208 PECOS RIVER BASIN

IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.208

Rio Ruidoso, Rio Bonito and Rio Hondo.

To determine if any species of concern are within the study area, a polygon was manually drawn from; Rio Hondo crossing at Border Hill then northwest along State Highway 70 to the confluence of Rio Bonito, then along Rio Bonito to NM 48 near Angus, then south to the town of Ruidoso, then southeast along NM 48 all the way to Highway 70, then east along Highway 70 and Rio Ruidoso up to Border HIll.

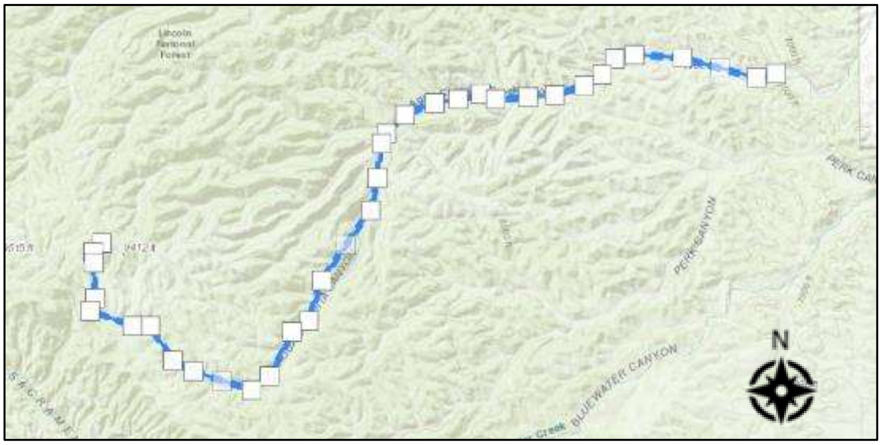


Rio Penasco

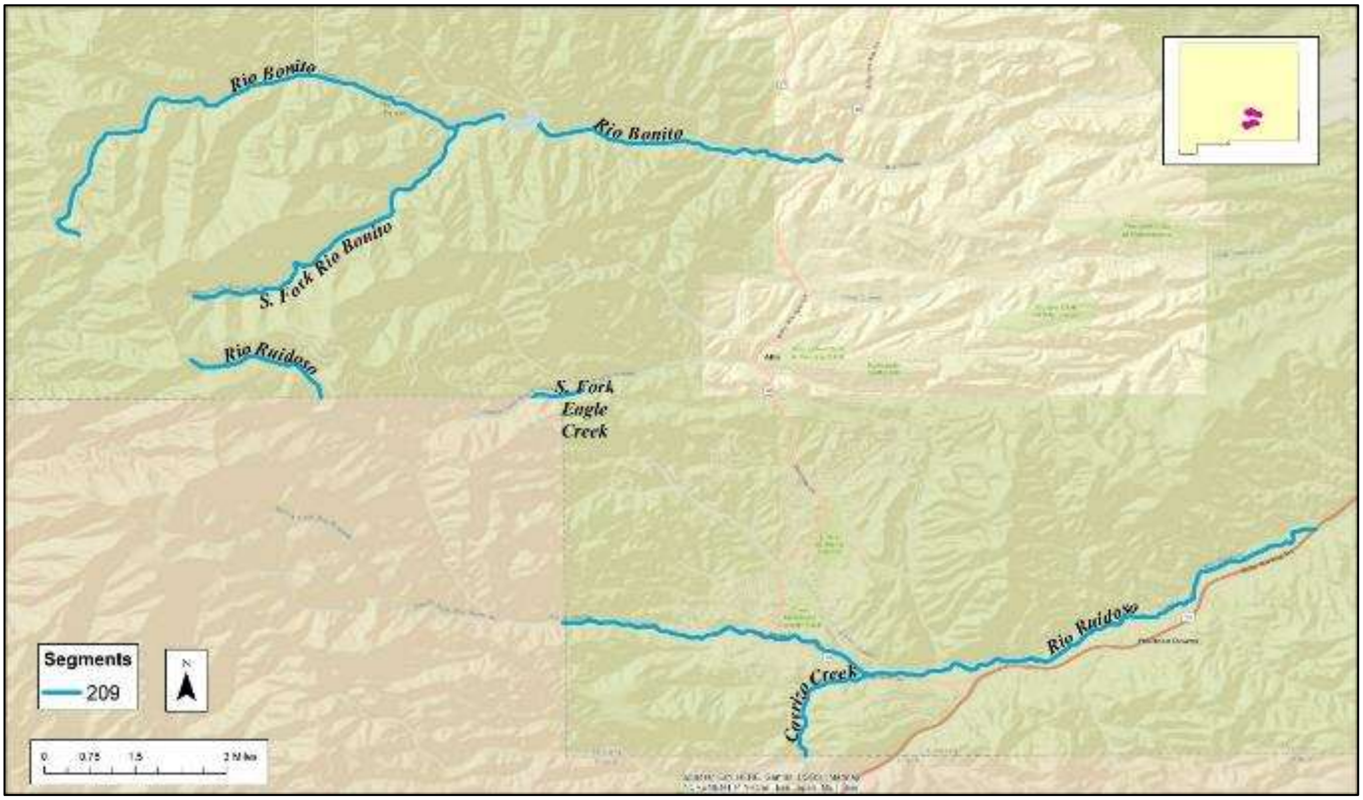
Assessment created with a line drawing too with a 500 ft buffer. Rio Penasco starting at Highway 24 to headwaters.

Agua Chiquita

Assessment created with a line drawing too with a 500 ft buffer. Agua Chiquita starting at Miller Flats road and NM24 to headwaters.



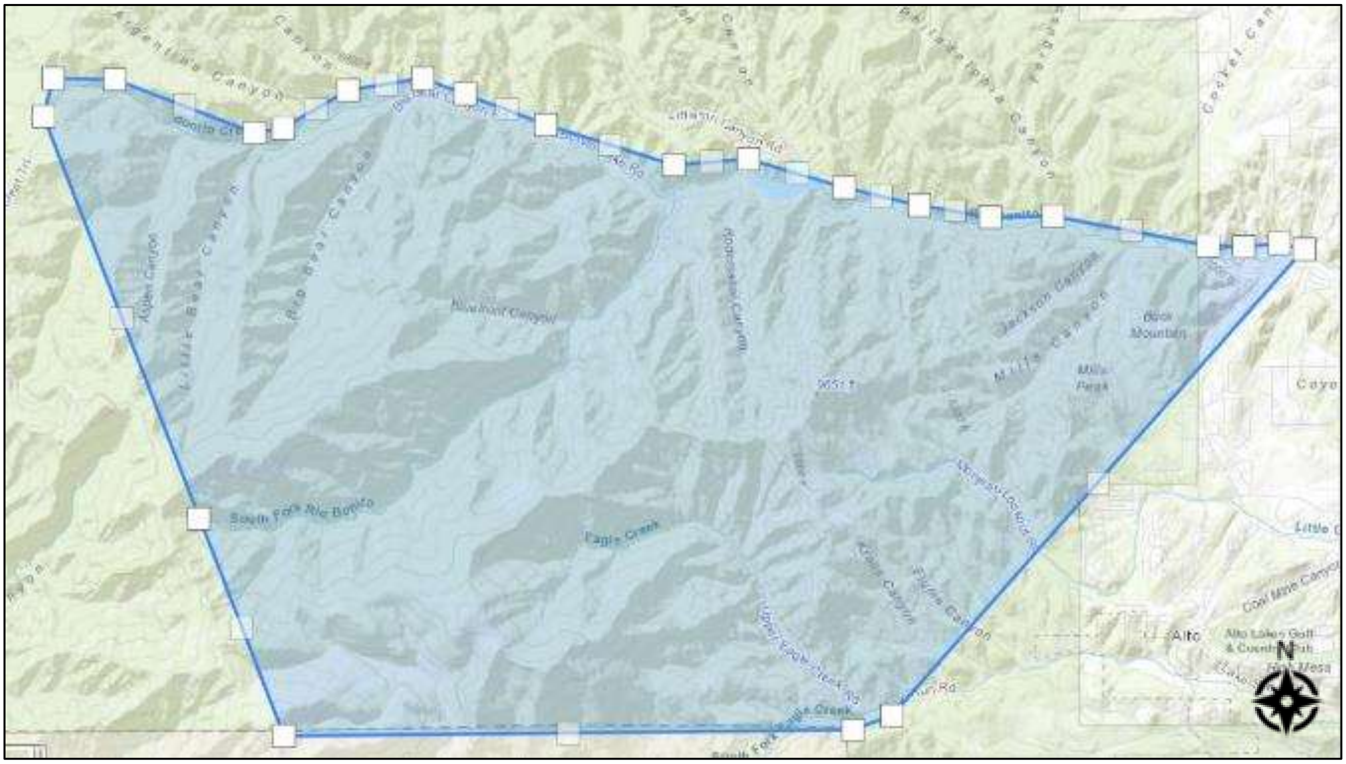
C-5. WQS 20.6.4.209 PECOS RIVER BASIN



IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.209

Rio Bonito, South Fork Rio Bonito, Rio Ruidoso and S. Fork Eagle Creek.

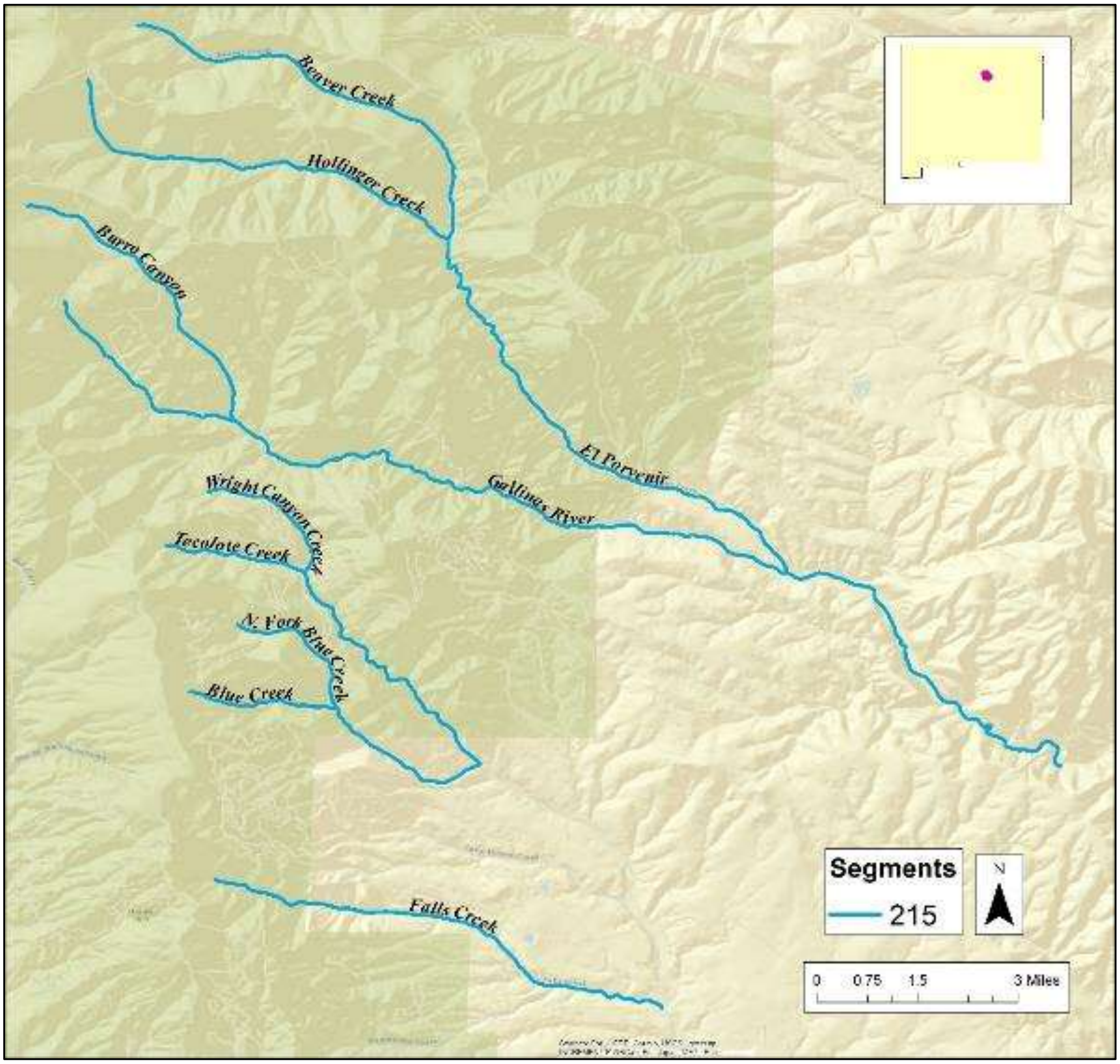
To determine if any species of concern are within the study area, a polygon was manually drawn from; Rio Bonito at Road 48 west to head waters, then southeast to S. Fork Rio Bonito headwaters, then south to Rio Ruidoso and Crest Trail, then south to Mescalero Reservation boundary, then east to S. Fork Eagle Creek, then east along S. Fork Eagle Creek to Eagle Creek, then northeast to Rio Bonito at Road 48.



Rio Ruidoso and Carrizo Creek

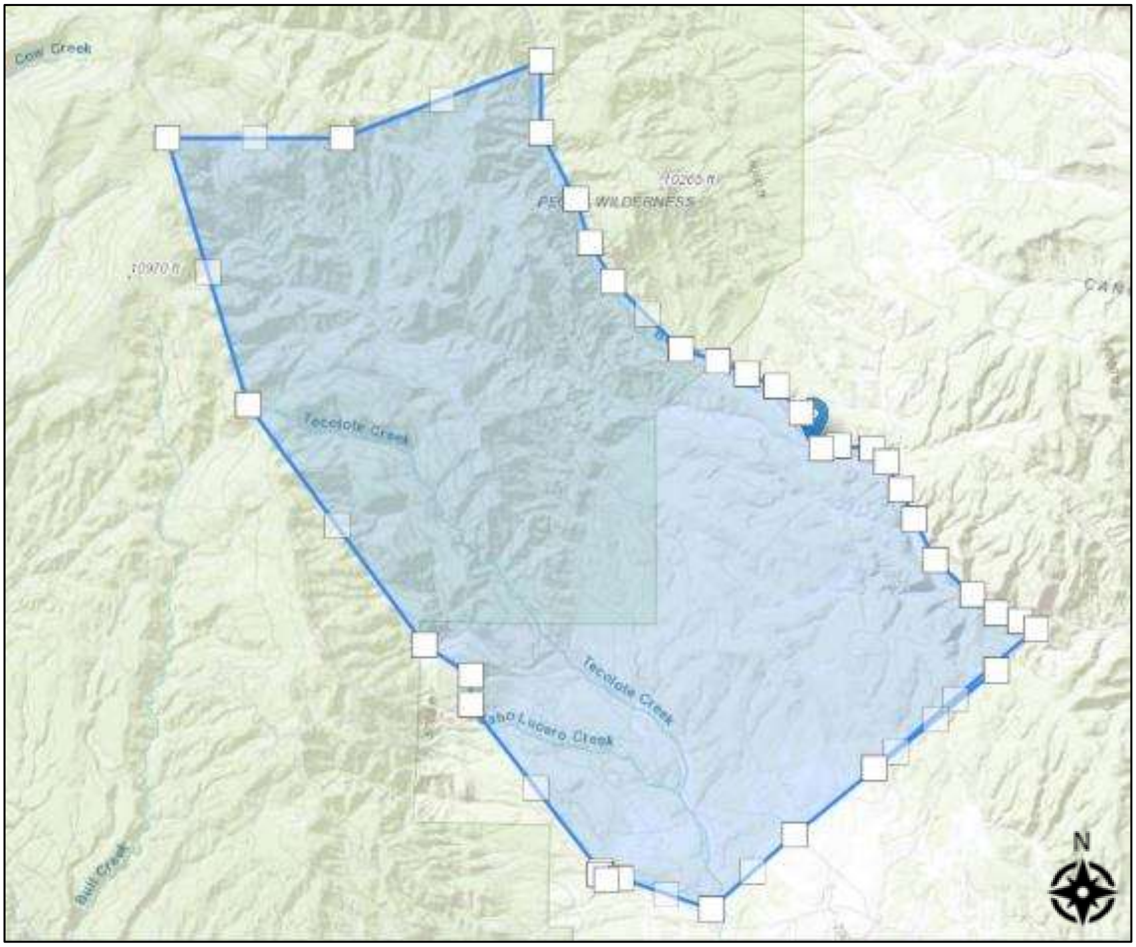
To determine if any species of concern are within the study area, a polygon was manually drawn from; Rio Ruidoso at the US Highway 70 bridge, then west along Rio Ruidoso up to Mescalero Reservation, then southeast to Carrizo Creek at the boundary of the Mescalero Reservation, then east along Rio Ruidoso up to the US Highway 70 bridge.

C-6. WQS 20.6.4.215 PECOS RIVER BASIN

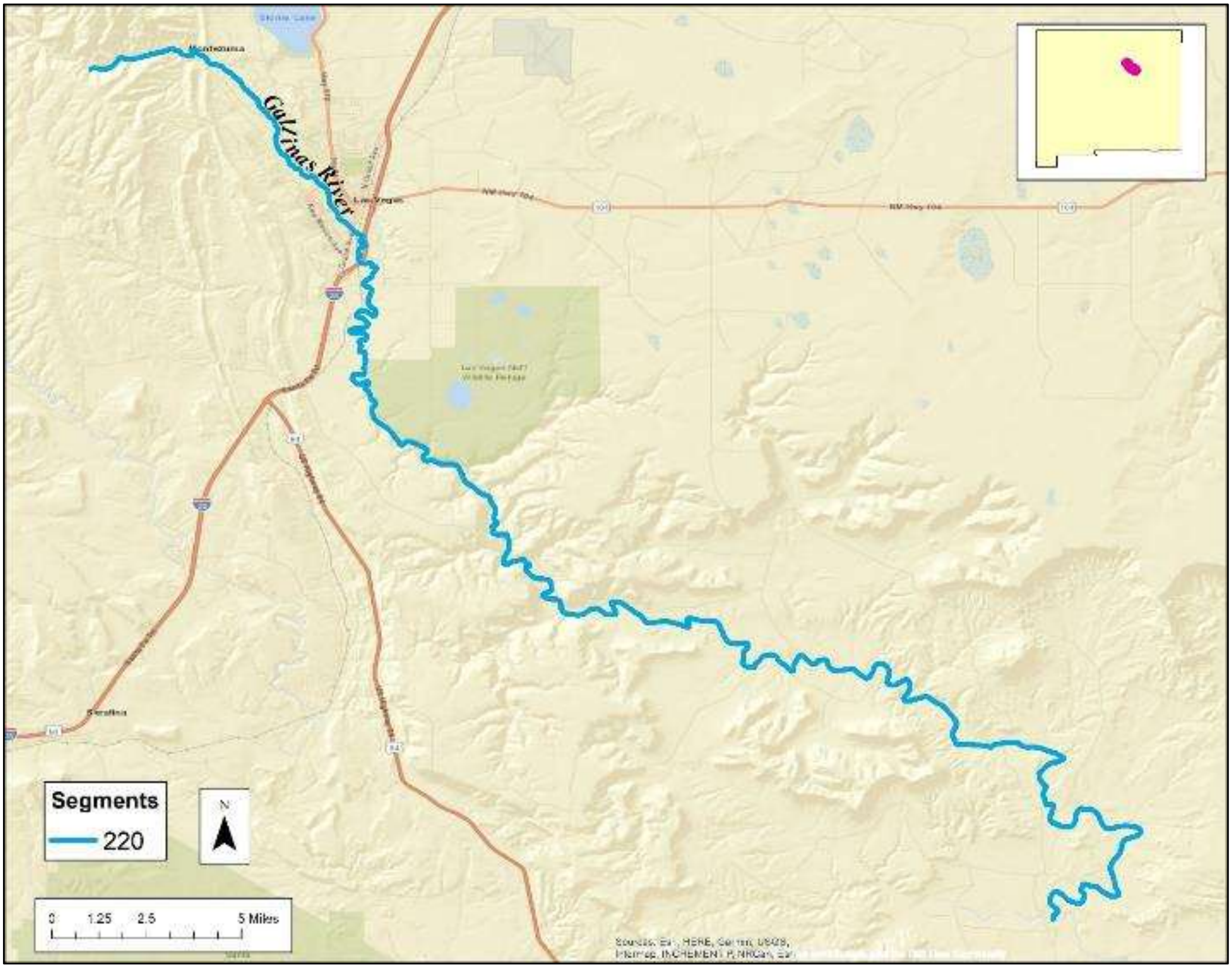


IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.215

To determine if any species of concern are within the study area, a polygon was manually drawn from; Gallinas River at end of Skating Pond Road, then northwest along Gallinas River up to the confluence with El Porvenir, then northwest along El Porvenir up to the confluence with Beaver Creek, then northwest up Beaver Creek to headwaters, then southwest to the headwaters of Holinger Creek, then southwest to the headwaters of Burro Canyon, then southeast to Gallinas River headwaters, then southeast to the Wright Canyon Creek headwaters, then southwest to Tecolote headwaters, then southeast to North Fork Blue Creek headwaters, then south to Blue Creek headwaters, then south to Falls Creek headwaters, then northeast to Gallinas River at the end of Skating Pond Road.

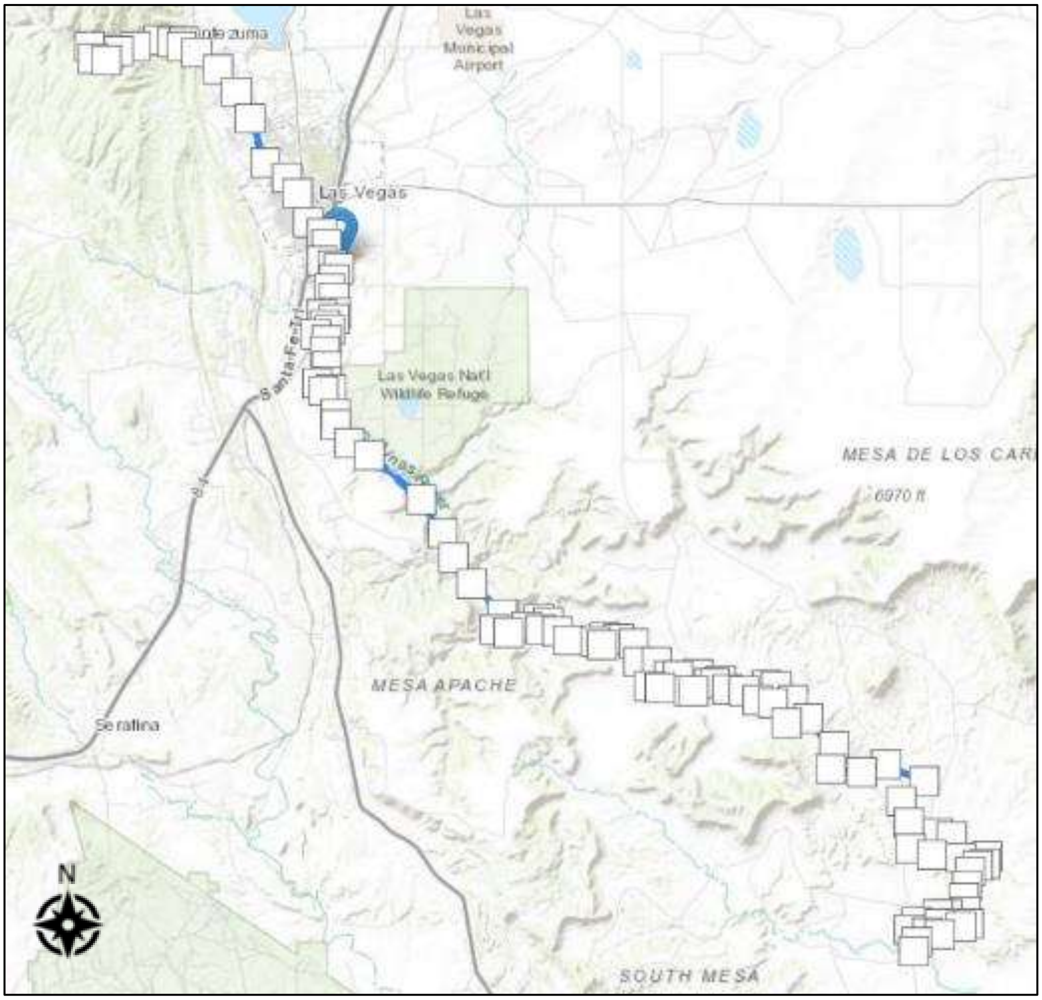

Cow Creek
10265 ft
PE WILDERNESS
10970 ft
CAN
Tecolote Creek
Tecolote Creek
cho Lucero Creek
Bull Creek
N

C-7. WQS 20.6.4.220 PECOS RIVER BASIN

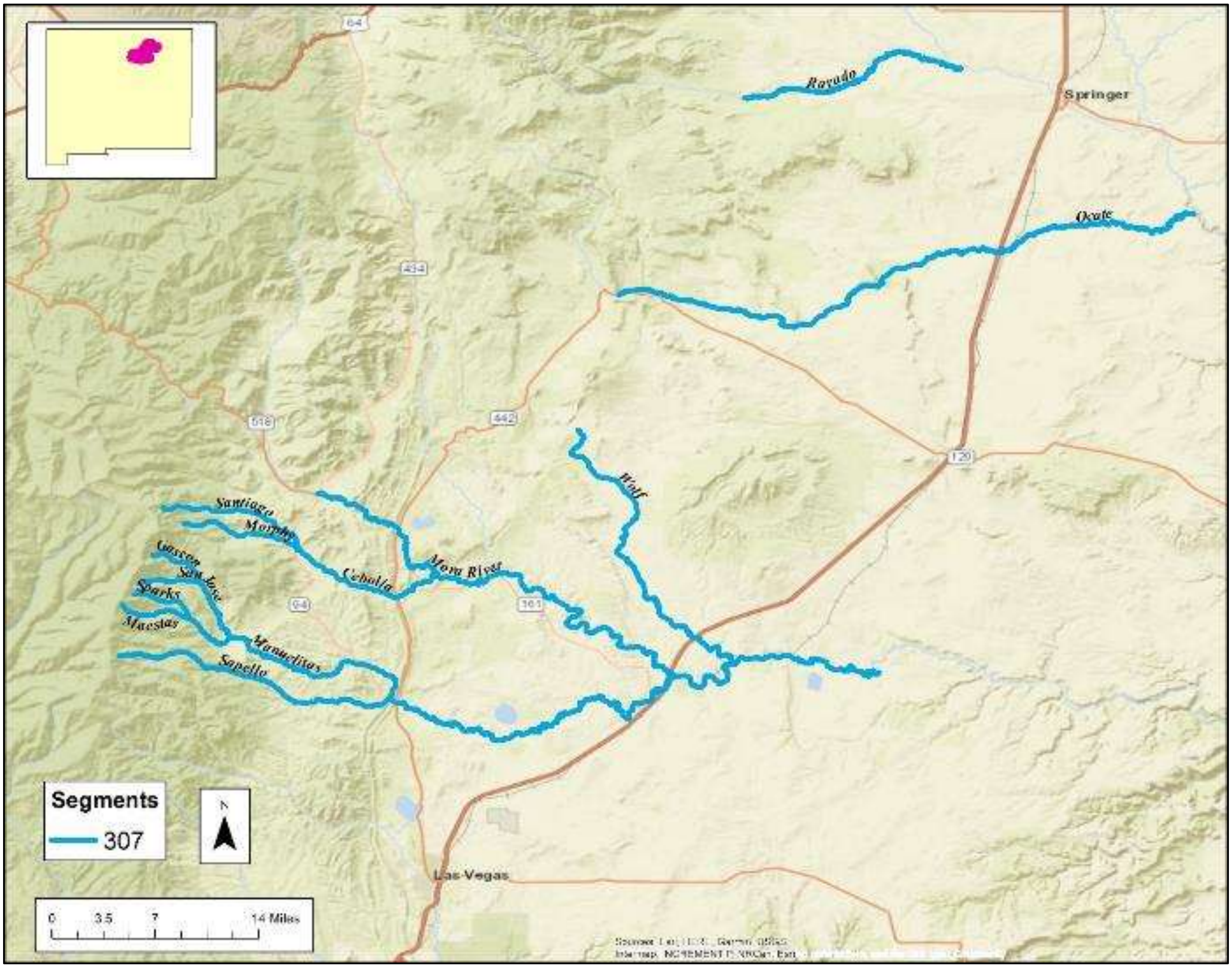


IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.220

Assessment created with a line drawing tool with a 500 ft buffer. Gallinas River at Aguilar Creek confluence, then north along Gallinas River up to then end of Skating Pond Road.

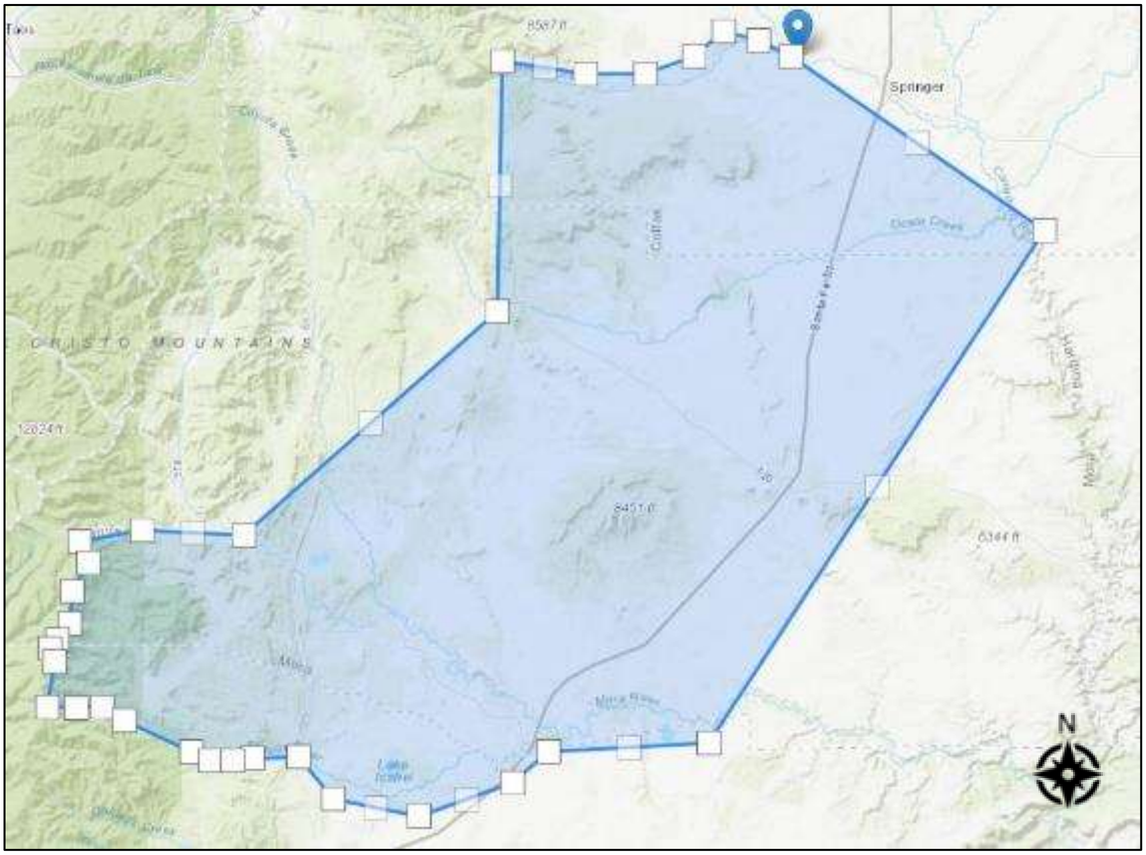

Montezuma
Las Vegas Municipal Airport
Las Vegas
Santa Fe Tr
Las Vegas Nat'l Wildlife Refuge
84
Gallinas R
MESA DE LOS CA
6970 ft
MESA APACHE
Serafina
SOUTH MESA
N

C-8. WQS 20.6.4.307 CANADIAN RIVER BASIN

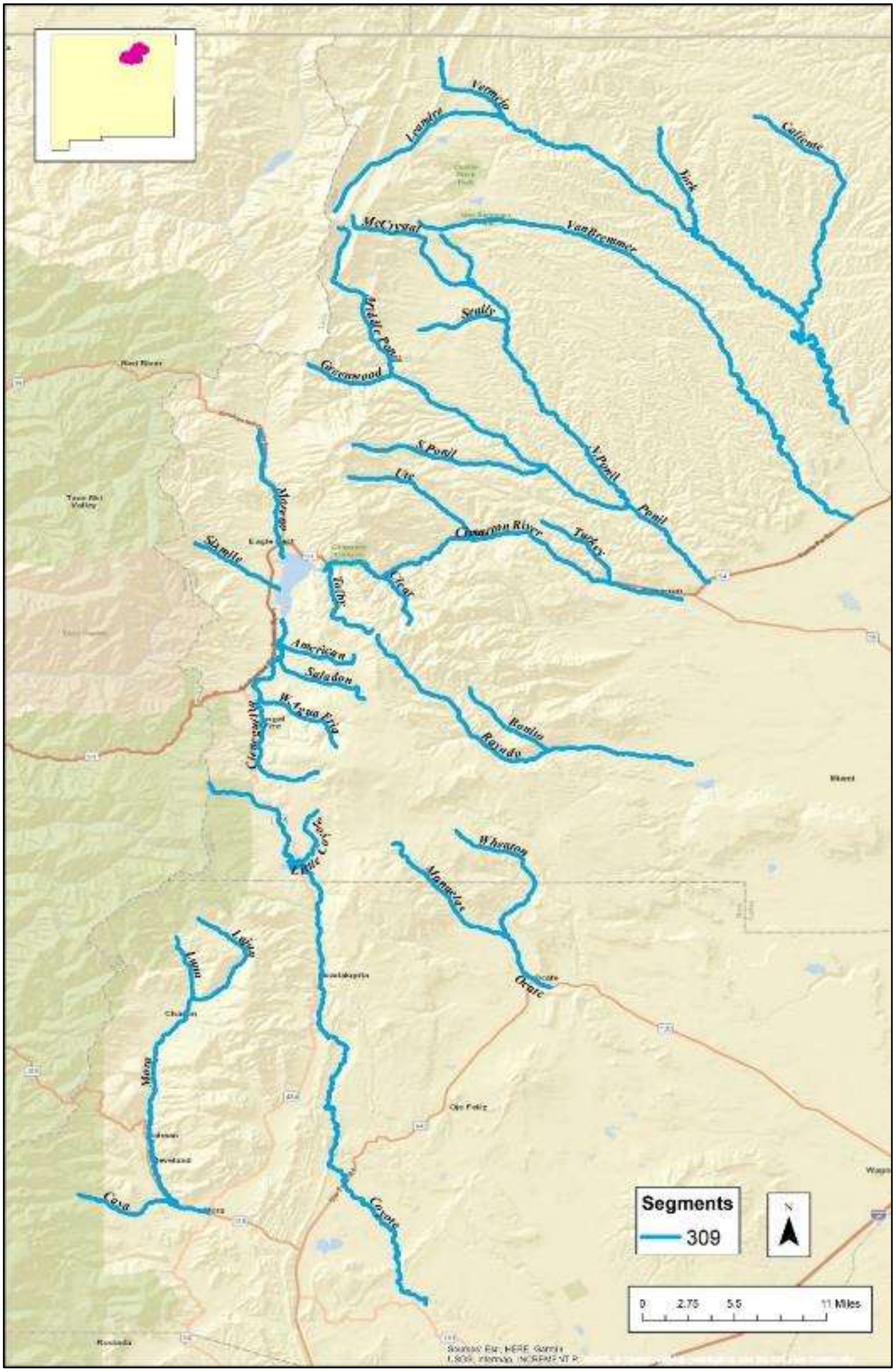


<u>IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.307</u>

To determine if any species of concern are within the study area, a polygon was manually drawn from; Rayado Creek at the confluence with Cimarron River, then west along Rayado Creek to Santa Fe Trail, then southwest to Ocate Creek at Ocate Village, then southwest to Wolf Creek at headwaters, then southwest to Mora River at State Highway 434, then southwest to Santiago Creek at headwaters, then southeast to Morphy at headwaters, then southwest to Gascon at headwaters, then southwest to Rito San Jose at headwaters, then south to Sparks Creek at headwaters, then south to Maestas Creek at headwaters, then south to Sapello at headwaters, then east along Sapello to Mora River confluence, then east along Mora River to 6 km east of Cherry Valley Lake, then north east to Ocate Creek at confluence with the Cimarron River, then northwest to Rayado Creek at confluence with Cimarron River.

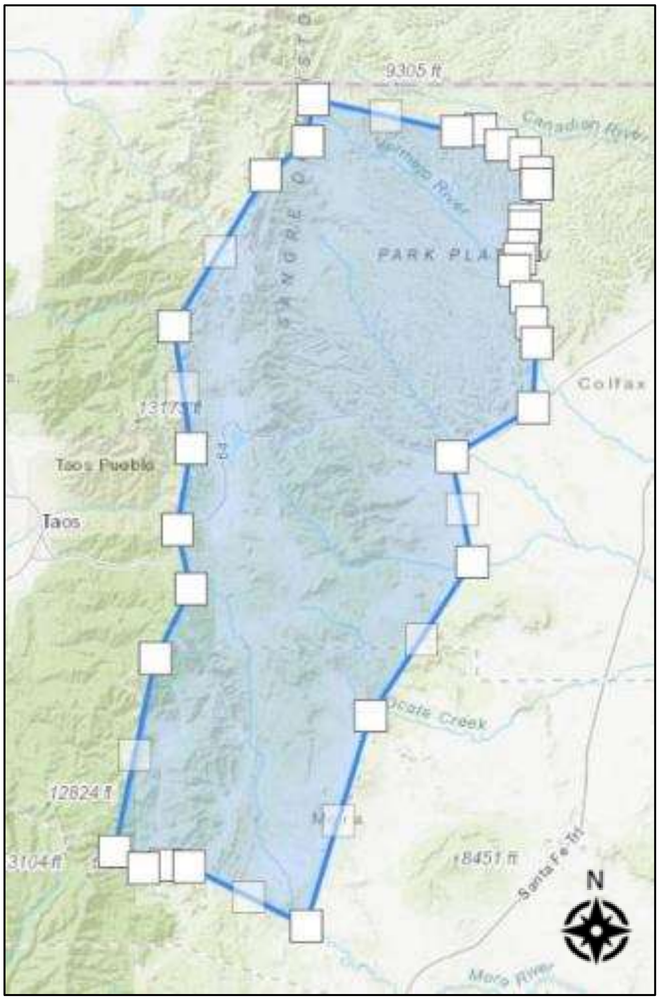

Taos
8587 ft
Springer
Colfax
Ocate Creek
Santa Fe Trl
CRISTO MOUNTAINS
12624 ft
8451 ft
6344 ft
Mora
Mora River
Lake Isabel
N

C-9. WQS 20.6.4.309 CANADIAN RIVER BASIN



IPaC delineation description (steps taken to obtain the delineation) and image of IPaC delineations for section 20.6.4.309

To determine if any species of concern are within the study area, a polygon was manually drawn from; Vermejo River at Rail Canyon Road, then northwest along Vermejo River to the confluence to Caliente Canyon, then along caliente Canyon to headwaters, then east to York Canyon at headwaters, then northeast to Vermejo River at confluence to North Fork Vermejo River, then southwest to Leandro Creek at headwaters, then south to Greenwood Creek at headwaters, then south to Moreno Creek at headwaters, then south to Sixmile at headwaters, then south to Luna Creek at headwates, then southwest to Rio la Casa at confluence with Middle Fork Rio la Casa, then southeast to Coyote Creek at confluence with Mora River, then northeast to Ocate Creek at Ocate Village, then north to Rayado at Santa Fe Trail, then north to Cimarron River at Cimarron Village, then northeast to Ponil Creek at Highway 64, then north to VanBrenner at Highway 64, then to Vermejo River at Rail Canyon Road.



[20.6.4.107 NMAC - Rp 20 NMAC 6.1.2105.5, 10-12-00; A, XX-XX-05]

211. The Commission adopts NMED's proposal to amend the segment description to include the Jemez River from the boundary of Jemez Pueblo upstream to the Rio Guadalupe because this segment is more appropriate here than Segment 20.6.4.105. The Commission adopts NMED's proposal to change the division point from "State highway 4" to "Soda dam" because it relies on a geologic rather than a cultural feature. Soda Dam is approximately 3/8 mile above the highway crossing. The use of highway crossings can cause ambiguity when highways are rerouted or renumbered. Because Soda Dam is less than 1/2 mile above the highway crossing, the changed segment is de minimis. In this segment, the change to the aquatic life use would result in a change of the temperature criterion from 20 degrees C to 25 degrees C. Considering the contributions of hot springs to the river at Soda Dam, this change appears to be reasonable.

212. The Commission adopts NMED's proposal to change the bacterial criteria type and values. The proposed changes are based on EPA guidance. This segment currently has a designated use of primary contact and criteria based upon EPA prior recommendations for fecal coliform bacteria of 200/100 mL (geometric mean) and 400/100 mL (single sample). The EPA primary contact recommendation for E. coli criteria is a geometric mean of 126/100 mL based upon an assumed illness rate of 8 illnesses per 1000 exposed persons. EPA guidance suggests a single sample maximum of 410/100 mL based upon lightly used full body contact with an upper 90% confidence limit. This criterion provides approximately the same level of protection provided by the existing fecal coliform criteria. NMED proposes to make similar changes in other segments for these reasons (Sections 114, 117, 127, 205, 212, 216, 218, 220, 403, 501, 502 and 602), and the Commission has adopted these changes below on the same basis.

20.6.4.108 RIO GRANDE BASIN - [~~The~~] Perennial reaches of the Jemez river and all its tributaries above [~~state highway 4~~] Soda dam near the town of Jemez Springs, except Sulphur creek above its confluence with Redondo creek, and perennial reaches of the Guadalupe river and all its tributaries.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat[~~,~~] and secondary contact.

B. [~~Standards~~]Criteria:

(1) In any single sample: [~~conductivity shall not exceed~~]specific conductance 400 µmhos/cm or less, pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 25 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single

sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.108 NMAC - Rp 20 NMAC 6.1.2106, 10-12-00; A, XX-XX-05]
[**NOTE: The segment covered by this section was divided effective XX-XX-05. The standards for the additional segment are under 20.6.4.124 NMAC.**]

213. The Commission adopts NMED's proposal to amend the segment description because it applies the designated uses to perennial reaches and changes the reference from "state highway 4" to "Soda dam" to use a geologic rather than a cultural feature. Currently, this segment includes all tributaries in the Jemez and Guadalupe River watersheds, instead of just perennial waters. Intermittent reaches will be covered by new Section 20.6.4.98. The Commission adopts NMED's proposal to move Sulphur Creek to a new section to reflect its unique conditions for the reasons stated in Section 20.6.4.124.

214. The Commission adopts NMED's proposal to change the bacterial criteria type and values. The proposed changes are based on EPA guidance. The segment currently has a secondary contact designated use and more stringent primary contact criteria for fecal coliform bacteria of 100/100 mL (geometric mean) and 200/100 mL (single sample). These criteria translate to E. coli criteria of 126/100 mL (geometric mean) and 235/100 mL (single sample). NMED's proposal to make similar changes in other segments is adopted for these reasons (Section 115, 119, 121, 123, 209, 215, 309, 405, 407, 503, 603, 701, 702, 801, 802, 803, and 804), and the Commission adopts those changes below on the same basis.

20.6.4.109 RIO GRANDE BASIN - Perennial reaches of Bluewater creek, Rio Moquino, Seboyeta creek, Rio Paguate, the Rio Puerco [~~within the Santa Fe national forest~~]above the village of Cuba[~~,~~] and all other perennial reaches of tributaries to the Rio Puerco including the Rio San Jose in Cibola county from the USGS gaging station at Correo upstream to Horace springs.

A. Designated Uses: coldwater [~~fishery~~]aquatic life, domestic water supply, fish culture, irrigation, livestock watering, wildlife habitat[~~,~~] and primary contact.

B. [~~Standards~~]Criteria:

(1) In any single sample: pH shall be within the range of 6.6 to 8.8, temperature [~~shall not exceed~~] 20°C (68°F) or less[~~,~~] and total phosphorus (as P) [~~shall not exceed~~] 0.1 mg/L[~~, and turbidity shall not exceed 25 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).
[20.6.4.109 NMAC - Rp 20 NMAC 6.1.2107, 10-12-00; A, XX-XX-05]

215. The Commission adopts NMED's proposal to amend the segment description to include the perennial reaches downstream from the Santa Fe national forest boundary because these perennial reaches are currently either unclassified or a part of Section 20.6.4.105 and are logically included

with the adjacent segment. The most logical hydrologic feature to use as a division point is Arroyo San Jose.

20.6.4.110 RIO GRANDE BASIN - The main stem of the Rio Grande from Angostura diversion works upstream to Cochiti dam.

A. **Designated Uses**: irrigation, livestock watering, wildlife habitat, secondary contact, coldwater [~~fishery~~]aquatic life[~~,~~] and warmwater [~~fishery~~]aquatic life.

B. **[~~Standards~~]Criteria**:

(1) In any single sample: pH [~~shall be~~] within the range of 6.6 to 9.0[~~,~~] and temperature [~~shall not exceed~~] 25°C (77°F) or less. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 mL; no single sample shall exceed 400/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 410 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.110 NMAC - Rp 20 NMAC 6.1.2108, 10-12-00; A, XX-XX-05]

216. The Commission rejects RGCDC's proposal to change the designated use to primary contact, as it does not want to encourage swimming in this segment, but accepts its proposal to change the criteria to primary contact. Swimming appears to be an existing use, and existing uses must be protected. The Commission has adopted this approach of just setting primary contact criteria for numerous segments in the past, most recently the lower Rio Grande in segment 101, and EPA has approved this approach.

20.6.4.111 RIO GRANDE BASIN - Perennial reaches of Las Huertas [~~and San Pedro creeks~~]creek.

A. **Designated Uses**: high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat[~~,~~] and secondary contact.

B. **[~~Standards~~]Criteria**:

(1) In any single sample: pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 25°C (77°F) or less. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 mL; no single sample shall exceed 400/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 410 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.111 NMAC - Rp 20 NMAC 6.1.2108.5, 10-12-00; A, 7-25-01; A, XX-XX-05]

[**NOTE: The segment covered by this section was divided effective XX-XX-05. The standards for the additional segment are under 20.6.4.125 NMAC**.]

217. Los Placitas Association ("LPA") proposes to change the designated use for the perennial reaches of Las Huertas Creek from coldwater to high quality coldwater aquatic life because the evidence supports high quality coldwater as an existing use. LPA submitted evidence of water quality and macroinvertebrates in Las Huertas Creek demonstrating that high quality coldwater aquatic life is the existing use. The high quality coldwater aquatic life use is protected by a criterion for specific conductance between 300 and 1500 umhos/cm. See Section 20.6.4.900.H(1). The data indicates that the specific conductance in Las Huertas Creek is generally below 500 umhos. Conversely,

there is no evidence that San Pedro Creek has an existing use of high quality coldwater aquatic life, nor has LPA attempted to demonstrate that the high quality coldwater aquatic life is an attainable use. It is appropriate to place San Pedro Creek in a separate segment with its current uses and criteria.

20.6.4.112 RIO GRANDE BASIN - Cochiti reservoir.

A. **Designated Uses**: livestock watering, wildlife habitat, warmwater [~~fishery~~]aquatic life, coldwater [~~fishery~~]aquatic life[~~,~~] and primary contact.

B. **[~~Standards~~]Criteria**:

(l) At any sampling site: pH [~~shall be~~] within the range of 6.6 to 9.0[~~,~~] and temperature [~~shall not exceed~~] 25°C (77°F)[~~, and turbidity shall not exceed 25 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.112 NMAC - Rp 20 NMAC 6.1.2109, 10-12-00; A, XX-XX-05]

218. The Commission adopts changes proposed by NMED and already described above.

20.6.4.113 RIO GRANDE BASIN - The Santa Fe river and perennial reaches of its tributaries from Cochiti reservoir upstream to the outfall of the Santa Fe wastewater treatment facility.

A. **Designated Uses**: irrigation, livestock watering, wildlife habitat, marginal coldwater [~~fishery~~]aquatic life, secondary contact[~~,~~], and warmwater [~~fishery~~]aquatic life.

B. **[~~Standards~~]Criteria**:

(l) In any single sample: pH [~~shall be~~] within the range of 6.6 to 9.0, temperature [~~shall not exceed~~] 30°C (86°F) or less[~~,~~] [~~turbidity shall not exceed 50 NTU,~~] and dissolved oxygen [~~shall not be less than~~] 4.0 mg/L or more. Dissolved oxygen [~~shall not be less than~~] 5.0 mg/L or more as a 24-hour average. Values used in the calculation of the 24-hour average for dissolved oxygen shall not exceed the dissolved oxygen saturation value. For a measured value above the dissolved oxygen saturation value, the dissolved oxygen saturation value will be used in calculating the 24-hour average. The dissolved oxygen saturation value shall be determined from the table set out in Subsection [~~P~~]N of 20.6.4.900 NMAC. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed l,000/100 mL; no single sample shall exceed 2,000/100 mL~~]The monthly geometric mean of E. coli bacteria 548 cfu/100 mL or less, single sample 2507 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.113 NMAC - Rp 20 NMAC 6.1.2110, 10-12-00; A, 10-11-02; A, XX-XX-05]

219. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the intermittent reaches are properly covered by new Section 20.6.4.98.

20.6.4.114 RIO GRANDE BASIN - The main stem of the Rio Grande from the headwaters of Cochiti reservoir upstream to [~~Taos Junction bridge~~]Rio Pueblo de Taos, Embudo creek from its mouth on the Rio Grande upstream to the junction of the Rio Pueblo and the Rio Santa Barbara, the Santa Cruz river below Santa Cruz dam, the Rio Tesuque below the Santa Fe national forest and the Pojoaque river below Nambe dam.

A. **Designated Uses**: irrigation, livestock watering, wildlife habitat, marginal coldwater [~~fishery~~]aquatic life, primary contact[~~,~~]and warmwater [~~fishery~~]aquatic life.

B. **[~~Standards~~]Criteria**:

(1) In any single sample: pH [~~shall be~~] within the range of 6.6 to 9.0[~~,~~] and temperature [~~shall not exceed~~] 22°C (71.6°F) or less[~~, and turbidity shall not exceed 50 NTU~~]. The use-specific numeric

[~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 mL; no single sample shall exceed 400/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 410 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

(3) At mean monthly flows above 100 cfs, the monthly average concentration for: TDS [~~shall not exceed~~] 500 mg/L or less, sulfate [~~shall not exceed~~] 150 mg/L or less[~~,~~] and chloride [~~shall not exceed~~]25 mg/L or less.

[20.6.4.114 NMAC - Rp 20 NMAC 6.1.2111, 10-12-00; A, XX-XX-05]

220. The Commission adopts NMED's proposal to replace "Taos Junction Bridge" with "Rio Pueblo de Taos" because the division point relies on a hydrologic rather than a cultural feature. The use of highway crossings can cause ambiguity when highways are rerouted or renumbered. The confluence of Rio Pueblo de Taos lies approximately 1/4 mile upstream from the bridge, and therefore constitutes a de minimis change.

20.6.4.115 RIO GRANDE BASIN - The perennial reaches of Rio Vallecitos and its tributaries, and perennial reaches of Rio del Oso[~~,~~] and perennial reaches of El Rito creek above the town of El Rito.

A. **Designated Uses**: domestic water supply, irrigation, high quality coldwater [~~fishery~~]aquatic life, livestock watering, wildlife habitat[~~,~~] and secondary contact.

B. **[~~Standards~~]Criteria**:

(1) In any single sample: [~~conductivity shall not exceed~~]specific conductance 300 μmhos/cm or less, pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~]and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 10 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.115 NMAC - Rp 20 NMAC 6.1.2112, 10-12-00; A, XX-XX-05]

221. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the intermittent reaches are properly covered by new Section 20.6.4.98.

20.6.4.116 RIO GRANDE BASIN - The Rio Chama from its mouth on the Rio Grande upstream to Abiquiu reservoir, perennial reaches of the Rio Tusas, perennial reaches of the Rio Ojo Caliente, perennial reaches of Abiquiu creek[~~,~~] and perennial reaches of El Rito creek below the town of El Rito.

A. **Designated Uses**: irrigation, livestock watering, wildlife habitat, coldwater [~~fishery~~]aquatic life, warmwater [~~fishery~~]aquatic life[~~,~~] and secondary contact.

B. **[~~Standards~~]Criteria**:

(1) In any single sample: pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 31°C (87.8°F) or less. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 1,000/100 mL; no single sample shall exceed 2,000/100 mL~~]The monthly geometric mean of E. coli bacteria 548 cfu/100 mL or less; single sample 2507 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.116 NMAC - Rp 20 NMAC 6.1.2113, 10-12-00; A, XX-XX-05]

222. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the intermittent reaches are properly covered by new Section 20.6.4.98.

20.6.4.117 RIO GRANDE BASIN - Abiquiu reservoir.

A. **Designated Uses**: irrigation storage, livestock watering, wildlife habitat, primary contact, coldwater [~~fishery~~]aquatic life[~~,~~] and warmwater [~~fishery~~]aquatic life.

B. **[~~Standards~~]Criteria**:

(1) At any sampling site: pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 25°C (77°F) or less. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli 126 cfu/100 mL or less; single sample 410 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.117 NMAC - Rp 20 NMAC 6.1.2114, 10-12-00; A, XX-XX-05]

223. The Commission adopts changes proposed by NMED and already described above.

20.6.4.118 RIO GRANDE BASIN - The Rio Chama from the headwaters of Abiquiu reservoir upstream to El Vado reservoir and perennial reaches of the Rio Gallina and Rio Puerco de Chama north of state highway 96.

A. **Designated Uses**: irrigation, livestock watering, wildlife habitat, coldwater [~~fishery~~]aquatic life, warmwater [~~fishery~~]aquatic life[~~,~~] and secondary contact.

B. **[~~Standards~~]Criteria**:

(1) In any single sample: pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 26°C (78.8°F) or less. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 200/100 mL; no single sample shall exceed 400/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 410 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.118 NMAC - Rp 20 NMAC 6.1.2115, 10-12-00; A, XX-XX-05]

224. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the intermittent reaches are properly covered by new Section 20.6.4.98.

20.6.4.119 RIO GRANDE BASIN - All perennial reaches of tributaries to the Rio Chama above Abiquiu dam except the Rio Gallina and Rio Puerco de Chama north of state highway 96 and the main stem of the Rio Chama from the headwaters of El Vado reservoir upstream to the New Mexico-Colorado line.

A. **Designated Uses**: domestic water supply, fish culture, high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat[~~,~~] and secondary contact.

B. **[~~Standards~~]Criteria**:

(1) In any single sample: [~~conductivity shall not exceed~~]specific conductance 500 µmhos/cm or less (1,000 µmhos or less for Coyote creek), pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 25 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.119 NMAC - Rp 20 NMAC 6.1.2116, 10-12-00; A, XX-XX-05]

225. The Commission adopts changes proposed by NMED and already described above.

20.6.4.120 RIO GRANDE BASIN - El Vado and Heron reservoirs.

A. Designated Uses: irrigation storage, livestock watering, wildlife habitat, primary contact[~~,~~] and coldwater [~~fishery~~]aquatic life.

B. [~~Standards~~]Criteria:

(1) At any sampling site: pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 25 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.120 NMAC - Rp 20 NMAC 6.1.2117, 10-12-00; A. XX-XX-05]

226. The Commission adopts changes proposed by NMED and already described above.

20.6.4.121 RIO GRANDE BASIN - Perennial tributaries to the Rio Grande in Bandelier national monument and their headwaters in Sandoval county[~~,~~] and all perennial reaches of tributaries to the Rio Grande in Santa Fe county unless included in other segments.

A. Designated Uses: domestic water supply, high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat, municipal and industrial water supply, secondary contact[~~,~~] and primary contact.

B. [~~Standards~~]Criteria:

(1) In any single sample: [~~conductivity shall not exceed~~]specific conductance 300 µmhos/cm or less, pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed l0 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.121 NMAC - Rp 20 NMAC 6.1.2118, 10-12-00; A. XX-XX-05]

[**NOTE: The segment covered by this section was divided effective XX-XX-05. The standards for the additional segments are under 20.6.4.126, 20.6.4.127 and 20.6.4.128 NMAC.**]

227. The Commission adopts changes proposed by NMED and already described above.

20.6.4.122 RIO GRANDE BASIN - The main stem of the Rio Grande from [~~Taos Junction bridge~~]Rio Pueblo de Taos upstream to the New Mexico-Colorado line, the Red river from its mouth on the Rio Grande upstream to the mouth of Placer creek, and the Rio Pueblo de Taos from its mouth on the Rio Grande upstream to the mouth of the Rio Grande del Rancho.

A. Designated Uses: coldwater [~~fishery~~]aquatic life, fish culture, irrigation, livestock watering, wildlife habitat[~~,~~] and primary contact.

B. [~~Standards~~]Criteria:

(1) In any single sample: pH [~~shall be~~] within the range of 6.6 to 8.8[~~,~~] and temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 50 NTU~~]. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.122 NMAC - Rp 20 NMAC 6.1.2119, 10-12-00; A, XX-XX-05]

228. The Commission adopts changes proposed by NMED and already described above.

229. The Commission rejects AB’s proposal of a new segment for the Red River from the fish hatchery to the mouth of Placer Creek with the designated use of high quality coldwater aquatic life. AB failed to present evidence to demonstrate that high quality coldwater aquatic life is either an

existing or attainable use. AB also failed to explain the legal basis for challenging a decision made 14 years ago.

20.6.4.123 RIO GRANDE BASIN - [~~The~~]Perennial reaches of the Red river upstream of the mouth of Placer creek, all perennial reaches of tributaries to the Red river, and all other perennial reaches of tributaries to the Rio Grande in Taos and Rio Arriba counties unless included in other segments.

A. Designated Uses: domestic water supply, fish culture, high quality coldwater [~~fishery~~]aquatic life, irrigation, livestock watering, wildlife habitat[~~,~~] and secondary contact.

B. [~~Standards~~]Criteria:

(1) In any single sample: [~~conductivity shall not exceed~~]specific conductance 400 µmhos/cm or less (500 µmhos or less for the Rio Fernando de Taos)[~~,~~] and pH [~~shall be~~] within the range of 6.6 to 8.8, temperature [~~shall not exceed~~] 20°C (68°F) or less[~~, and turbidity shall not exceed 25 NTU~~]. For the Red river in this segment, total phosphorus (as P) less than 0.1 mg/L. The use-specific numeric [~~standards~~]criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) [~~The monthly geometric mean of fecal coliform bacteria shall not exceed 100/100 mL; no single sample shall exceed 200/100 mL~~]The monthly geometric mean of E. coli bacteria 126 cfu/100 mL or less; single sample 235 cfu/100 mL or less (see Subsection B of [~~20.6.4.13~~]20.6.4.14 NMAC).

[20.6.4.123 NMAC - Rp 20 NMAC 6.1.2120, 10-12-00; A, XX-XX-05]

[**NOTE: The segment covered by this section was divided effective XX-XX-05. The standards for the additional segment are under 20.6.4.129 NMAC**.]

230. The Commission adopts NMED's proposal to amend the segment description to limit the designated uses to perennial reaches because the intermittent reaches are properly covered by new Section 20.6.4.98.

231. The Commission adopts NMED's proposed numeric segment-specific criterion for total phosphorus for the Red River (and for the Rio Hondo in segment 129) because it corrects an inadvertent error. The criterion was applicable to these streams until the 1998 triennial review, when it was inadvertently removed. Similar segment-specific criteria for total phosphorus are currently applicable to Sections 109, 208, 404, 406, and 407.

20.6.4.124 RIO GRANDE BASIN - Perennial reaches of Sulphur creek from its headwaters to its confluence with Redondo creek.

A. Designated Uses: limited aquatic life, wildlife habitat, livestock watering and secondary contact.

B. Criteria:

(1) In any single sample: pH within the range of 2.0 to 9.0 and temperature 30ºC (86ºF) or less. The use-specific criteria set forth in 20.6.4.900 NMAC are applicable to the designated uses listed above in Subsection A of this section.

(2) The monthly geometric mean of E. coli bacteria 548 cfu/100 mL or less, single sample 2507 cfu/100 mL or less (see Subsection B of 20.6.4.14 NMAC).

(3) The chronic aquatic life criteria of Subsections I and J of 20.6.4.900 NMAC shall also apply.

[20.6.4.124 NMAC - N, XX-XX-05]

232. The Commission adopts NMED's proposal of a new section based upon the unique conditions of Sulphur Creek because the current use and pH criterion are not appropriate. The pH in Sulphur Creek at normal base flows generally varies between 2.0 and 5.0.

United States
Environmental Protection
Agency

Office of Water
4304T

EPA 822-R-18-002
April 2013

AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA FOR AMMONIA – FRESHWATER

2013

NMED Exhibit 61

EPA-822-R-13-001

Aquatic Life
Ambient Water Quality Criteria For
Ammonia – Freshwater
2013

April 2013

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, DC

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

FOREWORD

This water quality criteria update provides scientific recommendations to states and tribes authorized to establish water quality standards under the Clean Water Act (CWA), to protect aquatic life from acute and chronic effects of ammonia in freshwater ecosystems. Under the CWA, states and tribes are to establish water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from those used in these criteria when appropriate. While this update constitutes United States Environmental Protection Agency (EPA) scientific recommendations regarding ambient concentrations of ammonia that protect freshwater aquatic life, this update does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. EPA may change these criteria in the future, as new scientific information becomes available. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGMENT

This 2013 criteria document is an update of the 1999 Update of Ambient Water Quality Criteria for Ammonia. The updates described herein were prepared by Lisa Huff (EPA Team Leader), Charles Delos, Kathryn Gallagher, and Joe Beaman with written and technical support provided by EPA contractor: Great Lakes Environmental Center, Inc. EPA received substantial input from Dave Mount, James (Russ) Hockett, Russell Erickson, and Charles Stephan of the EPA's Office of Research and Development (ORD) National Health and Environmental Effects Research Laboratory (NHEERL) Mid-Continent Ecology Division, Duluth, MN, and Cindy Roberts, ORD Office of Science Policy. Please submit comments or questions to: Lisa Huff, U.S. EPA, Mail Code 4304, Washington, DC 20460 (e-mail: huff.lisa@epa.gov).

EXECUTIVE SUMMARY

EPA has updated the freshwater ammonia aquatic life ambient water quality criteria in accord with the provisions of Section 304(a) of the Clean Water Act to revise Ambient Water Quality Criteria (AWQC) from time to time in order to reflect the latest scientific knowledge. Literature searches for laboratory toxicity tests of ammonia on freshwater aquatic life, published from1985 to 2012, identified new studies containing acute and chronic toxicity data acceptable for criteria derivation. The acute criterion dataset includes 12 species of aquatic animals Federally-listed as threatened, endangered or species of concern. In the chronic dataset for ammonia, Federally-listed species are represented by three salmonid fish species in the genus *Oncorhynchus*, including sockeye salmon, rainbow trout/steelhead, and the subspecies Lahontan cutthroat trout. Data were assessed from the perspective of EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (Stephan et al. 1985).

The 1999 recommended aquatic life criteria for ammonia were based on the most sensitive endpoints known at the time: the acute criterion was based primarily on effects on salmonids (where present) or other fish, and the chronic criterion was based primarily on reproductive effects on the benthic invertebrate *Hyalella* or on survival and growth of fish early life stages (when present), depending on temperature and season.

The 2013 recommended criteria of this document take into account data for several sensitive freshwater mussel species in the Family Unionidae that had not previously been tested. As noted in the 2009 draft ammonia criteria document, available data indicated that another freshwater mollusk taxon, non-pulmonate (gill-bearing) snails, are also sensitive to the effects of ammonia (EPA-822-D-09-001). The 2013 criteria include additional data confirming the sensitivity of freshwater non-pulmonate snails. Many states in the continental United States have freshwater unionid mussel fauna in at least some of their waters (Abell et al. 2000, Williams et al. 1993, Williams and Neves 1995). Moreover, approximately one-quarter of approximately 300 freshwater unionid mussel taxa in the United States are Federally-listed as endangered or threatened species. Freshwater mussels are broadly distributed across the U.S., as are freshwater non-pulmonate snails, another sensitive invertebrate taxon, and both of these groups are now included in the ammonia dataset. Thus, the 2013 freshwater acute and chronic aquatic life criteria for ammonia will more fully protect the aquatic community than previous criteria, and are represented by a single (non-bifurcated) value each for acute and chronic criteria.

The criteria magnitude is affected by pH and temperature. After analysis of the new data, EPA determined that the pH and temperature relationships established in the 1999 ammonia criterion document still hold. When expressed as total ammonia nitrogen (TAN), the effect concentrations for fish are normalized only for pH, reflecting the minimal influence of temperature on TAN toxicity to fish. For invertebrates, TAN effect concentrations are normalized for both pH and temperature. At water temperatures greater than 15.7°C, the 2013 acute criterion magnitude is determined primarily by effects on freshwater unionid mussels. At lower temperatures the acute criterion magnitude is based primarily on effects on salmonids and other fish. Throughout the temperature range, the 2013 chronic criterion magnitude is determined primarily by the effects on freshwater mollusks, particularly unionid mussels.

At an example pH of 7 and temperature of 20°C, the 2013 acute criterion magnitude is 17 mg TAN/L and the chronic criterion magnitude is 1.9 mg TAN/L. At pH 7 and 20°C the 2013 acute criterion magnitude is 1.4-fold lower than the 1999 acute criterion magnitude. At this pH and temperature, the 2013 chronic criterion magnitude is 2.4-fold lower than the 1999 chronic criterion magnitude. See the Criterion Statements (pages 40-49) for the criterion concentrations at other pH and temperature conditions. The decreases in acute and chronic criteria magnitudes below those of 1999 reflect the inclusion of the new data discussed above.

The acute criterion duration represents a one-hour average. The chronic criterion duration represents a 30-day rolling average with the additional restriction that the highest 4-day average within the 30 days be no greater than 2.5 times the chronic criterion magnitude. These values are not to be exceeded more than once in 3 years on average.

Criterion Duration	**1999 AWQC Update Criteria Magnitude**		**2009 Draft AWQC Update Criteria[c] Magnitude**		**2013 AWQC Update Criteria Magnitude**
	pH 8.0, (mg TAN/L)	pH 7.0, T=20°C (mg TAN/L)	pH 8.0, T=25°C (mg TAN/L)	pH 7.0, T=20°C (mg TAN/L)	pH 7.0, T=20°C (mg TAN/L)
Acute (1-hr average)	5.6[a]	24[a]	2.9	19	17[a]
Chronic (30-d rolling average)	1.2	4.5[b]	0.26	0.91	1.9*
*Not to exceed 2.5 times CCC or 4.8 mg TAN/L (at pH 7, 20°C) as a 4-day average within the 30-days, more than once in three years on average.					
Criteria frequency: Not to be exceeded more than once in three years on average.					

[a] Salmonids present

[b] Based on renormalization of data to pH 7 and 20°C

[c] Mussels present

ACRONYMS

ACR	Acute-Chronic Ratio
ASTM	American Society of Testing and Materials
AWQC	Ambient Water Quality Criteria
CCC	Criterion Continuous Concentration
CMC	Criterion Maximum Concentration
CV	Chronic Value (expressed in this document as an EC20 or MATC)
CWA	Clean Water Act
ECx	Effect Concentration at X Percent Effect Level
LCx	Lethal Concentration at X Percent Survival Level
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FACR	Final Acute-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
GMACR	Genus Mean Acute-Chronic Ratio
GMAV	Genus Mean Acute Value
GMCV	Genus Mean Chronic Value
LOEC	Lowest Observed Effect Concentration
MATC	Maximum Acceptable Toxicant Concentration (expressed mathematically as the geometric mean of the NOEC and LOEC)
NOEC	No Observed Effect Concentration
SD	Sensitivity Distribution
SMACR	Species Mean Acute-Chronic Ratio
SMAV	Species Mean Acute Value
SMCV	Species Mean Chronic Value
TAN	Total Ammonia Nitrogen
TRAP	EPA's Statistical Program: Toxicity Relationship Analysis Program (Version 1.21)
WER	Water Effect Ratio

INTRODUCTION AND BACKGROUND

National Ambient Water Quality Criteria (AWQC) are established by the United States Environmental Protection Agency (EPA) under the Clean Water Act (CWA). EPA will review and from time to time revise 304(a) AWQC as necessary to ensure the criteria are consistent with the latest scientific information. Section 304(a) aquatic life criteria serve as recommendations to states and tribes in defining ambient water concentrations that will protect against adverse ecological effects to aquatic life resulting from exposure to a pollutant found in water from direct contact or ingestion of contaminated water and/or food. Aquatic life criteria address the CWA goals of providing for the protection and propagation of fish and shellfish. When adopted into state standards, these criteria can become a basis for establishing permit limits and Total Maximum Daily Loads (TMDLs).

EPA first published aquatic life criteria recommendations for ammonia in 1976, followed nine years later by the 1985 criteria revision, which used updated procedures and additional information. The 1985 acute ammonia criterion was calculated from acute values expressed as unionized ammonia and normalized for pH (8.0) for all freshwater aquatic animals, and temperature (20°C) for freshwater fish only. Because the fraction of total ammonia that is unionized varies with pH and temperature, the 1985 toxicity data normalizations with *unionized* ammonia were necessarily structured differently than the current document's normalizations with *total* ammonia nitrogen. Because the 1985 chronic toxicity dataset was more limited than is available now, the 1985 chronic criterion was calculated by dividing the Final Acute Value by an acute-chronic ratio (ACR). The 1985 acute and chronic criteria concentrations were 19 and 1.2 mg/L expressed as total ammonia nitrogen at pH 7 and temperature 20°C for salmonids or other coldwater species present (e.g., rainbow trout). The durations for these criteria were one-hour (acute) and four-day (chronic) averaging periods. The 1985 freshwater acute criterion dataset was composed of acute values from tests involving 41 species (29 fish and 12 invertebrate) representing 34 genera (18 fish and 16 invertebrate). The data available for invertebrates at the time indicated they were not among the more acutely-sensitive organisms to ammonia.

In 1999 EPA revised the 1985 freshwater ammonia criteria to incorporate newer data, better models, and improved statistical methods. For its acute criterion, the revision included a re-examination of the temperature and pH relationships underlying the 1985 acute criterion, reworked from the perspective of total ammonia nitrogen rather than unionized ammonia. For its

NMED Exhibit 61

chronic criterion, EPA developed relationships for formulating a seasonal, pH- and temperature-dependent relationship, in part because the chronic criterion was based on endpoints that might not be of concern during cold-season conditions (e.g., fish early life stages). EPA analyzed all of the freshwater chronic data used in the 1985 criteria document as well as newer chronic data and was able to directly calculate a chronic criterion instead of calculating it from the acute criterion with an ACR. EPA did not conduct a comprehensive literature search for and critical review of all of the acute toxicity data published after 1985, but focused on the chronic criteria, in response to scientific issues raised by the public. Thus, the 1999 acute criterion relied on acute tests reported in Table 1 in the 1985 criteria document, supplemented by a limited number of newer studies relevant to the revised pH relationship.

The 1999 criteria were based on the most sensitive endpoints known at the time: the acute criterion was based primarily on effects on fish throughout the temperature range, and the chronic criterion was based primarily on effects on benthic macroinvertebrates or fish early life stages (when present), depending on temperature and season. For the 1999 acute criterion the effect concentrations for fish were normalized for pH only, reflecting the minimal influence of temperature on total ammonia toxicity to fish. The 1999 acute criterion was not adjusted for temperature because invertebrates that were included in the dataset, mollusks included, were not among the species highly sensitive to ammonia, thus, the invertebrate temperature slope did not affect the formulation of the 1999 acute criterion. The 1999 chronic criterion was adjusted for pH for fish and for pH and temperature for invertebrates. The chronic averaging period was increased from a 4- to a 30-day average in the 1999 update; the rationale for this change was based on analysis of chronic data from fathead minnow laboratory tests of different exposure durations and exposure concentrations with "limited variability" (see detailed discussion in the Problem Formulation of this document under Chronic Measures of Effect). For chronic toxicity, the 1999 updated dataset consisted of nine values representing four invertebrate and five fish genera. Two of the four most chronically sensitive species were invertebrates (the benthic amphipod *Hyalella azteca* and the bivalve mollusk, *Musculium transversum*). Missing were representative chronic values for the genus *Oncorhynchus* (salmonid) and an insect genus, although in both of these cases the calculation of the fifth percentile directly from the GMCVs in Table 5 of the 1999 update was deemed to adequately protect the freshwater aquatic community.

In 2004 EPA published a Federal Register Notice indicating its intent to re-evaluate the freshwater ammonia criteria and requesting new information on ammonia toxicity to freshwater mussel species in the Family Unionidae. This action was taken in response to concerns from U.S. Fish and Wildlife Service (USFWS) and mussel researchers about the sensitivity of unionid mussels to ammonia (summarized by Augspurger et al. 2003). The current document takes into account all such data, new toxicity data obtained by a search of the literature for all other species, and updated analyses of tests previously included in the 1999 document.

In 2009, EPA published a draft ammonia criteria document that included all available new data on the toxicity of ammonia to freshwater mussels (EPA-822-D-09-001). The draft 2009 document incorporated new toxicity data in the acute and chronic dataset while retaining the relationships describing the influence of pH and temperature on ammonia toxicity established in the 1999 criteria. The 2009 acute dataset represented 67 genera, including 12 species of freshwater mussels, compared to only 34 genera in the 1999 AWQC. Freshwater bivalve mollusks and snails were the predominant groups of genera ranked in the lowest (most sensitive) quartile, and the four most acutely sensitive genera were all bivalves. The 2009 chronic dataset incorporated two new fish species and new data for three freshwater mussel species, which represented two of the four most sensitive genera. The draft 2009 criteria recommendations were bifurcated, with a set of acute and chronic criteria values for waters with mussels present that reflects their greater sensitivity to ammonia, and a different set of criteria values for waters where mussels are absent. Including the new acceptable data for freshwater unionid mussels, the draft 2009 acute and chronic criteria magnitudes, respectively, were 19 and 0.91 mg TAN/L adjusted to pH 7.0 and 20°C.

For this 2013 update, EPA conducted a new literature search for both acute and chronic toxicity data and reanalyzed data considered in the 1999 criteria and the 2009 draft. EPA reviewed results from this literature search and reanalysis of previously considered data to identify data from laboratory toxicity tests that quantify the adverse effects of ammonia on freshwater aquatic life (amphibians, fishes, and macroinvertebrates), with particular attention given to tests conducted with freshwater unionid mussels and non-pulmonate snails, since such data were not available for many of these species previously. While unionid mussel species are not prevalent in some waters, such as in the arid west, non-pulmonate snails are broadly distributed across the U.S. Thus, considering that freshwater unionid mussels are among the most sensitive genera in the dataset, and that all states have at least one freshwater unionid mussel or bivalve mollusk, or non-pulmonate snail species, another relatively sensitive mollusk group, native or present in at least some of their waters, EPA is recommending a single national acute and a single national chronic criterion be applied to all waters rather than different criteria based on the presence or absence of mussels.

EPA also conducted a separate search and analysis of any relevant new data specific for freshwater mussels to evaluate whether the existing pH-acute TAN toxicity relationship established in the 1999 update document similarly applies to this group of invertebrates. Based on the results of the literature review, EPA concludes that the same pH and temperature relationships used to account for the influence of these two abiotic factors on ammonia toxicity in the 1999 AWQC document are still applicable (e.g., see *Additional Explanation and Justification Supporting the 2013 Temperature and pH-Dependent Calculations and Criteria Magnitudes* section for additional details, pg. 50).

PROBLEM FORMULATION

Problem formulation provides a strategic framework for water quality criteria development by focusing the effects assessment on the most relevant chemical properties and endpoints. The structure of this effects assessment is consistent with EPA's Guidelines for Ecological Risk Assessment (U.S. EPA 1998)

This ecological effects assessment defines scientifically-defensible water quality criteria values for ammonia under section 304(a)(1) of the Clean Water Act. The goal of the Clean Water Act is to protect and restore the biological, chemical and physical integrity of waters of the U.S. Clean Water Act Section 304(a)(1) requires EPA to develop criteria for water quality that accurately reflect the latest scientific knowledge. These criteria are based solely on data and best professional scientific judgments on toxicological effects. Criteria are developed following the guidance outlined in the Agency's *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Stephan et al. 1985).

Once Section 304(a) water quality criteria are finalized, states and authorized tribes may adopt the criteria into their water quality standards to protect designated uses of water bodies. States and tribes may also modify the criteria to reflect site-specific conditions or use other scientifically-defensible methods to develop standards. Water quality standards are subsequently approved by EPA.

Overview of Stressor Sources and Occurrence

Ammonia is considered one of the most important pollutants in the aquatic environment not only because of its highly toxic nature, but also its ubiquity in surface water systems (Russo 1985). Ammonia is produced for commercial fertilizers and other industrial applications using a reaction that converts atmospheric nitrogen to ammonia using hydrogen obtained from methane (natural gas) under high heat and pressure; the ammonia gas is then compressed under low temperature and stored in an anhydrous liquid form (Appl 1999). In agriculture, ammonia is used both directly (in anhydrous form), as well as a precursor for other nitrogen-based fertilizers such as ammonium nitrate, ammonium phosphate, urea, and ammonium sulfate (Environment Canada 2010). The agricultural industry uses approximately 90% of the U.S. annual domestic ammonia production (USGS 2004). Ammonia also has numerous industrial applications, including use as a protective atmosphere and as a source of hydrogen in metal finishing and treating applications (e.g., nitriding; Appl 1999), as well as many other uses in the chemical industry including the production of pharmaceuticals (Karolyi 1968) and dyes (Appl 1999). The petroleum industry utilizes ammonia for processing of crude oil and in corrosion protection (U.S. EPA 2004). Ammonia is also used in the mining industry for metals extraction (U.S. EPA 2004). Natural sources of ammonia include the decomposition or breakdown of organic waste matter, gas exchange with the atmosphere, forest fires, animal waste, the discharge of ammonia by biota, and nitrogen fixation processes (Environment Canada 1997; Environment Canada 2010; Geadah 1985).

Ammonia can enter the aquatic environment via anthropogenic sources or discharges such as municipal effluent discharges, agricultural runoff, and natural sources such as nitrogen fixation and the excretion of nitrogenous wastes from animals. While much of the early information regarding lethal concentrations of ammonia was driven by the consequences of ammonia buildup in aquaculture systems (i.e., fish culture ponds, hatchery raceways, and fish holding and transporting tanks), the introduction of ammonia into surface water systems from industrial processes, agricultural runoff, and sewage effluents has received considerable attention since the 1980s (Alabaster and Lloyd 1980; U.S. EPA 1985). Many effluents have to be treated extensively in order to keep the concentrations of ammonia in surface waters from being unacceptably high. In 2011, there were approximately 4.7 million pounds (lbs.) of ammonia documented as discharged from all reporting industries to surface waters (U.S. EPA 2011). In 2010, industrial releases of ammonia to ten large aquatic ecosystems (e.g., Chesapeake Bay, Puget Sound, Great Lakes) were reported to total approximately 1.3 million lbs. (U.S. EPA 2010).

Environmental Fate and Transport of Ammonia in the Aquatic Environment

Ammonia (NH_3) is formed in the natural environment by the fixation of atmospheric nitrogen and hydrogen by diazotrophic microbes, such as cyanobacteria (Latysheva et al. 2012). Trace amounts are also produced by lightning (Noxon 1976). Decomposition of manure, dead plants and animals by bacteria in the aquatic and terrestrial environments produce ammonia and other ammonium compounds through conversion of nitrogen during decomposition of tissues in a process called ammonification (ATSDR 2004; Sylvia 2005). In the aquatic environment, ammonia is also produced and excreted by fish. The chemical form of ammonia in water consists of two species, the more abundant of which is the ammonium ion (NH_4^+) and the less abundant of which is the non-dissociated or unionized ammonia (NH_3) molecule; the ratio of these species in a given aqueous solution is dependent upon both pH and temperature (Emerson et al. 1975; Erickson 1985; Thurston 1988; Whitfield 1974; Wood 1993). Chemically, ammonia in an aqueous medium behaves as a moderately strong base with pK_a values ranging from approximately 9 to slightly above 10 as a function of temperature and ionic strength (Emerson et al. 1975; Whitfield 1974). In general, the ratio of unionized ammonia to ammonium ion in fresh water increases by 10-fold for each rise of a single pH unit, and by approximately two-fold for each 10°C rise in temperature from 0-30°C (Erickson 1985). Basically, as values of pH and temperature tend to increase, the concentration of NH_3 increases and the concentration of NH_4^+ decreases.

The ionized ammonium ion (NH_4^+) and unionized ammonia molecule (NH_3) are interrelated through the chemical equilibrium $NH_4^+ \text{-} OH^- \leftrightarrow NH_3 \cdot H_2O \leftrightarrow NH_3 + H_2O$ (Emerson et al. 1975; Russo 1985). The concentration of total ammonia (often expressed on the basis of nitrogen as total ammonia nitrogen or TAN) is the sum of NH_4^+ and NH_3 concentrations. It is total ammonia that is analytically measured in water samples. To estimate the relative concentrations of NH_4^+ and NH_3 from total ammonia, Emerson et al.'s (1975) formulas are recommended (Adams and Bealing 1994; Alabaster and Lloyd 1980; Richardson 1997; Russo 1985). Figure 1 (below) shows the chemical speciation of ammonia over a range of pH levels in ambient waters at 25°C. It depicts the 10-fold increase in the ratio of unionized ammonia to ammonium ion in fresh water for each rise of a single pH unit as described above. This increase in unionized ammonia with increased pH is one hypothesis explaining why toxicity of total ammonia increases as pH increases.

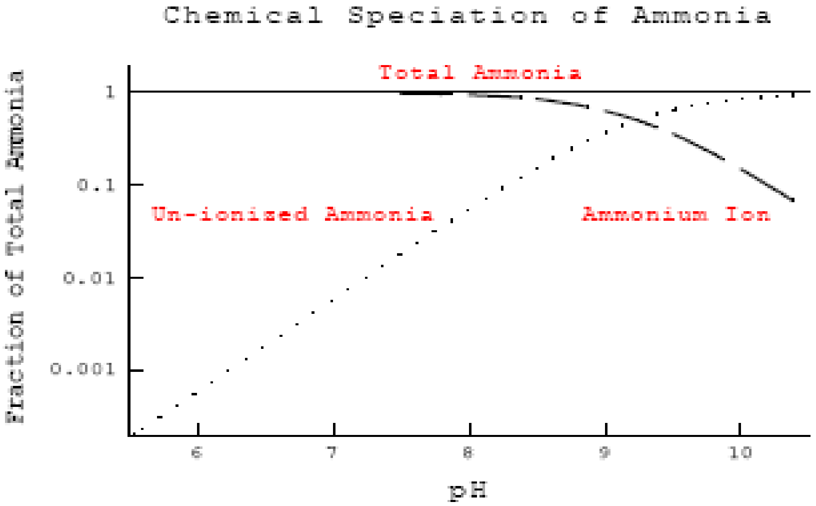


Figure 1. Fraction of Chemical Species of Ammonia Present with Change in pH (at 25°C).

Each separate fraction of total ammonia can be calculated in freshwater from the Henderson-Hasselbach equation if the pH and p*Ka* are known:

NH_4^+ = Total ammonia/(1+ antilog (pH-pKa)) = Total ammonia – NH_3 (Wood 1993)

and,

pKa = 0.09018 + (2729.92/(273.2 + T)) (Emerson et al. 1975)

where T is temperature in °C.

Mode of Action and Toxicity

Ammonia is unique among regulated pollutants because it is an endogenously produced toxicant that organisms have developed various strategies to excrete, which is in large part by passive diffusion of unionized ammonia from internal organs, such as the gills in fish. High external unionized ammonia concentrations reduce or reverse diffusive gradients and cause the buildup of ammonia in internal tissues and blood. Unionized ammonia may cause toxicity to *Nitrosomonas* spp. and *Nitrobacter* spp. bacteria, inhibiting the nitrification process (Russo 1985). Bacterial inhibition can result in the increased accumulation of ammonia in the aquatic environment, thereby intensifying the toxicity to beneficial bacteria and aquatic animals (Russo 1985).

The toxic action of unionized ammonia on aquatic animals, particularly in sensitive fish, may be due to one or more of the following causes: (1) proliferation in gill tissues, increased ventilation rates and damage to the gill epithelium (Lang et al. 1987); (2) reduction in blood oxygen-carrying capacity due to progressive acidosis (Russo 1985); (3) uncoupling oxidative phosphorylation causing inhibition of production and depletion of adenosine triphosphate (ATP) in the brain (Camargo and Alonso 2006); (4) and the disruption of osmoregulatory and circulatory activity disrupting normal metabolic functioning of the liver and kidneys (Arillo et. al.1981; Tomasso et al. 1980).

Among invertebrates, studies testing ammonia toxicity to bivalves, and particularly studies with freshwater mussels in the family Unionidae, have demonstrated their sensitivity to ammonia (Augspurger et al. 2003; Wang et al. 2007a, b; Wang et al. 2008). Toxic effects of unionized ammonia to both freshwater and marine bivalves include reduced opening of valves for respiration and feeding (Epifanio and Srna 1975); impaired secretion of the byssus, or anchoring threads in bivalves (Reddy and Menon 1979); reduced ciliary action in bivalves (U.S. EPA 1985); depletion of lipid and carbohydrate stores leading to metabolic alteration (Chetty and Indira 1995) as well as mortality (Goudreau et al. 1993). These negative physiological effects may lead to reductions in feeding, fecundity, and survivorship, resulting in decreased bivalve populations (Alonso and Camargo 2004; Constable et al. 2003).

Assessment Endpoints

Assessment endpoints are defined as “explicit expressions of the actual environmental value that is to be protected” and are defined by an ecological entity (species, community, or other entity) and its attribute or characteristics (U.S. EPA 1998). Assessment endpoints may be identified at any level of organization (e.g., individual, population, community). In the context of the Clean Water Act, aquatic life criteria for toxics are typically determined based on the results of toxicity tests with aquatic organisms in which unacceptable effects on growth, reproduction, or survival occurred. This information is aggregated into a species sensitivity analysis that evaluates the impact on the aquatic community. Criteria are designed to be protective of the vast majority of aquatic animal species in an aquatic community (i.e., approximately 95th percentile of tested aquatic animals representing the aquatic community). As a result, health of the aquatic ecosystem may be considered as an assessment endpoint indicated by survival, growth, and reproduction. To assess potential effects on the aquatic ecosystem by a particular stressor, and develop 304(a) aquatic life criteria under the CWA, EPA typically requires the following:

- Acute toxicity test data (mortality, immobility, loss of equilibrium) for aquatic animals from a minimum of eight diverse taxonomic groups. The diversity of tested species is intended to ensure protection of various components of an aquatic ecosystem. The acute freshwater toxicity testing requirement is fulfilled with the following eight minimum data requirements:
    - the family Salmonidae in the class Osteichthyes
    - a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish, etc.)
    - a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)
    - a planktonic crustacean (e.g., cladoceran, copepod, etc.)
    - a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish, etc.)
    - an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge, etc.)

    - a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca, etc.)
    - a family in any order of insect or any phylum not already represented

- Chronic toxicity test data (longer-term survival, growth, or reproduction) are required for a minimum of three taxa in order to use acute to chronic ratios to estimate a chronic value, which involves having acceptable chronic toxicity data for the following:
    - at least one fish
    - at least one invertebrate
    - at least one chronic test being from an acutely-sensitive species

  However, since acceptable chronic values were available for ammonia for all eight minimum data requirements, the chronic criterion was derived following the same genus level sensitivity distribution (SD) approach used to calculate the acute criterion (see 1985 Guidelines for additional detail).

- The Guidelines also require at least one acceptable test with a freshwater alga or vascular plant. If plants are among the aquatic organisms most sensitive to the material, results of a plant in another phylum should also be available. The data available on the toxicity of ammonia to freshwater plants indicate that plants are approximately two orders of magnitude less sensitive than the aquatic animals tested. Therefore, plant endpoints were not used in criteria derivation.

Measures of Effect

Each assessment endpoint requires one or more “measures of ecological effect,” which are defined as changes in the attributes of an assessment endpoint itself or changes in a surrogate entity or attribute in response to chemical exposure. Ecological effect data are used as measures of direct and indirect effects to biological receptors. The measures of effect selected represent the growth, reproduction, and survival of the organisms.

The amount of toxicity testing data available for any given pollutant varies significantly, depending primarily on whether any major environmental issues are raised due to interpretation of those data. An in-depth evaluation of available data is performed by EPA to determine test acceptability.

Acute measures of effect

Acute measures of effect used for organisms in this document are the LC_{50} and EC_{50}. LC stands for “Lethal Concentration” and the LC_{50} is the concentration of a chemical that is estimated to kill 50% of the test organisms. EC stands for “Effective Concentration” and the EC_{50} is the concentration of a chemical that is estimated to produce a specific effect in 50% of the test organisms.

As part of the evaluation of new acute data for ammonia, studies submitted using glochidia, the larval life stage of freshwater mussels in the family Unionidae, were reviewed for acceptability for use in the ammonia criteria development. In 2006 a new ASTM method was published for toxicity tests with glochidia. However, at the time of the 2009 draft revised criteria for ammonia, EPA and external peer reviewers were concerned that information was unavailable to determine whether the tests with glochidia were ecologically relevant. Specifically, the appropriate duration of the tests (24, 48, or 96 hrs) was uncertain because it was unclear how the tests of various durations related to the viability of this short parasitic life stage and its ability to successfully infect a fish host upon encountering the appropriate fish species. Since that time, studies by Bringolf et al. (2013) have resulted in the recommendation of a maximum test duration of 24 hours for glochidia corresponding with the ecologically relevant endpoint of infectivity for this parasitic life stage. EPA agreed with this recommendation and decided to include glochidia tests in the criterion dataset for test data with durations of up to 24 hours with survival of glochidia at the end of 24 hours of at least 90% in the control treatment. In addition, to account for species of mussels whose glochidia might not be expected to be viable at 24 hours (i.e., potentially mantle lure strategists), EPA examined available tests with glochidia that were conducted for 24 hours that included testing for viability at 6, 12, and 18 hours. If the viability was less than 90% at 24 hours in the control animals, then the next longest duration less than 24 hours that had at least 90% survival in the control, was considered acceptable for use in deriving the ammonia criteria.

Chronic measures of effect

Chronic measures of effect are EC_{20}, NOEC, LOEC, and MATC. EC_{20} values were used to estimate a low level of effect observed in chronic datasets that are available for ammonia (see U.S. EPA 1999). EC_{20} is the concentration of a chemical that is estimated to result in a 20 percent effect in a chronic endpoint (e.g., growth, reproduction, and survival) of the test organisms.

The NOEC (i.e., "No-Observed -Effect-Concentration") is the highest test concentration at which none of the observed effects are statistically different from the control. The LOEC (i.e., "Lowest-Observed- Effect-Concentration") is the lowest test concentration at which observed effects are found to be statistically different from the control. The MATC is the calculated geometric mean of the NOEC and LOEC.

For life-cycle (LC) and partial life-cycle (PLC) tests, the toxicological variables used in regression analyses were survival, embryo production, and embryo hatchability. For early life-stage (ELS) tests with fishes, the endpoints used were embryo hatchability, fry/larval survival, and fry/larval growth. If ammonia reduced both survival and growth, the product of these variables (biomass) was analyzed (when possible), rather than analyzing them separately. For other acceptable chronic and related (e.g., 28-day juvenile or adult) tests, the toxicological endpoints analyzed were survival, reproduction, hatchability, or growth as appropriate.

Regression analysis was used, both to demonstrate that a concentration-effect relationship was present, and to estimate chronic values at a consistent level of effect. Estimates of effect concentrations can generally be made with precision for a 50 percent reduction in response (EC_{50}), but at low percent reductions such precision is decreased. A major reduction, such as 50 percent, is not consistent with the intent of establishing chronic criteria to protect the population from long-term effects. In contrast, a concentration that causes a low level of reduction in response, such as an EC_5 or EC_{10}, is rarely statistically significantly different from the control treatment. EPA selected EC_{20} values to be used to estimate a low level of effect that would be statistically different from control effects, yet not so severe as to be expected to cause chronic impacts at the population level (see U.S. EPA 1999). For calculation of the chronic criterion, the EC_{20} point estimate was selected for use over a NOEC or LOEC as the measure of effect to use, as NOECs and LOECs are highly dependent on test concentrations selected. Furthermore, point estimates provide additional information that is difficult to determine using NOEC and LOEC effect measures, such as a measure of effect level across the range of tested concentrations, and the confidence intervals around those measures of effect.

The typical assessment endpoints for aquatic life criteria are based on unacceptable effects on growth, reproduction, or survival of the assessed taxa. These measures of effect on toxicological endpoints of consequence to populations are provided by results from the acute and chronic toxicity tests with aquatic plants and animals. The toxicity values (i.e., measures of effect expressed as genus means) are used in the genus sensitivity distribution of the aquatic community to derive the aquatic life criteria. Endpoints used in this assessment are listed in Table 1.

Table 1. Summary of Assessment Endpoints and Measures of Effect Used in Criteria Derivation for Ammonia.

Assessment Endpoints for the Aquatic Community	Measures of Effect
Survival, growth, and reproduction of freshwater fish, other freshwater vertebrates, and invertebrates	For acute effects: LC_{50} or EC_{50} For chronic effects: EC_{20}, NOEC and LOEC, calculated MATC
Maintenance and growth of aquatic plants from standing crop or biomass	Not relevant for ammonia because plants are substantially less sensitive than animals

MATC = maximum acceptable toxicant concentration (geometric mean of NOEC and LOEC)
NOEC = No observed effect concentration
LOEC = Lowest observed effect concentration
LC_{50} = Lethal concentration to 50% of the test population
EC_{50}/EC_{20} = Effect concentration to 50/20% of the test population

Chronic averaging period of 30 days

The 30-day averaging period for chronic effects has been retained from the 1999 chronic criterion, as is the restriction that the highest 4-day average within the 30 days may be no greater than 2.5 times the chronic concentration (CCC) more than once every three years on average. This is based on analysis of chronic data from fathead minnow laboratory tests of different exposure durations and starting with different age test organisms as summarized below and described in greater detail in the 1999 ammonia criteria update.

The 1985 ammonia criteria document specified a CCC averaging period of 4 days as recommended in the 1985 Guidelines (Stephan et al. 1985), except that an averaging period of 30 days could be used when exposure concentrations were shown to have "limited variability". For ammonia, the toxicity data on the fathead minnow demonstrate how long the averaging period should be when concentrations have limited variability, and what restriction applies in terms of the maximum concentration that can be reached and for how long within that averaging period. Based on 7-day tests, EC_{20}s of 29.34 and 24.88 mg TAN/L were calculated from the data of Willingham (1987), adjusted to pH 7. Chronic values of 20.32 mg TAN/L at pH 7 and 20.99 mg TAN/L similarly adjusted to pH 7 were reported by Camp Dresser and McKee (1997). The geometric mean of the four values is 23.62 mg TAN/L. This is approximately 2.5 times the geometric mean EC_{20} (i.e., 9.396 mg TAN/L at pH 7) for the 30-day early life-stage tests conducted on the same species by Swigert and Spacie (1983) and Mayes et al. (1986), [see also Appendix B].

Thus, in the 1999 criteria document, EPA determined that because the mean chronic value from the shorter 7-day toxicity tests with slightly older (< 1 day old) fish is substantially higher than the mean chronic value from the longer 30-day ELS tests initiated with newly fertilized embryos, the CCC averaging period under this “limited variability” can be 30 days, as long as excursions above the CCC are restricted sufficiently to not exceed the mean chronic value from the 7-day tests. As indicated in the 1999 AWQC document, a more rigorous definition of this excursion restriction is not possible with the data available, especially because the information is not available concerning the effects to fish or other animals of variations in ammonia concentration within a 7-day test period. It is useful, however, to base the excursion restriction on a 4-day period, because this period is the default that already has to be considered in calculations of water quality-based effluent limits, and because it provides a substantial limitation of variability relative to the 7-day chronic values. While it may be uncertain how much higher than the CCC the 4-day average can be, based on the fathead minnow test results summarized above, 2.5 -fold higher concentrations should be acceptable. Other data and justification supporting the use of a longer averaging period for ammonia and the excursion restriction is provided in the 1999 AWQC document under Chronic Averaging Period (page 81).

Ammonia toxicity data fulfilling minimum data requirements

Table 2 provides a summary of the number of toxicity data currently available for genera and species that fulfill the 1985 Guidelines minimum requirements for calculation of acute and chronic criteria for freshwater species exposed to ammonia.

Table 2. 1985 Guidelines Minimum Data Requirements Summary Table Reflecting the Number of Species and Genus Level Mean Values Represented in the Acute and Chronic Toxicity Datasets for Ammonia in Freshwater.

	Genus Mean Acute Value (GMAV)	Species Mean Acute Value (SMAV)	Genus Mean Chronic Value (GMCV)	Species Mean Chronic Value (SMCV)
Freshwater				
Family Salmonidae in the class Osteichthyes	4	11	1	3
Second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species	22	33	6	7
Third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian, etc.)	3	4	1	1
Planktonic Crustacean	4	6	2	3
Benthic Crustacean	6	8	1	1
Insect	9	11	1	1
Family in a phylum other than Arthropoda or Chordata (*e.g.*, Rotifera, Annelida, or Mollusca)	17	23	4	5
Family in any order of insect or any phylum not already represented	4	4	1[a]	1[a]
Total	69	100	17	22

[a] In the absence of other chronic data to fulfill this MDR for another phylum not already represented in the chronic dataset, the acute data for species within the phylum Annelida were used to calculate a surrogate chronic value, by applying a geometric mean ACR from the available invertebrate ACRs.

Since the data available regarding the toxicity of ammonia to freshwater phytoplankton and vascular plants reported in the 1985 AWQC document indicate that aquatic plants appear to be two orders of magnitude less sensitive than the aquatic animals tested, it is assumed that any ammonia criterion appropriate for the protection of freshwater aquatic animals will also be protective of aquatic vegetation (U.S. EPA 1985, 1999, 2009). The greater tolerance of these taxa to ammonia is due in part to the fact that ammonia is a readily available and energy-efficient source of nitrogen for plants; although ammonia can be toxic when present at high concentrations. For example, the experimental data concerning the toxicity of ammonia to freshwater phytoplankton show negative effects occurring in the green alga, *Scenedesmus obliquus*, ranging from approximately 26.88 to 70.14 mg TAN/L with regards to oxygen evolution and reduction in carbon dioxide photoassimilation (Abeliovich and Azov 1976). Additionally, ammonia caused growth inhibition and cell death of the green alga, *Chlorella vulgaris*, at concentrations ranging from 326 to 1,330 mg TAN/L (Przytocka-Jusiak 1976); and for another algal species, *Ochromonas sociabilis*, a concentration of 256 mg TAN/L was algicidal while a concentration of approximately half that (128 mg TAN/L) reduced population development (assuming pH 6.5 and 30˚C; see Bretthauer 1978). Furthermore, Champ et al. (1973) investigated the effects of treating a Texas pond with a mean ammonia concentration of 25.6 mg/L NH_3 (unionized ammonia) for two weeks. A diverse population of dinoflagellates, diatoms, desmids, and blue-green algae had been reduced by 95% at the end of the experiment. At the same time, the pond was virtually eradicated of all rooted aquatic vegetation. Compared to the 2013 chronic criterion magnitude of 1.9 mg TAN/L, the results from these plant tests, which are considered as chronic effects according to the 1985 Guidelines, indicate that the 2013 CCC for ammonia will be protective of aquatic plants.

Much of the early work concerning the response of freshwater vegetation to high ammonia concentrations is not quantitative or the result of research exploring the possible use of ammonia as an aquatic herbicide (U.S. EPA 1985). There is no new evidence to suggest that freshwater phytoplankton and vascular species are more sensitive to ammonia than invertebrates or fish. Until such a time as those data are produced, EPA will continue to assume that any ammonia criterion appropriate for the protection of freshwater aquatic animals will also be protective of aquatic vegetation.

Conceptual Model

A conceptual model consists of a written description and diagram (U.S. EPA 1998) that illustrates the relationships between human activities, stressors, and ecological effects on assessment endpoints. The conceptual model links exposure characteristics with the ecological endpoints important for management goals. Under the CWA, these management goals are established by states and tribes as designated uses of waters of the United States (for example, aquatic life support). In deriving aquatic life criteria, EPA is developing acceptable thresholds for pollutants that, if not exceeded, are expected to protect designated uses. A state and/or tribe may implement these criteria by adopting them into their respective water quality standards.

Conceptual diagram

Environmental exposure to ammonia, while ultimately determined by various site specific conditions and processes, occurs from human activities related to agricultural practices, urbanization and industrial processes, or from natural sources. Point and non-point sources contribute to elevated concentrations in ambient surface water. The environmental fate properties of ammonia indicate that direct discharge, runoff, groundwater transport, and atmospheric deposition represent the pathways of greatest transport to the ambient surface waters which serve as habitat for aquatic organisms. These sources and transport mechanisms are depicted in the conceptual model below (Figure 2). The model also depicts exposure pathways for biological receptors of concern (e.g., aquatic animals) and the potential attribute changes (i.e., effects such as reduced survival, growth and reproduction) in the ecological receptors due to ammonia exposure.

The conceptual model provides a broad overview of how aquatic organisms can potentially be exposed to ammonia. Transport mechanisms and exposure pathways are not quantitatively considered in the derivation of aquatic life criteria, which are effects assessments, not risk assessments. Derivation of criteria focuses on effects on survival, growth and reproduction of aquatic organisms. However, the pathways, receptors, and attribute changes depicted in Figure 2 may be helpful for states and tribes as they adopt criteria into standards and need to evaluate potential exposure pathways affecting designated uses.

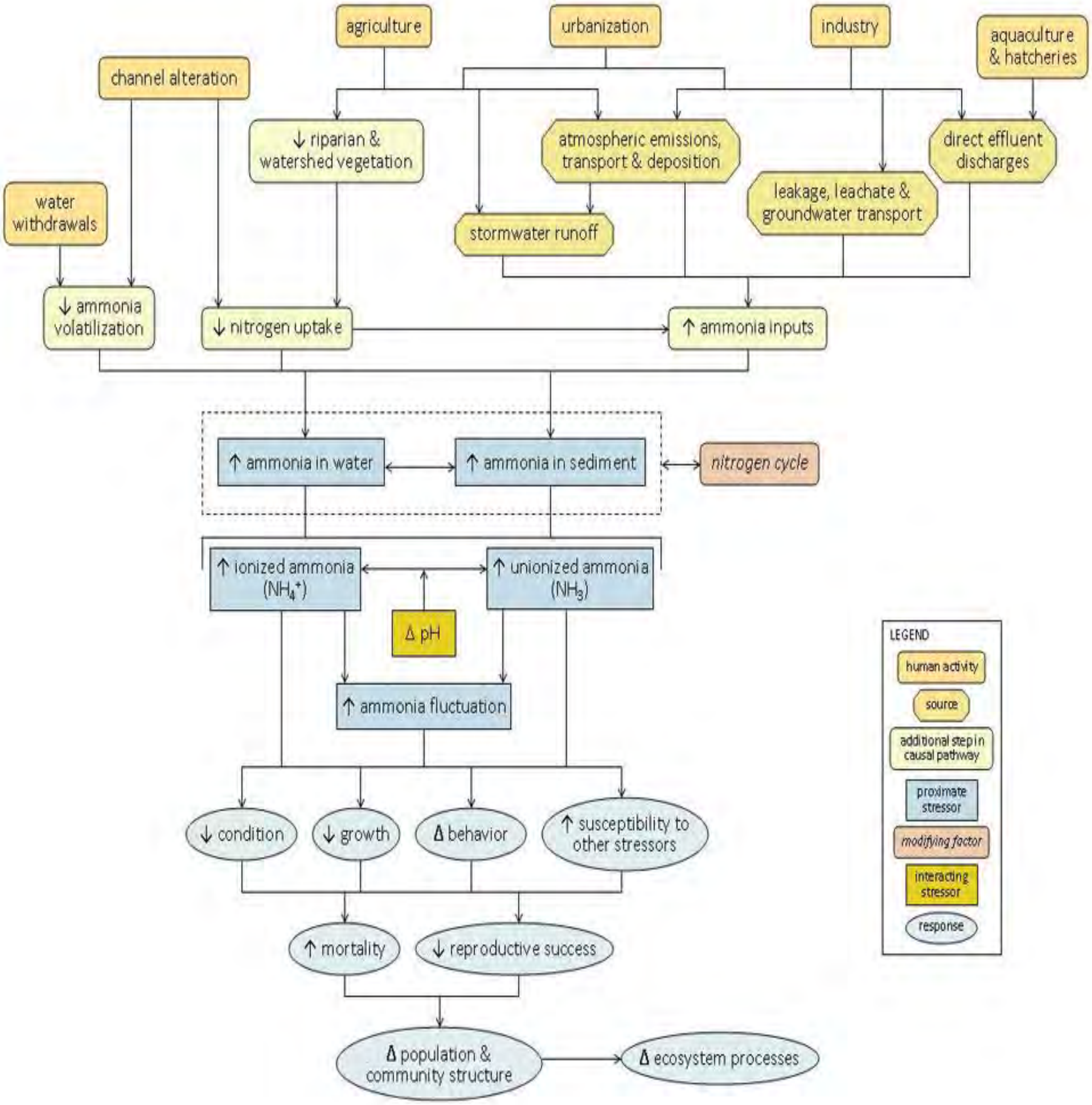


Figure 2: Conceptual Model for Ammonia Effects on Aquatic Animals.
(Available at: http://www.epa.gov/caddis/ssr_amm_int.html)

Analysis Plan

During development of CWA section 304(a) criteria, EPA assembles all available toxicity test data and considers which data are relevant that also meet data quality acceptance standards for all genera. Where data allow, two to four criterion values are developed (acute and chronic freshwater, acute and chronic saltwater). If plants are the most sensitive relative to vertebrates and invertebrates, plant criteria are developed. This criteria update document is specific to ammonia in fresh water, and thus, only two criterion values (freshwater acute and chronic) are derived in this document. Available data indicate freshwater plants are not more sensitive to ammonia than freshwater animals, thus, plant criteria are not developed. Finally, ammonia does not bioaccumulate in aquatic animals, thus, final tissue values are not developed.

These criteria are based on a sensitivity distribution (SD) comprised of ranked genus mean acute values (GMAVs), calculated from combined species mean acute values (SMAVs within each genus) for acceptable data. SMAVs are calculated using the geometric mean for all acceptable measures of effect based on the results of toxicity tests within a given species (e.g., all EC_{50}s from acceptable acute tests for *Daphnia magna*). GMAVs are then calculated using the geometric means of all SMAVs within a given genus (e.g., all SMAVs for genus Daphnia, such as *Daphnia pulex, Daphnia magna*). If only one SMAV is available for a genus, then the GMAV is represented by that value. GMAVs are then rank-ordered by sensitivity from most sensitive to least sensitive. The final acute value (FAV) is determined by regression analysis using a log-triangular fit based on the four most sensitive genera (reflected as GMAVs) in the data set to interpolate or extrapolate (as appropriate) to the 5th percentile of the distribution represented by the tested genera. If there are 59 or more GMAVs, as is the case with ammonia, the four GMAVs closest to the 5th percentile of the distribution are used to calculate the FAV. The acute criterion magnitude is the FAV divided by two, in order to provide an acute criterion magnitude protective of nearly all individuals in 95% of all genera, since the effect endpoint is a 50th percentile effect (e.g., LC_{50} or EC_{50}) (see 1985 Guidelines, Section XI. Criterion, B.).

Although the aquatic life criteria derivation process relies on selected toxicity endpoints from the sensitive species tested, it does not necessarily mean that the selected toxicity endpoints reflect the sensitivity of the most sensitive species existing in a given environment. The intent of the eight minimum data requirements is to serve as a sample representative of the aquatic community. These minimum data requirements represent different ecological, trophic, taxonomic and functional differences observed in the natural aquatic ecosystem. The use of the four most sensitive genera to determine the final criterion value is a censored statistical approach than improves estimation of the lower tail (most sensitive) of the distribution when the shape of the overall distribution, particularly in the less sensitive part of the distribution, is uncertain.

The chronic criterion may be determined by one of two methods. If all eight minimum data requirements are met with acceptable chronic test data (as is the case with ammonia), then the chronic criterion is derived using the same method used for the acute criterion. Genus Mean Chronic Values (GMCVs) are derived from available Species Mean Chronic Values (SMCVs) and are then rank-ordered from least to most sensitive, and the Final Chronic Value (FCV) is calculated based on regression analysis of a censored distribution using the four most sensitive GMCVs, similar to calculation of the FAV. Unlike the FAV, however, the FCV directly serves as the basis for the chronic criterion without further adjustment because the endpoint measured represents a low level (e.g., EC_{20} or NOEC) of effect (see 1985 Guidelines).

In addition, whenever adequately justified, a state can develop a site-specific criterion in lieu of the use of a national recommended criterion (U.S. EPA 1983). The site-specific criterion may include not only site-specific criterion concentrations, but also site-specific durations or averaging periods, site-specific frequencies of allowed excursions, and representative species present at a given site, where supported by sound science (U.S. EPA 1991). The *Revised Deletion Process for the Site-Specific Recalculation Procedure for Aquatic Life Criteria* (U.S. EPA 2013) provides guidance on revising the taxonomic composition of the toxicity data set used for the sensitivity distribution upon which a site-specific criterion is based, in order to better reflect the assemblage of organisms that resides at the site. For more information on criteria derivation, see: *http://water.epa.gov/scitech/swguidance/waterquality/standards/upload/2009_01_13_criteria_85guidelines.pdf*.

The criteria presented are the Agency's best estimate of maximum ambient concentrations of ammonia to protect most freshwater aquatic organisms from unacceptable short- or long-term effects. Results of intermediate calculations such as Species Mean Acute Values (see in Appendix A) and chronic values (see in Appendix B) are specified to four significant figures to prevent rounding error in subsequent calculations, not to reflect the precision of the value. All of the ammonia acute values (LC_{50}s and EC_{50}s) in Appendix A of this document were converted to TAN acute values using the reported temperatures and pHs as described using an example in Appendix D (Conversion of Acute Results of Toxicity Tests). Similarly, all of the ammonia chronic values (EC_{20}s) in Appendix B were converted to TAN chronic values as described in Appendix E (Conversion of Chronic Results of Toxicity Tests).

EFFECTS ANALYSES FOR FRESHWATER AQUATIC ORGANISMS

The acute and chronic ammonia toxicity data used here to update the acute and chronic criteria for ammonia (freshwater) were collected via literature searches of EPA's ECOTOX database, EPA's Ambient Aquatic Life Water Quality Criteria for Ammonia (U.S. EPA 1985, 1998, 1999), data provided by the U.S. Fish and Wildlife Service and the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (collectively known as the Services), and EPA regional and field offices. Relevant papers were identified, by title and abstract, and their data screened according to data quality criteria described in the 1985 Guidelines. All available, reliable acute and chronic toxicity values published since 1985 were incorporated into the appropriate ammonia AWQC tables and used to recalculate the CMC and the CCC, as outlined in detail in the 1985 Guidelines. The most recent literature search covered the period from 1985 through October 2012.

Acute Toxicity to Aquatic Animals

All available data relating to the acute effects of ammonia on aquatic animals were considered in deriving the ammonia criteria and were subjected to a data quality review per the 1985 Guidelines. The acute effects concentrations are all normalized to pH 7.0 (for all organisms) and temperature 20°C (for invertebrates) as indicated via the equations provided in Appendix D. The pH and temperature conditions to which these data are normalized were deemed to be generally representative of ambient surface water. Data that were suitable for the derivation of a freshwater FAV are presented in Appendix A**.**

The GMAVs ranked according to sensitivity, as well as the new (2013) and previous (1999) acute criterion values (CMCs), are shown in Figure 3. The GMAVs represent LC_{50}s or EC_{50}s, whereas the CMC (the FAV/2) values represent concentrations that are expected to be lethal to less than 50% of the individuals in either the fifth percentile genus, or, a sensitive commercially or recreationally important species (e.g., adult rainbow trout).

For this 2013 AWQC document, results from acute toxicity tests that met test acceptability and quality (according to the 1985 Guidelines) were available for 44 species of fish, 52 species of invertebrates and four species of amphibians. This data includes ammonia toxicity test data on 52 new species of aquatic animals not previously included in the 1999 acute criterion dataset. There are now 69 genera represented in the freshwater acute toxicity dataset for ammonia, and of the 69 genera (represented in Appendix A and listed according to sensitivity in Table 3), approximately half are invertebrates. The acute dataset more than fulfills the eight minimum data requirements outlined in the 1985 Guidelines with between three and 22 genera represented for each taxa category specified (see Table 2 above). The acute criterion dataset now includes 12 species of aquatic animals Federally-listed as threatened, endangered or species of concern. Freshwater invertebrates in the Phylum Mollusca, particularly freshwater mussels in the family Unionidae, freshwater clams, and some non-pulmonate snails, are the predominant group of aquatic organisms ranked in the lowest quartile. The four most acutely sensitive genera are all freshwater bivalve mussels (Table 3). GMAVs for freshwater mollusks in general, are now among the most influential in the 2013 acute criterion dataset.

Data for glochidia and juvenile life stages of freshwater unionid mussels were evaluated for acceptability based on the 1985 Guidelines, the approved ASTM protocol for toxicity testing with these life stages of unionid mussels (ASTM 2006), and recent studies on the most ecologically relevant toxicological endpoint(s) and exposure duration(s) for glochidia tests by Bringolf et al. (2013). The acute unionid mussel dataset for ammonia now includes acceptable data for 11 genera, totaling 16 species of freshwater mussels, as well as two sensitive species of non-pulmonate snails. Of these, four of the 18 mollusk species included in 2013 acute dataset are Federally-listed as threatened or endangered (as identified in Table 3).

Nearly all states in the continental United States have freshwater unionid mussel fauna in at least some of their waters (Abell et al. 2000; Williams et al. 1993; Williams and Neves 1995). While the number of freshwater unionid mussel species is less and the distribution is sparse in the dry western states, even New Mexico and Arizona have at least one native mussel species (Williams et al. 1993). Moreover, approximately one-quarter of nearly 300 freshwater unionid mussel taxa in the USA are Federally-listed as endangered, threatened or of special concern. In addition, non-pulmonate snails are relatively ubiquitous compared to mussels and of the 650 freshwater snail species, 25 species are Federally-listed. Every state in the continental U.S. has at least one family of non-pulmonate snail in at least some of their waters. Thus, considering that freshwater unionid mussels are among some of the most sensitive genera in the dataset, and that all states have at least one freshwater unionid mussel or bivalve mollusk, or non-pulmonate snail species, another relatively sensitive mollusk group, native or present in at least some of their waters, EPA is recommending a single national acute criterion to be applied to all waters rather than different criteria based on the presence or absence of mussels.

The most sensitive fish SMAV is for mountain whitefish, *Prosopium williamsoni* (SMAV of 51.93 mg TAN/L), representing one of the four genera of salmonids in the acute dataset, followed by the second most sensitive fish, the Lost River sucker (SMAV of 56.62 mg TAN/L), which is an endangered species (Table 3). The mountain whitefish GMAV is ranked eighth most sensitive after seven more sensitive GMAVs for freshwater mussel species, thus, salmonids should be adequately protected by the new acute criterion. The next most sensitive salmonid genus is Oncorhynchus, represented by data for six different species, three of which are threatened or endangered, with SMAVs ranging from 78.92 mg TAN/L for Cutthroat trout, *O. clarkii,* to 180.7 mg TAN/L for pink salmon, *O. gorbuscha.* The GMAV for Oncorhynchus (99.15 mg TAN/L) is ranked #25 in acute sensitivity rank at pH 7 and temperature 20°C (Table 3).

The four lowest GMAVs in this 2013 ammonia AWQC update are for invertebrate species (specifically, freshwater bivalve mollusks dominated by mussels in the family Unionidae). Because the most sensitive GMAVs are all represented by invertebrate species, the CMC is both pH-dependent, in accordance with the acute pH-toxicity relationship for all aquatic organisms, and temperature-dependent, due to the invertebrate acute-temperature relationship.

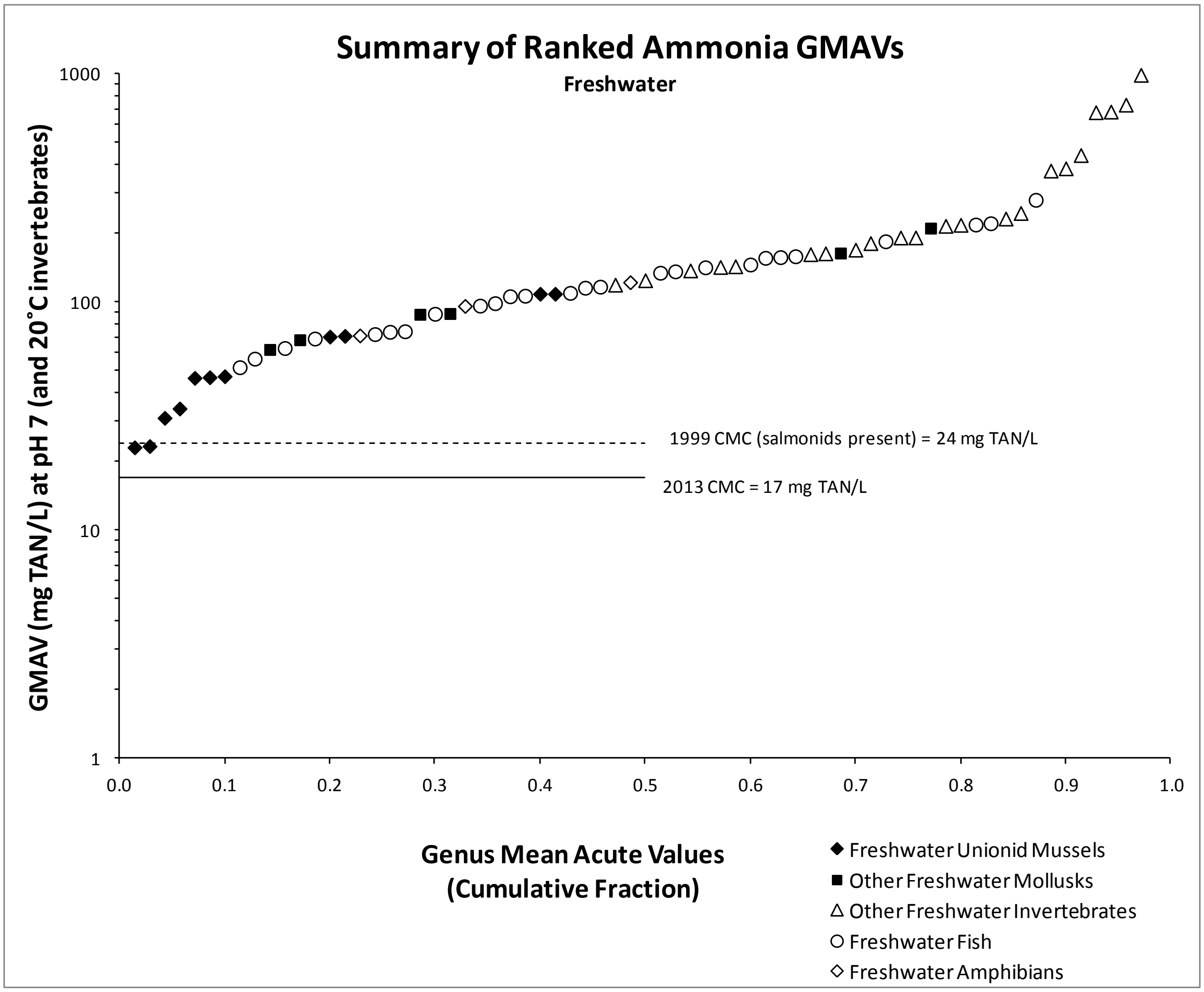


Figure 3. Ranked Freshwater Genus Mean Acute Values (GMAVs) with Criterion Maximum Concentrations (CMCs).

Summaries of studies used in acute criterion determination

Presented in this section are brief summaries of the results of acute toxicity tests that meet the data quality acceptability criteria and that are used directly for deriving the FAV (i.e., serve as the basis for the SMAV or GMAV of one of the most sensitive genera). As per the 1985 Guidelines, whenever there are 59 or more GMAVs in the acute criteria dataset, the FAV is calculated using the four GMAVs closest to the 5th percentile of the distribution.

The four species and associated endpoints (SMAV or GMAV) used in calculating the acute criterion (sensitivity rank 2-5) are ranked below from most to least sensitive:

2. *Lasmigona subviridis*, Green Floater (GMAV= 23.41 mg TAN/L)
3. *Epioblasma capsaeformis*, Oyster mussel (GMAV= 31.14 mg TAN/L)
4. *Villosa iris*, Rainbow Mussel (GMAV= 34.23 mg TAN/L)
5. *Lampsilis* sp. (GMAV=46.63 mg TAN/L)

The most sensitive species *Venustaconcha ellipsiformis* (SMAV=23.12 mg TAN/L) is not included in the criteria numeric calculation, because it falls below the 5th percentile in sensitivity in the distribution of 69 genera included in the dataset.

Summaries are provided on the basis of individual species or genera (in cases where more than one species is included in the calculation of the GMAV). All values are provided in terms of total ammonia nitrogen (TAN), either as reported by the authors or as converted from the reported values for unionized ammonia, pH, and temperature (using the speciation relationship) applied in the 1999 AWQC document (i.e., Emerson et al. 1975). In the special cases where the result of a test is considered an upper limit on an acute value, the value is ascribed a greater than (">") sign indicating as much.

Lasmigona subviridis (green floater)

The GMAV/SMAV for the green floater, a freshwater bivalve mollusk, of 23.41 mg TAN/L is based on the geometric mean of three 96-hr EC_{50}s from tests using less than two-month old juveniles as reported in Black (2001). Test solutions were renewed after 48 hours. The mean pH and test temperature for two of the tests was 7.73 and 24°C, and for the third, 7.92 and 24.8°C. Control survival exceeded 90 percent in all three tests. The reported EC_{50}s at test temperature and pH expressed on the basis of TAN were 6.613, 6.613 and 3.969 mg TAN/L, respectively. Adjusted to pH 7 and 20°C, the EC_{50}s are 24.24, 24.24 and 21.84 mg TAN/L, respectively (Appendix A). The GMAV for juvenile green floaters of 23.41 mg TAN/L represents the second lowest in the acute dataset, and the lowest of the four GMAVs used to calculate the FAV (Table 3).

Epioblasma capsaeformis (oyster mussel)

The GMAV/SMAV for the endangered oyster mussel (31.14 mg TAN/L) is the third lowest in the acute dataset (Table 3), and is based on the geometric mean of a 96-hr EC_{50} from a renewal test using less than five-day old juveniles, and two 6-hr EC_{50}s from static tests conducted with two-hour old glochidia (Wang et al. 2007b). The mean pH and test temperature for all three tests was 8.5 and 20°C. Control survival exceeded 90 percent in all tests. The estimated measured EC_{50} for juvenile oyster mussels at test temperature and pH was 4.760 mg TAN/L, after adjusting the reported nominal EC_{50} by multiplying by a factor of 0.835 (i.e., measured total ammonia concentrations were 83.5 percent of nominal concentrations for 96 hour juvenile exposures). The reported EC_{50}s for glochidia were 3.4 and 5.0 mg TAN/L, respectively (no further adjustment necessary). These EC_{50}s normalized to pH 7 and 20°C are 53.63, 17.81 and 31.61 mg TAN/L, for the two glochidia and juveniles respectively (Appendix A).

Villosa iris (rainbow mussel)

Ten EC_{50}s from several studies (Goudreau et al. 1993; Scheller 1997; Mummert et al. 2003; Wang et al. 2007b) using two different life stages (glochidia and juvenile) and range of ages within each life-stage were used to calculate the GMAV/SMAV for rainbow mussel (Appendix A). All tests were either static or static renewal where concentrations were measured. The GMAV of 34.23 mg TAN/L is the fourth lowest in the acute dataset (Table 3), and is composed of individual EC_{50} values (expressed as TAN and normalized to pH 7 and 20°C) ranging from 12.62 to 99.28 mg TAN/L (Appendix A). The difference in pH and test temperature among the 10 different tests ranged from 7.29 to 8.40 and 12.6 to 25.0°C, respectively. Control survival exceeded 90 percent in all tests regardless of life-stage tested. The glochidia were not substantially more sensitive than the juveniles (less than a factor of 2 difference).

Mussels in Genus *Lampsilis*

Freshwater unionid mussels within the Genus *Lampsilis* represent the most widely tested genus to date. The GMAV of 46.63 mg TAN/L reflects the geometric mean of SMAVs for six species, two (*Lampsilis abrupta* and *L. higginsii*) which are endangered and a third (*L. rafinesqueana*) that is a Federal species of concern (Table 3). The SMAVs for this genus range from 26.03 mg TAN/L (*L. abrupta*) to 69.97 mg TAN/L (*L. rafinesqueana*), and are composed of anywhere from one (*L. abrupta*) to fourteen (*L. siliquoidea*) individual EC_{50}s (Appendix A). The range of EC_{50}s used to calculate the FAV, normalized to pH 7 and 20°C across all species of

Lampsilis is from 24.30 to 160.5 mg TAN/L (see Appendix A). The GMAV for *Lampsilis* is the fifth most sensitive in the acute dataset, and the highest of the four GMAVs used to calculate the FAV (Table 3). Both glochidia and juvenile data were available for three of the six *Lampsilis* species, showing an inconsistent pattern of relative sensitivity.

Table 3. Ranked Genus Mean Acute Values.

Table 3. Ranked Genus Mean Acute Values

Rank	GMAV (mg TAN/L)	Species	SMAV (mg TAN/L)
69	2515	Insect, *Erythromma najas*	2515
68	994.5	Caddisfly, *Philarctus quaeris*	994.5
67	735.9	Beetle, *Stenelmis sexlineata*	735.9
66	686.2	Crayfish, *Orconectes immunis*	1550
		Crayfish, *Orconectes nais*	303.8
65	681.8	Midge, *Chironomus riparius*	1029
		Midge, *Chironomus tentans*	451.8
64	442.4	Mayfly, *Drunella grandis*	442.4
63	387.0	Aquatic sowbug, *Caecidotea racovitzai*	387.0
62	378.2	Isopod, *Asellus aquaticus*	378.2
61	281.5	Threespine stickleback, *Gasterosteus aculeatus*	281.5
60	246.5	Mayfly, *Callibaetis skokianus*	364.6
		Mayfly, *Callibaetis* sp.	166.7
59	233.0	Dragonfly, *Pachydiplax longipennis*	233.0
58	222.2	Mottled sculpin, *Cottus bairdii*	222.2
57	219.3	Western mosquitofish, *Gambusia affinis*	219.3
56	218.7	Oligochaete worm, *Lumbriculus variegatus*	218.7
55	216.5	Tubificid worm, *Tubifex tubifex*	216.5
54	211.6	Marsh ramshorn snail, *Planorbella trivolvis*	211.6

Table 3. Ranked Genus Mean Acute Values			
Rank	**GMAV (mg TAN/L)**	**Species**	**SMAV (mg TAN/L)**
53	192.6	Scud, *Hyalella azteca*	192.6
52	192.4	Stonefly, *Skwala americana*	192.4
51	185.2	Mozambique tilapia, *Oreochromis mossambicus*	185.2
50	181.8	Amphipod, *Crangonyx pseudogracilis*	270.5
		Amphipod, *Crangonyx* sp.	122.2
49	170.2	Tubificid worm, *Limnodrilus hoffmeisteri*	170.2
48	164.5	Pouch snail, *Physa gyrina*	164.5
47	164.0	Damselfly, *Enallagma* sp.	164.0
46	162.6	Water flea, *Chydorus sphaericus*	162.6
45	159.2	Fathead minnow, *Pimephales promelas*	159.2
44	157.8	Brook trout, *Salvelinus fontinalis*	156.3
		Lake trout, *Salvelinus namaycush*	159.3
43	156.7	Shortnose sturgeon, *Acipenser brevirostrum (LS)*	156.7
42	146.5	White sucker, *Catostomus commersonii*	157.5
		Mountain sucker, *Catostomus platyrhynchus*	136.2
41	143.9	Water flea, *Ceriodaphnia acanthine*	154.3
		Water flea, *Ceriodaphnia dubia*	134.2
40	142.9	Water flea, *Simocephalus vetulus*	142.9
39	142.4	Channel catfish, *Ictalurus punctatus*	142.4
38	138.0	Red swamp crayfish, *Procambarus clarkii*	138.0
37	136.7	Atlantic salmon, *Salmo salar (LS)*	183.3
		Brown trout, *Salmo trutta*	102.0
36	134.8	White perch, *Morone americana*	132.7
		White bass, *Morone chrysops*	144.0

Table 3. Ranked Genus Mean Acute Values			
Rank	**GMAV (mg TAN/L)**	**Species**	**SMAV (mg TAN/L)**
		Striped bass, *Morone saxatilis*	246.2
		Sunshine bass, *Morone saxatilis x chrysops*	70.22
35	125.0	Water flea, *Daphnia magna*	157.7
		Water flea, *Daphnia pulicaria*	99.03
34	122.5	Clawed toad, *Xenopus laevis*	122.5
33	119.5	Flatworm, *Dendrocoelum lacteum*	119.5
32	117.1	Walleye, *Sander vitreus*	117.1
31	115.9	Central stoneroller, *Campostoma anomalum*	115.9
30	110.0	Rainbow dace, *Cyprinella lutrensis*	196.1
		Spotfin shiner, *Cyprinella spiloptera*	83.80
		Steelcolor shiner, *Cyprinella whipplei*	80.94
29	109.0	Dwarf wedgemussel, *Alasmidonta heterodon (LS)*	109.0
28	109.0	Pink papershell, *Potamilus ohiensis*	109.0
27	106.9	Green sunfish, *Lepomis cyanellus*	150.8
		Pumpkinseed, *Lepomis gibbosus*	77.53
		Bluegill, *Lepomis macrochirus*	104.5
26	106.3	Common carp, *Cyprinus carpio*	106.3
25	99.15	Golden trout, *Oncorhynchus aguabonita*	112.1
		Cutthroat trout, *Oncorhynchus clarkii*	78.92
		Pink salmon, *Oncorhynchus gorbuscha*	180.7
		Coho salmon, *Oncorhynchus kisutch (LS)*	87.05
		Rainbow trout, *Oncorhynchus mykiss (LS)*	82.88
		Chinook salmon, *Oncorhynchus tshawytscha (LS)*	82.39
24	96.72	Topeka shiner, *Notropis topeka (LS)*	96.72

Table 3. Ranked Genus Mean Acute Values			
Rank	**GMAV (mg TAN/L)**	**Species**	**SMAV (mg TAN/L)**
23	96.38	Leopard frog, *Rana pipiens*	96.38
22	89.36	Long fingernailclam, *Musculium transversum*	89.36
21	89.06	Smallmouth bass, *Micropterus dolomieu*	150.6
		Largemouth bass, *Micropterus salmoides*	86.02
		Guadalupe bass, *Micropterus treculii*	54.52
20	88.62	Great pond snail, *Lymnaea stagnalis*	88.62
19	74.66	Guppy, *Poecilia reticulata*	74.66
18	74.25	Johnny darter, *Etheostoma nigrum*	71.45
		Orangethroat darter, *Etheostoma spectabile*	77.17
17	72.55	Rio Grande silvery minnow, *Hybognathus amarus*	72.55
16	71.56	Spring peeper, *Pseudacris crucifer*	61.18
		Pacific tree frog, *Pseudacris regilla*	83.71
15	71.25	Mucket, *Actinonaias ligamentina*	63.89
		Pheasantshell, *Actinonaias pectorosa*	79.46
14	70.73	Giant floater mussel, *Pyganodon grandis*	70.73
13	69.36	Shortnose sucker, *Chasmistes brevirostris*	69.36
12	68.54	Pagoda hornsnail, *Pleurocera uncialis*	68.54
11	63.02	Golden shiner, *Notemigonus crysoleucas*	63.02
10	62.15	Pebblesnail, *Fluminicola* sp.	62.15
9	56.62	Lost River sucker, *Deltistes luxatus(LS)*	56.62
8	51.93	Mountain whitefish, *Prosopium williamsoni*	51.93
7	47.40	Atlantic pigtoe, *Fusconaia masoni*	47.40
6	46.93	Pondshell mussel, *Utterbackia imbecillis*	46.93
5	46.63	Pink mucket, *Lampsilis abrupta (LS)*	26.03

Table 3. Ranked Genus Mean Acute Values

Rank	GMAV (mg TAN/L)	Species	SMAV (mg TAN/L)
		Plain pocketbook, *Lampsilis cardium*	50.51
		Wavy-rayed lampmussel, *Lampsilis fasciola*	48.11
		Higgin's eye, *Lampsilis higginsii (LS)*	41.90
		Neosho mucket, *Lampsilis rafinesqueana (LS)*	69.97
		Fatmucket, *Lampsilis siliquoidea*	55.42
4	34.23	Rainbow mussel, *Villosa iris*	34.23
3	31.14	Oyster mussel, *Epioblasma capsaeformis (LS)*	31.14
2	23.41	Green floater, *Lasmigona subviridis*	23.41
1	23.12	Ellipse, *Venustaconcha ellipsiformis*	23.12
FAV = 33.52			
CMC = 17			

LS = Federally-listed as threatened or endangered species

Chronic Toxicity to Freshwater Aquatic Animals

Freshwater chronic toxicity data that meet the test acceptability and quality assurance/control criteria are presented in Appendix B. All tests were conducted with measured concentrations of ammonia. Ammonia chronic toxicity data are available for 21 species of freshwater organisms: ten invertebrate species (mussels, clam, snail, cladocerans, daphnid, and insect) and 11 fish species, including three Federally-listed salmonid species. The chronic dataset includes data for three freshwater unionid mussel species, one freshwater non-pulmonate snail species, and two fish species not included in the 1999 criteria (see Appendix B). It also includes an estimate of chronic effects for the Phylum Annelida, to meet the data requirement of a species in "a family in any order of insect or any phylum not already represented," as described below.

Each chronic test was reviewed to determine acceptability based on the dilution water, control mortality, experimental design, organism loading, etc., as consistent with ASTM standards, including for freshwater mussels via E2455-06 (ASTM 2006). The concentration of dissolved oxygen was also reviewed to determine acceptability based on the general limits specified in the 1999 AWQC document. The mean measured dissolved oxygen concentration and the lower limit for dissolved oxygen concentration required to be protective varies based on taxa group. The mean dissolved oxygen concentration for toxicity tests should be at least 6.5 mg/L for salmonids, 6.0 mg/L for invertebrates, and the lower limit of dissolved oxygen should be 5.0 mg/L to be protective of both of these groups of organisms (U.S. EPA 1999).

Based on the determination that the test methodology used was acceptable, the studies were evaluated to determine whether the ammonia caused a reduction in (a) survival (if over a period of at least seven days), (b) growth, or (c) reproduction. If the test demonstrated reduction in any of these toxicological endpoints, the test could be accepted for use in calculating the chronic value (CV).

Acceptable 28-day survival tests using juvenile freshwater mussels and juvenile freshwater snails and growth tests using juvenile freshwater snails were evaluated for inclusion in the derivation of the chronic aquatic life criterion when the test concentration caused a reduction in survival or growth of 20 percent or more of these types of organisms at those life stages. Based on evaluation of the individual studies (Wang et al. 2007a; Wang et al. 2011), growth data for juvenile mussels was not used in the derivation of the chronic criterion due to uncertainty in method of measurement for the growth endpoint (see Effects Characterization for further discussion).

All chronic data in individual studies were analyzed using regression analysis to demonstrate the presence of a concentration-effect relationship within the test. For those studies that demonstrated a concentration-effect relationship, EPA used regression analysis to estimate the EC_{20}.

Sixteen GMCVs are presented in Appendix B and ranked according to sensitivity in Table 4. The four lowest values were used to calculate the FCV, because values for fewer than 59 genera exist. EPA calculated the chronic criterion based on fifth percentile of the GMCVs in Table 4. The GMCVs for the four most sensitive species are ranked below from most to least sensitive:

1. *Lampsilis* spp, Wavy-rayed lamp mussel and Fatmucket (GMCV=2.126 mg TAN/L*)*
2. *Villosa iris,* Rainbow mussel (GMCV= 3.501 mg TAN/L)

3. *Lepomis* spp., Bluegill and Green sunfish (GMCV= 6.920 mg TAN/L)

4. *Musculium transversum,* Long fingernailclam (GMCV= 7.547 mg TAN/L)

The chronic criterion magnitude is 1.9 mg TAN/L at 20°C and pH 7. The four most sensitive species are predominantly mollusks although *Lepomis* species (bluegill and green sunfish) comprise the third most sensitive GMCV. Figure 4 shows the GMCVs ranked according to sensitivity and shows the 2013 chronic criteria magnitude as well as the 1999 criterion value (based on fish early life stages) for comparative purposes.

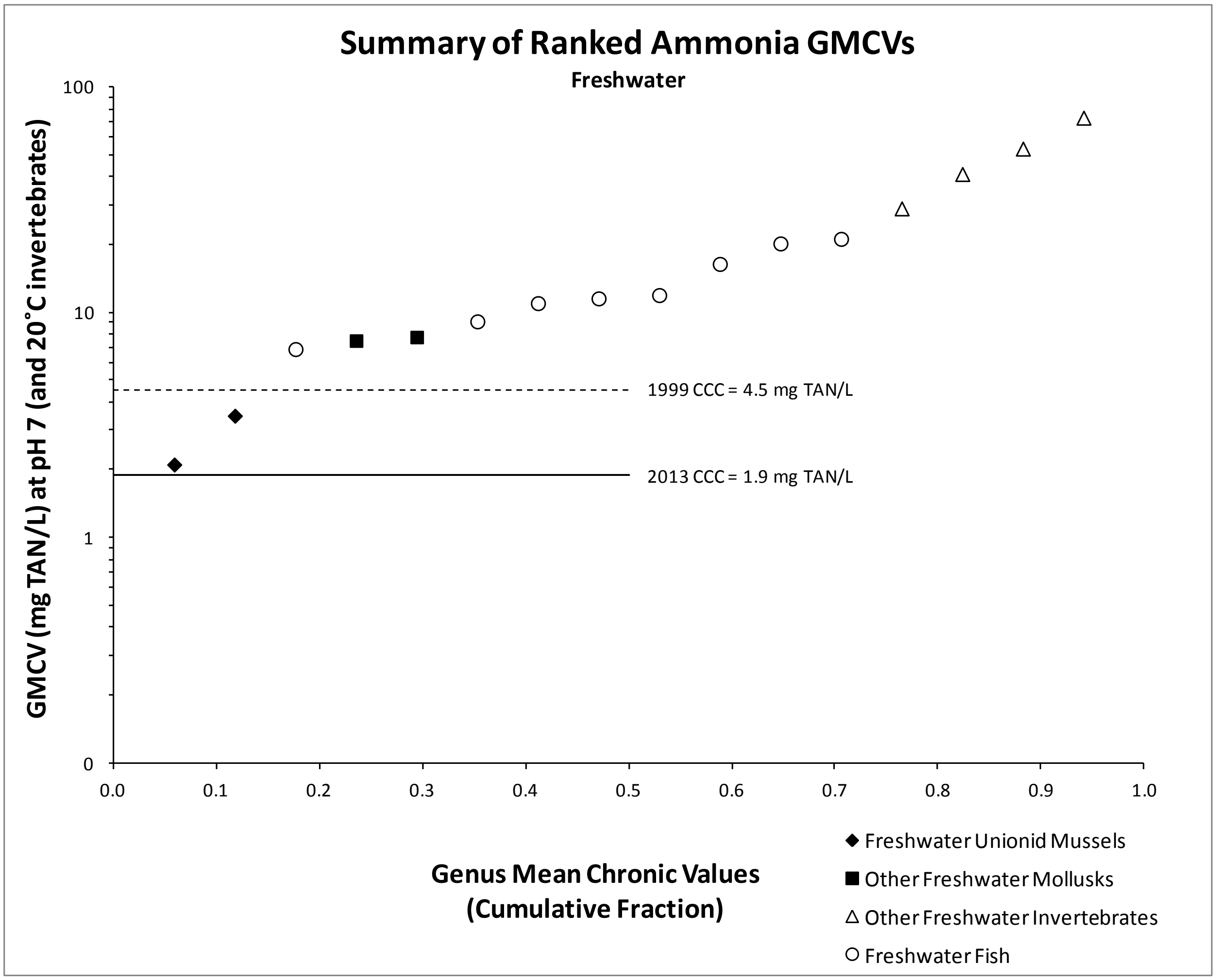


Figure 4. Ranked Freshwater Genus Mean Chronic Values (GMCVs) with Criterion Continuous Concentrations (CCCs).

Summaries of studies used in chronic criterion determination

The following presents a species-by-species discussion of freshwater chronic data used in deriving the chronic criterion magnitude for ammonia. All analyses were conducted in terms of TAN, either as reported by the authors or as converted from the reported values for unionized ammonia, pH, and temperature (using the speciation relationship in Emerson et al. 1975). EC_{20} values were adjusted to pH 7, and for invertebrates, also adjusted to a temperature of 20°C. SMCVs were used when data were available for only one species. When data for more than one species in a taxon were available, GMCVs were calculated from the SMCVs. All of the CVs (EC_{20} values), SMCVs, and GMCVs derived are tabulated and included in Appendix B. For some of the new chronic data, authors reported EC_{20} values on the basis of TAN. In such cases these reported CVs were normalized to pH 7 and 20°C (temperature normalization for invertebrates only), and utilized for the analysis. The results of all intermediate calculations such as ECs, SMCVs and GMCVs are given to four significant figures to prevent round-off error in subsequent calculations, not to reflect the precision of the value.

Lampsilis species

Lampsilis fasciola (wavy-rayed lampmussel)

Wang et al. (2007a) published results of the effect of ammonia on survival and growth of 2-month old juvenile freshwater unionid mussels. The 28-day juvenile test was part of a series of studies designed to refine the methods for conducting acute and chronic toxicity tests with early life stages of freshwater mussels. Dissolved oxygen was maintained above 7.0 mg/L during the 28-day test. Survival in the control treatment and lowest ammonia test concentration (0.13 mg TAN/L) were 100 and 83 percent, respectively. Survival decreased to 30 percent at 1.02 mg TAN/L, and zero at 1.98 mg TAN/L. There was no concentration-response relationship for either length at 28 days or change in length after 28 days. Using EPA's TRAP model (see Appendix G), the survival EC_{20} for this freshwater unionid mussel species is 0.4272 mg TAN/L at test temperature (20°C) and pH (8.2), or 1.408 mg TAN/L when adjusted to pH 7 and 20°C (Appendix B).

Lampsilis siliquoidea (fatmucket)

In a recent study, Wang et al. (2011) evaluated the influence of substrate on the sensitivity of two-month-old juvenile mussels to ammonia in 28-day water-only exposure and substrate exposure. The methods used were similar to those in an earlier study (Wang et al. 2007a) except for how the organisms were exposed. In this study, the organisms were housed in a glass tube with a screen bottom that was suspended in a beaker. The authors conducted two exposure conditions simultaneously for comparison of the water-only and substrate exposure. The organisms used in the water-only exposure were simply placed on the screen at the bottom of the tube. The substrate treatment involved substrate that was screened, eliminating both large and small particles, with only particles between 300-500 microns retained, which is essentially the grain size of medium sand. A layer of substrate was placed on the screen and the organisms were placed on top of the relatively inert substrate. In the substrate treatment, the water actively flowed past the organisms and through the substrate. Water chemistry was characterized before and after passing through the substrate and found not to be substantially altered. Furthermore, the pH was maintained consistently at approximately pH 8.25 in overlying water and porewater.

The survival response between the water-only and substrate treatments was similar with a reported LOEC of 0.53 mg TAN/L in the water-only and 0.88 mg TAN/L for the substrate treatment at the test pH 8.25 and temperature 20°C. Mean control survival in both the water-only and substrate treatments was 95% at the end of the 28-day exposures, which met acceptability requirements. Dry weight measurements of the mussels increased by 165% in the water-only exposure compared to 590% increase in the substrate exposure suggesting that the presence of the substrate increased food availability, as noted by the authors.

Using TRAP threshold sigmoid regression of the survival response results in an EC_{20} of 0.5957 mg TAN/L for the water-only and EC_{20} 0.8988 mg TAN/L for the substrate exposure at the test pH and temperature, or adjusted to pH 7 and 20°C, chronic values equivalent to 2.128 and 3.211 mg TAN/L, respectively (Appendix B). Based on the apparent improved health of the test organisms in the substrate exposures, and the lack of any significant alteration of water chemistry in the exposure, the SMCV 3.211 mg TAN/L, based on survival of juvenile fatmucket from the substrate exposures is used to calculate the CCC rather than the water-only exposure.

The geometric mean of SMCVs for fatmucket and wavy-rayed lamp mussel of 3.211 and 1.408 mg TAN/L, respectively, results in a GMCV of 2.126 mg TAN/L for the genus *Lampsilis* (Table 4).

Villosa iris (rainbow mussel)

The effect of ammonia on survival and growth of this freshwater unionid mussel species was also reported in the study by Wang et al. (2007a). Juvenile (2-month-old) rainbow mussels were tested via a 28-day test under similar conditions as described above. Survival was ≥ 98 percent up to the 0.81 mg TAN/L exposure, but fell to 15 percent at 1.67 mg TAN/L and zero percent at 3.45 and 7.56 mg TAN/L. EPA's TRAP was used to generate a chronic value for this species based on survival resulting in EC_{20} of 1.063 mg TAN/L at test temperature (20°C) and pH (8.2) – (Appendix G), or 3.501 mg TAN/L adjusted to pH 7.0. Wang et al. (2007a) elected to exclude length estimates for concentrations above those where significant survival effects were measured (or in this case, 1.67 mg TAN/L). As a result, growth data are available for only three effect concentrations, even though there was 15% survival at the 1.67 mg TAN/L treatment level. Due to the uncertainties in the limited growth data for this test the growth data was not used in the calculation of the GMCV.

The SMCV and GMCV for this freshwater unionid mussel species is 3.501 mg TAN/L when adjusted to pH 7 and 20°C (Appendix B).

Lepomis species

Lepomis cyanellus (green sunfish)

Reinbold and Pescitelli (1982a) conducted a 31-day early life-stage (ELS) test that started with <24-hour-old embryos. No information was reported concerning the DO concentration, but it averaged 70 to 76 percent of saturation (5.7 to 6.2 mg/L) in a similar test in the same report with another fish species at about the same temperature. The weight data were not used in the calculation of an EC_{20} because of the greater weight of the fish in test chambers containing fewer fish, which indicated that weight was density-dependent. Although overflows resulted in loss of fish from some chambers, survival was 96 percent in one of the chambers affected by overflow, indicating that the survival data were either adjusted or not affected by the overflows. Survival by the end of the test was reduced at test concentrations of 6.3 mg TAN/L and above. TRAP analysis of the survival data resulted in an EC_{20} of 5.840 mg TAN/L at pH 8.16 and 25.4°C (U.S. EPA 1999). Adjusted to pH 7, the EC_{20} is 18.06 mg TAN/L (Appendix B).

McCormick et al. (1984) conducted a 44-day ELS test starting with <24-hour-old embryos. During this test, no effect was found on percent hatch, but survival and growth were both reduced at measured test concentrations of 14 mg TAN/L and above. TRAP analysis using biomass resulted in an EC_{20} of 5.61 mg TAN/L at pH 7.9 and 22.0°C for the test (U.S. EPA 1999). Adjusted to pH 7, the EC_{20} calculated using the data as previously reported in U.S. EPA (1999) is 11.85 mg TAN/L (Appendix B).

The pH-adjusted EC_{20}s of 18.06 mg TAN/L from Reinbold and Pescitelli (1982a) and 11.85 mg TAN/L from McCormick et al. (1984) agree well with one another. It is possible that the second value is lower because it was based on survival and growth, whereas the first value was based only on survival. The results of the tests were deemed acceptable for use in calculating a SMCV for the species, which is 14.63 mg TAN/L (Table 4) at pH 7.

Lepomis macrochirus (bluegill)

Similar to the studies summarized above for *L. cyanellus*, Smith et al. (1984) conducted a 30-day ELS test starting with <28-hour old embryos of *L. macrochirus*. No information was reported concerning the DO concentration, but the flow-rate was kept high during the test. In this study, the authors found no significant reduction in percent hatch up to a test concentration of 37 mg TAN/L, but hatched larvae were deformed at this concentration and died within six days. By the end of the test, both survival and growth were greatly reduced at measured test concentrations ranging from 3.75 to 18 mg TAN/L. TRAP analysis of biomass resulted in calculation of an EC_{20} of 1.85 mg TAN/L at pH 7.76 and 22.5°C (U.S. EPA 1999). The EC_{20} adjusted to pH 7 is 3.273 mg TAN/L (Appendix B).

The SMCV for the bluegill is 3.273 mg TAN/L, which, when calculated as a geometric mean with the SMCV of 14.63 mg TAN/L for green sunfish, results in a GMCV of 6.920 for the genus *Lepomis* (Table 4).

Musculium transversum

Anderson et al. (1978) conducted two 42-day tests of the effect of ammonia on survival of field-collected juvenile clams whose length averaged 2.2 mm. The results of the two tests were similar so the data were pooled for analysis. Survival in the control treatment and low ammonia concentrations (<5.1 mg TAN/L) ranged from 79 to 90%, but decreased to zero at 18 mg TAN/L. TRAP analysis of the survival data resulted in a calculated EC_{20} of 5.820 mg TAN/L at 23.5°C and pH 8.15. The EC_{20} is 22.21 mg TAN/L when adjusted to pH 7 and 20°C (Appendix B).

Sparks and Sandusky (1981) conducted a test similar to Anderson et al. (1978) with field-collected juvenile clams whose average length was 2.1 mm. The test was conducted in the same laboratory and used test organisms from the same location in the Mississippi River as Anderson et al. (1978), but employed a feeding regime and food for the test that was deemed by the authors to be better suited to maintaining the health of fingernail clams during chronic toxicity testing. Survival in the control treatment was 92% and decreased with increasing concentration of ammonia to 17% at 18 mg TAN/L. Effects on survival were evident at lower concentrations, resulting in an EC_{20} of only 1.23 mg TAN/L at 21.8°C and pH 7.80 when calculated using TRAP. The EC_{20} adjusted to pH 7 and 20°C is 2.565 mg TAN/L (Appendix B).

Although this latter EC_{20} determined for the test reported by Sparks and Sandusky (1981) is substantially lower than that obtained by Anderson et al. (1978), the difference is less than a factor of 10, and thus, the SMCV for this species (at pH 7 and 20°C) is the geometric mean of the two values, or 7.547 mg TAN/L (Table 4).

Table 4. Ranked Genus Mean Chronic Values.

Rank	GMCV (mg TAN/L)	Species	SMCV (mg TAN/L)
16	73.74	Stonefly, *Pteronarcella badia*	73.74
15	53.75	Water flea, *Ceriodaphnia acanthina*	64.10
		Water flea, *Ceriodaphnia dubia*	45.08
14	41.46	Water flea, *Daphnia magna*	41.46
13	29.17	Amphipod, *Hyalella azteca*	29.17
12	21.36	Channel catfish, *Ictalurus punctatus*	21.36
11	20.38	Northern pike, *Esox lucius*	20.38
10	16.53	Common carp, *Cyprinus carpio*	16.53
9	12.02	Lahontan cutthroat trout, *Oncorhynchus clarkii henshawi (LS)**	25.83
		Rainbow trout, *Oncorhynchus mykiss (LS)*	6.663
		Sockeye salmon, *Oncorhynchus nerka (LS)*	10.09
8	11.62	White sucker, *Catostomus commersonii*	11.62
7	11.07	Smallmouth bass, *Micropterus dolomieu*	11.07
6	9.187	Fathead minnow, *Pimephales promelas*	9.187
5	7.828	Pebblesnail, *Fluminicola* sp.	7.828
4	7.547	Long fingernailclam, *Musculium transversum*	7.547
3	6.920	Green sunfish, *Lepomis cyanellus*	14.63
		Bluegill, *Lepomis macrochirus*	3.273
2	3.501	Rainbow mussel, *Villosa iris*	3.501
1	2.126	Fatmucket, *Lampsilis siliquoidea*	3.211
		Wavy-rayed lamp mussel, *Lampsilis fasciola*	1.408
FCV = 1.887 mg TAN/L			
CCC = 1.9 mg TAN/L			

LS= Federally-listed species as threatened or endangered

*LS** = Listed at the subspecies only for specific populations

The National Criteria for Ammonia in Fresh Water

This ammonia criteria update document recommends an acute criterion magnitude of 17 mg TAN/L and a chronic criterion magnitude of 1.9 mg TAN/L at pH 7 and 20°C, with the stipulation that the chronic criterion cannot exceed 4.8 mg TAN/L as a 4-day average. All criteria magnitudes are recommended not to be exceeded more than once in three years on average.

2013 Final Aquatic Life Criteria for Ammonia (Magnitude, Frequency, and Duration) (mg TAN/L) pH 7.0, T=20°C	
Acute (1-hour average)	17
Chronic (30-day rolling average)	1.9*
*Not to exceed 2.5 times the CCC as a 4-day average within the 30-days, i.e. 4.8 mg TAN/L at pH 7 and 20°C, more than once in three years on average.	
Criteria frequency: Not to be exceeded more than once in three years on average.	

The available data for ammonia indicate that, except possibly where an unusually sensitive species is important at a site, freshwater aquatic life will be protected if these criteria are met. Tables 5a and 5b below provide the temperature and pH-dependent values of the CMC (acute criterion magnitude) and Table 6 provides the temperature and pH-dependent values of the CCC (chronic criterion magnitude) based on the following recommended criterion calculations derived for this update.

Acute criterion calculations

The one-hour average concentration of total ammonia nitrogen (in mg TAN/L) is not to exceed, more than once every three years on the average, the CMC (acute criterion magnitude) calculated using the following equation:

$$CMC = MIN\left(\left(\frac{0.275}{1+10^{7.204-pH}}+\frac{39.0}{1+10^{pH-7.204}}\right),\right.$$
$$\left.\left(0.7249\times\left(\frac{0.0114}{1+10^{7.204-pH}}+\frac{1.6181}{1+10^{pH-7.204}}\right)\times\left(23.12\times\ 10^{0.036\times(20-T)}\right)\right)\right)$$

The 2013 CMC equation is predicated on the following:

1. The lowest GMAV in this criterion update is for an invertebrate species; thus, the CMC is both pH- **and** temperature-dependent and varies with temperature according to the invertebrate acute temperature relationship. The lowest GMAV is 23.12 mg TAN/L for *Venustaconcha* (Table 3). The updated CMC (rounded to 4 significant figures) of 16.76 mg TAN/L at pH 7 and 20°C is 27.5 percent lower than this value. The CMC divided by the lowest GMAV is 0.7249.

2. Where salmonids in the Genus *Oncorhynchus* are present, EPA's recommended acute criterion magnitude is protective of the commercially and recreationally important adult rainbow trout, which becomes the most sensitive endpoint at lower temperatures (see footnotes pertaining to the 1999 FAV in Table 7 and Appendix A). Vertebrate sensitivity to ammonia is independent of temperature, while invertebrate sensitivity to ammonia decreases as temperature decreases. Therefore, across all temperatures the CMC equals the lower of: a) 0.7249 times the temperature adjusted lowest invertebrate GMAV (for Ellipse 23.12 mg TAN/L times 0.7249, or 16.76 mg TAN/L at pH 7.0 and 20ºC), or (b) the FAV protective of adult rainbow trout (48.21 mg TAN/L) divided by two, or 24.10 mg TAN/L at pH 7.0 and across all temperatures, according to the following temperature relationship:

$$CMC(at\ pH\ 7) = MIN\left(24.10, \left(0.7249\times 23.12\ \left(10^{0.036\times(20-T)}\right)\right)\right)$$

Thus, the CMC increases with decreasing temperature as a result of increased invertebrate insensitivity until it reaches a plateau of 24.10 mg TAN/L at 15.7°C and below, where the most sensitive taxa is the temperature invariant rainbow trout (Table 5a; see also *Oncorhynchus* present line in Figure 5a).

3. Where *Oncorhynchus* species are absent, EPA retains all tested species in the order Salmoniformes as tested surrogate species representing untested freshwater fish resident in the U.S. from another order, but does not lower the criterion to protect them as commercially and recreationally important species. The lowest GMAV for a freshwater fish is 51.93 mg TAN/L for mountain whitefish *(Prosopium williamsoni)* (Table 3). Therefore, in this case, the CMC equals the lower of: a) 0.7249 times the temperature adjusted lowest invertebrate GMAV (for Ellipse 23.12 mg TAN/L times 0.7249, or 16.76 mg TAN/L at pH 7.0 and 20ºC), or (b) 0.7249 times the lowest freshwater fish GMAV (51.93 mg TAN/L at pH 7.0 and all temperatures), according to the following temperature relationship:

$$CMC(at\ pH\ 7) = 0.7249 \times MIN\left(51.93, 23.12 \times 10^{0.036\times(20-T)}\right)$$

Thus, the CMC increases with decreasing temperature as a result of increased invertebrate insensitivity until it reaches a plateau of 37.65 mg TAN/L at 10.2°C and below (51.93 mg TAN/L x 0.7249), where the most sensitive taxa switches to the temperature invariant fish genus *Prosopium* (Table 5b; see also *Oncorhynchus* absent line in Figure 5a). Note: while the mountain whitefish (*Prosopium williamsoni*) is a species in the same family as *Oncorhynchus* sp. (i.e., Family: Salmonidae), it is also an appropriately sensitive surrogate species amongst all freshwater fish in the Class Actinopterygii.

The CMC, where *Oncorhynchus* species are absent, extrapolated across both temperature and pH is as follows:

$$CMC = 0.7249 \times \left(\frac{0.0114}{1+10^{7.204-pH}} + \frac{1.6181}{1+10^{pH-7.204}}\right) \times MIN\left(51.93, 23.12 \times 10^{0.036\times(20-T)}\right)$$

4. When a threatened or endangered species occurs at a site and sufficient data indicate that it is sensitive at 1-hour average concentrations below the CMC, it is appropriate to consider deriving a site-specific criterion magnitude. It should be noted that the dataset used to derive the 2013

ammonia criteria magnitudes included some threatened or endangered species, none of which were the most sensitive of the species tested.

In summary, at pH 7 and 20°C the CMC is 17 mg TAN/L, as primarily determined by the sensitivity of invertebrates. As temperature decreases to 15.7°C and below, invertebrates no longer are the most sensitive taxa, and thus in this range the CMC is 24 mg TAN/L. Where recreationally and/or commercially important *Oncorhynchus* species are not present, the CMC is determined according to statement three above. Below 15.7°C, if *Oncorhynchus* species are not present the criterion continues to increase with decreasing temperature to 10.2°C and below, where the CMC is 38 mg TAN/L.

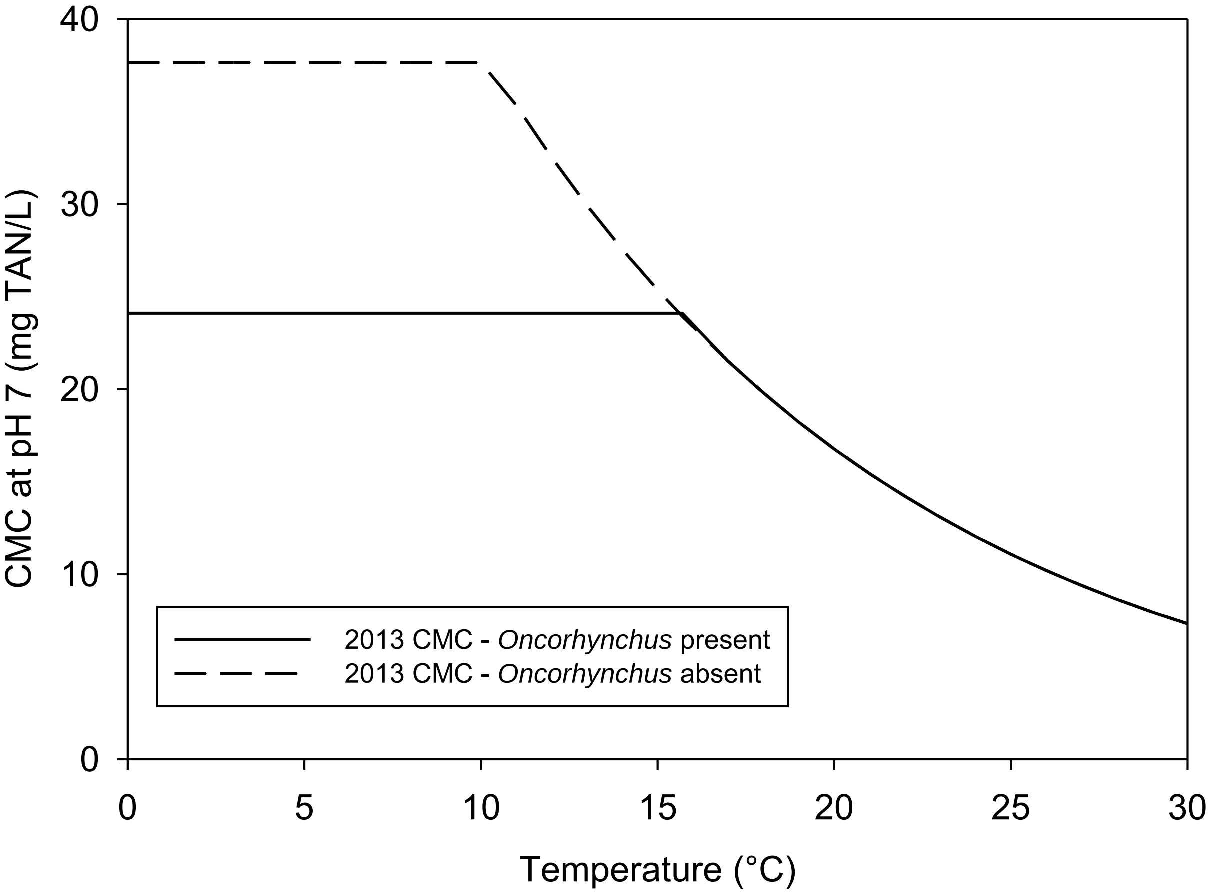


Figure 5a. 2013 Acute Criterion Magnitudes Extrapolated Across a Temperature Gradient at pH 7.

Table 5a. Temperature and pH-Dependent Values of the CMC (Acute Criterion Magnitude) – *Oncorhynchus spp.* Present.

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	**<u>17</u>**	15	14	13	12	11	10	9.4	8.6	8.0	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	3.0
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.5	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	2.6	2.6	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.59	0.54
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.2	1.2	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.0	1.0	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	0.88	0.88	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

Table 5b. Temperature and pH-Dependent Values of the CMC (Acute Criterion Magnitude) – *Oncorhynchus spp.* Absent.

	Temperature (°C)																				
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	**17**	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	3.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7.0	6.4	5.9	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	6.0	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2.0	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

Chronic criterion calculations

The thirty-day rolling average concentration of total ammonia nitrogen (in mg TAN/L) is not to exceed, more than once every three years on the average, the chronic criterion magnitude (CCC) calculated using the following equation:

$$CCC = 0.8876 \times \left(\frac{0.0278}{1 + 10^{7.688-pH}} + \frac{1.1994}{1 + 10^{pH-7.688}}\right) \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

In addition, the highest four-day average within the 30-day averaging period should not be more than 2.5 times the CCC (e.g., 2.5 x 1.9 mg TAN/L at pH 7 and 20°C or 4.8 mg TAN/L) more than once in three years on average.

The 2013 CCC equation is predicated on the following:

1. The lowest GMCV in this criteria update is for an invertebrate species; thus, the CCC is both pH- **and** temperature-dependent (based on the invertebrate chronic temperature relationship). The lowest GMCV is 2.126 mg TAN/L for *Villosa iris* (Table 4). The updated CCC (rounded to 4 significant figures) of 1.887 mg TAN/L at pH 7and 20°C is 11.2 percent lower than the lowest GMCV. The CCC to lowest GMCV ratio is 0.8876.

2. The most sensitive freshwater fish to chronic ammonia exposure are early life stages of *Lepomis* with a GMCV of 6.920 mg TAN/L (Table 4). At a pH of 7 and temperature of 7°C and below, the CCC plateaus (see Figure 5b) at 4.363 mg TAN/L, which is lower than the GMCV for *Lepomis*, the most sensitive fish, multiplied by the CCC to lowest GMCV ratio (or 6.920 mg TAN/L x 0.8876 = 6.142 mg TAN/L); thus, at pH 7, the CCC is expressed as:

$$CCC = 0.8876 \times \left(2.126 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

This function increases steadily with decreasing temperature (T), until it reaches a maximum at 7°C, below which it remains constant (see Table 6; also shown graphically in Figure 5b). The rationale for the 7°C plateau in extrapolated invertebrate sensitivities is described in detail in

Appendix M. The assumption of invertebrate insensitivity to temperatures of 7°C and below is based on an interpretation of the empirical relationship between acute ammonia toxicity of invertebrates and temperature, first described by Arthur et al. (1987), and in Appendix M).

3. All new chronic fish data added to this update of the freshwater AWQC for ammonia are from early life-stage tests of the species (see new data for *Oncorhynchus clarkii henshawi*, *Oncorhynchus mykiss*, *Esox lucius*, and *Cyprinus carpio* in Appendix B), and since the new chronic criterion magnitude lies far below all chronic values for these fishes (as well as for *Lepomis* spp.), the early life stage of fish no longer warrants special consideration.

4. Where a threatened or endangered species occurs at a site and sufficient data indicate that it is sensitive at concentrations below the CCC, it is appropriate to consider deriving a site-specific criterion magnitude.

In summary, at pH 7 and 20°C the CCC of 1.9 mg TAN/L is determined by the sensitivity of invertebrates. As temperature decreases, invertebrate sensitivity to ammonia decreases until the CCC reaches a maximum of 4.4 mg TAN/L at pH 7 and temperature of 7°C and below.

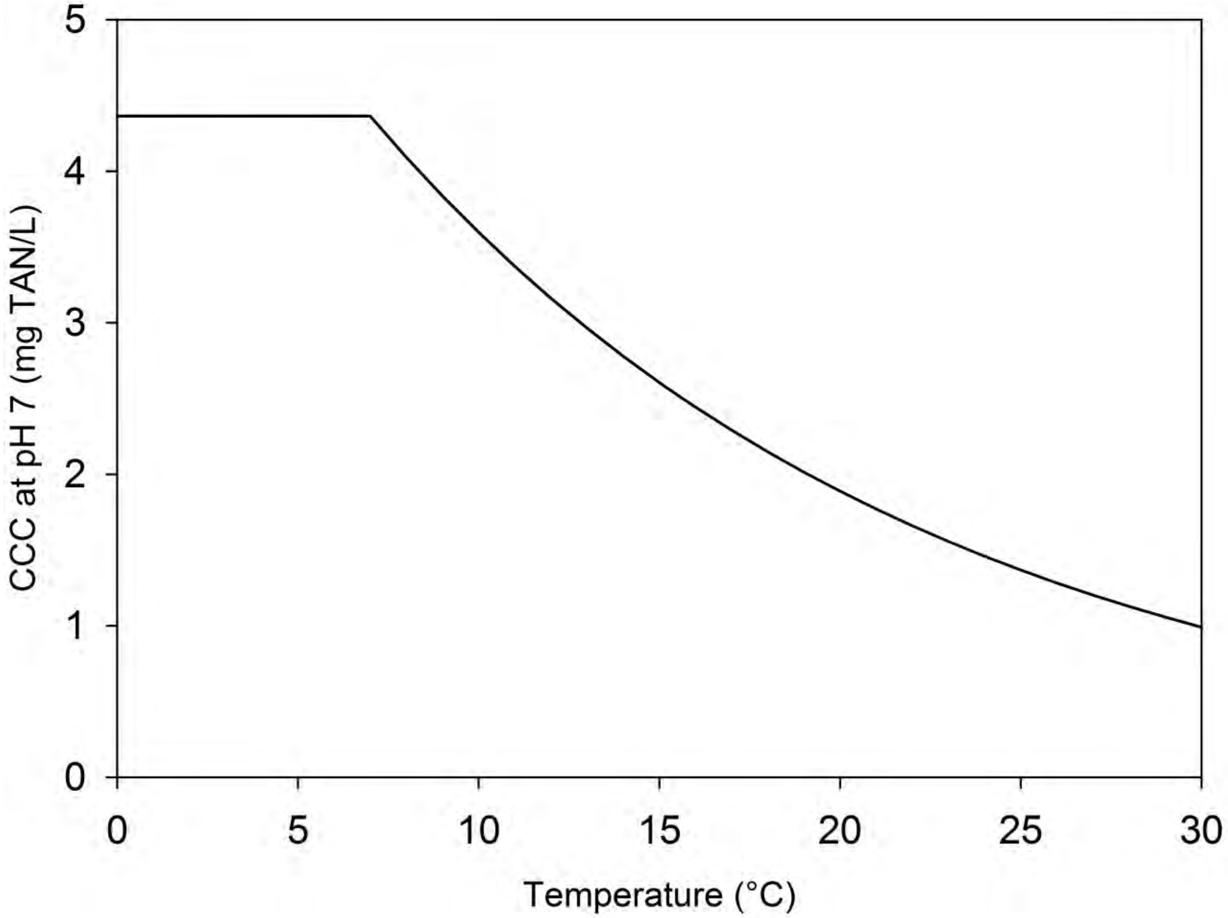


Figure 5b. 2013 Chronic Criterion Magnitudes Extrapolated Across a Temperature Gradient at pH 7.

Table 6. Temperature and pH-Dependent Values of the CCC (Chronic Criterion Magnitude).

	Temperature (°C)																							
pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.5	1.4	1.3	1.2	1.1
6.6	4.8	4.5	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.2	2.0	**1.9**	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99
7.1	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95
7.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.96	0.90
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.85
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.96	0.90	0.85	0.79
7.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.83	0.78	0.73
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.1	0.98	0.92	0.86	0.81	0.76	0.71	0.67
7.7	2.6	2.4	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60
7.8	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60	0.56	0.53	0.50	0.44	0.44	0.41
8.1	1.5	1.5	1.4	1.3	1.2	1.1	1.1	0.99	0.92	0.87	0.81	0.76	0.71	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35
8.2	1.3	1.2	1.2	1.1	1.0	0.96	0.90	0.84	0.79	0.74	0.70	0.65	0.61	0.57	0.54	0.50	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30
8.3	1.1	1.1	0.99	0.93	0.87	0.82	0.76	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26
8.4	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47	0.44	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22
8.5	0.80	0.75	0.71	0.67	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.24	0.22	0.21	0.20	0.18
8.6	0.68	0.64	0.60	0.56	0.53	0.49	0.46	0.43	0.41	0.38	0.36	0.33	0.31	0.29	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.16	0.15
8.7	0.57	0.54	0.51	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13
8.8	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.13	0.13	0.12	0.11
8.9	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.10	0.09
9.0	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.08

Additional explanation and justification supporting the 2013 temperature and pH-dependent calculations and criteria magnitudes

Part of a criterion magnitude derivation is the estimation of the CMC or CCC based on the set of toxicity values available for different genera. The CMC or CCC estimate is intended to be equivalent to what would be obtained by simple inspection if many genera had been tested. Generally, the CMC or CCC is below the lowest value. For small datasets (<19) it is assumed that the fifth percentile is lower than the lowest toxicity value. Because the CMC is one half of the fifth percentile (i.e., FAV/2), it is frequently lower than the lowest GMAV even in large datasets. Because the extrapolation procedure used to calculate the FAV or FCV/CCC is based on the slope of the four most sensitive genera, when there are data for less than 59 genera, if the genera vary widely in sensitivity, the extrapolated criterion value is further below the lowest value than if the criteria were tightly grouped. This is statistically appropriate because when variance is high (i.e., values are widely spaced), the fifth percentile of the distribution would be expected to lie further below the lowest value of a small dataset than if the variance was low.

This extrapolation procedure, while appropriate for criteria derivations across chemicals with different variances for genus sensitivities, is not necessarily appropriate when the genera are following different temperature or life stage dependencies. Sensitivities can change with temperature or life stage, and as a result, the spread of the four lowest GMAVs or GMCVs, and the resulting degree of extrapolation to the fifth percentile of sensitivity, can also change. Rather than develop separate sets of GMAVs and GMCVs for each temperature and re-computing iteratively the CMC or CCC from the four most sensitive GMAVs or GMCVs at each temperature-pH combination, the extrapolation approach described below was used.

This issue of extrapolation to different temperatures and pH values with regard to chronic toxicity was addressed in the 1999 AWQC document for ammonia by first calculating the ratio of the CCC to the lowest GMCV, and then applying that ratio to subsequent criteria calculations for all possible pH and temperature combinations. The rationale of this approach was that it offered a degree of extrapolation that was modest and reasonable given the relatively low number of tested genera, and that it was a preferable approach to the alternative procedure of calculating CCCs directly from new sets of GMCVs for each pH-temperature combination, as each combination could result in different degrees of extrapolation, some of which could be more than 50 percent below the lowest GMCV.

In the 1999 AWQC document, the temperature extrapolations for the CCC determination described above were conducted separately for adult fish, fish early life stages, and invertebrates. This was because fish GMCVs are not affected by temperature, and because the most sensitive fish species was an early life stage of *Lepomis*. As a consequence, even though the lowest GMCV at 20°C was for an invertebrate, as temperature decreases, invertebrates, but not fish, become less sensitive to ammonia, and below 14.6°C, fish genera become the most sensitive. However, the above scenario is not applicable now because at the new recommended CCC (1.9 mg TAN/L), invertebrate genera are the most sensitive across the entire temperature range.

In the 1999 AWQC document, the most sensitive GMAVs were for fish, and because the sensitivities of fish to ammonia did not vary with temperature, no temperature extrapolation was performed. In contrast, the lowest GMAVs in this document are for invertebrates, and as a consequence, the temperature extrapolation procedure is similarly applied to the CMC as well as the CCC.

For the reassessment of the pH-TAN acute toxicity relationship, EPA has determined that the current pH-TAN acute toxicity relationship equation effectively represents the pH-TAN toxicity relationship for *L. siliquoidea* (as determined by Wang et al. 2008), as well as for other invertebrates, *Potamopyrgus antipodarum (snail)*, *Macrobrachium rosenbergii (freshwater shrimp)*, and *H. azteca (amphipod),* as tested by Hickey and Vickers (1994), Straus et al. (1991), and Borgmann and Borgmann (1997), respectively. Also, for the reassessment of the temperature-TAN acute toxicity relationship, EPA similarly determined that the current temperature-TAN acute toxicity relationship equation effectively represents the temperature-TAN toxicity relationship for other invertebrates, *P. antipodarum (snail)*, *Branchiura sowerbyi (oligochaete)*, and *Viviparus bengalensis (snail)* as tested by Hickey and Vickers (1994) and Sarkar (1997), respectively.

Protection of downstream waters

EPA regulations at 40 CFR 131.10(b) provide that “[i]n designating uses of a water body and the appropriate criteria for those uses, the state shall take into consideration the water quality standards of downstream waters and ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters.” In cases where downstream waters are characterized by higher pH and/or temperature, or harbor more sensitive species, ammonia criteria more stringent than those required to protect in-stream uses may be necessary in order to ensure that water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters.

Considerations for site-specific criteria derivation

At water temperatures above 15.7°C, the 2013 acute criteria magnitude is based on effects to freshwater unionid mussels. However, when the temperature is below 15.7°C, and salmonids are present (even when mussels or other sensitive mollusk species are present), salmonid sensitivity determines the acute criterion (regardless of pH), similar to the 1999 acute criterion, which was based on effects on salmonids (i.e., adult rainbow trout). Where unionid mussels and other sensitive related mollusk species are absent, the commercially and recreationally important adult rainbow trout is the most sensitive species. Site-specific criteria derivation must take into account the temperature at the site. As an example, the acute criterion magnitude at pH 7 and temperature 20°C cannot exceed 24 mg TAN/L (the rainbow trout SMAV of 48.21 mg TAN/L, divided by two, used in this 2013 update as being representative of the most sensitive fish in general).

The 1999 chronic criterion (CCC) magnitude was based on the effects on fish early life stages, whereas based on the new data, the 2013 CCC magnitude is based on the effects on sensitive invertebrate genera, including unionid mussels. When mussels are present, the 2013 CCC magnitude is protective of fish early life stages regardless of temperature. See Appendix N for additional information on site-specific criteria for ammonia.

EFFECTS CHARACTERIZATION

The purpose of this section is to characterize the potential effects of ammonia on aquatic life considering available test data and to describe additional lines of evidence not used directly in the criteria calculations, but which support the 2013 aquatic life criteria values. This section will also provide a summary of the uncertainties and assumptions, as well as provide explanations for decisions regarding data acceptability and usage in the effects assessment. In addition, this section will describe substantive differences between the 1999 ammonia AWQC and the 2013 update resulting from the incorporation of the latest scientific knowledge.

All acceptable acute and chronic values for freshwater aquatic animal species, including those from the 1999 AWQC document (re-normalized to pH 7 and 20°C in the case of invertebrates), are presented in Appendices A (acute) and B (chronic). These tables include new acute and chronic ammonia toxicity data for freshwater mussels in the Family Unionidae and reflect the latest science informing the determinations regarding acceptable test conditions and associated data for glochidia and juvenile mussels.

Freshwater Acute Toxicity Data

Acute toxicity data for freshwater mussels and non-pulmonate (gill-bearing) snails

Prior to publishing the 2009 draft ammonia AWQC, concerns had been raised about the appropriateness of using data obtained from tests conducted with the parasitic glochidia life-stage of freshwater unionid mussels. Glochidia of different species have different life history strategies for finding an appropriate fish host; glochidia may be free living in the water column (and potentially exposed to pollutants) for a duration ranging from seconds to days, depending on the particular species. EPA concluded it was useful to consider potential adverse effects on glochidia, because effects of chemicals on this early life stage of mussels could potentially have broad impacts on mussel populations. In order for the toxicity test results with glochidia to be ecologically relevant, the duration of the acute toxicity test must be comparable to the duration of the free-living stage of the glochidia prior to attaching to a host. Supported by research conducted by Bringolf et al. (2013) demonstrating the appropriate duration of exposure for this life stage, acceptable acute toxicity data for glochidia with an exposure duration of 24 hours or less have been included in this 2013 AWQC Update, with the stipulation that control survival for the time period used is at least 90%.

In addition to the four sensitive bivalve mollusk species in Table 7, there are three other unionid mussel species among the seven genera found to be most acutely sensitive to ammonia as well as two non-pulmonate snail species are ranked tenth and twelfth in sensitivity. These GMAVs represent mollusk toxicity data that were not in the 1999 acute criteria dataset.

New test data for the ellipse (*Venustaconcha ellipsiformis)*, the most sensitive species tested, was not directly used in the acute criterion calculation because the methodology used calculated the acute value using the second through fifth most sensitive species to approximate effects for a 5th percentile of species as noted in the effects assessment. The GMAV for ellipse

(23.12 mg TAN/L at pH 7 and 20°C) is greater than the acute criterion of 17 mg TAN/L and thus provides additional evidence supporting the protectiveness of the calculated acute criterion (Table 3).

Available data on non-pulmonate snails show that they are another taxon within the Phylum Mollusca sensitive to ammonia in freshwater ecosystems. The calculated GMAV of 62.15 mg TAN/L for *Fluminicola* sp. (pebblesnail) is the tenth most sensitive in the acute dataset (Table 3). Another non-pulmonate snail species *Pleurocera uncialis* (pagoda hornsnail) was ranked 12th in acute sensitivity. The LC_{50} for *P. uncialis* (reported in Goudreau et al. 1993), normalized to pH 7 and 20°C, is 68.54 mg TAN/L (Appendix A). To date, few studies have been attempted with this group of species; additional testing would improve understanding of their relative sensitivity to ammonia compared to other aquatic animals.

The draft 2009 acute criterion magnitude recommended for waters with mussels present was slightly higher than the 2013 acute criteria (19 vs. 17 mg TAN/L at pH 7, T 20°C) due to a number of differences in the data used in the CMC derivations. In response to comments received on the 2009 draft criteria, EPA removed the six invasive species from the acute dataset for ammonia; one of the invasive species removed from the dataset was Asiatic clam, which had been ranked as the fourth most sensitive GMAVs in the 2009 draft AWQC. Because the acute dataset for ammonia is extensive and contains toxicity data for other bivalves that are native North American species, the Asiatic clam was not needed as a bivalve surrogate. Also in the 2013 CMC, the most sensitive GMAV used to derive the CMC is for *Lasmigona subviridis* (green floater mussel) (GMAV=23.41 mg TAN/L) which is lower than the lowest GMAV (32.73 mg TAN/L) in the draft 2009 CMC used in the derivation of the CMC. Based on new scientific information regarding determination of test acceptability, EPA included acceptable data for glochidia (mussel larvae) and *Hyalella azteca*, which added five GMAVs for derivation of the CMC. Since the number of GMAVs is a factor in the equation used to derive the CMC, a change to the number of GMAVs results in a change in the resulting FAV and CMC.

Table 7. Comparison of the Four Taxa Used to Calculate the FAV and CMC in the 1999, 2009 Draft and 2013 AWQC.

1999 Update CMC Magnitude			**2009 Draft Update CMC Magnitude**			**2013 Final CMC Magnitude**	
Species	**pH 8.0, T=25°C (mg TAN/L)**	**pH 7.0, T=20°C (mg TAN /L)**	**Species**	**pH 8.0, T=25°C (mg TAN/L)**	**pH 7.0, T=20°C (mg TAN/L)**	**Species**	**pH 7.0, T=20°C (mg TAN/L)**
Oncorhynchus sp. (salmonids), includes: *O. aquabonita*, *O. clarkii*, *O. gorbuscha*, *O. kisutch*, *O. mykiss*, and *O. tshawytscha*	21.95	99.15	Oyster mussel, *Epioblasma capsaeformis*	6.037	39.24	*Lampsilis* sp. (Unionidae), includes: *L. abrupta*, *L. cardium*, *L. fasciola*, *L. higginsii*, *L. rafinesqueana*, and *L. siliquoidea*	46.63
Orangethroat darter, *Etheostoma spectabile*	17.96	74.25	Asiatic clam, *Corbicula fluminea*	6.018	39.12	Rainbow mussel, *Villosa iris*	34.23
Golden shiner, *Notemigonus crysoleucas*	14.67	63.02	*Lampsilis* sp. (Unionidae), includes: *L. abrupta*, *L. cardium*, *L. fasciola*, *L. higginsii*, *L. rafinesqueana*, and *L. siliquoidea*	5.919	38.48	Oyster mussel, *Epioblasma capsaeformis*	31.14
Mountain whitefish, *Prosopium williamsoni*	12.11	51.93	Rainbow mussel, *Villosa iris*	5.036	32.73	Green floater, *Lasmigona subviridis*	23.41
FAV[1]	11.23	**48.21**	**FAV**	5.734	**37.27**	**FAV**	**33.52**
CMC	5.6	**24**	**CMC**	2.9	**19**	**CMC**	**17**

---

[1] The FAV in the 1999 AWQC document of 11.23 mg TAN/L at pH 8 was lowered to the geometric mean of these seven LC50 values at the time in order to protect large rainbow trout which were shown in Thurston and Russo (1983) to be measurably more sensitive than other life stages. The FAV prior to adjusting it to protect the commercially and recreationally important adult rainbow trout was calculated to be 14.32 mg TAN/L (CMC = 7.2 mg TAN/L) at pH 8. This FAV based on protection of adult rainbow trout at pH 7 is 48.21 mg TAN/L (see also Appendix A in this document).

Freshwater Chronic Toxicity Data

Use of 28-day juvenile unionid mussel data

EPA decided that growth data from 28-day tests with juvenile unionid mussels presented in the Wang et al. studies from 2007 and 2011 would not be used in calculating the 2013 chronic criterion. The decision not to use the growth data was based on the uncertainty in the test methods for assessing the growth endpoint and the need, as stated by the authors, for additional research "to optimize feeding conditions, to conduct longer-term exposures (e.g., 90 d), and to compare growth effect to potential reproductive effect in partial life-cycle exposure" (Wang et al. 2011). The growth endpoint showed a high degree of variability, and the test methods for assessing growth, based on substrate or water-only exposures, are currently being evaluated. For these reasons, the survival data for 28-day juvenile mussels were used in the calculation of the CCC and not the growth data. Appendix G provides the TRAP EC_{20}s for survival for rainbow mussel and both *Lampsilis* species, and a comparison to the growth of fatmucket mussel from 28-day tests reported by Wang et al. (2007a, 2011), which shows the additional uncertainty in the concentration-response relationship based on growth.

28-day toxicity data for freshwater snails

As noted in the 2009 draft ammonia criteria document, non-pulmonate snails have been demonstrated to be sensitive to ammonia in freshwater ecosystems, in addition to other taxa within the Phylum Mollusca. Besser et al. (2010) data from a repeat test with pebblesnail (referred to in this document as Besser 2011) support the conclusion that non-pulmonate snails may be slightly less sensitive to ammonia than freshwater mussels. Additional toxicity tests are recommended for non-pulmonate snails and other freshwater mollusks to further substantiate the findings from the 28-day tests summarized in Appendices H and I. The calculated EC_{20} values using TRAP for *P. idahoensis*, *F. aldrichi*, and *T. serptenticola*, and the recommended 28-day ammonia survival effects concentration of <7.667 mg TAN/L for *P. canaliculata*, are considered representative of non-pulmonate snail sensitivity in general and are included in Appendix C for the purpose of comparison.

Based on the 28-day toxicity test results for the gill-bearing, non-pulmonate snail species (Appendices B and C), EPA concludes that the overall sensitivity of this particular group of snail species (Sub-class Prosobranchia, Order Neotaenioglossa) appears high. Furthermore, the sensitivity of juvenile and adult mixed-age non-pulmonate snails to ammonia may be greater than that of their air-breathing, pulmonate counterparts such as *L. stagnalis*.

Although the GMCV for *Fluminicola* species is not ranked as one of the four most sensitive used to calculate the FCV, the value is ranked the 5th most sensitive in the chronic criterion dataset. The 28-day growth EC_{20} for this freshwater non-pulmonate snail species, calculated using EPA's TRAP, is 2.281 mg TAN/L at test pH (8.22) and temperature (20.1°C), or 7.828 mg TAN/L after adjustment to pH 7 and 20°C (see Appendix B). Appendix H includes a summary of the 28-day toxicity test results for *Fluminicola* species which are acceptable for use quantitatively in the chronic dataset. The TRAP output for this test is provided in Appendix H.

28-day toxicity data for *Hyalella azteca*: Minimum Data Requirement Number 5

Literature data indicate that the response of *Hyalella azteca* is influenced not only by pH, but also by sodium concentration in the dilution water. Borgmann and Borgmann (1997) demonstrated that increasing sodium decreased the toxicity of ammonia to *Hyalella*, and applied these findings to explain differences in toxicity observed by Ankley et al. (1995), which were originally attributed to water hardness. Further unpublished experiments by EPA's Office of Research and Development confirm Borgmann's assertion that sodium concentration plays a key role in determining the acute response of *Hyalella* to ammonia (personal communication, D.R. Mount, EPA, ORD). Because sodium is not known to affect ammonia toxicity to other species, this criterion does not consider sodium concentration, and this variation is not explicitly addressed. For purposes of deriving a GMAV for *Hyalella*, tests were selected that had a moderate sodium concentration (e.g., "moderately hard" water tests from Ankley et al. 1995, see Appendix A), and tests with extremely low sodium concentrations were excluded (e.g., "soft" water tests from Ankley et al. 1995; data from Whiteman et al. 1996, see Appendix J). The available acute data for ammonia did not include tests conducted in natural waters with a sodium concentration below about 3 mg/L; at that sodium concentration, the acute values for *Hyalella* were near the FAV reported in this document. Whether acute toxicity of ammonia to *Hyalella* would occur below the FAV in waters with less than 3 mg/L sodium is unknown (Appendix H).

For the 2013 chronic criterion, EPA re-evaluated the available data for *Hyalella azteca* based on recent research regarding the appropriate test conditions, including water chemistry (e.g., appropriate concentrations for specific ions such as chloride) and feeding regimes. The concentrations of sodium are important to *H. azteca* health as discussed previously and the sodium concentrations in the chronic test used in the CCC represent approximately the mid-range of U.S. waters. Based on this re-evaluation, EPA determined that certain tests met the new recommended conditions that would support healthy test organisms, and accepted those data for use in the calculation of the CCC. The specific tests used were from Borgmann (1994); details on these tests are included in Appendix H under Chronic Toxicity Tests with Juvenile *Hyalella azteca*. As a result of inclusion of acceptable *H. azteca* data, the minimum data requirement (MDR) for a benthic crustacean is fulfilled for the chronic criterion provided in this document. The GMCV of 29.17 mg TAN/L ranks *Hyalella azteca* as the thirteenth (of 16) most sensitive GMCV.

Reconsideration of the chronic toxicity data available for aquatic insects: Minimum Data Requirement Number 6

EPA chose not to include a chronic value for the stonefly, *Pteronarcella badia*, from Thurston et al. (1984a) in the 1999 AWQC update document because this aquatic insect species is relatively insensitive. Upon further consideration, EC_{20}s for 30-day nymph mortality were calculated for field collected *Pteronarcella badia* for two separate partial life cycle tests in consecutive years, in order to develop a GMCV for insects to fulfill the sixth minimum data requirement (MDR), and to clearly specify the expected lack of sensitivity of insects to ammonia based on available data. EC_{20}s were calculated for each test, and, as the authors themselves noted, the results were variable between the two tests. The normalized EC_{20} for the test conducted with *P. badia* collected from the Gallatin R. was 207.0 mg TAN/L, and was 26.27 mg TAN/L for the test conducted with *P. badia* collected from the Rocky River (Appendix B). The geometric mean for these two tests is 73.74 mg TAN/L. It is not known if these tests were conducted using the most sensitive life stage; however, the authors did note that the length of individuals used in both tests was similar. EPA used the two EC_{20}s based on 30-day nymph mortality to calculate a GMCV of 73.74 mg TAN/L for this species. The stonefly is listed as sixteenth GMCV in chronic sensitivity, fulfilling the sixth MDR. Additional data on insect sensitivity to ammonia would be useful in confirming the conclusion that insects are relatively insensitive to ammonia in freshwater environments, given the limited data available.

New chronic toxicity data for salmonid species and derivation of a GMCV for *Oncorhynchus:* Minimum Data Requirement Number 1

Chronic values from two additional studies with *Oncorhynchus* species (salmonids) are included in this AWQC document that were not included in the 1999 document (see Appendix H for more detailed descriptions of the results from these studies). Koch et al. (1980) exposed Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*), an endangered species, for 103 days in an ELS test. There were no successful hatches at exposure levels of 148 mg TAN/L or higher and no significant mortality at exposure levels below 32.9 mg TAN/L. Regression analysis of the survival data resulted in a calculated EC_{20} value of 17.89 mg TAN/L at 13.7°C and pH 7.57. The EC_{20} value is 25.83 mg TAN/L when adjusted to pH 7 (Appendix B).

The results of a more recent 90-day ELS test using a wild strain of rainbow trout exposed to ammonia were reported by Brinkman et al. (2009), and are included in this criteria document. The test was initiated with newly fertilized embryos exposed under flow-through conditions through hatch, swim-up, and early fry development. Survival, growth and biomass of swim-up fry were significantly reduced at 16.8 mg TAN/L compared to controls, but unaffected at 7.44 mg TAN/L. The EC_{20} calculated for biomass using TRAP and normalized to pH 7 is 15.60 mg TAN/L (Appendix B).

In the 1999 AWQC document, the results of six chronic tests conducted with ammonia for *Oncorhynchus mykiss* and *Oncorhynchus nerka* were included in Table 5 of that document as "acceptable" chronic tests for criteria development. A GMCV was not derived for *Oncorhynchus* at that time, however, because of the degree of variability among test results, as well as a preponderance of "greater than" or "less than" values, preventing the calculation of definitive SMCVs within the genus. The results of these chronic tests were only used at that time to assess the appropriateness of the CCC.

For this 2013 document, these six studies and the data from the two additional studies summarized above, have been re-evaluated and re-considered for inclusion in deriving a new chronic criterion for ammonia in order to consider and include all available, reliable toxicity test information for this recreationally, commercially and ecologically important taxon. The data were re-examined with specific consideration of whether unbounded (greater or less than) values add relevant information to determination of final SMCVs for *Oncorhynchus clarkii, O. mykiss, and O. nerka*. A decision rule was developed for evaluating chronic values (EC_{20}s) for potential use in deriving an SMCV for a salmon species. In developing the decision rule, it was noted that "greater than" values for concentrations of low magnitude, and "less than" values for concentrations of high magnitude do not add significant information to the analysis. That is, if a researcher only tested very low concentrations and found no chronic effects or very high concentrations and found 100% response for a chronic endpoint, those data do not significantly enhance understanding of the toxicity of ammonia. Conversely, if a researcher only tested very low concentrations and found significant chronic effects, indicating the test material was highly toxic, or relatively high concentrations and found incomplete response for a chronic endpoint, indicating low toxicity of the materials, those data do significantly enhance understanding of the toxicity of ammonia. Thus, the decision rule was applied as follows: "greater than" (>) low CVs and “less than” (<) high CVs were not used in the calculation of the SMCV; but “less than” (<) low CVs and a “greater than” (>) high CVs were included in the SMCV.

Following this decision rule, the SMCV for *O. clarkii* is the normalized EC_{20} of 25.83 mg TAN/L from Koch et al. (1980). The SMCV for *O. mykiss* is 6.663 mg TAN/L at pH 7, which is the geometric mean of the <3.246 mg TAN/L value from Calamari et al. (1977, 1981), the <3.515 mg TAN/L value from Solbe and Shurben (1989), the >11.08 mg TAN/L value from Thurston et al. (1984b), and the 15.60 mg TAN/L value from Brinkman et al. (2009). With respect to the SMCV for *O. mykiss*, both the Calamari et al. (1977, 1981) and the Solbe and Shurben (1989) values are low “less than” values, indicating demonstrated toxicity at low concentrations of ammonia, while the Thurston et al. (1984b) value is a relatively high “greater than” value, indicating lower toxicity to *O. mykiss* in this test, compared to the Calamari (1977, 1981) and Solbe and Shurben (1989) values with respect to the SMCV for *O. mykiss.* Finally, the SMCV for *O. nerka* is <10.09 mg TAN/L (Rankin 1979), and has been included as a relatively low “less than” value, indicating relative sensitivity to the effects of ammonia in this test. The <48 mg TAN/L value (at pH 7) from Thurston et al. (1978) re-calculated for *O. clarkii* (see Appendix C; value represents the geometric mean of four values) and the <45.50 mg TAN/L value from Burkhalter and Kaya (1977) for *O. mykiss* (retained in Appendix B) are not included in the SMCV calculations because they are high “less than” values, and do not add important information to the analyses. The new GMCV for *Oncorhynchus* in this 2013 Update document is 12.02 mg TAN/L, which is the geometric mean of the three SMCVs for *Oncorhynchus clarkii* (25.83 mg TAN/L)*, O. mykiss* (6.663 mg TAN/L)*, and O. nerka* (<10.09 mg TAN/L) (Appendix B), resulting in *Oncorhynchus* as being seventh most sensitive GMCV (Table 4).

Another order of insect or a phylum not already represented: Minimum Data Requirement Number 8

For the MDR identified earlier as “#8,” “another order of insect or a phylum not already represented,” there are no additional chronic toxicity data for any freshwater animal that would fulfill this MDR in the chronic dataset (the acute dataset fulfills all eight MDRs). Therefore, EPA developed a surrogate ammonia CV for the Phylum Annelida by using the geometric mean acute value from the four available genera (*Dendrocoelus, Limnodrilus, Lumbriculus, and Tubifex*) and applying an ACR from other invertebrate groups. There is less than a factor of two difference between the GMAVs for the most (*Dendrocoelus*, 119.5 mg TAN/L) and least (*Lumbriculus,* 218.7 mg TAN/L) sensitive genus (see Table 3). A surrogate chronic value was derived by dividing the GMAV for all four annelids (176.2 mg TAN/L) by a geometric mean species level invertebrate acute to chronic ratio (6.320), represented by pelagic crustaceans (cladocerans), a benthic crustacean (amphipod) and prosobranch snail (see Appendix F Acute-Chronic Ratios). The resulting surrogate CV for Phylum Annelida is 27.88 mg TAN/L (at pH 7 and 20°C).

Protection of Endangered Species

The dataset for ammonia is particularly extensive and includes data representing species that are Federally-listed as threatened or endangered by the U.S. Fish and Wildlife Service and/or NOAA National Marine Fisheries Service. Summaries are provided here describing the data for the listed species and demonstrating that the 2013 ammonia criteria update is protective of these species, based on best available scientific data.

Key acute toxicity data for listed species

The acute criterion dataset for ammonia now includes 12 aquatic species that are Federally-listed as threatened, endangered or of concern.

For unionid mussels, the 2013 criterion acute dataset includes acceptable data for 16 freshwater species across 11 genera. Of these, five of the mussel species are Federally-listed as threatened or endangered (as identified in Table 3). The oyster mussel (*Epioblasma capsaeformis*) is a Federally-listed species and is the third most sensitive in the acute dataset with a GMAV, based on a single SMAV, of 31.14 mg TAN/L. The SMAV/2 for the oyster mussel is approximately 16 mg TAN/L, similar to the 2013 acute criterion value of 17 mg TAN/L. The SMAV/2 is a value considered statistically indistinguishable from control mortality or effect based on analysis of 219 acute toxicity tests on a range of chemicals, as described in the *Federal Register* on May 18, 1978 (43 FR 21506-18). Thus, the magnitude of acute effects to this species at the SMAV/2 are not expected to significantly impact the species, because it is expected to be statistically indistinguishable from effects to control (unexposed) organisms. Furthermore, the acute criterion specifies that this concentration should not be exceeded for more than one hour once every three years on average, providing further protection through the limitation of any excursions above the criterion. Thus, the 2013 recommended CMC for ammonia of 17 mg TAN/L should be protective of oyster mussels. In waters where this listed species is present, a site-specific criterion could be considered using the SMAV for that species as the FAV from which to derive the CMC.

The *Lampsilis* GMAV of 46.63 mg TAN/L reflects the geometric mean of SMAVs for six mussel species, two (*L. abrupta* and *L. higginsii*) of which are endangered and a third (*L. rafinesqueana*) that is a Federal species of concern (Table 3). The SMAVs for this genus range from 26.03 mg TAN/L (*L. abrupta*) to 69.97 mg TAN/L (*L. rafinesqueana*) (Appendix A). Given the range of sensitivity within this genus with listed species at both the most and least sensitive ends of the range, the CMC of 17 mg TAN/L should be protective of the genus as a whole, with SMCVs/2 ranging from 13 to 34 mg TAN/L. Again, the acute criterion specifies that a concentration of 17 mg TAN/L should not be exceeded for more than one hour once every three years on average, providing further protection of species, through the limitation of any excursions above the criterion. In waters where the listed species are present, a site-specific criterion could be considered using the SMAV for that species as the FAV from which to derive the CMC.

Also among the ten most sensitive GMAVs in the acute dataset is the GMAV for the endangered Lost River sucker (*Deltistes luxatis*) endemic to the Klamath Basin of northern California and southern Oregon (Appendix A). The reported LC_{50}s at test temperature 20°C and pH 8.0 were 10.35 and 16.81 mg TAN/L for larval and juvenile fish, expressed as total ammonia (Appendix A). The LC_{50}s normalized to pH 7 and 20°C are 44.42 and 72.18 mg TAN/L, respectively (Appendix A). The GMAV for Lost River sucker is calculated as the geometric mean of the two normalized LC_{50}s, or 56.62 mg TAN/L (Table 3), with an SMAV/2, or expected low mortality level, of approximately 28 mg TAN/L, significantly above the CMC. Lost River sucker represents the ninth most sensitive genus in the acute dataset, and second most sensitive fish species (following mountain whitefish which is the most sensitive fish GMAV), and thus is expected to be protected by the CMC of 17 mg TAN/L.

The second most acutely sensitive salmonid genus (after *Prosopium,* represented by the mountain whitefish, *Prosopium williamsoni,* acute sensitivity rank 8) is *Oncorhynchus*, represented by data for six different species, three of which are threatened or endangered, with SMAVs ranging from 78.92 mg TAN/L for Cutthroat trout, *O. clarkii,* to 180.7 mg TAN/L for pink salmon, *O. gorbuscha.* The GMAV for *Oncorhynchus* (99.15 mg TAN/L) is ranked #25 in acute sensitivity (Table 3). All SMAV/2 values for the threatened or endangered species tested in this genus are significantly above the acute criterion magnitude. Thus, the acute criterion is expected to be protective of threatened and endangered salmonid species.

Key chronic toxicity data for listed species

In the chronic dataset for ammonia, the Federally-listed species are represented by three salmonid species in the genus *Oncorhynchus*, including sockeye salmon, rainbow trout, and the subspecies Lahontan cutthroat trout. The GMCV for *Oncorhynchus* of 12.02 mg TAN/L includes the three SMCVs ranging from 6.663 (rainbow trout) to 25.83 mg TAN/L (Lahontan cutthroat trout) (Table 4). The CCC for ammonia of 1.9 mg TAN/L is expected to be protective of this genus as a whole. At pH 7, the CCC is 3.5 times lower than the chronic value for the most sensitive tested listed salmonid species, *O. mykiss,* which includes populations of rainbow trout and steelhead trout.

In addition, three other studies provide useful information with which to assess the protectiveness of the CCC for threatened and endangered fish species (data included in Appendix C). All three studies indicate that the chronic criterion is expected to be protective of the endangered or listed species tested by the researchers, as described below.

Meyer and Hansen (2002) conducted a 30-day toxicity test with late-stage larvae (0.059 g) of Lost River suckers (*Deltistes luxatus*) at pH 9.5. The exposure duration and pH were chosen to represent the period of combined elevated unionized ammonia concentrations and elevated pH that occur during cyanobacterial blooms in surface waters of Upper Klamath Lake, which have been shown to last for several weeks to a month. Survival decreased significantly at 1.23 and 2.27 mg TAN/L, whereas the highest NOEC for all endpoints (survival, growth, body ions, and swimming performance) was 0.64 mg TAN/L. Control survival was > 90 percent. The calculated LOEC of 1.23 mg TAN/L at test pH and temperature when normalized to pH 7 corresponds to a value of 25.31 mg TAN/L, again, substantially higher than the 2013 chronic criterion value (Appendix C).

In order to determine if whole effluent toxicity testing is protective of threatened and endangered fish species, Dwyer et al. (2005) conducted 7-day chronic toxicity tests with *Ceriodaphnia dubia* (neonates, <24 h old) and fathead minnow larvae (*Pimephales promelas,*

<24 h) in addition to the following six threatened and endangered fish species: bonytail chub (*Gila elegans*), spotfin chub (*Erimonax*, formerly *Cyprinella, monachus*), Cape Fear shiner (*Notropis mekistocholas*), gila topminnow (*Poeciliopsis occidentalis*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*). The age of the six threatened and endangered fish species used during the 7-day ammonia exposures ranged from <1 to 7 days. The combined effect on test species survival and growth were determined as EC_{25} values. The six endangered species, presented in the same order as they are listed above, have reported EC_{25} values of: 11.0, 15.8, 8.80, 24.1, 8.90 and 13.4 mg TAN/L; or 23.24, 33.37, 18.59, 50.91, 18.80 and 28.30 mg TAN/L when adjusted to a pH of 7.0 (Appendix C). These values are all substantially higher than the 2013 chronic criterion concentration value of 1.9 mg TAN/L. Based on the results, the two species typically used for whole effluent toxicity testing (*C. dubia and P. promelas)* were more sensitive to ammonia and are protective of the six listed fish species when used as surrogate test species.

Fairchild et al. (2005) conducted 28-day toxicity tests with early life stages of Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*), and compared the results of those tests with a test using a surrogate fish species, the fathead minnow (*Pimephales promelas*). Effect concentrations based on the survival and growth endpoints of the fathead minnow and razorback sucker tests were not different; however, growth was the more sensitive endpoint for the Colorado pikeminnow test. The 28-day growth LOEC for the Colorado pikeminnow was 8.60 mg TAN/L, or 29.75 mg TAN/L at pH 7, substantially greater than the 2013 chronic criterion. The 28-day survival LOEC for the razorback sucker was 13.25 mg TAN/L, or 46.58 mg TAN/L at pH 7. Both endangered fish species exhibited similar sensitivity to ammonia as the fathead minnow (LOEC of 32.71 mg TAN/L at pH 7; see Appendix C). The same can be said for the Lost River sucker, which indicates that these particular endangered fish species are expected to be protected by the CCC value calculated in this 2013 AWQC Update.

Comparison of 1999, 2009, and 2013 Criteria Values

Table 8 provides a comparison of the four most sensitive taxa used to calculate the CCC in this 2013 AWQC Update document compared to the four most sensitive taxa used to calculate the CCC in the 1999 AWQC document.

The 2013 CCC is about twice the magnitude of the draft 2009 CCC recommended for waters with mussels present (1.9 vs. 0.91 mg TAN/L, respectively, at pH 7, T=20°C) as a result of differences in the data used in the CCC derivations. Based on a new study by Wang et al. (2011) described in the *Effects Analysis* section under *Summaries of Studies Used in Chronic Criterion Determination*, pg. 34, above, the lowest GMCV for the mussel genus *Lampsilis* increased from 1.154 mg TAN/L in the 2009 draft AWQC to 2.216 mg TAN/L in the 2013 AWQC. As a result, compared to the four lowest GMCVs in the 2009 draft CCC, the four lowest GMCVs in the 2013 CCC have a smaller range of variation in values (2.216 to 7.547 mg TAN/L) which decreases the uncertainty of the 5th percentile GMCV estimation. Also in the 2009 draft CCC, there were only 13 GMCVs in the dataset used to derive the CCC while in the 2013 CCC, there are 16 GMCVs used to derive the CCC, because of the addition of the GMCVs for *Hyalella azteca*, the insect *Pteronarcella badia*, and salmonids (*Oncorhynchus spp.*). The new GMCVs affect the chronic species sensitivity distribution. The cumulative probability (P) decreases as a function of the increased number of GMCVs and results in an increase in the FCV.

Table 8. Comparison of the Four Taxa Used to Calculate the FCV and CCC in the 1999 Update, 2009 Draft and the 2013 AWQC.

1999 Update CCC Magnitude			**2009 Draft Update CCC Magnitude**			**2013 Final CCC Magnitude**	
Species	**pH 8.0, T=25°C (mg TAN/L)**	**pH 7.0, T=20°C (mg TAN/L)**	**Species**	**pH 8.0, T=25°C (mg TAN/L)**	**pH 7.0, T=20°C (mg TAN/L)**	**Species**	**pH 7.0, T=20°C (mg TAN/L)**
Fathead minnow, *Pimephales promelas*	3.09	7.503	Long fingernailclam, *Musculium transversum*	<2.260	7.552	Long fingernailclam, *Musculium transversum*	7.547
Lepomis sp. (Centrarchidae), includes: Bluegill sunfish, *L. macrochirus*, and Green sunfish, *L. cyanellus*	2.85	6.92	*Lepomis* sp. (Centrarchidae), includes: Bluegill sunfish, *L. macrochirus*, and Green sunfish, *L. cyanellus*	2.852	6.924	*Lepomis* sp. (Centrarchidae), includes: Bluegill sunfish, *L. macrochirus*, and Green sunfish, *L. cyanellus*	6.92
Long fingernailclam, *Musculium transversum*	<2.26	7.547	Rainbow mussel, *Villosa iris*	<0.9805	3.286	Rainbow mussel, *Villosa iris*	3.501
Amphipod, *Hyalella azteca*	<1.45	4.865	*Lampsilis* sp. (Unionidae), includes: Wavy-rayed lamp mussel, *L. fasciola* and Fatmucket, *L. siliquoidea*	<0.3443	1.154	*Lampsilis* sp. (Unionidae), includes: Wavy-rayed lamp mussel, *L. fasciola* and Fatmucket, *L. siliquoidea*	2.216
CCC	1.2	**4.5**	**CCC**	0.26	**0.91**	**CCC**	**1.9**

Comparison of statistical approaches to develop the chronic criterion: EC20 vs. MATC

In this 2013 ammonia criteria update, the CCC is based on a 20 percent reduction in survival, growth, or reproduction, which is a risk management decision made by EPA in 1999 and also retained for this document. When an EC_{20} was not provided in a study, the EPA's TRAP program was used to estimate the EC_{20} as the basis for the GMCV and included the resultant CCC derivation of 1.9 mg TAN/L. An alternative chronic measure of effect that is commonly used is the MATC, which is the geometric mean of the NOEC and LOEC. In the case of the current ammonia dataset, using MATCs to derive the chronic criteria would result in an FCV of 1.972 and CCC of 2.0 mg TAN/L. This comparison demonstrates that, for the current ammonia chronic dataset, the use of TRAP to estimate EC_{20} values does not result in a significant difference from the MATC, another statistical approach frequently used to develop chronic effects assessments and criteria.

The concentrations of TAN affecting freshwater animals in this 2013 AWQC update are normalized to pH 7.0 for all aquatic organisms and 20°C for invertebrates. In contrast, the concentrations of TAN affecting freshwater animals in the 1999 AWQC were normalized to pH 8.0 for all organisms and temperature 25°C for invertebrates. The current pH (7) and temperature (20°C) used are considered to more closely reflect ambient pH and temperatures found generally in surface waters in the U.S. The acute and chronic criterion values can be adjusted to reflect local pH and temperature using the values in Tables 5a, 5b, and 6 derived from the equations presented in *The National Criteria for Ammonia in Fresh Water* section (pages 40-49).

UNUSED DATA

For this 2013 criteria update document, EPA considered and evaluated all available data that could possibly be used to derive the new acute and chronic criteria for ammonia in fresh water. A substantial amount of those data were associated with studies that did not meet the basic QA/QC requirements described in the 1985 Guidelines (see Stephan et al. 1985). In such cases, EPA further scrutinized those studies where either: (1) the study included tests with a species associated with one of the four most sensitive GMAVs or GMCVs used to derive the 2013 criterion; or (2) the study provided results of tests where the normalized acute or chronic value for the test was within a factor of approximately two of the fourth ranked most sensitive GMAV or GMCV, and thus might be considered potentially influential to the acute or chronic criterion. For each study that was potentially influential, but did not meet the additional data quality requirements for its use in deriving criteria for ammonia, the study and its results were included in Appendix J (acute studies) and K (chronic studies), and a rationale is provided for its exclusion. A list of all other studies considered but removed from consideration for use in deriving the criteria is provided in Appendix L with a code (and in some cases comments) indicating the reason(s) for exclusion.

REFERENCES

Abeliovich, A. and Y. Azov. 1976. Toxicity of ammonia to algae in sewage oxidation ponds. Appl. Environ. Microbiol. 31(6): 801-806.

Abell, R.A., D.M. Olson, E. Dinerstein, P.T. Hurley, J. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnutt, C. Loucks and P. Hedao. 2000. Freshwater ecoregions of North America. A conservation assessment. Island Press (WWF), Washington, DC.

Adams, N. and D. Bealing. 1994. Organic pollution: Biochemical oxygen demand and ammonia. In: Handbook of ecotoxicology, vol. 2. Calow, P. (Ed.). Blackwell Scientific Publications, Oxford. pp. 264-285.

Adelman, I.R., L.I. Kusilek, J. Koehle and J. Hess. 2009. Acute and chronic toxicity of ammonia, nitrite and nitrate to the endangered Topeka shiner (*Notropis topeka*) and fathead minnows (*Pimephales promelas*). Environ. Toxicol. Chem. 28(10): 2216-2223.

Agency for Toxic Substances and Disease Registry. 2004. A toxicological profile for ammonia. U.S. Dept. Health and Human Services, Public Health Service, Atlanta, GA.

Alabaster, J.S. and R. Lloyd. 1980. Ammonia. In: Water quality criteria for fish. Alabaster, J.S. and R. Lloyd (Eds.). Butterworths, London. pp. 85-102.

Alonso, A. and J.A. Camargo. 2004. Toxic effects of unionized ammonia on survival and feeding activity of the freshwater amphipod *Eulimnogammarus toletanus* (Gammaridae, Crustacea). Bull. Environ. Contam. Toxicol. 72: 1052-1058.

American Society for Testing and Materials. 2006. Standard guide for conducting laboratory toxicity tests with freshwater mussels. In: Annual Book of ASTM Standards. Vol. 11.06. ASTM E2455-06. American Society for Testing and Materials, West Conshohocken, PA.

Andersen, H. and J. Buckley. 1998. Acute toxicity of ammonia to *Ceriodaphnia dubia* and a procedure to improve control survival. Bull. Environ. Contam. Toxicol. 61(1): 116-122.

Anderson, K.B., R.E. Sparks and A.A. Paparo. 1978. Rapid assessment of water quality, using the fingernail clam, *Musculium transversum*. WRC Research Report No. 133. University of Illinois, Water Resources Center, Urbana, IL.

Ankley, G.T., M.K. Schubauer-Berigan and P.D. Monson. 1995. Influence of pH and hardness on toxicity of ammonia to the amphipod *Hyalella azteca*. Can. J. Fish. Aquat. Sci. 52(10): 2078-2083.

Appl, M. 1999. Ammonia: Principles and industrial practice. Wiley-VCH Verlag, Weinheim, Germany.

Arillo, A., C. Margiocco, F. Melodia, P. Mensi and G. Schenone. 1981. Ammonia toxicity mechanism in fish: Studies on rainbow trout (*Salmo gairdneri* Richardson.). Ecotoxicol. Environ. Saf. 5(3): 16-328.

Arthur, J.W., C.W. West, K.N. Allen and S.F. Hedtke. 1987. Seasonal toxicity of ammonia to five fish and nine invertebrates species. Bull. Environ. Contam. Toxicol. 38(2): 324-331.

Ashe, D., J.R. Tomasso, A.G. Eversole and T.I.J. Smith. 1996. Toxicity of ammonia to fingerling white bass: Effect of selected environments on uptake dynamics. Prog. Fish Cult. 58(4): 277-280.

Augspurger, T., A.E. Keller, M.C. Black, W.G. Cope and F.J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environ. Toxicol. Chem. 22: 2569-2575.

Bader, J.A. and J.M. Grizzle. 1992. Effects of ammonia on growth and survival of recently hatched channel catfish. J. Aquat. Anim. Health. 4(1): 17-23.

Bailey, H.C., J.R. Elphick, R. Krassoi and A. Lovell. 2001. Joint acute toxicity of diazinon and ammonia to *Ceriodaphnia dubia*. Environ. Toxicol. Chem. 20: 2877-2882.

Beamish, F.W.H. and A. Tandler. 1990. Ambient ammonia, diet and growth in lake trout. Aquat. Toxicol. 17: 155-166.

Beketov, M.A. 2002. Ammonia toxicity to larvae of *Erythromma najas* (Hansemann), *Lestes sponsa* (Hansemann) and *Sympetrum flaveolum* (Linnaeus) (Zygoptera: Coenagrionidae, Lestidae; Anisoptera: Libellulidae). Odonatologica 31(3): 297-304.

Besser, J.M. 2011. U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO. (Memorandum to L.F. Huff, U.S. Environmental Protection Agency, Office of Water, Health and Ecological Criteria Division, Washington, DC. February 23. Report: Besser, J.M, C.G. Ingersoll, N. Wang and D.R. Mount. 2010. Chronic toxicity of ammonia to pebblesnails (*Fluminicola* sp.). CERC project number 8335C2F).

Besser, J.M., C.G. Ingersoll, E.N. Leonard and D.R. Mount. 1998. Effect of zeolite on toxicity of ammonia in freshwater sediments: Implications for toxicity identification evaluation procedures. Environ. Toxicol. Chem. 17(11): 2310-2317.

Besser, J.M., D.L. Hardesty, I.E. Greer and C.G. Ingersoll. 2009. Sensitivity of freshwater snails to aquatic contaminants: Survival and growth of endangered snail species and surrogates in 28-day exposures to copper, ammonia and pentachlorophenol. Administrative Report CERC-8335-FY07-20-10, U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO.

Bianchini, A., W. Wasielesky, Jr. and K.C. Miranda Filho. 1996. Toxicity of nitrogenous compounds to juveniles of flatfish *Paralichthys orbignyanus*. Bull. Environ. Contam. Toxicol. 56(3): 453-459.

Black, M. 2001.Water quality standards for North Carolina's endangered mussels. Department of Environmental Health Science, Athens, GA.

Blahm, T.H. 1978. Toxicity of chemical fire retardants to juvenile coho salmon and rainbow trout. Ph.D. Thesis, University of Idaho, Moscow, ID. Available from: Diss. Abstr. Int. B Sci. Eng. 39(9): 4115.

Borgmann, U. 1994. Chronic toxicity of ammonia to the amphipod *Hyalella azteca*; importance of ammonium ion and water hardness. Environ. Pollut. 86(3): 329-335.

Borgmann, U. and A.I. Borgmann. 1997. Control of ammonia toxicity to *Hyalella azteca* by sodium, potassium and pH. Environ. Pollut. 95(3): 325-331.

Bretthauer, R. 1978. Some ecological limits of tolerance to *Ochromonas sociabilis*. Verh. Internat. Verein. Limnol. 20(3): 1850-1854.

Bringolf, R.B., M.C. Barnhardt, and W.G. Cope. 2013. Determining the appropriate duration of toxicity tests with glochidia of native freshwater mussels. Final Completion Report for the period August 1, 2010 through July 31, 2012. U.S. EPA Region V

Brinkman, S.C., J.D. Woodling, A.M. Vajda and D.O. Norris. 2009. Chronic toxicity of ammonia to early life stage rainbow trout. Trans. Am. Fish. Soc. 138: 433-440.

Broderius, S.J. and L.L. Smith, Jr. 1979. Lethal and sublethal effects of binary mixtures of cyanide and hexavalent chromium, zinc, or ammonia to the fathead minnow (*Pimephales promelas*) and rainbow trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 36(2): 164-172.

Broderius, S., R. Drummond, J. Fiandt and C. Russom. 1985. Toxicity of ammonia to early life stages of the smallmouth bass at four pH values. Environ. Toxicol. Chem. 4(1): 87-96.

Buckley, J.A. 1978. Acute toxicity of unionized ammonia to fingerling coho salmon. Prog. Fish Cult. 40(1): 30-32.

Buhl, K.J. 2002. The relative toxicity of waterborne inorganic contaminants to the Rio Grande silvery minnow (*Hybognathus amarus*) and fathead minnow (*Pimephales promelas*) in a water quality simulating that in the Rio Grande, Albuquerque, NM. Final Report to the U.S. Fish and Wildlife Service, New Mexico Ecological Services Field Office, Albuquerque, NM.

Buhl, K.J. and S.J. Hamilton. 2000. Acute toxicity of fire-control chemicals, nitrogenous chemicals, and surfactants to rainbow trout. Trans. Amer. Fish. Soc. 129(2): 408-418.

Burkhalter, D.E. and C.M. Kaya. 1977. Effects of prolonged exposure to ammonia on fertilized eggs and sac fry of trout (*Salmo gairdneri*). Trans. Amer. Fish. Soc. 106: 470-475.

Calamari, D., R. Marchetti and G. Vailati. 1977. Effect of prolonged treatments with ammonia on stages of development of *Salmo gairdneri*. Nuovi. Ann. Ig. Microbiol. 28(5): 333-345.

Calamari, D., R. Marchetti and G. Vailati. 1981. Effects of long-term exposure to ammonia on the developmental stages of rainbow trout (*Salmo gairdneri*). Rapp. P.-V. Reun. Cons. Int. Explor. Mer. 178: 81-86.

Camargo J. and A. Alonso. 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environ. Internat. 32: 831-849.

Camp Dresser and McKee. 1997. Site-specific limits for unionized ammonia – Red River of the North. Report to the City of Moorhead, MN.

Champ, Y.A., J.T. Lock, C.D. Bjork, W.G. Klussmann and J.D. McCullough, Jr. 1973. Effects of anhydrous ammonia on a central Texas pond and a review of previous research with ammonia in fisheries management. Trans. Am. Fish. Soc. 102(l): 73-82.

Cary, G.A. 1976. A report on the assessment of aquatic environmental impact of Union Carbide's Uravan operations. Aquatic Environmental Sciences, Tarrytown, NY. 67 pp.

Chetty, A.N. and K. Indira. 1995. Adaptive changes in the glucose metabolism of a bivalve to ambient ammonia stress. Bull. Environ. Contam. Toxicol. 54: 83-89.

Colt, J. and G. Tchobanoglous. 1976. Evaluation of the short-term toxicity of nitrogenous compounds to channel catfish, *Ictalurus punctatus*. Aquaculture 8: 209-224.

Colt, J. and G. Tchobanoglous. 1978. Chronic exposure of channel catfish, *Ictalurus punctatus*, to ammonia: Effects on growth and survival. Aquaculture 15: 353-372.

Constable, M., M. Charlton, F. Jensen, K. McDonald, G. Craig, K.W. Taylor. 2003. An ecological risk assessment of ammonia in the aquatic environment. Hum. Ecol. Risk Assess. 9: 527-548.

Cowgill, U.M. and D.P. Milazzo. 1991. The response of the three brood *Ceriodaphnia* test to fifteen formulations and pure compounds in common use. Arch. Environ. Contam. Toxicol. 21(1): 35-40.

Craig, G.R. and G.L. Beggs. 1979. Evaluation of fish loading rates in regulatory static bioassays. Fish Mar. Serv. Tech. Rep. 862. In: Proceedings of the fifth annual aquatic toxicity workshop, Hamilton, Ontario, November 7-9, 1978. Wong, P.T.S., P.V. Hodson, A.J. Niimi, V.W. Cairns and U. Borgmann (Eds.). Great Lakes Biolimnology Laboratory, Canada Centre for Inland Waters, Burlington, Ontario, Canada. pp. 146-160 (Author Communication Used).

DeGraeve, G.M., R.L. Overcast and H.L. Bergman. 1980. Toxicity of underground coal gasification condenser water and selected constituents to aquatic biota. Arch. Environ. Contam. Toxicol. 9(5): 543-555.

DeGraeve, G.M., W.D. Palmer, E.L. Moore, J.J. Coyle and P.L. Markham. 1987. The effect of temperature on the acute and chronic toxicity of unionized ammonia to fathead minnows and channel catfish. Battelle, Columbus, OH.

Dehedin, A., C. Piscart and P. Marmonier. In Press. Seasonal variations of the effect of temperature on lethal and sublethal toxicities of ammonia for three common freshwater shredders. Chemosphere (2012), http://dx.doi.org/10.1016/j.chemosphere.2012.07.055

Dekker, T., G.D. Greve, T.L. Ter Laak, M.E. Boivin, B. Veuger, G. Gortzak, S. Dumfries, S.M.G. Lucker, M.H.S. Kraak, W. Admiraal and H.G. van der Geest. 2006. Development and application of a sediment toxicity test using the benthic cladoceran *Chydorus sphaericus*. Environ. Pollut. 140: 231-238.

Diamond, J.M., D.G. Mackler, W.J. Rasnake and D. Gruber. 1993. Derivation of site-specific ammonia criteria for an effluent-dominated headwater stream. Environ. Toxicol. Chem. 12(4): 649-658.

Draper, N.R. and H. Smith. 1981. Applied regression analysis. Second Edition. Wiley, New York. 709 pp.

Dwyer, F.J., D.K. Hardesty, C.E. Henke, C.G. Ingersoll, D.W. Whites, T. Augspurger, T.J. Canfield, D.R. Mount and F.L. Mayer. 2005. Assessing contaminant sensitivity of endangered and threatened aquatic species: Part III. Effluent toxicity tests. Arch. Environ. Contam. Toxicol. 48: 174-183.

EA Engineering. 1985. Proposed modified effluent limitations for ammonia: Application for a 301(g) demonstration for the Sparrows Point Plant. Bethlehem Steel Corp., Sparrows Point, MD.

Emerson, K., R.C. Russo, R.E. Lund and R.V. Thurston. 1975. Aqueous ammonia equilibrium calculations: Effect of pH and temperature. J. Fish. Res. Board Can. 32: 2379-2383.

Emery, R.M. and E.B. Welch. 1969. The toxicity of alkaline solutions of ammonia to juvenile bluegill sunfish (*Lepomis macrochirus* Raf.). Tennessee Valley Authority, Division of Health and Safety, Chattanooga, TN.

Environment Canada. 1997. Problem formulation for ammonia in the aquatic environment. Canadian Environmental Protection Act Priority Substances List 2. Version 5.0, November 4, 1997.

Environment Canada. 2004. Acute lethality results from 96 hour LC50 ammonia toxicity testing with rainbow trout (*Oncorhynchus mykiss*). North Vancouver, BC, Canada.

Environment Canada. 2010. Canadian water quality guidelines for the protection of aquatic life: Ammonia. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg, .

Epifanio, C.E. and R.F. Srna. 1975. Toxicity of ammonia, nitrite ion, nitrate ion, and orthophosphate to *Mercenaria mercenaria* and *Crassostrea virginica*. Mar. Biol. 33(3): 241-246.

Erickson, R.J. 1985. An evaluation of mathematical models for the effects of pH and temperature on ammonia toxicity to aquatic organisms. Water Res. 19: 1047-1058.

Evans, J.W. 1979. The construction and use of a continuous-flow bioassay apparatus to determine a preliminary unionized ammonia 96-hour LC50 for the crayfish. M.S. Thesis, University of Kansas, Lawrence, KS.

Fairchild, J.F., A.L. Allert, L.C. Sappington and B. Waddell. 2005. Chronic toxicity of unionized ammonia to early life-stages of endangered Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) compared to the surrogate fathead minnow (*Pimephales promelas*). Arch. Environ. Contam. Toxicol. 49: 378-384.

Fontenot, Q.C., J.J. Isely and J.R. Tomasso. 1998. Acute toxicity of ammonia and nitrite to shortnose sturgeon fingerlings. Prog. Fish Cult. 60: 315-318.

Geadah. M. 1985. National inventory of natural and anthropogenic sources and emissions of ammonia (1980). Environmental Protection Programs Directorate, Environmental Protection Service, Environment Canada Report EPS5/IC/1.

Gersich, F.M. and D.L. Hopkins. 1986. Site-specific acute and chronic toxicity of ammonia to *Daphnia magna* Straus. Environ. Toxicol. Chem. 5(5): 443-447.

Gersich, F.M., D.L. Hopkins, S.L. Applegath, C.G. Mendoza and D.P. Milazzo. 1985. The sensitivity of chronic end points used in *Daphnia magna Straus* life-cycle tests. In: Aquatic toxicology and hazard assessment: Eighth Symposium, Fort Mitchell, KY., USA, Apr. 15-17, 1984. Bahner, R.C. and D.J. Hansen (Ed.). ASTM STP 891. American Society for Testing and Materials. Philadelphia, PA. pp. 245-252.

Great Lakes Environmental Center (GLEC). 2011. 28-day ammonia toxicity testing of non-pulmonate snails. Final Draft Report. U.S. Environmental Protection Agency Contract Number: EP-C-09-001, Work Assignment 2-31.

Goudreau, S.E., R.J. Neves and R.J. Sheehan. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, USA. Hydrobiologia 252(3): 211-230.

Gulyas, P. and E. Fleit. 1990. Evaluation of ammonia toxicity on *Daphnia magna* and some fish species. Aquacult. Hung. 6: 171-183.

Harcke, J.E. and H.V. Daniels. 1999. Acute toxicity of ammonia and nitrite to different life stages of reciprocal cross hybrid striped bass eggs and larvae. Aquaculture 30: 496-500.

Harrahy, E.A., M. Barman, S. Geis, J. Hemming, D. Karner and A. Mager. 2004. Effects of ammonia on the early life stages of northern pike (*Esox lucius*). Bull. Environ. Contam. Toxicol. 72: 1290-1296.

Hasan, M.R. and D.J. Macintosh. 1986. Acute toxicity of ammonia to common carp fry. Aquaculture 54(1-2): 97-107.

Hazel, C.R., W. Thomsen and S.J. Meith. 1971. Sensitivity of striped bass and stickleback to ammonia in relation to temperature and salinity. Calif. Fish Game. 57(3): 138-153.

Hazel, R.H., C.E. Burkhead and D.G. Huggins. 1979. The development of water quality criteria for ammonia and total residual chlorine for the protection of aquatic life in two Johnson County, Kansas streams. Project completion report for period July 1977 to September 1979. Kansas Water Resources Research Institute, University of Kansas, KS.

Hickey, C.W. and M.L. Vickers. 1994. Toxicity of ammonia to nine native New Zealand freshwater invertebrate species. Arch. Environ. Contam. Toxicol. 26(3): 292-298.

Holt, G.J. and S.A. Malcolm. 1979. Evaluation of fish loading rates in regulatory static bioassays. Tech. Rep. Fish. Mar. Serv. (Can.). 862: 146-160.

Invasive Species Advisory Committee (ISAC). 2006. Invasive species definition clarification and guidance white paper, Submitted by the Definitions Subcommittee of the ISAC, Approved April 27, 2006. pp. 11. (Available at: http://www.invasivespecies.gov/global/ISAC/ISAC_documents/ISAC%20Definititions%20White%20Paper%20%20-%20FINAL%20VERSION.pdf, accessed April 2013)

Jofre, M.B. and W.H. Karasov. 1999. Direct effect of ammonia on three species of North American anuran amphibians. Environ. Toxicol. Chem. 18(8): 1806-1812.

Jude, D.J. 1973. Sublethal effects of ammonia and cadmium on growth of green sunfish (*Lepomis cyanellus*). Ph.D. Thesis, Michigan Department of Fish and Wildlife, Michigan State University, East Lansing, MI.

Karolyi, J. 1968. Production of sorbitol by use of ammonia synthesis gas. Ind. Eng. Chem. Process Des. Dev. 7(1): 107-110.

Keller, A.E. 2000. Memorandum to Rob Pepin. Subject: Water quality and toxicity data for unpublished unionid mussels tests.

Knoph, M.B. 1992. Acute toxicity of ammonia to Atlantic salmon (*Salmo salar*) parr. Comp. Biochem. Physiol. Comp. Pharmacol. Toxicol. 10(2): 275-282.

Koch, D.L., E.L. Lider and S.C. Vigg. 1980. Evaluation of the combined effects of ammonia, nitrite and nitrate on the egg incubation, hatching and fry development of Lahontan cutthroat trout (*Salmo clarki henshawi*). University of Nevada, Desert Research Institute, Reno, NV.

Kolarevic, J., H. Takle, O. Felip, E. Ytteborg, R. Selset, C.M. Good, G. Baeverfjord, T. Asgard and B.F. Terjesen. 2012. Molecular and physiological responses to long-term sublethal ammonia exposure in Atlantic salmon (*Salmo salar*). Aquat. Toxicol. 124-125: 48-57.

Kumar, N.J. and K.P. Krishnamoorthi. 1983. Evaluation of toxicity of ammoniacal fertilizer effluents. Environ. Pollut. Ser. A. 30(1): 77-86.

Lang, T., G. Peters, R. Hoffmann and E. Meyer. 1987. Experimental investigations on the toxicity of ammonia: Effects on ventilation frequency, growth, epidermal mucous cells, and gill structure of rainbow trout *Salmo gairdneri*. Dis. Aquat. Org. 3: 159-165.

Latysheva, N., V.L. Junker, W.J. Palmer, G.A. Codd and D. Barker. 2012. The evolution of nitrogen fixation in cyanobacteria. Bioinformatics 28(5): 603-606.

Lubinski, K.S., R.E. Sparks and L.A. Jahn. 1974. The development of toxicity indices for assessing the quality of the Illinois River. WRC Research Report No. 96, University of Illinois, Water Resources Center, Urbana, IL.

Mallet, M.J. and I. Sims. 1994. Effects of ammonia on the early life stages of carp (*Cyprinus carpio*) and roach (*Rutilus rutilus*). In: Sublethal and chronic effects of pollutants on freshwater fish. Muller, R. and R. Lloyd (Eds.), Fishing News Books, London. pp. 211-228.

Manning, T.M., S.P. Wilson and J.C. Chapman. 1996. Toxicity of chlorine and other chlorinated compounds to some Australian aquatic organisms. Bull. Environ. Contam. Toxicol. 56(6): 971-976.

Markle, P.J., J.R. Gully, R.B. Baird, K.M. Nakada and J.P. Bottomley. 2000. Effects of several variables on whole effluent toxicity test performance and interpretation. Environ. Toxicol. Chem. 19: 123-132.

Mayes, M.A., H.C. Alexander, D.L. Hopkins and P.B. Latvaitis. 1986. Acute and chronic toxicity of ammonia to freshwater fish: A site-specific study. Environ. Toxicol. Chem. 5(5): 437-442.

McCormick, J.H., S.J. Broderius and J.T. Findt. 1984. Toxicity of ammonia to early life stages of the green sunfish *Lepomis cyanellus* (with erratum). Environ. Pollut. Ser. A 36: 147-163.

Meyer, J.S. and J.A. Hansen. 2002. Subchronic toxicity of low dissolved oxygen concentrations, elevated pH, and elevated ammonia concentrations to Lost River suckers. Trans. Amer. Fish. Soc. 131: 656-666.

Miao, J., M.C. Barnhart, E.L. Brunson, D.K. Hardesty, C.G. Ingersoll and N. Wang. 2010. An evaluation of the influence of substrate on the response of juvenile freshwater mussels (fatmucket, *Lampsilis siliquoidea*) in acute water exposure to ammonia. Environ. Toxicol. Chem. 29(9): 2112-2116.

Ministry of Technology. 1967. Effects of pollution on fish. In: Water Pollution Research 1967. H.M. Stationery Office, London. pp. 56-65.

Monda, D.P., D.L. Galat, S.E. Finger and M.S. Kaiser. 1995. Acute toxicity of ammonia (NH3-N) in sewage effluent to *Chironomus riparius*: II. Using a generalized linear model. Arch. Environ. Contam. Toxicol. 28(3): 385-390.

Mount, D.I. 1982. Ammonia toxicity tests with *Ceriodaphnia acanthina* and *Simocephalus vetulus*. U.S. EPA, Duluth, MN. (Letter to R.C. Russo, U.S. EPA, Duluth, MN.)

Mummert, A.K., R.J. Neves, T.J. Newcomb and D.S. Cherry. 2003. Sensitivity of juvenile freshwater mussels (*Lampsilis fasciola*, *Villosa iris*) to total and unionized ammonia. Environ. Toxicol. Chem. 22: 2545-2553.

Myers-Kinzie, M. 1998. Factors affecting survival and recruitment of unionid mussels in small midwestern streams. Purdue University, West Lafayette, IN.

Newton, T.J. and M.R. Bartsch. 2007. Lethal and sublethal effects of ammonia to juvenile *Lampsilis* mussels (Unionidae) in sediment and water-only exposures. Environ. Toxicol. Chem. 26(10): 2057–2065.

Newton, T.J., J.W. Allran, J.A. O'Donnell, M.R. Bartsch and W.B. Richardson. 2003. Effects of ammonia on juvenile unionid mussels (*Lampsilis cardium*) in laboratory sediment toxicity tests. Environ. Toxicol. Chem. 22(10): 2554-2560.

Nimmo, D.W.R., D. Link, L.P. Parrish, G.J. Rodriguez, W. Wuerthele and P.H. Davies. 1989. Comparison of on-site and laboratory toxicity tests: Derivation of site-specific criteria for unionized ammonia in a Colorado transitional stream. Environ. Toxicol. Chem. 8(12): 1177-1189.

Noxon J.F. 1976. Atmospheric nitrogen fixation by lightning. Geophysics Lett. 3: 463-465.

Oppenborn, J.B. and C.A. Goudie. 1993. Acute and sublethal effects of ammonia on striped bass and hybrid striped bass. J. World Aquacult. Soc. 24(1): 90-101.

Parkhurst, B.R., A.S. Bradshaw, J.L. Forte and G.P. Wright. 1979. An evaluation of the acute toxicity to aquatic biota of a coal conversion effluent and its major components. Bull. Environ. Contam. Toxicol. 23(3): 349-356.

Parkhurst, B.R., J.S. Meyer, G.M. DeGraeve and H.L. Bergman. 1981. Reevaluation of the toxicity of coal conversion process waters. Bull. Environ. Contam. Toxicol. 26(1): 9-15.

Prenter, J., C. MacNeil, J.T.A. Dick, G.E. Riddell and A.M. Dunn. 2004. Lethal and sublethal toxicity of ammonia to native, invasive, and parasitised freshwater amphipods. Water Res. 38: 2847-2850.

Przytocka-Jusiak, M. 1976. Growth and survival of *Chlorella vulgaris* in high concentrations of nitrogen. Acta Microbial. Pol. 25(3): 237-289.

Qureshi, A.A., K.W. Flood, S.R. Thompson, S.M. Janhurst, C.S. Inniss and D.A. Rokosh. 1982. Comparison of a luminescent bacterial test with other bioassays for determining toxicity of pure compounds and complex effluents. In: Aquatic toxicology and hazard assessment, 5th conference. Pearson, J.G., R.B. Foster and W.E. Bishop (Eds.). ASTM STP 766. American Society for Testing and Materials, Philadelphia, PA. pp. 179-195.

Rani, E.F., M. Elumalal and M.P. Balasubramanian. 1998. Toxic and sublethal effects of ammonium chloride on a freshwater fish *Oreochromis mossambicus*. Water Air Soil Pollut. 104: 1-8.

Rankin, D.P. 1979. The influence of unionized ammonia on the long-term survival of sockeye salmon eggs. Fisheries and Marine Service Technical Report No. 912. Pacific Biological Station, Nanaimo, B.C., Canada.

Rao, T.S., M.S. Rao and S.B.S.K. Prasad. 1975. Median tolerance limits of some chemicals to the fresh water fish *Cyprinus carpio*. Indian J. Environ. Health 17(2): 140-146.

Reddy, N.A and N.R. Menon. 1979. Effects of ammonia and ammonium on tolerance and byssogenesis in *Perna viridis*. Marine Ecology - Progress Series. 1(4): 315-322.

Reinbold, K.A. and S.M. Pescitelli. 1982a. Effects of exposure to ammonia on sensitive life stages of aquatic organisms. Project Report, Contract No. 68-01-5832, Illinois Natural History Survey, Champaign, IL.

Reinbold, K.A. and S.M. Pescitelli. 1982b. Effects of cold temperature on toxicity of ammonia to rainbow trout, bluegills and fathead minnows. Project Report, Contract No. 68-01-5832. Illinois Natural History Survey, Champaign, IL.

Reinbold, K.A. and S.M. Pescitelli. 1982c. Acute toxicity of ammonia to the white sucker. Final report, Contract No. 2W-3946 NAEX. Illinois Natural History Survey, Champaign, IL.

Reinbold, K.A. and S.M. Pescitelli. 1982d. Acute toxicity of ammonia to channel catfish. Final report, Contract No. J 2482 NAEX. Illinois Natural History Survey, Champaign, IL.

Rice, S.D. and J.E. Bailey. 1980. Survival, size and emergence of pink salmon, *Oncorhynchus gorbuscha*, alevins after short and long-term exposures to ammonia. Fish. Bull. 78(3): 641-648.

Richardson, J. 1997. Acute ammonia toxicity for eight New Zealand indigenous freshwater species. N.Z. J. Mar. Freshw. Res. 31:185-190.

Robinson-Wilson, E.F. and W.K. Seim. 1975. The lethal and sublethal effects of a zirconium process effluent on juvenile salmonids. Water Res. Bull. 11(5): 975-986.

Rosage, T.F., R.M. Schutsky and K.M. Rapp. 1979. Toxicity of unionized ammonia to the spotfin shiner (*Notropis spilopterus*). Proc. Pa. Acad. Sci. 53: 39-42.

Roseboom, D.P. and D.L. Richey. 1977. Acute toxicity of residual chlorine and ammonia to some native Illinois fishes. Report of Investigations 85. U.S. NTIS PB-170871. Office of Water Research and Technology, Washington, D.C.

Rubin, A.J. and M.A. Elmaraghy. 1976. Studies on the toxicity of ammonia, nitrate and their mixtures to the common guppy. Water Resource Center Report No.490. U.S. NTIS PB-255721 Ohio State University, Columbus, OH.

Russo, R.C. 1985. Ammonia, nitrite, and nitrate. In: Fundamentals of aquatic toxicology and chemistry. Rand, G.M. and S.R. Petrocelli (Eds.). Hemisphere Publishing Corp., Washington, D.C. pp. 455-471.

Russo, R.C., A. Pilli and E.L. Meyn. 1985. (Memorandum to N.A. Jaworski. 4 March 1985.)

Russo, R.C., D.J. Randall, and R.V. Thurston. 1988. Ammonia toxicity and metabolism in fishes. In: Protection of River Basins, Lakes, and Estuaries. Ryans, R.C. (Ed.). American Fisheries Society, Bethesda, MD. pp. 159-173.

Saiki, M.K., D.P. Monda and B.L. Bellerud. 1999. Lethal levels of selected water quality variables to larval and juvenile Lost River and shortnose suckers. Environ. Pollut. 105(1): 37-44.

Sarda, N. 1994. Spatial and temporal heterogeneity in sediments with respect to pore water ammonia and toxicity of ammonia to *Ceriodaphnia dubia* and *Hyalella azteca*. M.S. Thesis. Wright State University, Dayton, OH.

Sarkar, S.K. 1997. Toxicity of simazine, diammonium phosphate, and rockphosphate to fish, snail and worm at various water temperatures. Geobios 24: 142-145.

Scheller, J.L. 1997. The effect of dieoffs of Asian clams (*Corbicula fluminea*) on native freshwater mussels (unionidae). Virginia Polytechnic Institute and State University, Blacksburg, VA.

Schubauer-Berigan, M.K., P.D. Monson, C.W. West and G.T. Ankley. 1995. Influence of pH on the toxicity of ammonia to *Chironomus tentans* and *Lumbriculus variegatus*. Environ. Toxicol. Chem. 14: 713-717.

Schuytema, G.S. and A.V. Nebeker. 1999a. Comparative effects of ammonium and nitrate compounds on Pacific treefrog and African clawed frog embryos. Arch. Environ. Contam. Toxicol. 36: 200-206.

Schuytema, G.S. and A.V. Nebeker. 1999b. Comparative toxicity of ammonium and nitrate compounds to Pacific treefrog and African clawed frog tadpoles. Environ. Toxicol. Chem. 18(10): 2251-2257.

Servizi, J. and R. Gordon. 1990. Acute lethal toxicity of ammonia and suspended sediment mixtures to Chinook salmon (*Oncorhynchus tshawytscha*). Bull. Environ. Contam. Toxicol. 44(4): 650-656.

Smith, W.E., T.H. Roush and J.T. Fiandt. 1984. Toxicity of ammonia to early life stages of bluegill (*Lepomis macrochirus*). Internal Report 600/X-84-175. Environmental Research Laboratory-Duluth, U.S. Environmental Protection Agency, Duluth, MN.

Soderberg, R.W. and J.W. Meade. 1992. Effects of sodium and calcium on acute toxicity of unionized ammonia to Atlantic salmon and lake trout. J. Appl. Aquacult. 1(4): 82-92.

Solbe, J.F.D. and D.G. Shurben. 1989. Toxicity of ammonia to early life stages of rainbow trout (*Salmo gairdneri*). Water Res. 23(1): 127-129.

Sparks, R.E. 1975. The acute, lethal effects of ammonia on channel catfish (*Ictalurus punctatus*), bluegills (*Lepomis macrochirus*) and fathead minnows (*Pimephales promelas*). Report to Illinois, Project No. 20.060. Institute for Environmental Quality, Chicago, IL.

Sparks, R.E. and M.J. Sandusky. 1981. Identification of factors responsible for decreased production of fish food organisms in the Illinois and Mississippi Rivers. Final Report Project No. 3-291-R. Illinois Natural History Survey, River Research Laboratory, Havana, IL.

Stammer, H.A. 1953. The effect of hydrogen sulfide and ammonia on characteristic animal forms in the saprobiotic system (Der einfly von schwefelwasserstoff und ammoniak auf tierische leitformen des sparobiensystems). Vom Wasser. 20: 34-71.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Genile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. National Technical Information Service, Springfield, VA.

Stevenson, T.J. 1977. The effects of ammonia, pH and salinity on the white perch, *Morone americana*. Ph.D. Thesis. University of Rhode Island, Kingston, RI. Available from: Diss. Abstr. Int. B Sci. Eng. 39(1): 35 (Author Communication Used).

Straus, D.L., R. Robinette and J.M. Heinen. 1991. Toxicity of unionized ammonia and high pH to post-larval and juvenile freshwater shrimp *Macrobrachium rosenbergii*. J. World Aquacult. Soc. 22(2): 128-133.

Swigert, J.P. and A. Spacie. 1983. Survival and growth of warmwater fishes exposed to ammonia under low-flow conditions. Technical Report 157. Purdue University, Water Resource Research Center, West Lafayette, IN.

Sylvia, D.M. 2005. Principles and applications of soil microbiology. Fuhrmann, J.J., P. Hartel and D.A. Zuberer (Eds.). Pearson Prentice Hall, NJ.

Thurston, R.V. 1981. (Memorandum to R.C. Russo. November 16, 1981.)

Thurston, R.V. 1988. Ammonia toxicity to fishes. In: Fish physiology, fish toxicology, and fisheries management: Proceedings of an International Symposium, Guangzhou, PRC. EPA/600/9-90/01. pp. 183-196.

Thurston, R.V. and E.L. Meyn. 1984. Acute toxicity of ammonia to five fish species from the northwest United States. Technical Report No.84-4. Fisheries Bioassay Laboratory, Montana State University, Bozeman, MT.

Thurston, R.V. and R.C. Russo. 1981. Acute toxicity of ammonia to golden trout (*Salmo aguabonita*) and mottled sculpin (*Cottus bairdi*). Technical Report No. 81-1. Fisheries Bioassay Laboratory, Montana State University, Bozeman, MT.

Thurston, R.V. and R.C. Russo. 1983. Acute toxicity of ammonia to rainbow trout. Trans. Amer. Fish. Soc. 112: 696-704.

Thurston, R.V., R.C. Russo and C.E. Smith. 1978. Acute toxicity of ammonia and nitrite to cutthroat trout fry. Trans. Amer. Fish. Soc. 107(2): 361-368.

Thurston, R.V., C. Chakoumakos and R.C. Russo. 1981a. Effect of fluctuating exposures on the acute toxicity of ammonia to rainbow trout (*Salmo gairdneri*) and cutthroat trout (*S. clarki*). Water Res. 15(7): 911-917.

Thurston, R.V., G.R. Phillips, R.C. Russo and S.M. Hinkins. 1981b. Increased toxicity of ammonia to rainbow trout (*Salmo gairdneri*) resulting from reduced concentrations of dissolved oxygen. Can. J. Fish. Aquat. Sci. 38(8): 983-988.

Thurston, R.V., R.C. Russo and G.A. Vinogradov. 1981c. Ammonia toxicity to fishes: Effect of pH on the toxicity of the unionized ammonia species. Environ. Sci. Technol. 15(7): 837-840.

Thurston, R.V., R.C. Russo and G.R. Phillips. 1983. Acute toxicity of ammonia to fathead minnows. Trans. Amer. Fish. Soc. 112(5): 705-711.

Thurston, R.V., R.C. Russo, R.J. Luedtke, C.E. Smith, E.L. Meyn, C. Chakoumakos, K.C. Wang and C.J.D. Brown. 1984a. Chronic toxicity of ammonia to rainbow trout. Trans. Amer. Fish. Soc. 113(1): 56-73.

Thurston, R.V., R.J. Luedtke and R.C. Russo. 1984b. Toxicity of ammonia to freshwater insects of three families. Technical Report No. 84-2. Fisheries Bioassay Laboratory, Montana State University, Bozeman, MT.

Thurston, R.V., R.C. Russo, E.L. Meyn, R.K. Zajdel and C.E. Smith. 1986. Chronic toxicity of ammonia to fathead minnows. Trans. Amer. Fish. Soc. 115(2): 196-207.

Tietge, J.E., G.T. Ankley, D.L. DeFoe, G.W. Holcombe and K.M. Jensen. 2000. Effects of water quality on development of *Xenopus laevis*: A frog embryo teratogenesis assay--*Xenopus* assessment of surface water associated with malformations in native anurans. Environ. Toxicol. Chem. 19(8): 2114-2121.

Tomasso, J. and G. Carmichael. 1986. Acute toxicity of ammonia, nitrite, and nitrate to the Guadalupe bass, *Micropterus treculi*. Bull. Environ. Contam. Toxicol. 36(6): 866-870.

Tomasso J.R., C.A. Goudie, B.A. Simco and K.B. Davis. 1980. Effects of environmental pH and calcium on ammonia toxicity in channel catfish. Trans. Am. Fish Soc. 109: 229-234.

Tudorache, C., R.A. O'Keefe and T.J. Benfey. 2010. The effect of temperature and ammonia exposure on swimming performance of brook charr (*Salvelinus fontinalis*). Comp. Biochem. Physiol. A Mol. Integr. Physiol. 156: 523-528.

United States Environmental Protection Agency. 1983. Water quality standards regulation. Federal Register. 48(217): 51400-51413.

United States Environmental Protection Agency. 1985. Ambient water quality criteria for ammonia - 1984. EPA-440/5-85-001. National Technical Information Service, Springfield, VA.

United States Environmental Protection Agency. 1991. Technical support document for water quality-based toxics control. EPA/505/2-90-001. National Technical Information Service, Springfield, VA.

United States Environmental Protection Agency. 1998. Guidelines for ecological risk assessment. EPA/630/R-95/002F. Risk Assessment Forum. Office of Research and Development, Washington, D.C.

United States Environmental Protection Agency. 1999. 1999 Update of ambient water quality criteria for ammonia. EPA-822-R-99-014. National Technical Information Service, Springfield, VA.

United States Environmental Protection Agency. 2004. Estimating ammonia emissions from anthropogenic nonagricultural sources. Draft Final Report. Emission Inventory Improvement Program. Mr. Roy Huntley Project Manager. Available at: http://www.epa.gov/ttnchie1/eiip/techreport/volume03/eiip_areasourcesnh3.pdf. (Accessed March 2013).

United States Environmental Protection Agency. 2009. Draft 2009 update aquatic life ambient water quality criteria for ammonia – freshwater. EPA-822-D-09-001. Office of Water, Office of Science and Technology, Washington, DC.

United States Environmental Protection Agency. 2010. Toxics Release Inventory (TRI) National Analysis: Geo-Specific Analyses - Large Aquatic Systems. Data retrieved from http://www.epa.gov/tri/tridata/tri11/nationalanalysis/tri-lae-intro.html (accessed December 2012).

United States Environmental Protection Agency. 2011. The Toxics Release Inventory (TRI) Explorer: Chemical Report for Ammonia - year of data 2011 (all industries). Retrieved from http://iaspub.epa.gov/triexplorer/tri_release.chemical (accessed December 2012).

United States Environmental Protection Agency. 2013. The revised deletion process for the site-specific recalculation procedure for aquatic life criteria. EPA 822-R-13-001. National Technical Information Service, Springfield, VA.

United States Geologic Survey. 2004. Nitrogen (fixed) – Ammonia. Mineral commodity summaries, January 2007. Available at: http://minerals.usgs.gov/minerals/pubs/commodity/nitrogen/nitromcs07.pdf.

Wade, D., J. Posey and D.J. Simbeck. 1992. Definitive evaluation of Wheeler Reservoir sediments toxicity using juvenile freshwater mussels (*Andodonta imbecillis* Say). TVA/WR-92/25. Tennessee Valley Authority, Water Resources Division, TN.

Wallen, I.E., W.C. Greer and R. Lasater. 1957. Toxicity to *Gambusia affinis* of certain pure chemicals in turbid waters. Sewage Ind. Wastes. 29: 695-711.

Wang, N., C.G. Ingersoll, D.K. Hardesty, I.E. Greer, D.J. Hardesty, C.D. Ivey, J.L. Kunz, W.G. Brumbaugh, F.J. Dwyer, A.D. Roberts, J.T. Augspurger, C.M. Kane, R.J. Neves and M.C. Barnhart. 2007a. Contaminant sensitivity of freshwater mussels: Chronic toxicity of copper and ammonia to juvenile freshwater mussels (Unionidae). Environ. Toxicol. Chem. 26(10): 2048-2056.

Wang, N., C.G. Ingersoll , D.K. Hardesty, C.D. Ivey, J.L. Kunz, T.W. May, F.J. Dwyer, A.D. Roberts, T. Augspurger, C.M. Kane, R.J. Neves and M.C. Barnhart. 2007b. Contaminant sensitivity of freshwater mussels: Acute toxicity of copper, ammonia, and chlorine to glochidia and juveniles of freshwater mussels (Unionidae). Environ. Toxicol. Chem. 26(10): 2036-2047.

Wang, N., R.J. Erickson, C.G. Ingersoll, C.D. Ivey, E.L. Brunson, T. Augspurger and M.C. Barnhart. 2008. Influence of pH on the acute toxicity of ammonia to juvenile freshwater mussels (fatmucket, *Lampsilis siliquoidea*). Environ. Toxicol. Chem. 27: 1141-1146.

Wang, N. R.A. Consbrock, C.G. Ingersoll, and M.C. Barnhart. 2011. Evaluation of influence of sediment on the sensitivity of unionid mussel (*Lampsilis siliquoidea*) to ammonia in 28-day water exposures. Environ. Toxicol. Chem. 30(10): 2270-2276.

Weirich, C.R., J.R. Tomasso and T.I.J. Smith. 1993. Toxicity of ammonia and nitrite to sunshine bass in selected environments. J. Aquat. Anim. Health 5(1): 64-72.

West, C.W. 1985. Acute toxicity of ammonia to 14 freshwater species. Internal Report. U.S. Environmental Protection Agency, Environmental Research Laboratory, Duluth, MN.

Whitfield, M. 1974. The hydrolysis of ammonium ions in sea water – a theoretical study. J. Mar. Biol. Assoc. U.K. 54: 565-580.

Wicks, B.J. and D.J. Randall. 2002. The effect of feeding and fasting on ammonia toxicity in juvenile rainbow trout, *Oncorhynchus mykiss*. Aquat. Toxicol. 59(1-2): 71-82.

Wicks, B.J., R. Joensen, Q. Tang and D.J. Randall. 2002. Swimming and ammonia toxicity in salmonids: The effect of sub-lethal ammonia exposure on the swimming performance of coho salmon and the acute toxicity of ammonia in swimming and resting rainbow trout. Aquat. Toxicol. 59(1-2): 55-69.

Williams, K.A., D.W.J. Green and D. Pascoe. 1986. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates. 3. Ammonia. Arch. Hydrobiol. 106(1): 61-70.

Williams, J.D., M.L. Warren, K.S. Cummins, J.L. Harris and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18: 6-22.

Williams, J.D. and R.J. Neves. 1995. Freshwater mussels: A neglected and declining aquatic resource. In: LaRoe, E.T., G.S. Farris, C.E. Puckett, P.D. Doran and M.J. Mac (Eds.). Our Living Resources. National Biological Service, Washington, DC. pp. 177-199.

Willingham, T. 1987. Acute and short-term chronic ammonia toxicity to fathead minnows (*Pimephales promelas*) and *Ceriodaphnia dubia* using laboratory dilution water and Lake Mead dilution water. U.S. Environmental Protection Agency, Denver, CO.

Wilson, E.F. 1974. The lethal and sub-lethal effects of a zirconium process effluent on juvenile salmonids. Ph.D. thesis. Oregon State University, Corvallis, OR.

Wood, C.M. 1993. Ammonia and urea metabolism and excretion. In: The physiology of fishes. Evans, D.H. (Ed.). CRC Press, Ann Arbor, MI. pp. 379-424.

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals.

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Insect (8th-10th instar), *Erythromma najas*	Ammonium chloride	4 d	R,U	7.5	25	589	**1618**			Beketov 2002
Insect (8th-10th instar), *Erythromma najas*	Ammonium chloride	4 d	R,U	8.7	25	168	**4163**			Beketov 2002
Insect (8th-10th instar), *Erythromma najas*	Ammonium chloride	4 d	R,U	9.1	25	49.2	**2361**	2515	2515	Beketov 2002
Caddisfly, *Philarctus quaeris*	Ammonium chloride	4 d	F,M	7.8	21.9	296.5	**1032**			Arthur et al. 1987
Caddisfly, *Philarctus quaeris*	Ammonium chloride	4 d	F,M	7.8	13.3	561.7	**958.4**	994.5	994.5	West 1985; Arthur et al. 1987
Beetle, *Stenelmis sexlineata*	Ammonium chloride	4 d	F,M	8.7	25	29.7	**735.9**	735.9	735.9	Hazel et al. 1979
Crayfish, *Orconectes immunis*	Ammonium chloride	4 d	F,M	7.9	17.1	488.1	**1367**			Arthur et al. 1987
Crayfish (adult), *Orconectes immunis*	Ammonium chloride	4 d	F,M	8.2	4.6	999.4	**1757**	1550		West 1985; Arthur et al. 1987
Crayfish (2.78 cm), *Orconectes nais*	Ammonium chloride	4 d	F,M	8.3	26.5	23.15	**303.8**	303.8	686.2	Evans 1979
Midge (10 d old, 2-3 instar), *Chironomus riparius*	Ammonium chloride	4 d	R,M	7.7	21.7	357.7	**1029**	1029		Monda et al. 1995
Midge, *Chironomus tentans*	Ammonium chloride	4 d	S,M	6.69	23	430	443.0			Besser et al. 1998
Midge, *Chironomus tentans*	Ammonium chloride	4 d	S,M	7.56	23	564	1439			Besser et al. 1998
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	6.5	25	371	**415.1**			Schubauer-Berigan et al. 1995

NMED Exhibit 61

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	8.1	25	78.1	**614.0**			Schubauer-Berigan et al. 1995
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	6.5	25	368	**411.7**			Schubauer-Berigan et al. 1995
Midge (2nd instar), *Chironomus tentans*	Ammonium chloride	4 d	F,M	8.1	25	50.5	**397.0**	451.8	681.8	Schubauer-Berigan et al. 1995
Mayfly (middle to late instar), *Drunella grandis*	Ammonium chloride	4 d	F,M	7.84	12.8	259.1	**455.5**			Thurston et al. 1984b
Mayfly (middle to late instar), *Drunella grandis*	Ammonium chloride	4 d	F,M	7.84	13.2	195.6	**355.6**			Thurston et al. 1984b
Mayfly (middle to late instar), *Drunella grandis*	Ammonium chloride	4 d	F,M	7.85	12	319	**534.5**	442.4	442.4	Thurston et al. 1984b
Aquatic sowbug, *Caecidotea racovitzai* (previously *Asellus racovitzai*)	Ammonium chloride	4 d	F,M	7.8	22	148.8	**522.3**			Arthur et al. 1987
Aquatic sowbug (adult), *Caecidotea racovitzai*	Ammonium chloride	4 d	F,M	8	4	357.8	**407.7**			West 1985; Arthur et al. 1987
Aquatic sowbug, *Caecidotea racovitzai*	Ammonium chloride	4 d	F,M	7.81	11.9	176	**272.2**	387.0	387.0	Thurston et al. 1983
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	12	2.60	**575.2**			Dehedin et al. 2012
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	12	1.25	**276.6**			Dehedin et al. 2012
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	12	1.70	**376.1**			Dehedin et al. 2012
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	18	2.61	**603.8**			Dehedin et al. 2012
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	18	1.40	**323.9**			Dehedin et al. 2012
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	18	1.95	**451.1**			Dehedin et al. 2012
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	24	1.00	**246.6**			Dehedin et al. 2012

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	24	1.00	**246.6**			Dehedin et al. 2012
Isopod (adult), *Asellus aquaticus*	Ammonium chloride	4 d	F,M	7.05	24	2.00	**493.1**	378.2	378.2	Dehedin et al. 2012
Threespine stickleback (juvenile-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.1	23.3	198.1	**216.5**			Hazel et al. 1971
Threespine stickleback (juvenile-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.15	15	577	**667.4**			Hazel et al. 1971
Threespine stickleback (juvenile-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.25	23.3	203.8	**264.0**			Hazel et al. 1971
Threespine stickleback (juvenile-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	15	143.9	**261.1**			Hazel et al. 1971
Threespine stickleback (juvenile-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	23.3	78.7	**142.8**			Hazel et al. 1971
Threespine stickleback (juvenile-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	23.3	115.4	**209.5**			Hazel et al. 1971
Threespine stickleback (juvenile-adult, 32-60 mm), *Gasterosteus aculeatus*	Ammonium chloride	4 d	S,M	7.5	15	259	**470.0**	281.5	281.5	Hazel et al. 1971
Mayfly, *Callibaetis skokianus*	Ammonium chloride	4 d	F,M	7.7	10.8	263.5	**307.2**			Arthur et al. 1987
Mayfly, *Callibaetis skokianus*	Ammonium chloride	4 d	F,M	7.9	13.3	211.7	**432.7**	364.6		West 1985; Arthur et al. 1987
Mayfly (middle to late instar), *Callibaetis* sp.	Ammonium chloride	4 d	F,M	7.81	11.9	107.8	**166.7**	166.7	246.5	Thurston et al. 1984b

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Dragonfly (<233 d old), *Pachydiplax longipennis*	Ammonium chloride	4 d	F,M	8	12	76.92	**170.1**			Diamond et al. 1993
Dragonfly (<140 d old), *Pachydiplax longipennis*	Ammonium chloride	4 d	F,M	8	20	74.37	**319.2**	233.0	233.0	Diamond et al. 1993
Mottled sculpin (1.8 g, 5.4 cm), *Cottus bairdii*	Ammonium chloride	4 d	F,M	8.02	12.4	49.83	**222.2**	222.2	222.2	Thurston and Russo 1981
Western mosquitofish, *Gambusia affinis*	-	4 d	S,U	7.75	19	129.6	**352.9**			Wallen et al. 1957
Western mosquitofish, *Gambusia affinis*	-	4 d	S,U	8.2	19.5	34.54	**217.7**			Wallen et al. 1957
Western mosquitofish, *Gambusia affinis*	-	4 d	S,U	8.5	23	14.64	**165.0**			Wallen et al. 1957
Western mosquitofish, *Gambusia affinis*	-	4 d	S,U	8	24	42.53	**182.6**	219.3	219.3	Wallen et al. 1957
Oligochaete worm, *Lumbriculus variegatus*	Ammonium chloride	4 d	S,M	7.56	23	286	729.5			Besser et al. 1998
Oligochaete worm, *Lumbriculus variegatus*	Ammonium chloride	4 d	S,M	6.69	23	302	311.1			Besser et al. 1998
Oligochaete worm (10-25 mm), *Lumbriculus variegatus*	Ammonium chloride	4 d	R,M	8.2	15	13.66	56.88			Hickey and Vickers 1994
Oligochaete worm (adult), *Lumbriculus variegatus*	-	4 d	F,M	6.5	25	100	**111.9**			Schubauer-Berigan et al. 1995
Oligochaete worm (adult), *Lumbriculus variegatus*	-	4 d	F,M	6.5	25	200	**223.8**			Schubauer-Berigan et al. 1995
Oligochaete worm (adult), *Lumbriculus variegatus*	-	4 d	F,M	8.1	25	34	**267.3**			Schubauer-Berigan et al. 1995
Oligochaete worm (adult), *Lumbriculus variegatus*	-	4 d	F,M	8.1	25	43.5	**342.0**	218.7	218.7	Schubauer-Berigan et al. 1995
Tubificid worm, *Tubifex tubifex*	Ammonium chloride	4 d	S,U	8.2	12	66.67	**216.5**	216.5	216.5	Stammer 1953

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Marsh ramshorn snail, *Planorbella trivolvis* (previously *Helisoma trivolvis*)	Ammonium chloride	4 d	F,M	7.9	22	47.73	**200.7**			Arthur et al. 1987
Marsh ramshorn snail, *Planorbella trivolvis*	Ammonium chloride	4 d	F,M	8.2	12.9	63.73	**223.0**	211.6	211.6	Arthur et al. 1987
Scud (7-14 d old), *Hyalella azteca*	Ammonium chloride	4 d	R,M	8.3	25	39.8	**461.2**			Ankley et al. 1995
Scud (7-14 d old), *Hyalella azteca*	Ammonium chloride	4 d	R,M	7.31	25	64	**135.1**			Ankley et al. 1995
Scud (7-14 d old), *Hyalella azteca*	Ammonium chloride	4 d	R,M	6.43	25	105	**114.6**	192.6	192.6	Ankley et al. 1995
Stonefly, Little golden stonefly (middle to late instar), *Skwala americana*	Ammonium chloride	4 d	F,M	7.81	13.1	109.3	**186.7**			Thurston et al. 1984b
Stonefly, Little golden stonefly (middle to late instar), *Skwala americana*	Ammonium chloride	4 d	F,M	7.76	13.8	119.6	**198.3**	192.4	192.4	Thurston et al. 1984b
Mozambique tilapia (juvenile), *Oreochromis mossambicus*	Ammonium chloride	4 d	R,U	7.2	28	151.5	**185.2**	185.2	185.2	Rani et al. 1998
Amphipod (4-6 mm), *Crangonyx pseudogracilis*	Ammonium chloride	4 d	S,U	7.5	12	43.36	40.54			Prenter et al. 2004
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	4	199.5	**227.3**			West 1985; Arthur et al. 1987
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	12.1	216	**481.7**			West 1985; Arthur et al. 1987
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	13.3	115.3	**284.1**			West 1985; Arthur et al. 1987
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8	24.9	25.1	**161.7**			West 1985; Arthur et al. 1987
Amphipod, *Crangonyx pseudogracilis*	Ammonium chloride	4 d	F,M	8.2	13	81.6	**287.9**	270.5		West 1985; Arthur et al. 1987

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Amphipod (13 d), *Crangonyx* sp.	Ammonium chloride	4 d	F,M	8	12	79.23	**175.3**			Diamond et al. 1993
Amphipod (8-42 d), *Crangonyx* sp.	Ammonium chloride	4 d	F,M	8	20	19.83	**85.13**	122.2	181.8	Diamond et al. 1993
Tubificid worm (30-40 mm), *Limnodrilus hoffmeisteri*	-	4 d	F,M	7.9	11.5	96.62	**170.2**	170.2	170.2	Williams et al. 1986
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8	4	114.9	**131.0**			West 1985; Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8.2	5.5	85.13	**161.3**			West 1985; Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8.1	12.1	76.29	**205.9**			West 1985; Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8.2	12.8	50.25	**174.4**			West 1985; Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8	13.3	62.39	**153.7**			West 1985; Arthur et al. 1987
Pouch snail, *Physa gyrina*	Ammonium chloride	4 d	F,M	8	24.9	26.33	**169.7**	164.5	164.5	West 1985; Arthur et al. 1987
Damselfly (8-10 mm), *Enallagma* sp.	-	4 d	F,M	7.9	11.5	93.1	**164.0**	164.0	164.0	Williams et al. 1986
Water flea (<24 hr), *Chydorus sphaericus*	Ammonium chloride	4 d	S,M	8	20	37.88	**162.6**	162.6	162.6	Dekker et al. 2006
Fathead minnow (larva, 14 d), *Pimephales promelas*	-	4 d	S,U	7.6	20	37.56	79.59			Markle et al. 2000
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.52	20.25	36.73	68.17			EA Engineering 1985
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.48	19.85	40.93	72.10			EA Engineering 1985
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.52	20.25	37.49	69.59			EA Engineering 1985

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.48	19.85	41.79	73.61			EA Engineering 1985
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	S,M	7.48	19.85	43.49	76.61			EA Engineering 1985
Fathead minnow (4-6 d old), *Pimephales promelas*	Ammonium chloride	4 d	R,M	8.01	25	14.4	63.00			Buhl 2002
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	R,M	8	20	5.389	23.13			Diamond et al. 1993
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	R,M	8	20	6.1	26.19			Diamond et al. 1993
Fathead minnow (1.9 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.9	3.4	229.7	**818.4**			West 1985; Arthur et al. 1987
Fathead minnow (1.8 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	12.1	56.07	**291.3**			West 1985; Arthur et al. 1987
Fathead minnow (1.6 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8	17.1	52.22	**224.2**			West 1985; Arthur et al. 1987
Fathead minnow (1.7 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	26.1	29.23	**151.8**			West 1985; Arthur et al. 1987
Fathead minnow, *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.05	14	47.29	**223.2**			DeGraeve et al. 1980
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.46	6	97.27	**166.4**			DeGraeve et al. 1987
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.46	10	101.7	**174.0**			DeGraeve et al. 1987
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.41	15	76.58	**122.0**			DeGraeve et al. 1987
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.41	20	78.22	**124.6**			DeGraeve et al. 1987
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.45	20	66.94	**112.9**			DeGraeve et al. 1987
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.4	25	81.81	**128.5**			DeGraeve et al. 1987
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.41	25	91.4	**145.6**			DeGraeve et al. 1987
Fathead minnow (4-5 mo), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.44	30	64.12	**106.6**			DeGraeve et al. 1987

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Fathead minnow (0.28 g, 26.6 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.14	22	25.16	**141.2**			Mayes et al. 1986
Fathead minnow (10 mm length), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.9	20.6	28.9	**103.0**			Nimmo et al. 1989
Fathead minnow (10 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.2	6.2	7.322	**46.15**			Nimmo et al. 1989
Fathead minnow (10 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.8	20.1	18.73	**55.68**			Nimmo et al. 1989
Fathead minnow (10 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.8	19.8	32.12	**95.49**			Nimmo et al. 1989
Fathead minnow (25 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	19.6	24.89	**129.3**			Nimmo et al. 1989
Fathead minnow (25 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.2	6.2	11.56	**72.86**			Nimmo et al. 1989
Fathead minnow (25 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	5.8	19.94	**103.6**			Nimmo et al. 1989
Fathead minnow (25 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.1	5.8	21.44	**111.4**			Nimmo et al. 1989
Fathead minnow (25 mm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.7	20.1	32.25	**80.61**			Nimmo et al. 1989
Fathead minnow (15 mm, 0.0301 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.46	4.1	18.54	**193.5**			Reinbold and Pescitelli 1982b
Fathead minnow (16 mm, 0.0315 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.02	23.9	19.55	**87.16**			Reinbold and Pescitelli 1982b
Fathead minnow (19 mm, 0.0629 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.26	4.6	30.57	**216.5**			Reinbold and Pescitelli 1982b
Fathead minnow (21 mm, 0.0662 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.16	25.2	17.65	**102.9**			Reinbold and Pescitelli 1982b

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Fathead minnow (5.2 cm, 1.1 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.7	21.65	63.02	**157.5**			Sparks 1975
Fathead minnow (0.2 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.78	25.9	40.85	**117.3**			Swigert and Spacie 1983
Fathead minnow (0.5 g), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.8	25.6	42.65	**126.8**			Swigert and Spacie 1983
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.83	11.8	45.71	**143.4**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.82	12	62.72	**193.3**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	6.51	13	260	**192.9**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	9.03	13.2	5.94	**169.6**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.51	13.5	18.88	**216.9**			Thurston et al. 1981c
Fathead minnow (1.9 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.01	13.8	145.9	**147.2**			Thurston et al. 1981c
Fathead minnow (0.09 g, 2.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.91	16.3	51.55	**187.1**			Thurston et al. 1983
Fathead minnow (0.09 g, 2.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.89	13.1	50.2	**175.6**			Thurston et al. 1983
Fathead minnow (0.13 g, 2.3 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.64	13.6	58.4	**132.1**			Thurston et al. 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Fathead minnow (0.19 g, 2.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.68	13.5	64.7	**156.3**			Thurston et al. 1983
Fathead minnow (0.22 g, 2.7 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.03	22.1	47.6	**216.3**			Thurston et al. 1983
Fathead minnow (0.22 g, 2.9 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.06	22	42.6	**205.0**			Thurston et al. 1983
Fathead minnow (0.26 g, 3.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.67	13.9	58.8	**139.7**			Thurston et al. 1983
Fathead minnow (0.31 g, 3.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.05	13	74.65	**352.4**			Thurston et al. 1983
Fathead minnow (0.31 g, 3.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.05	13.6	66.48	**313.8**			Thurston et al. 1983
Fathead minnow (0.35 g, 3.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.94	19.1	42.3	**162.3**			Thurston et al. 1983
Fathead minnow (0.42 g, 3.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.76	19	50.28	**139.3**			Thurston et al. 1983
Fathead minnow (0.42 g, 3.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.66	13.4	58.2	**136.0**			Thurston et al. 1983
Fathead minnow (0.47 g, 3.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.87	15.8	58.91	**198.7**			Thurston et al. 1983
Fathead minnow (0.47 g, 3.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.83	22	50.6	**158.7**			Thurston et al. 1983
Fathead minnow (0.5 g, 3.8 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.91	18.9	49.3	**178.9**			Thurston et al. 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Fathead minnow (0.8 g, 4.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.77	14.3	66.7	**188.1**			Thurston et al. 1983
Fathead minnow (1.0 g, 4.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.77	14.1	72.71	**205.1**			Thurston et al. 1983
Fathead minnow (1.4 g, 4.9 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.04	22.4	36.59	**169.5**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.08	21.4	44.8	**224.0**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.0 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	8.16	21.4	47.39	**276.4**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.88	21.7	50.9	**174.8**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.4 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.68	12.9	91.8	**221.8**			Thurston et al. 1983
Fathead minnow (1.4 g, 5.5 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.63	13.2	89.85	**199.9**			Thurston et al. 1983
Fathead minnow (1.5 g, 5.6 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.76	12.9	107.5	**298.0**			Thurston et al. 1983
Fathead minnow (1.7 g, 5.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.84	21.7	55.43	**177.0**			Thurston et al. 1983
Fathead minnow (2.1 g, 6.1 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.76	13.1	66.73	**184.9**			Thurston et al. 1983
Fathead minnow (2.2 g, 6.2 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.74	12.8	52.2	**139.7**			Thurston et al. 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Fathead minnow (2.3 g, 6.3 cm), *Pimephales promelas*	Ammonium chloride	4 d	F,M	7.91	15.9	47.43	**172.1**	159.2	159.2	Thurston et al. 1983
Brook trout (3.12 g, 7.2 cm), *Salvelinus fontinalis*	Ammonium chloride	4 d	F,U	7.86	13.6	45.21	**149.7**			Thurston and Meyn 1984
Brook trout (3.40 g, 7.4 cm), *Salvelinus fontinalis*	Ammonium chloride	4 d	F,U	7.83	13.8	52.03	**163.2**	156.3		Thurston and Meyn 1984
Lake trout, siscowet (0.9 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	90.43	**152.5**			Soderberg and Meade 1992
Lake trout, siscowet (0.9 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	110.2	**185.9**			Soderberg and Meade 1992
Lake trout, siscowet (8 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	96.25	**162.3**			Soderberg and Meade 1992
Lake trout, siscowet (8 g), *Salvelinus namaycush*	Ammonium chloride	4 d	S,M	7.45	8.5	83.11	**140.1**	159.3	157.8	Soderberg and Meade 1992
Shortnose sturgeon (fingerling), *Acipenser brevirostrum*	Ammonium chloride	4 d	S,M	7.05	18	149.8	**156.7**	156.7	156.7	Fontenot et al. 1998
White sucker (5.6 g), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	7.8	3.6	89.57	**266.3**			West 1985; Arthur et al. 1987
White sucker (5.2 g), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	8.1	11.3	60.86	**316.1**			West 1985; Arthur et al. 1987
White sucker (12.6 g), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	8.2	12.6	40.85	**257.4**			West 1985; Arthur et al. 1987
White sucker (9.6 g), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	8.2	15.3	43.01	**271.0**			West 1985; Arthur et al. 1987
White sucker (110 mm), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	7.8	20.2	31.21	**92.80**			Nimmo et al. 1989
White sucker (110 mm), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	7.8	20.2	18.93	**56.28**			Nimmo et al. 1989
White sucker (92 mm, 6.3 g), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	8.16	15	30.28	**176.6**			Reinbold and Pescitelli 1982c

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
White sucker (92 mm, 6.3 g), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	8.14	15.4	29.65	**166.3**			Reinbold and Pescitelli 1982c
White sucker (11.4 g), *Catostomus commersonii*	Ammonium chloride	4 d	F,M	7.8	22.5	22.3	**66.32**	157.5		Swigert and Spacie 1983
Mountain sucker (63.3 g, 18.2 cm), *Catostomus platyrhynchus*	Ammonium chloride	4 d	F,U	7.67	12	66.91	**159.0**			Thurston and Meyn 1984
Mountain sucker (45.3 g, 16.2 cm), *Catostomus platyrhynchus*	Ammonium chloride	4 d	F,U	7.69	13.2	47.59	**117.0**			Thurston and Meyn 1984
Mountain sucker (47.8 g, 15.9 cm), *Catostomus platyrhynchus*	Ammonium chloride	4 d	F,U	7.73	11.7	51.62	**135.8**	136.2	146.5	Thurston and Meyn 1984
Water flea, *Ceriodaphnia acanthina*	Ammonium chloride	2 d	F,M	7.06	24	104.8	**154.3**	154.3		Mount 1982
Water flea (<24 hr), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.02	24.8	21.26	**141.1**			Andersen and Buckley 1998
Water flea (<24 hr), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.5	25	47.05	**129.2**			Bailey et al. 2001
Water flea (<24 hr), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.5	25	56.84	**156.1**			Bailey et al. 2001
Water flea (<24 hr), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.16	22	24.77	**170.5**			Black 2001
Water flea (<24 hr), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.4	23	28.06	**334.5**			Black 2001
Water flea (<24 hr), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.4	23	32.63	**389.0**			Black 2001
Water flea (<24 hr), *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8	25	14.52	**94.35**			Scheller 1997
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	8.08	24.75	15.6	**114.5**			Andersen and Buckley 1998
Water flea, *Ceriodaphnia dubia*	Ammonium hydroxide	2 d	R,M	8.4	26.4	7.412	**117.1**			Cowgill and Milazzo 1991

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Water flea, *Ceriodaphnia dubia*	Ammonium sulfate	2 d	R,NR	7.4	23	48.59	**97.89**			Manning et al. 1996
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	R,M	7.8	25	33.98	**152.9**			Nimmo et al. 1989
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	R,M	8.2	7	16.65	**35.72**			Nimmo et al. 1989
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.85	23	28.65	**119.5**			Sarda 1994
Water flea, *Ceriodaphnia dubia*	Ammonium chloride	2 d	S,M	7.85	23	28.77	**120.0**	134.2	143.9	Sarda 1994
Water flea (adult), *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	8.3	17	31.58	**188.5**			West 1985; Arthur et al. 1987
Water flea (adult), *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	8.1	20.4	21.36	**114.7**			Arthur et al. 1987
Water flea, *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	7.25	24.5	83.51	**157.0**			Mount 1982
Water flea, *Simocephalus vetulus*	Ammonium chloride	2 d	F,M	7.06	24	83.51	**122.9**	142.9	142.9	Mount 1982
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,U	8.7	22	10.56	172.9			Colt and Tchobanoglous 1976
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,U	8.7	26	10.19	166.9			Colt and Tchobanoglous 1976
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,U	8.7	30	10.88	178.1			Colt and Tchobanoglous 1976
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,M	7.49	19.7	131.5	235.0			EA Engineering 1985
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	S,M	7.53	19.75	99.67	189.3			EA Engineering 1985
Channel catfish (larvae, 1 d), *Ictalurus punctatus*	Ammonium chloride	4 d	R,M	8.2	23.8	13.03	82.10			Bader and Grizzle 1992
Channel catfish (juvenile, 7 d), *Ictalurus punctatus*	Ammonium chloride	4 d	R,M	8.2	23.9	17.22	108.5			Bader and Grizzle 1992
Channel catfish (3.5 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.8	19.6	44.71	**132.9**			West 1985; Arthur et al. 1987

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Channel catfish (5.8 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8	3.5	37.64	**161.6**			West 1985; Arthur et al. 1987
Channel catfish (6.4 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.1	14.6	24.94	**129.5**			West 1985; Arthur et al. 1987
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.4	28	10.71	**99.59**			Colt and Tchobanoglous 1978
Channel catfish (3-11 mo), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.46	10	124.8	**213.5**			DeGraeve et al. 1987
Channel catfish (3-11 mo), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.41	15	113.1	**180.2**			DeGraeve et al. 1987
Channel catfish (3-11 mo), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.41	20	89.63	**142.8**			DeGraeve et al. 1987
Channel catfish (3-11 mo), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.45	20	72.15	**121.7**			DeGraeve et al. 1987
Channel catfish (3-11 mo), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.4	25	89.41	**140.5**			DeGraeve et al. 1987
Channel catfish (3-11 mo), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.41	25	85.69	**136.5**			DeGraeve et al. 1987
Channel catfish (3-11 mo), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.44	30	65.25	**108.5**			DeGraeve et al. 1987
Channel catfish (<110 d), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8	20	15.09	**64.77**			Diamond et al. 1993
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.94	23.8	33.1	**127.0**			Reinbold and Pescitelli 1982d
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.98	23.8	30.49	**126.1**			Reinbold and Pescitelli 1982d
Channel catfish (4.5-10.8 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.08	28	44.44	**222.2**			Roseboom and Richey 1977
Channel catfish (7.1-12.7 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.09	22	32.33	**164.8**			Roseboom and Richey 1977
Channel catfish (14.3 mm, 19.0 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.93	20	74.35	**277.4**			Sparks 1975
Channel catfish (0.5 g), *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	7.8	25.7	32.85	**97.67**			Swigert and Spacie 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8	26	32.34	**138.8**			West 1985
Channel catfish, *Ictalurus punctatus*	Ammonium chloride	4 d	F,M	8.1	17	40.83	**212.1**	142.4	142.4	West 1985
Red swamp crayfish (2.1 cm), *Procambarus clarkii*	Ammonium chloride	4 d	F,M	8	20	26.08	**112.0**			Diamond et al. 1993
Red swamp crayfish (<2.5 cm), *Procambarus clarkii*	Ammonium chloride	4 d	F,M	8	12	76.92	**170.1**	138.0	138.0	Diamond et al. 1993
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.4	1.8	123	**87.86**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.4	1.8	133.9	**95.64**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	2.1	297.2	**195.1**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	2.1	341.1	**223.9**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	2.5	400	**264.4**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	2.5	491.7	**325.0**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	7.3	581.5	**381.7**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6	7.3	587.6	**385.7**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	7.4	171.3	**124.4**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	7.4	214.4	**155.7**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	12.5	230.6	**167.4**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.45	12.5	248.3	**180.3**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	12.5	403.5	**266.7**			Knoph 1992

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	12.5	451.5	**298.5**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	17.1	356.1	**235.4**			Knoph 1992
Atlantic salmon (4.8-9.2 cm), *Salmo salar*	Ammonium sulfate	4 d	S,M	6.05	17.1	373	**246.6**			Knoph 1992
Atlantic salmon (1.5 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	60.29	**101.7**			Soderberg and Meade 1992
Atlantic salmon (1.5 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	35.74	**60.26**			Soderberg and Meade 1992
Atlantic salmon (36 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	118.2	**199.3**			Soderberg and Meade 1992
Atlantic salmon (36 g), *Salmo salar*	Ammonium chloride	4 d	S,M	7.45	8.5	70.62	**119.1**	183.3		Soderberg and Meade 1992
Brown trout (1.20 g, 5.4 cm), *Salmo trutta*	Ammonium chloride	4 d	F,U	7.85	13.2	29.58	**96.20**			Thurston and Meyn 1984
Brown trout (1.17 g, 5.3 cm), *Salmo trutta*	Ammonium chloride	4 d.	F,U	7.86	13.8	32.46	**107.5**			Thurston and Meyn 1984
Brown trout (0.91 g, 4.9 cm), *Salmo trutta*	Ammonium chloride	4 d	F,U	7.82	14.2	33.3	**102.6**	102.0	136.7	Thurston and Meyn 1984
White perch (76 mm), *Morone americana*	Ammonium chloride	4 d	S,M	8	16	14.93	**64.09**			Stevenson 1977
White perch (76 mm), *Morone americana*	Ammonium chloride	4 d	S,M	6	16	418.4	**274.7**	132.7		Stevenson 1977
White bass (4.4 g), *Morone chrysops*	Ammonium chloride	4 d	S,M	7.09	19.7	132.4	**144.0**	144.0		Ashe et al. 1996
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.4	23.3	92.17	**144.8**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	23.3	73.45	**133.3**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.35	15	259.7	**378.9**			Hazel et al. 1971

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	15	182.3	**330.7**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.93	23.3	48.03	**180.8**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	23.3	125.9	**228.5**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.84	15	165.7	**524.6**			Hazel et al. 1971
Striped bass (20-93 mm), *Morone saxatilis*	Ammonium chloride	4 d	S,M	7.5	15	354.9	**644.0**			Hazel et al. 1971
Striped bass (126.6 g), *Morone saxatilis*	Ammonium chloride	4 d	S,M	8.3	21	12.86	**98.43**	246.2		Oppenborn and Goudie 1993
Sunshine bass (larvae, 12 h), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	8.5	18.7	3.903	**43.99**			Harcke and Daniels 1999
Sunshine bass (367.2 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	8.3	21	8.147	**62.37**			Oppenborn and Goudie 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	63.62	**63.62**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	83.06	**83.06**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	56.55	**56.55**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	65.39	**65.39**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	60.09	**60.09**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	64.51	**64.51**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	79.53	**79.53**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	86.6	**86.60**			Weirich et al. 1993
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	95.43	**95.43**			Weirich et al. 1993

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Sunshine bass (42.7 g), *Morone saxatilis x chrysops*	Ammonium chloride	4 d	S,M	7	25	105.2	**105.2**	70.22	134.8	Weirich et al. 1993
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.5	20	26.34	**296.9**			Gersich and Hopkins 1986
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.92	21	9.463	**37.66**			Gulyas and Fleit 1990
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.2	25	20.71	**197.5**			Parkhurst et al. 1979, 1981
Water flea, *Daphnia magna*	Ammonium chloride	2 d	R,U	8.34	19.7	51.92	**419.1**			Reinbold and Pescitelli 1982a
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.07	19.6	51.09	**242.4**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.51	20.1	48.32	**89.74**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.53	20.1	55.41	**106.1**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.5	20.3	43.52	**80.98**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.4	20.6	42.31	**69.88**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.09	20.9	41.51	**227.9**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	7.95	22	51.3	**236.7**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.15	22	37.44	**252.8**			Russo et al. 1985
Water flea, *Daphnia magna*	Ammonium chloride	2 d	S,M	8.04	22.8	38.7	**226.1**	157.7		Russo et al. 1985
Water flea, *Daphnia pulicaria*	Ammonium chloride	2 d	F,M	8.05	14	34.5	**99.03**	99.03	125.0	DeGraeve et al. 1980
Clawed toad (embryo), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.2	22	38.59	**40.91**			Schuytema and Nebeker 1999a

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Clawed toad (embryo), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.2	22	119.6	**126.8**			Schuytema and Nebeker 1999a
Clawed toad (embryo), *Xenopus laevis*	Ammonium nitrate	4 d	R,M	7.2	24	32.37	**39.55**			Schuytema and Nebeker 1999a
Clawed toad (embryo), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.2	24	60.71	**74.17**			Schuytema and Nebeker 1999a
Clawed toad (17 mg, Gosner Stage 26-27), *Xenopus laevis*	Nitric acid ammonium salt	4 d	R,M	7.15	22	101.4	**117.2**			Schuytema and Nebeker 1999b
Clawed toad (17 mg, Gosner Stage 26-27), *Xenopus laevis*	Ammonium sulfate	4 d	R,M	7.15	22	135.9	**157.2**			Schuytema and Nebeker 1999b
Clawed toad (21 mg, Gosner Stage 26-27), *Xenopus laevis*	Ammonium chloride	4 d	R,M	7.15	22	128.3	**148.4**			Schuytema and Nebeker 1999b
Clawed toad (embryo), *Xenopus laevis*	Ammonium phosphate	4 d	R,M	8.43	25	37.3	**367.4**			Tietge et al. 2000
Clawed toad (embryo), *Xenopus laevis*	Ammonium phosphate	4 d	R,M	8.62	25	28.7	**405.6**	122.5	122.5	Tietge et al. 2000
Flatworm, *Dendrocoelum lacteum*	Ammonium chloride	4 d	S,U	8.2	18	22.37	**119.5**	119.5	119.5	Stammer 1953
Walleye, *Sander vitreus*	Ammonium chloride	4 d	F,U	8.08	18.2	17.43	87.13			Reinbold and Pescitelli 1982a
Walleye (22.6 g), *Sander vitreus*	Ammonium chloride	4 d	F,M	7.9	3.7	48.37	**172.3**			West 1985; Arthur et al. 1987
Walleye (19.4 g), *Sander vitreus*	Ammonium chloride	4 d	F,M	7.7	11.1	89.93	**224.8**			West 1985; Arthur et al. 1987
Walleye (13.4 g), *Sander vitreus*	Ammonium chloride	4 d	F,M	8.3	19	6.123	**46.87**			West 1985; Arthur et al. 1987
Walleye (3.0 g, 65.6 mm), *Sander vitreus*	Ammonium chloride	4 d	F,M	8.06	21.5	21.49	**103.4**	117.1	117.1	Mayes et al. 1986
Central stoneroller (2.1 g), *Campostoma anomalum*	Ammonium chloride	4 d	F,M	7.8	25.7	38.97	**115.9**	115.9	115.9	Swigert and Spacie 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Rainbow dace, *Cyprinella lutrensis*	Ammonium chloride	4 d	F,M	8.3	24	24.37	**186.5**			Hazel et al. 1979
Rainbow dace, *Cyprinella lutrensis*	Ammonium chloride	4 d	F,M	9.1	24	6.502	**206.1**	196.1		Hazel et al. 1979
Spotfin shiner (31-85 mm), *Cyprinella spiloptera*	Ammonium chloride	4 d	F,M	7.95	26.5	18.52	**72.39**			Rosage et al. 1979
Spotfin shiner (41-78 mm), *Cyprinella spiloptera*	Ammonium chloride	4 d	F,M	8.15	26.5	16.27	**93.07**			Rosage et al. 1979
Spotfin shiner (0.5 g), *Cyprinella spiloptera*	Ammonium chloride	4 d	F,M	7.9	25.7	24.52	**87.36**	83.80		Swigert and Spacie 1983
Steelcolor shiner (0.5 g), *Cyprinella whipplei*	Ammonium chloride	4 d	F,M	7.9	25.7	22.72	**80.94**	80.94	110.0	Swigert and Spacie 1983
Dwarf wedgemussel (glochidia), *Alasmidonta heterodon*	Ammonium chloride	1 d	S,M	8.3	20	>14.24 [c]	**>109.0**	>109.0	>109.0	Wang et al. 2007b
Pink papershell (glochidia), *Potamilus ohiensis*	Ammonium chloride	1 d	S,M	8.3	20	>14.24 [c]	**>109.0**	>109.0	>109.0	Wang et al. 2007b
Green sunfish (larvae, 9 d swim up fry), *Lepomis cyanellus*	Ammonium chloride	4 d	F,U	8.28	26.2	8.43	62.07			Reinbold and Pescitelli 1982a
Green sunfish, *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	7.84	12.3	33.09	**105.7**			Jude 1973
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	7.2	22.4	142.9	**174.5**			McCormick et al. 1984
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	6.61	22.4	254.5	**197.0**			McCormick et al. 1984
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	7.72	22.4	55.79	**144.3**			McCormick et al. 1984
Green sunfish (62.5 mg), *Lepomis cyanellus*	Ammonium chloride	4 d	F,M	8.69	22.4	9.24	**148.6**	150.8		McCormick et al. 1984

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Pumpkinseed (4.13-9.22 g), *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.77	12	9.11	**25.69**			Jude 1973
Pumpkinseed, *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.77	14	48.09	**135.6**			Thurston 1981
Pumpkinseed, *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.77	14.5	42.02	**118.5**			Thurston 1981
Pumpkinseed, *Lepomis gibbosus*	Ammonium chloride	4 d	F,M	7.71	15.7	48.54	**87.54**	77.53		Thurston 1981
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.51	20.35	40.41	73.88			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.51	20.35	41.96	76.72			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.52	20.65	41.9	78.36			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.51	20.35	44.3	80.98			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.52	20.65	42.63	79.73			EA Engineering 1985
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	S,M	7.52	20.65	44.1	82.48			EA Engineering 1985
Bluegill (1.7 cm), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8	20	21.56	**92.54**			Diamond et al. 1993
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8	12	25.12	**107.9**			Diamond et al. 1993
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.11	18.5	16.73	**88.57**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.24	18.5	42.01	**286.1**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.75	18.5	12.7	**227.4**			Emery and Welch 1969

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.05	18.5	6.581	**193.8**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.19	18.5	3.755	**135.0**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.62	18.5	0.7859	**44.84**			Emery and Welch 1969
Bluegill (20.0-70.0 mm, young of year), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	9.85	18.5	1.346	**89.70**			Emery and Welch 1969
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.6	24	5.509	**75.01**			Hazel et al. 1979
Bluegill (5.2 cm), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.9	24.25	33.06	**117.8**			Lubinski et al. 1974
Bluegill (0.38 g, 26.3 mm), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.1	22	19.39	**100.7**			Mayes et al. 1986
Bluegill (19 mm, 0.0781 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.4	4	14.64	**136.1**			Reinbold and Pescitelli 1982b
Bluegill (22 mm, 0.1106 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.12	25	23.37	**126.2**			Reinbold and Pescitelli 1982b
Bluegill (28 mm, 0.250 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.16	4.5	12.55	**73.19**			Reinbold and Pescitelli 1982b
Bluegill (30 mm, 0.267 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.09	24.8	17.22	**87.75**			Reinbold and Pescitelli 1982b
Bluegill (217 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8	22	12.75	**54.74**			Roseboom and Richey 1977
Bluegill (342 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.2	28	14.81	**93.31**			Roseboom and Richey 1977
Bluegill (646 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.93	22	24.08	**90.66**			Roseboom and Richey 1977
Bluegill (72 mg), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	8.07	22	8.846	**43.38**			Roseboom and Richey 1977
Bluegill, *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.6	21.7	44.03	**93.31**			Smith et al. 1984

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Bluegill (4.8 cm, 1.1 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.85	22.05	59.93	**194.9**			Sparks 1975
Bluegill (0.9 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.8	24.2	33.88	**100.7**			Swigert and Spacie 1983
Bluegill (0.9 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.6	26.5	58.69	**124.4**			Swigert and Spacie 1983
Bluegill (1.2 g), *Lepomis macrochirus*	Ammonium chloride	4 d	F,M	7.8	26.6	37.52	**111.6**	104.5	106.9	Swigert and Spacie 1983
Common carp (206 mg), *Cyprinus carpio*	Ammonium chloride	4 d	R,M	7.72	28	51.78	**133.9**			Hasan and MacIntosh 1986
Common carp (299 mg), *Cyprinus carpio*	Ammonium chloride	4 d	R,M	7.72	28	48.97	**126.6**			Hasan and MacIntosh 1986
Common carp (4-5 cm), *Cyprinus carpio*	Ammonium chloride	4 d	R,M	7.4	28	45.05	**70.78**	106.3	106.3	Rao et al. 1975
Golden trout (0.09 g, 24 cm), *Oncorhynchus aguabonita*	Ammonium chloride	4 d	F,M	8.06	13.2	23.3	**112.1**	112.1		Thurston and Russo 1981
Cutthroat trout (3.6 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.7	10	17.3	**43.24**			Thurston et al. 1981a
Cutthroat trout (3.6 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.7	10	29.1	**72.73**			Thurston et al. 1981a
Cutthroat trout (4.1 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.7	10	19.3	**48.24**			Thurston et al. 1981a
Cutthroat trout (4.1 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.7	10	26.3	**65.73**			Thurston et al. 1981a
Cutthroat trout (3.4 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.78	12.2	32.57	**93.49**			Thurston et al. 1978
Cutthroat trout (3.3 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.8	12.4	36.55	**108.7**			Thurston et al. 1978
Cutthroat trout (1.0 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.8	12.8	37.75	**112.2**			Thurston et al. 1978
Cutthroat trout (1.0 g), *Oncorhynchus clarkii*	Ammonium chloride	4 d	F,M	7.81	13.1	43.72	**132.3**	78.92		Thurston et al. 1978

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Pink salmon (late alevins), *Oncorhynchus gorbuscha*	Ammonium sulfate	4 d	S,M	6.4	4.3	230.5	**164.6**			Rice and Bailey 1980
Pink salmon (fry), *Oncorhynchus gorbuscha*	Ammonium sulfate	4 d	S,M	6.4	4.3	277.7	**198.3**	180.7		Rice and Bailey 1980
Coho salmon (6 g), *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8.1	17.2	11.59	**60.20**			Buckley 1978
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7	15	82.02	**82.02**			Wilson 1974; Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7	15	84.43	**84.43**			Wilson 1974; Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7.5	15	50.65	**91.90**			Wilson 1974; Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	7.5	15	52.76	**95.73**			Wilson 1974; Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8	15	21.63	**92.84**			Wilson 1974; Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8	15	22	**94.44**			Wilson 1974; Robinson-Wilson and Seim 1975
Coho salmon, *Oncorhynchus kisutch*	Ammonium chloride	4 d	F,M	8.5	15	9.093	**102.5**	87.05		Wilson 1974; Robinson-Wilson and Seim 1975
Rainbow trout (0.5-3.0 g), *Oncorhynchus mykiss*	Ammonium sulfate	4 d	S,U	7.95	15	51.06	199.6			Qureshi et al. 1982
Rainbow trout (McConaughy strain, 251 mg), *Oncorhynchus mykiss*	Ammonium chloride	4 d	S,M	6.84	12	112	98.86			Buhl and Hamilton 2000
Rainbow trout, *Oncorhynchus mykiss*	Ammonium chloride	4 d	S,M	7.55	15	34.23	67.04			Craig and Beggs 1979
Rainbow trout (0.80 g), *Oncorhynchus mykiss*	-	4 d	S,M	6.95	14.7	163.6	156.9			Environment Canada 2004
Rainbow trout (0.60 g), *Oncorhynchus mykiss*	-	4 d	S,M	6.97	14.5	144	140.3			Environment Canada 2004
Rainbow trout (0.63 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.02	15.4	146.7	149.4			Environment Canada 2004

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Rainbow trout (0.80 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.02	14.6	159	161.8			Environment Canada 2004
Rainbow trout (0.80 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.03	15.1	156.6	160.9			Environment Canada 2004
Rainbow trout (0.90 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.18	15.1	141.6	169.2			Environment Canada 2004
Rainbow trout (2.01 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.45	15.1	104.4	176.0			Environment Canada 2004
Rainbow trout (1.30 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.47	14.7	72.65	126.1			Environment Canada 2004
Rainbow trout (0.78 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.47	14.5	79.67	138.3			Environment Canada 2004
Rainbow trout (0.40 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.51	14.2	73.71	135.8			Environment Canada 2004
Rainbow trout (1.64 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.54	14.6	75.3	145.2			Environment Canada 2004
Rainbow trout (1.13 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.59	13.9	59.4	123.9			Environment Canada 2004
Rainbow trout (1.50 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.87	15.1	42.9	144.7			Environment Canada 2004
Rainbow trout (1.38 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.93	15.2	41.15	155.0			Environment Canada 2004
Rainbow trout (0.90 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.97	15.2	36.17	145.4			Environment Canada 2004
Rainbow trout (1.00 g), *Oncorhynchus mykiss*	-	4 d	S,M	7.98	15.1	35.29	145.9			Environment Canada 2004
Rainbow trout (1.30 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.03	14.9	23.03	104.6			Environment Canada 2004
Rainbow trout (1.26 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.04	14.3	25.84	119.7			Environment Canada 2004
Rainbow trout (1.60 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.34	15.3	19.15	158.5			Environment Canada 2004
Rainbow trout (1.30 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.39	15.3	12.05	109.9			Environment Canada 2004
Rainbow trout (1.11 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.4	14.9	12.84	119.4			Environment Canada 2004

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Rainbow trout (1.40 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.44	14.7	14.41	144.7			Environment Canada 2004
Rainbow trout (0.90 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.46	14.5	11.82	123.4			Environment Canada 2004
Rainbow trout (1.26 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.47	14.3	17.2	183.0			Environment Canada 2004
Rainbow trout (1.01 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.93	14.2	4.8	117.0			Environment Canada 2004
Rainbow trout (1.44 g), *Oncorhynchus mykiss*	-	4 d	S,M	8.93	15	5.4	131.6			Environment Canada 2004
Rainbow trout (1.42 g), *Oncorhynchus mykiss*	-	4 d	S,M	9.46	14.6	1.6	79.03			Environment Canada 2004
Rainbow trout, *Oncorhynchus mykiss*	-	4 d	S,M	7.5	15	38.37	69.63			Holt and Malcolm 1979
Rainbow trout (129 mm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,U	7	15	207.5	207.5			Blahm 1978
Rainbow trout (1.7-1.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,U	7.4	14.5	20.03	31.47			Calamari et al. 1981
Rainbow trout, *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,U	7.4	14.5	46.31	72.77			Calamari et al. 1981
Rainbow trout (8-10 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,U	7.4	14.5	55.07	86.53			Calamari et al. 1981
Rainbow trout (129 mm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,U	8	15	70	300.5			Blahm 1978
Rainbow trout (10.9 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.7	3.6	38.52	**96.27**			West 1985; Arthur et al. 1987
Rainbow trout (14.0 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.7	9.8	55.15	**137.8**			West 1985; Arthur et al. 1987
Rainbow trout (22.4 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	16.2	15.23	**54.24**			West 1985; Arthur et al. 1987
Rainbow trout (10.3 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	11.3	30.15	**107.4**			West 1985; Arthur et al. 1987
Rainbow trout (3.3 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.3	18.7	12.75	**97.57**			West 1985; Arthur et al. 1987

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Rainbow trout (53 mm, 1.48 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.95	10	35.14	**137.3**			Broderius and Smith Jr. 1979
Rainbow trout (stage 8), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.4	14.4	40.99	**64.40**			Calamari et al. 1977
Rainbow trout, *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.05	14	22.9	**108.1**			DeGraeve et al. 1980
Rainbow trout (45 mm, 0.86 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.16	14.2	23.39	**136.4**			Reinbold and Pescitelli 1982b
Rainbow trout (119 mm, 20.6 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.28	12.8	15.4	**113.4**			Reinbold and Pescitelli 1982b
Rainbow trout (115 mm, 18.1 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.34	5	17.32	**143.3**			Reinbold and Pescitelli 1982b
Rainbow trout (42 mm, 0.61 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.43	3	11.86	**116.8**			Reinbold and Pescitelli 1982b
Rainbow trout (52 mm, 1.47 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.5	14.9	10.09	**113.7**			Reinbold and Pescitelli 1982b
Rainbow trout (44 mm, 0.76 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.6	3.3	15.27	**207.9**			Reinbold and Pescitelli 1982b
Rainbow trout (6.3 g, 8.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.44	12.8	32.49	**54.00**			Thurston and Russo 1983
Rainbow trout (8.0 g, 8.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.5	14.5	24.2	**43.91**			Thurston and Russo 1983
Rainbow trout (29.8 g, 13.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.59	12.7	32.62	**68.03**			Thurston and Russo 1983
Rainbow trout (28.0 g, 13.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.6	13	23.8	**50.43**			Thurston and Russo 1983
Rainbow trout (24.5 g, 12.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.6	12.9	25.14	**53.27**			Thurston and Russo 1983
Rainbow trout (2596 g, 57.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.62	7.9	20.53	**44.93[f]**			Thurston and Russo 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Rainbow trout (15.1 g, 10.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.62	14.4	28.62	**62.64**			Thurston and Russo 1983
Rainbow trout (29.6 g, 13.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.63	12.9	25.65	**57.06**			Thurston and Russo 1983
Rainbow trout (1496 g, 48.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.64	9.8	25.82	**58.38**[f]			Thurston and Russo 1983
Rainbow trout (18.9 g, 11.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.64	13.1	29.28	**66.21**			Thurston and Russo 1983
Rainbow trout (558 g, 37.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.64	10	31.85	**72.02**			Thurston and Russo 1983
Rainbow trout (1698 g, 50.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.65	9.8	19.46	**44.73**[f]			Thurston and Russo 1983
Rainbow trout (22.8 g, 12.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.65	13.2	28.64	**65.84**			Thurston and Russo 1983
Rainbow trout (12.3 g, 10.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.65	14.3	29.02	**66.71**			Thurston and Russo 1983
Rainbow trout (513 g, 35.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.66	9.8	25.95	**60.65**			Thurston and Russo 1983
Rainbow trout (22.6 g, 12.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.66	13.6	28.27	**66.07**			Thurston and Russo 1983
Rainbow trout (26.0 g, 13.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.66	12.8	33.97	**79.39**			Thurston and Russo 1983
Rainbow trout (14.8 g, 10.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.67	14	27.3	**64.87**			Thurston and Russo 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (°C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Rainbow trout (38.0 g, 14.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.68	13	33.15	**80.11**			Thurston and Russo 1983
Rainbow trout (1122 g, 45.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	10.4	17.75	**43.62**[f]			Thurston and Russo 1983
Rainbow trout (1140 g, 46.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	10.7	20.18	**49.59**[f]			Thurston and Russo 1983
Rainbow trout (152 g, 23.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	10.7	25.62	**62.96**			Thurston and Russo 1983
Rainbow trout (23.6 g, 13.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.69	13.4	27.51	**67.60**			Thurston and Russo 1983
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	12.7	20.03	**71.36**			Thurston and Russo 1983
Rainbow trout (4.3 g, 7.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.71	11.5	30.22	**76.83**			Thurston and Russo 1983
Rainbow trout (4.0 g, 7.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.71	11.4	32.02	**81.40**			Thurston and Russo 1983
Rainbow trout (248 g, 25.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.74	10.4	25.76	**68.95**			Thurston and Russo 1983
Rainbow trout (25.8 g, 13.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	11.8	31.53	**85.87**			Thurston and Russo 1983
Rainbow trout (8.1 g, 9.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	12.3	33.94	**92.43**			Thurston and Russo 1983
Rainbow trout (380 g, 32.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.76	10	22.44	**62.19**			Thurston and Russo 1983
Rainbow trout (42.0 g, 16.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.77	13.6	31.81	**89.71**			Thurston and Russo 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Rainbow trout (1.7 g, 5.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.79	12.4	41.97	**122.6**			Thurston and Russo 1983
Rainbow trout (11.2 g, 10.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.8	9.7	23.65	**70.32**			Thurston and Russo 1983
Rainbow trout (5.7 g, 8.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.8	13.3	42.02	**124.9**			Thurston and Russo 1983
Rainbow trout (2.3 g, 6.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.8	12.4	47.87	**142.3**			Thurston and Russo 1983
Rainbow trout (8.0 g, 9.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.82	13.2	33.67	**103.7**			Thurston and Russo 1983
Rainbow trout (4.6 g, 7.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.83	13.5	33.55	**105.2**			Thurston and Russo 1983
Rainbow trout (6.7 g, 8.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	12.2	24.54	**78.38**			Thurston and Russo 1983
Rainbow trout (9.0 g, 9.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	12.9	32.3	**103.2**			Thurston and Russo 1983
Rainbow trout (1.8 g, 5.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	13.8	33.09	**105.7**			Thurston and Russo 1983
Rainbow trout (4.3 g, 7.1 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.84	13	38.69	**123.6**			Thurston and Russo 1983
Rainbow trout (0.47 g, 4.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	12.5	29.77	**96.81**			Thurston and Russo 1983
Rainbow trout (2.5 g, 6.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	13.1	31.55	**102.6**			Thurston and Russo 1983
Rainbow trout (0.61 g, 4.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	13.1	33.59	**109.2**			Thurston and Russo 1983
Rainbow trout (1.02 g, 4.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	12.3	33.99	**110.5**			Thurston and Russo 1983
Rainbow trout (9.4 g, 9.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.85	16.1	34.17	**111.1**			Thurston and Russo 1983
Rainbow trout (0.33 g, 3.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	13	20.7	**68.55**			Thurston and Russo 1983
Rainbow trout (0.33 g, 3.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	13.4	23.71	**78.52**			Thurston and Russo 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Rainbow trout (0.47 g, 4.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	12.7	28.77	**95.27**			Thurston and Russo 1983
Rainbow trout (1.7 g, 5.8 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	14.1	34.95	**115.7**			Thurston and Russo 1983
Rainbow trout (48.6 g, 15.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	10.2	35.31	**116.9**			Thurston and Russo 1983
Rainbow trout (0.15 g, 2.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.9	16.81	**56.69**			Thurston and Russo 1983
Rainbow trout (0.18 g, 2.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.9	18.99	**64.04**			Thurston and Russo 1983
Rainbow trout (0.23 g, 3.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	13.1	19.08	**64.34**			Thurston and Russo 1983
Rainbow trout (7.0 g, 8.8 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.2	20.02	**67.51**			Thurston and Russo 1983
Rainbow trout (0.18 g, 2.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	13	21.15	**71.32**			Thurston and Russo 1983
Rainbow trout (2.6 g, 6.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	12.1	31.8	**107.2**			Thurston and Russo 1983
Rainbow trout (11.1 g, 9.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.87	13	34.32	**115.7**			Thurston and Russo 1983
Rainbow trout (0.12 g, 2.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	12.8	11.07	**38.02**			Thurston and Russo 1983
Rainbow trout (0.14 g, 2.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	12.9	15.91	**54.64**			Thurston and Russo 1983
Rainbow trout (0.23 g, 3.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	13.4	19.43	**66.73**			Thurston and Russo 1983
Rainbow trout (52.1 g, 15.5 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.88	10	28.6	**98.22**			Thurston and Russo 1983
Rainbow trout (1.8 g, 5.9 cm), *Oncorhynchus mykiss*	Ammonium sulfate	4 d	F,M	7.89	12.4	36.73	**128.5**			Thurston and Russo 1983
Rainbow trout (0.06 g, 1.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	13.4	19.44	**69.26**			Thurston and Russo 1983
Rainbow trout (0.06 g, 1.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.7	13.9	28.54	**71.33**			Thurston and Russo 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Rainbow trout (7.9 g, 9.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	11.9	22.65	**80.69**			Thurston and Russo 1983
Rainbow trout (9.7 g, 9.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	13	35.75	**127.4**			Thurston and Russo 1983
Rainbow trout (9.3 g, 9.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.9	13	37.41	**133.3**			Thurston and Russo 1983
Rainbow trout (0.08 g, 2.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	13.1	12.68	**46.01**			Thurston and Russo 1983
Rainbow trout (0.06 g, 1.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	13	20.99	**76.17**			Thurston and Russo 1983
Rainbow trout (7.1 g, 8.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	19	25.36	**92.03**			Thurston and Russo 1983
Rainbow trout (10.1 g, 9.8 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.91	19.1	26.44	**95.95**			Thurston and Russo 1983
Rainbow trout (1.7 g, 5.8 cm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,M	7.94	12.8	26.49	**101.6**			Thurston and Russo 1983
Rainbow trout (2.1 g, 6.2 cm), *Oncorhynchus mykiss*	Ammonium sulfate	4 d	F,M	7.94	12.5	39.25	**150.6**			Thurston and Russo 1983
Rainbow trout (0.15 g, 2.7 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.95	12.5	19.75	**77.19**			Thurston and Russo 1983
Rainbow trout (8.6 g, 8.9 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.96	19.2	23.21	**92.42**			Thurston and Russo 1983
Rainbow trout (2.1 g, 6.2 cm), *Oncorhynchus mykiss*	Phosphoric acid, Diammonium salt	4 d	F,M	7.98	12.5	27.02	**111.7**			Thurston and Russo 1983
Rainbow trout (1.01 g, 4.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.06	13.2	33.64	**161.8**			Thurston and Russo 1983
Rainbow trout (0.36 g, 3.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.08	12.8	23.05	**115.2**			Thurston and Russo 1983
Rainbow trout (1.7 g, 5.9 cm), *Oncorhynchus mykiss*	Ammonium bicarbonate	4 d	F,M	8.1	13.9	18.14	**94.23**			Thurston and Russo 1983
Rainbow trout (1.8 g, 5.8 cm), *Oncorhynchus mykiss*	Ammonium bicarbonate	4 d	F,M	8.12	13.6	17.34	**93.61**			Thurston and Russo 1983
Rainbow trout (2596 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.62	7.9	21.6	**47.27**			Thurston et al. 1981a

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Rainbow trout (2080 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.67	7.7	17	**40.40**			Thurston et al. 1981a
Rainbow trout (293 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.71	8.5	20.7	**52.62**			Thurston et al. 1981a
Rainbow trout (230 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.72	8.2	10.5	**27.15**			Thurston et al. 1981a
Rainbow trout (244 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.72	8.1	19.8	**51.20**			Thurston et al. 1981a
Rainbow trout (230 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.74	8.3	22.3	**59.69**			Thurston et al. 1981a
Rainbow trout (247 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.74	8.1	28	**74.94**			Thurston et al. 1981a
Rainbow trout (18 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	9.6	19.3	**63.91**			Thurston et al. 1981a
Rainbow trout (21 g), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.86	9.7	31.6	**104.6**			Thurston et al. 1981a
Rainbow trout (4.6 g, 7.3 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	12.7	32.09	**87.39**			Thurston et al. 1981b
Rainbow trout (5.7 g, 8.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.75	12.5	36.97	**100.7**			Thurston et al. 1981b
Rainbow trout (5.0 g, 7.6 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.76	12.5	39.08	**108.3**			Thurston et al. 1981b
Rainbow trout (5.7 g, 8.0 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.79	12.9	40.88	**119.4**			Thurston et al. 1981b
Rainbow trout (4.0 g, 7.2 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.83	12.8	36.49	**114.5**			Thurston et al. 1981b
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.51	14.1	157.4	**116.8**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.8	14.1	94.05	**80.83**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.3	14	74.2	**102.2**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.29	14.1	13.85	**104.0**			Thurston et al. 1981c
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	8.82	13.9	3.95	**80.02**			Thurston et al. 1981c

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Rainbow trout (9.5 g, 9.4 cm), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	9.01	14.5	2.51	**69.50**			Thurston et al. 1981c
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	7.2	10	174	**212.6**			Wicks and Randall 2002
Rainbow trout (40.0 g; swimming fish), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.97	16.6	32.38	**31.56**			Wicks et al. 2002
Rainbow trout (40.0 g; resting fish), *Oncorhynchus mykiss*	Ammonium chloride	4 d	F,M	6.97	16.6	207	**201.7**	82.88		Wicks et al. 2002
Chinook salmon (1.0-7 g), *Oncorhynchus tshawytscha*	Ammonia	4 d	S,M	7.96	7	28.03	**111.6**			Servizi and Gordon 1990
Chinook salmon (14.4 g, 11.9 cm), *Oncorhynchus tshawytscha*	Ammonium chloride	4 d	F,U	7.87	13.5	18.47	**62.29**			Thurston and Meyn 1984
Chinook salmon (15.3 g, 12.1 cm), *Oncorhynchus tshawytscha*	Ammonium chloride	4 d	F,U	7.82	12.2	27.23	**83.90**			Thurston and Meyn 1984
Chinook salmon (18.1 g, 12.7 cm), *Oncorhynchus tshawytscha*	Ammonium chloride	4 d	F,U	7.84	12.3	24.74	**79.02**	82.39	99.15	Thurston and Meyn 1984
Topeka shiner (adult, 29 mo), *Notropis topeka*	Ammonium chloride	4 d	F,M	7.85	24.6	21.40	**69.59**			Adelman et al. 2009
Topeka shiner (juvenile, 16 mo), *Notropis topeka*	Ammonium chloride	4 d	F,M	8.05	25.0	18.70	**88.27**			Adelman et al. 2009
Topeka shiner (juvenile, 15 mo), *Notropis topeka*	Ammonium chloride	4 d	F,M	8.09	13.2	28.90	**147.3**	96.72	96.72	Adelman et al. 2009
Leopard frog (embryo), *Rana pipiens*	Ammonium chloride	4 d	F,M	8	20	31.04	**133.3**			Diamond et al. 1993
Leopard frog (8 d), *Rana pipiens*	Ammonium chloride	4 d	F,M	8	12	16.23	**69.69**	96.38	96.38	Diamond et al. 1993

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Long fingernailclam, *Musculium transversum*	Ammonium chloride	4 d	F,M	8.1	14.6	32.83	**109.0**			West 1985; Arthur et al. 1987
Long fingernailclam, *Musculium transversum*	Ammonium chloride	4 d	F,M	8.2	5.4	38.18	**71.74**			West 1985; Arthur et al. 1987
Long fingernailclam, *Musculium transversum*	Ammonium chloride	4 d	F,M	8.6	20.5	6.429	**91.24**	89.36	89.36	West 1985; Arthur et al. 1987
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieu*	Ammonium chloride	4 d	F,M	7.16	22.3	123.4	**144.3**			Broderius et al. 1985
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieu*	Ammonium chloride	4 d	F,M	6.53	22.3	359.9	**269.2**			Broderius et al. 1985
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieu*	Ammonium chloride	4 d	F,M	7.74	22.3	39.3	**105.2**			Broderius et al. 1985
Smallmouth bass (26-29 mm, 264-267 mg), *Micropterus dolomieu*	Ammonium chloride	4 d	F,M	8.71	22.3	7.56	**126.0**	150.6		Broderius et al. 1985
Largemouth bass (0.086-0.322 g), *Micropterus salmoides*	Ammonium chloride	4 d	F,M	8.04	28	19.59	**90.72**			Roseboom and Richey 1977
Largemouth bass (2.018-6.286 g), *Micropterus salmoides*	Ammonium chloride	4 d	F,M	7.96	22	20.48	**81.56**	86.02		Roseboom and Richey 1977
Guadalupe bass (6.5 g), *Micropterus treculii*	Ammonium chloride	4 d	S,M/	8	22	12.7	**54.52**	54.52	89.06	Tomasso and Carmichael 1986
Great pond snail (25-30 mm), *Lymnaea stagnalis*	-	4 d	F,M	7.9	11.5	50.33	**88.62**	88.62	88.62	Williams et al. 1986
Guppy (0.13 g, 2.03 cm), *Poecilia reticulata*	Ammonium chloride	4 d	S,U	7.5	27.55	5.929	**10.76**			Kumar and Krishnamoorthi 1983

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Guppy (8.0 mm), *Poecilia reticulata*	-	4 d	S,U	7.22	25	129.4	**161.8**			Rubin and Elmaraghy 1976
Guppy (8.25(6.3-11.0) mm), *Poecilia reticulata*	-	4 d	S,U	7.45	25	75.65	**127.6**			Rubin and Elmaraghy 1976
Guppy (8.70(6.8-10.6) mm), *Poecilia reticulata*	-	4 d	S,U	7.45	25	82.95	**139.9**	74.66	74.66	Rubin and Elmaraghy 1976
Johnny darter (38 mm), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	7.9	20.6	28.9	**103.0**			Nimmo et al. 1989
Johnny darter (38 mm), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8	20.1	24.61	**105.7**			Nimmo et al. 1989
Johnny darter (38 mm), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8.2	6.2	6.937	**43.72**			Nimmo et al. 1989
Johnny darter (38 mm), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8.1	5.8	11.47	**59.57**			Nimmo et al. 1989
Johnny darter (38 mm), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8.1	5.8	13.46	**69.93**			Nimmo et al. 1989
Johnny darter (38 mm), *Etheostoma nigrum*	Ammonium chloride	4 d	F,M	8	20.1	15.63	**67.08**	71.45		Nimmo et al. 1989
Orangethroat darter, *Etheostoma spectabile*	Ammonium chloride	4 d	F,M	8.1	22	16.12	**83.74**			Hazel et al. 1979
Orangethroat darter, *Etheostoma spectabile*	Ammonium chloride	4 d	F,M	8.4	21	7.65	**71.12**	77.17	74.25	Hazel et al. 1979
Rio Grande silvery minnow (3-5 d old), *Hybognathus amarus*	Ammonium chloride	4 d	R,M	8	25	16.9	**72.55**	72.55	72.55	Buhl 2002
Spring peeper (embryo), *Pseudacris crucifer*	Ammonium chloride	4 d	F,U	8	12	17.78	**76.33**			Diamond et al. 1993
Spring peeper, *Pseudacris crucifer*	Ammonium chloride	4 d	F,U	8	20	11.42	**49.04**	61.18		Diamond et al. 1993
Pacific tree frog (embryo), *Pseudacris regilla*	Ammonium nitrate	4 d	R,M	6.7	22	41.19	**33.36**			Schuytema and Nebeker 1999a

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Pacific tree frog (embryo), *Pseudacris regilla*	Ammonium chloride	4 d	R,M	6.7	22	60.44	**48.95**			Schuytema and Nebeker 1999a
Pacific tree frog (embryo), *Pseudacris regilla*	Ammonium sulfate	4 d	R,M	6.7	22	103.1	**83.53**			Schuytema and Nebeker 1999a
Pacific tree frog (90 mg, Gosner Stage 26-27), *Pseudacris regilla*	Nitric acid ammonium salt	4 d	R,M	7.3	22	136.6	**188.1**			Schuytema and Nebeker 1999b
Pacific tree frog (60 mg, Gosner Stage 26-27), *Pseudacris regilla*	Ammonium sulfate	4 d	R,M	7.3	22	116.4	**160.2**	83.71	71.56	Schuytema and Nebeker 1999b
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	1 d	S,M	8.6	20	6.141[c]	**83.61**			Wang et al. 2007b
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	1 d	S,M	8.4	20	8.099[c]	**75.29**			Wang et al. 2007b
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	1 d	S,M	8.3	20	5.073[c]	**38.84**			Wang et al. 2007b
Mucket (glochidia), *Actinonaias ligamentina*	Ammonium chloride	1 d	S,M	8.3	20	8.900[c]	**68.13**	63.89		Wang et al. 2007b
Pheasantshell (juvenile), *Actinonaias pectorosa*	Ammonium chloride	4 d	S,M	7.9	25	14.06	**75.80**			Keller 2000
Pheasantshell (juvenile), *Actinonaias pectorosa*	Ammonium chloride	4 d	S,M	7.95	25	14.08	**83.30**	79.46	71.25	Keller 2000
Giant floater mussel (adult), *Pyganodon grandis*	Ammonium chloride	4 d	S,M	7.71	25	18.84	**72.49**			Scheller 1997
Giant floater mussel (adult), *Pyganodon grandis*	Ammonium chloride	4 d	S,M	7.5	25	25.13	**69.02**	70.73	70.73	Scheller 1997
Shortnose sucker (0.53-2.00 g), *Chasmistes brevirostris*	Ammonium chloride	4 d	F,M	8	20	11.42	**49.04**			Saiki et al. 1999
Shortnose sucker, *Chasmistes brevirostris*	Ammonium chloride	4 d	F,M	8	20	22.85	**98.09**	69.36	69.36	Saiki et al. 1999

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Pagoda hornsnail (adult), *Pleurocera uncialis*	Ammonium chloride	4 d	R,M	8.1	22	11.18	**68.54**	68.54	68.54	Goudreau et al. 1993
Golden shiner, *Notemigonus crysoleucas*	Ammonium chloride	4 d	S,M	7.5	19.6	89.61	162.6			EA Engineering 1985
Golden shiner, *Notemigonus crysoleucas*	Ammonium chloride	4 d	S,M	7.55	19.5	73.85	144.6			EA Engineering 1985
Golden shiner (8.7 g), *Notemigonus crysoleucas*	Ammonium chloride	4 d	F,M	7.5	24.5	34.73	**63.02**	63.02	63.02	Swigert and Spacie 1983
Pebblesnail (1.8 mm), *Fluminicola* sp.	Ammonium chloride	4 d	F,M	8.25	20.2	>8.801	**>62.15**	>62.15	>62.15	Besser 2011
Lost River sucker (0.49-0.80 g), *Deltistes luxatus*	Ammonium chloride	4 d	F,M	8	20	16.81	**72.18**			Saiki et al. 1999
Lost River sucker (larvae), *Deltistes luxatus*	Ammonium chloride	4 d	F,M	8	20	10.35	**44.42**	56.62	56.62	Saiki et al. 1999
Mountain whitefish (177 g, 27.0 cm), *Prosopium williamsoni*	Ammonium chloride	4 d	F,U	7.68	12.1	11.3	**27.31**			Thurston and Meyn 1984
Mountain whitefish (56.9 g, 19.1 cm), *Prosopium williamsoni*	Ammonium chloride	4 d	F,U	7.84	12.4	25.47	**81.35**			Thurston and Meyn 1984
Mountain whitefish (63.0 g, 20.4 cm), *Prosopium williamsoni*	Ammonium chloride	4 d	F,U	7.8	12.3	21.2	**63.04**	51.93	51.93	Thurston and Meyn 1984
Atlantic pigtoe (glochidia), *Fusconaia masoni*	Ammonium chloride	6 h	S,M	7.6	24.9	15.9	**47.40**	47.40	47.40	Black 2001
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	S,M	7.9	24	8.235	**40.87**			Keller 2000
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	S,M	8.35	25	3.269	**41.75**			Keller 2000

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Pondshell mussel (juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	S,M	7.9	25	9.355	**50.45**			Keller 2000
Pondshell mussel (8 d old juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	7.8	24	14.29	**59.19**			Wade et al. 1992
Pondshell mussel (<2 d old juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8.16	25	5.254	**46.38**			Black 2001
Pondshell mussel (<2 d old juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8.17	25	5.781	**52.03**			Black 2001
Pondshell mussel (<2 d old juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8.29	25	8.845	**100.5**			Black 2001
Pondshell mussel (<2 d old juvenile), *Utterbackia imbecillis*	Ammonium chloride	4 d	R,M	8	25.1	2.734	**17.91**			Black 2001
Pondshell mussel (glochidia), *Utterbackia imbecillis*	Ammonium chloride	1 d	S,M	8.02	25	7.395	**49.90**	46.93	46.93	Black 2001
Pink mucket (2 mo old juvenile), *Lampsilis abrupta*	Ammonium chloride	4 d	R,M	8.3	20	1.921[d]	14.71			Wang et al. 2007b
Pink mucket (2 mo old juvenile), *Lampsilis abrupta*	Ammonium chloride	4 d	F,M	8.4	20	2.8	**26.03**	26.03		Wang et al. 2007a
Plain pocketbook (3-5 d old juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	S,M	8.2	20.5	23.50[e]	154.4			Newton et al. 2003
Plain pocketbook (3-5 d old juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	S,M	8.2	21.2	23.70[e]	165.0			Newton et al. 2003
Plain pocketbook (1-2 d old juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	F,M	7.6	21.2	23.1	**54.07**			Newton and Bartsch 2007

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Plain pocketbook (1-2 d old juvenile), *Lampsilis cardium*	Ammonium chloride	4 d	F,M	7.1	21.2	38.9	**47.19**	50.51		Newton and Bartsch 2007
Wavy-rayed lampmussel (2-5 d old juvenile), *Lampsilis fasciola*	Ammonium chloride	4 d	R,M	7.83	12.6	14.9	**25.31**			Mummert et al. 2003
Wavy-rayed lampmussel (<5 d old juvenile), *Lampsilis fasciola*	Ammonium chloride	4 d	R,M	8.5	20	6.179[d]	**69.63**			Wang et al. 2007b
Wavy-rayed lampmussel (glochidia), *Lampsilis fasciola*	Ammonium chloride	1 d	S,M	8.3	20	7.743 [c]	**59.28**			Wang et al. 2007b
Wavy-rayed lampmussel (glochidia), *Lampsilis fasciola*	Ammonium chloride	1 d	S,M	8.4	20	5.518 [c]	**51.30**	48.11		Wang et al. 2007b
Higgin's eye (1-2 d old juvenile), *Lampsilis higginsii*	Ammonium chloride	4 d	F,M	7.6	21.2	19.5	**45.64**			Newton and Bartsch 2007
Higgin's eye (1-2 d old juvenile), *Lampsilis higginsii*	Ammonium chloride	4 d	F,M	7.1	21.2	31.7	**38.46**	41.90		Newton and Bartsch 2007
Neosho mucket (<5 d old juvenile), *Lampsilis rafinesqueana*	Ammonium chloride	4 d	R,M	8.3	20	9.185[d]	**70.31**			Wang et al. 2007b
Neosho mucket (<5 d old juvenile), *Lampsilis rafinesqueana*	Ammonium chloride	4 d	R,M	8.4	20	9.269[d]	**86.17**			Wang et al. 2007b
Neosho mucket (glochidia), *Lampsilis rafinesqueana*	Ammonium chloride	1 d	S,M	8.3	20	7.387 [c]	**56.55**	69.97		Wang et al. 2007b
Fatmucket (juvenile), *Lampsilis siliquoidea*	Ammonium chloride	4 d	S,M	8.3	24	1.275	13.60			Myers-Kinzie 1998

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Fatmucket (3 mo old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	8.35	20	8.80	**74.25**			Miao et al. 2010
Fatmucket (2 mo old juvenile), *Lampsilis siliquoidea*	Ammonium chloride	4 d	R,M	8.1	20	4.092[d]	21.26			Wang et al. 2007b
Fatmucket (2 mo old juvenile), *Lampsilis siliquoidea*	Ammonium chloride	4 d	F,M	8.2	20	4.6	**28.99**			Wang et al. 2007a
Fatmucket (7 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	7.6	20.5	11	**24.30**			Wang et al. 2008
Fatmucket (7 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	8.1	20.6	5.2	**28.39**			Wang et al. 2008
Fatmucket (7 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	8.5	20.6	3.4	**40.27**			Wang et al. 2008
Fatmucket (7 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	9	20.6	0.96	**27.51**			Wang et al. 2008
Fatmucket (7 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	6.6	19.6	88	**65.59**			Wang et al. 2008
Fatmucket (7 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride, ammonium hydroxide	4 d	F,M	8.1	19.4	11	**54.37**			Wang et al. 2008
Fatmucket (<5 d old juvenile), *Lampsilis siliquoidea*	Ammonium chloride	4 d	R,M	8.5	20	8.350[d]	94.09			Wang et al. 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	1 d	S,M	8.4	20	9.790 [c]	**91.01**			Wang et al. 2007b

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals										
Species	**Chemical Name**	**Duration**	**Methods**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Total Ammonia**[b] **(mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)**	**SMAV (mg TAN/L)**	**GMAV (mg TAN/L)**	**Reference**
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	1 d	S,M	8.2	20	13.35 [c]	**84.14**			Wang et al. 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	1 d	S,M	8.4	20	11.57 [c]	**107.6**			Wang et al. 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	1 d	S,M	8.5	20	>14.24 [c]	**160.5**			Wang et al. 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	1 d	S,M	8.3	20	6.497 [c]	**49.74**			Wang et al. 2007b
Fatmucket (glochidia), *Lampsilis siliquoidea*	Ammonium chloride	1 d	S,M	8.3	20	8.772 [c]	**66.77**	55.42	46.63	Wang et al. 2007b
Rainbow mussel (2 mo old juvenile), *Villosa iris*	Ammonium chloride	4 d	R,M	8.4	20	2.505[d]	**23.29**			Wang et al. 2007b
Rainbow mussel (2 mo old juvenile), *Villosa iris*	Ammonium chloride	4 d	R,M	8.3	20	8.935[d]	**68.40**			Wang et al. 2007b
Rainbow mussel (5 d old juvenile), *Villosa iris*	Ammonium chloride	4 d	S,M	8.18	25	7.81	**71.66**			Scheller 1997
Rainbow mussel (<5 d old juvenile), *Villosa iris*	Ammonium chloride	4 d	R,M	8.1	20	5.261[d]	**27.33**			Wang et al. 2007b
Rainbow mussel (2-5 d old juvenile), *Villosa iris*	Ammonium chloride	4 d	R,M	7.29	12.6	20.6	**15.17**			Mummert et al. 2003
Rainbow mussel (<3 d old juvenile), *Villosa iris*	Ammonium chloride	4 d	S,M	8.18	25	7.07	**64.87**			Scheller 1997
Rainbow mussel (< 24 h old glochidia), *Villosa iris*	Ammonium chloride	1 d	S,M	7.94	20.0	3.290	**12.62**			Scheller 1997
Rainbow mussel (glochidia), *Villosa iris*	Ammonium chloride	1 d	S,M	8.4	20	10.68 [c]	**99.28**			Wang et al. 2007b

Appendix A. Acute Toxicity of Ammonia to Aquatic Animals

Species	Chemical Name	Duration	Methods[a]	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Total Ammonia[b] (mg TAN/L) adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*)	SMAV (mg TAN/L)	GMAV (mg TAN/L)	Reference
Rainbow mussel (<1 h old glochidia), *Villosa iris*	Ammonium chloride	1 d	R,M	8.1	22	3.570	**21.89**			Goudreau et al. 1993
Rainbow mussel (<1 h old glochidia), *Villosa iris*	Ammonium chloride	1 d	R,M	8.1	22	4.278	**26.23**	34.23	34.23	Goudreau et al. 1993
Oyster mussel (<5 d old juvenile), *Epioblasma capsaeformis*	Ammonium chloride	4 d	R,M	8.5	20	4.760[d]	**53.63**			Wang et al. 2007b
Oyster mussel (glochidia), *Epioblasma capsaeformis*	Ammonium chloride	6 h	R,M	8.5	20	5.0[c]	**17.81**			Wang et al. 2007b
Oyster mussel (glochidia), *Epioblasma capsaeformis*	Ammonium chloride	6 h	R,M	8.5	20	3.4[c]	**31.61**	31.14	31.14	Wang et al. 2007b
Green floater (<2 d old juvenile), *Lasmigona subviridis*	Ammonium chloride	4 d	R,M	7.73	24	6.613	**24.24**			Black 2001
Green floater (<2 d old juvenile), *Lasmigona subviridis*	Ammonium chloride	4 d	R,M	7.73	24	6.613	**24.24**			Black 2001
Green floater (<2 d old juvenile), *Lasmigona subviridis*	Ammonium chloride	4 d	R,M	7.92	24.8	3.969	**21.84**	23.41	23.41	Black 2001
Ellipse (glochidia), *Venustaconcha ellipsiformis*	Ammonium chloride	1 d	S,M	8.1	20	4.550[c]	**23.12**	23.12	23.12	Wang et al. 2007b

[a] S = static, R = renewal, F = flow-through, and NR= not reported (uncertain) exposure types; M = measured and U = unmeasured tests.

[b] Acute values are normalized to pH 7 (all organisms) and temperature 20°C (invertebrates) as per the equations provided in this document (see also 1999 AWQC document for the basis of the pH- and temperature-dependence of ammonia toxicity and Appendix D for an example calculation).

[c] The EC_{50}s reported in this study were based on nominal concentrations. Percent nominal concentrations of measured ammonia concentrations on exposure days 0 and 2 declined from 104 to 44. EC_{50}s based on measured concentrations were estimated from the reported EC_{50}s based on nominal concentrations by multiplying by 0.890 for the 24 hr test; this factor is the average of the percent nominal concentrations of measured concentrations from ammonia measurements made on exposure day 0 (i.e., 104) and estimated for day 1 (i.e, 74) of the study.

[d] The EC_{50}s reported in this study were based on nominal concentrations. Percent nominal concentrations of measured ammonia concentrations on exposure days 0 and 4 declined from 104 to 63. EC_{50}s based on measured concentrations were estimated from the reported EC_{50}s based on nominal concentrations by multiplying by 0.835 or the average of the percent nominal concentrations of measured concentrations from ammonia measurements made on exposure days 0 and 4 in the study.

[e] EC_{50} values based on sediment porewater concentrations. **Note**: these EC_{50}s were not used to calculate the SMAV for the species.

[f] This small subset of LC_{50}s for adult rainbow trout from Thurston and Russo (1983) was used as the basis for the FAV calculated in the 1999 AWQC document. The FAV in the 1999 AWQC document of 11.23 mg TAN/L at pH 8 was lowered to the geometric mean of these five LC_{50} values at the time in order to protect large rainbow trout, which were shown to be measurably more sensitive than other life stages. The FAV prior to adjusting it to protect the commercially and recreationally important adult rainbow trout was calculated to be 14.32 mg TAN/L (CMC = 7.2 mg TAN/L) at pH 8. This FAV based on protection of adult rainbow trout at pH 7 is 48.21 mg TAN/L (see Table 7 in this document). Because several equivalent LC_{50}s representing different ages and life-stages have been added to the current (updated) acute criteria dataset, it no longer seems appropriate to lower the SMAV for rainbow trout based on only these five LC_{50}s considering the several other additional acute values which now exist.

Note: Each SMAV was calculated from the associated bold-face number(s) in the preceding column.

Appendix B. Chronic Toxicity of Ammonia to Aquatic Animals.

Appendix B. Chronic Toxicity of Ammonia to Aquatic Animals								
Species	**Test and Effect**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Chronic value[a] Adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*) (mg TAN/L)**	**SMCV (mg TAN/L)**	**GMCV (mg TAN/L)**	**Reference**
Stonefly, *Pteronarcella badia*	30-d Juv Survival	8.04	12.1	133.8	**207.0**			Thurston et al. 1984b
Stonefly, *Pteronarcella badia*	24-d Juv Survival	7.81	13.2	21.66	**26.27**	73.74	73.74	Thurston et al. 1984b
Water flea, *Ceriodaphnia acanthina*	7-d LC Reproduction	7.15	24.5	44.90	**64.10**	64.10		Mount 1982
Water flea, *Ceriodaphnia dubia*	7-d LC Reproduction	7.80	25.0	15.20	**38.96**			Nimmo et al. 1989
Water flea, *Ceriodaphnia dubia*	7-d LC Reproduction	8.57	26.0	5.800	**52.15**	45.08	53.75	Willingham 1987
Water flea, *Daphnia magna*	21-d LC Reproduction	8.45	19.8	7.370	**36.27**			Gersich et al. 1985
Water flea, *Daphnia magna*	21-d LC Reproduction	7.92	20.1	21.70	**47.40**	41.46	41.46	Reinbold and Pescitelli 1982a
Amphipod, *Hyalella azteca*	28-d PLC Biomass	8.04	25.0	8.207	**29.17**	29.17	29.17	Borgmann 1994
Channel catfish, *Ictalurus punctatus*	30-d ELS Weight	7.80	25.8	12.20	**22.66**			Reinbold and Pescitelli 1982a
Channel catfish, *Ictalurus punctatus*	30-d Juv Survival	8.35	27.9	5.020	**21.15**			Colt and Tchobanoglous 1978
Channel catfish, *Ictalurus punctatus*	30-d ELS Biomass	7.76	26.9	11.50	**20.35**	21.36	21.36	Swigert and Spacie 1983
Northern pike (fertilized), *Esox lucius*	52-d ELS Biomass	7.62	8.70	13.44	**20.38**	20.38	20.38	Harrahy et al. 2004
Common carp (fertilized), *Cyprinus carpio*	28-d ELS Weight	7.85	23.0	8.360	**16.53**	16.53	16.53	Mallet and Sims 1994

Appendix B. Chronic Toxicity of Ammonia to Aquatic Animals

Species	Test and Effect	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Chronic value[a] Adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*) (mg TAN/L)	SMCV (mg TAN/L)	GMCV (mg TAN/L)	Reference
Lahontan cutthroat trout (fertilized), *Oncorhynchus clarkii henshawi*	103-d ELS Survival	7.57	13.7	17.89	**25.83**	25.83		Koch et al. 1980
Rainbow trout (fertilized), *Oncorhynchus mykiss*	42-d ELS Survival	7.50	10.0	<33.6	**<45.5**			Burkhalter and Kaya 1977
Rainbow trout, *Oncorhynchus mykiss*	72-d ELS Survival	7.40	14.5	2.600	**3.246**			Calamari et al. 1977, 1981
Rainbow trout (fertilized), *Oncorhynchus mykiss*	73-d ELS Survival	7.52	14.9	<2.55	**<3.515**			Solbe and Shurben 1989
Rainbow trout, *Oncorhynchus mykiss*	5-year LC	7.70	7.5-10.5	>6.71	**>11.08**			Thurston et al. 1984a
Rainbow trout, *Oncorhynchus mykiss*	90-d ELS Survival	7.75	11.4	8.919	**15.60**	6.663		Brinkman et al. 2009
Sockeye salmon, *Oncorhynchus nerka*	62-d Embryos Hatchability	8.42	10.0	<2.13	**<10.09**	10.09	12.02	Rankin 1979
White sucker (3 d old embryo), *Catostomus commersonii*	30-d ELS Biomass	8.32	18.6	2.900	**>11.62**	11.62	11.62	Reinbold and Pescitelli 1982a
Smallmouth bass, *Micropterus dolomieu*	32-d ELS Biomass	6.60	22.3	9.610	**8.650**			Broderius et al. 1985
Smallmouth bass, *Micropterus dolomieu*	32-d ELS Biomass	7.25	22.3	8.620	**9.726**			Broderius et al. 1985
Smallmouth bass, *Micropterus dolomieu*	32-d ELS Biomass	7.83	22.3	8.180	**15.77**			Broderius et al. 1985
Smallmouth bass, *Micropterus dolomieu*	32-d ELS Biomass	8.68	22.3	1.540	**11.31**	11.07	11.07	Broderius et al. 1985
Fathead minnow (embryo-larvae), *Pimephales promelas*	28-d ELS Survival	8.00	24.8	5.120	**12.43**			Mayes et al. 1986
Fathead minnow (embryo-larvae), *Pimephales promelas*	32-d ELS Biomass	7.95	25.5	7.457	**16.87**			Adelman et al. 2009
Fathead minnow, *Pimephales promelas*	30-d ELS Biomass	7.82	25.1	3.730	**7.101**			Swigert and Spacie 1983

Appendix B. Chronic Toxicity of Ammonia to Aquatic Animals

Species	Test and Effect	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Chronic value[a] Adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*) (mg TAN/L)	SMCV (mg TAN/L)	GMCV (mg TAN/L)	Reference
Fathead minnow, *Pimephales promelas*	LC Hatchability	8.00	24.2	1.970	**4.784**	9.187	9.187	Thurston et al. 1986
Pebblesnail (1.81 mm, juvenile), *Fluminicola* sp.	28-d Juv Change in Length	8.22	20.1	2.281	**7.828**	7.828	7.828	Besser 2011
Long fingernailclam, *Musculium transversum*	42-d Juv Survival	8.15	23.5	5.820	**22.21**			Anderson et al. 1978
Long fingernailclam, *Musculium transversum*	42-d Juv Survival	7.80	21.8	1.230	**2.565**	7.547	7.547	Sparks and Sandusky 1981
Green sunfish, *Lepomis cyanellus*	30-d ELS Biomass	7.90	22.0	5.610	**11.85**			McCormick et al. 1984
Green sunfish, *Lepomis cyanellus*	30-d ELS Survival	8.16	25.4	5.840	**18.06**	14.63		Reinbold and Pescitelli 1982a
Bluegill, *Lepomis macrochirus*	30-d ELS Biomass	7.76	22.5	1.850	**3.273**	3.273	6.920	Smith et al. 1984
Rainbow mussel (2 mo old juvenile), *Villosa iris*	28-d Juv Survival	8.20	20.0	1.063	**3.501**	3.501	3.501	Wang et al. 2007a
Fatmucket (2 mo old juvenile), *Lampsilis siliquoidea*	28-d Juv Survival	8.25	20.0	0.8988	**3.211**	3.211		Wang et al. 20011
Wavy-rayed lamp mussel (2 mo old juvenile), *Lampsilis fasciola*	28-d Juv Survival	8.20	20.0	0.4272	**1.408**	1.408	2.126	Wang et al. 2007a

[a] The chronic value is an EC_{20} value calculated using EPA's TRAP (Versions 1.0 or 1.21a). Note: all chronic values were normalized to pH 7 (all organisms) and 20°C (invertebrates) as per the equations provided in this document (see also 1999 AWQC document for the basis of the pH- and temperature-dependence of ammonia toxicity and Appendix E for an example calculation).

<u>**Note:**</u> Each SMCV was calculated from the associated bold-face number(s) in the preceding column.

Appendix C. Other Chronic Ammonia Toxicity Data.

Appendix C. Other Chronic Ammonia Toxicity Data							
Species	**Test and Effect**	**Method**[a]	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Chronic value Adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*) (mg TAN/L)**	**Reference**
FRESHWATER INVERTEBRATES							
Pulmonate pondsnail (<1 wk post hatch), *Lymnaea stagnalis*	28-d NOEC - Growth	F,M	8.25	20.1	>8.00	>28.76	Besser et al. 2009
Pulmonate pondsnail (<1 wk post-hatch), *Lymnaea stagnalis*	28-d NOEC - Survival	F,M	8.25	20.1	>8.00	>28.76	Besser et al. 2009
Idaho springsnail (7-9 and 11-13 wk post hatch juvenile), *Pyrgulopsis idahoensis*	28-d NOEC - Growth	F,M	8.25	20.1	>8.00	>28.76	Besser et al. 2009
Idaho springsnail (7-9 and 11-13 wk post hatch juvenile), *Pyrgulopsis idahoensis*	28-d EC_{20} - Survival	F,M	8.25	20.1	0.480	1.726	Besser et al. 2009
Idaho springsnail (mixed-aged, adults), *Pyrgulopsis idahoensis*	28-d EC_{20} - Survival	F,M	8.26	20.8	3.24	12.39[b]	Besser et al. 2009
Pebblesnail (mixed-aged, field collected), *Fluminicola* sp.	28-d EC_{20} - Survival	F,M	8.26	20.8	1.02	3.900[c]	Besser et al. 2009
Pebblesnail (small, field collected), *Fluminicola* sp.	28-d MATC - Survival	F,M	8.19	20.1	2.75	8.977[d]	Besser 2011
Ozark springsnail (mixed age, field collected), *Fontigens aldrichi*	28-d EC_{20} - Survival	F,M	8.26	20.8	0.61	2.332[b]	Besser et al. 2009
Bliss Rapids snail (mixed age, field collected), *Taylorconcha serpenticola*	28-d EC_{20} - Survival	F,M	8.26	20.8	3.42	13.08[b]	Besser et al. 2009

Appendix C. Other Chronic Ammonia Toxicity Data

Species	Test and Effect	Method^{a}	pH	Temp. (˚C)	Total Ammonia (mg TAN/L)	Chronic value Adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*) (mg TAN/L)	Reference
Silty hornsnail (mixed age, mature and field collected), *Pleurocera canaliculata*	28-d EC$_{20}$ - Survival; (Alt Effect Conc.)	F,M	8.15	24.7	0.45 (≤1.86)	1.845 (≤7.667)$^{b, e}$	GLEC 2011
Wavy-rayed lamp mussel (2 mo old juvenile), *Lampsilis fasciola*	28-d IC$_{25}$ - Growth	F,M	8.20	20.0	0.5700	1.878	Wang et al. 2007a
Fatmucket (2 mo old juvenile), *Lampsilis siliquoidea*	28-d IC$_{25}$ - Growth	F,M	8.20	20.0	0.4400	1.450	Wang et al. 2007a
Rainbow mussel (2 mo old juvenile), *Villosa iris*	28-d IC$_{25}$ - Growth	F,M	8.20	20.0	0.7300	2.406	Wang et al. 2007a
Water flea, (<24 hr), *Ceriodaphnia dubia*	7-d; 3 broods in control IC$_{25}$ Reproduction	R,U	7.90	25.0	1.300	3.790	Dwyer et al. 2005
FRESHWATER VERTEBRATES							
Cutthroat trout (3.3 g), *Oncorhynchus clarkii*	29-d LC$_{50}$	F,M	7.80	12.4	21.60	40.11	Thurston et al. 1978
Cutthroat trout (3.4 g), *Oncorhynchus clarkii*	29-d LC$_{50}$	F,M	7.78	12.2	21.40	38.78	Thurston et al. 1978
Cutthroat trout (1.0 g), *Oncorhynchus clarkii*	36-d LC$_{50}$	F,M	7.81	13.1	30.80	57.91	Thurston et al. 1978
Cutthroat trout (1.0 g), *Oncorhynchus clarkii*	36-d LC$_{50}$	F,M	7.80	12.8	32.20	59.79	Thurston et al. 1978
Atlantic salmon, *Salmo salar*	105-d Juv NOEC - Survival	F,M	6.84	12.1	>32.29	>30.64	Kolarevic et al. 2012
Lake trout, siscowet, *Salvelinus namaycush*	60-d LOEC- Weight gain	F,M	8.02	11.6	6.440	16.10	Beamish and Tandler 1990
Brook trout (juvenile), *Salvelinus fontinalis*	4-d Juv LOEC - Swimming Perf	F,M	9.10	15.0	0.7765	10.86	Tudorache et al. 2010
Bonytail chub (2 and 7 d post hatch), *Gila elegans*	7-d IC$_{25}$ - Growth	R,U	7.90	25.0	11.00	23.24	Dwyer et al. 2005

Appendix C. Other Chronic Ammonia Toxicity Data							
Species	**Test and Effect**	**Method[a]**	**pH**	**Temp. (˚C)**	**Total Ammonia (mg TAN/L)**	**Chronic value Adjusted to pH 7 (all *organisms*) and 20°C (*invertebrates*) (mg TAN/L)**	**Reference**
Spotfin chub (<24 hr), *Erimonax monachus*	7-d IC_{25} - Growth	R,U	7.90	25.0	15.80	33.37	Dwyer et al. 2005
Cape Fear shiner (<24 hr), *Notropis mekistocholas*	7-d IC_{25} - Growth	R,U	7.90	25.0	8.800	18.59	Dwyer et al. 2005
Topeka shiner (adult), *Notropis topeka*	30-d EC_{20} - Survival	F,M	7.94	23.9	10.85	24.21	Adelman et al. 2009
Topeka shiner (juvenile, 11 mo), *Notropis topeka*	30-d EC_{20} - SGR	F,M	8.07	12.4	6.483	17.45	Adelman et al. 2009
Gila topminnow (<24, 48 and 72 hr), *Poeciliopsis occidentalis*	7-d IC_{25} - Growth	R,U	7.90	25.0	24.10	50.91	Dwyer et al. 2005
Fathead minnow (<24 hr), *Pimephales promelas*	7-d IC_{25} - Growth	R,U	7.90	25.0	7.200	15.21	Dwyer et al. 2005
Fathead minnow (4 d post hatch), *Pimephales promelas*	28-d LOEC- Survival	R,M	8.25	19.9	9.160	32.71	Fairchild et al. 2005
Colorado pikeminnow (5 and 6-d post hatch), *Ptychocheilus lucius*	7-d IC_{25} - Growth	R,U	7.90	25.0	8.900	18.80	Dwyer et al. 2005
Colorado pikeminnow (juvenile, 8 d), *Ptychocheilus lucius*	28-d LOEC- Growth	R,M	8.23	19.9	8.600	29.75	Fairchild et al. 2005
Razorback sucker (7 d post hatch), *Xyrauchen texanus*	7-d IC_{25} - Growth	R,U	7.90	25.0	13.40	28.30	Dwyer et al. 2005
Razorback sucker (9 d), *Xyrauchen texanus*	28-d LOEC- Survival	R,M	8.24	19.9	13.25	46.58	Fairchild et al. 2005
Lost River sucker (late-stage larva), *Deltistes luxatus*	30-d LOEC- Survival	F,M	9.43	22.3	1.230	25.31	Meyer and Hansen 2002
Green frog (Stage 24-26), *Rana clamitans*	103-d NOEC- Growth	R,M	8.70	24.0	>2.20	>16.74	Jofre and Karasov 1999

[a] R = renewal and F = flow-through exposure types; M = measured and U = unmeasured tests.

[b] Not used in the calculation of the SMCV because of the uncertainty of the chronic value, but included here as weight of evidence supporting the sensitivity of non-pulmonate snail species in general as determined by 28-day toxicity tests (see Additional 28-day Toxicity test Data for Freshwater Snails in Appendix I for more detail).

[c] Not used in the calculation of the SMCV because of the uncertainty of the chronic value, but included here as weight of evidence supporting the sensitivity of non-pulmonate snail species in general as determined by 28-day toxicity tests (see Chronic Toxicity Test Data: 28-day Tests with Juvenile and Adult Pebblesnails in Appendix H for more detail).

[d] Not used in the calculation of the SMCV because of low control survival (75 percent) for this size class.

[e] Value represents a 28-day ammonia survival effects concentration used in place of the EC_{20} due to the high degree of temporal variability in measured total ammonia concentrations in the test, as well as the unequal response among test replicates near this concentration (see Additional 28-day Toxicity test Data for Freshwater Snails in Appendix I for more detail).

Appendix D. Conversion of Acute Results of Toxicity Tests.

All of the ammonia acute values (LC_{50}s and EC_{50}s) in Appendix A of this document were converted to TAN acute values using the reported temperatures and pHs, and using the pKa relationship from Emerson et al. (1975). Conversions were dependent on the form of ammonia the acute values were expressed, e.g., unionized ammonia (UIA), unionized ammonia expressed as nitrogen (UIA-N), total ammonia (TA) and total ammonia nitrogen (TAN). After acute values were converted to TAN they were then normalized to pH 7 using the pH relationship developed in the 1999 AWQC document. Following the adjustment to pH 7, the TAN acute values were further normalized to a temperature of 20°C for invertebrates only, following recommendations in the 1999 AWQC document. It is worth noting here that while the relationship between pH and ammonia toxicity was first addressed in the 1985 criteria document, it was not fully developed until the 1999 AWQC update document. Detailed information regarding the development and parameterization of the pH-ammonia toxicity equations (acute and chronic) can be found in the 1999 AWQC document (pH-Dependence of Ammonia Toxicity – U.S. EPA 1999). In contrast to the pH-toxicity relationship, which applies to both vertebrates and invertebrates, the temperature-ammonia toxicity relationship only applies to invertebrates. Based on the results of the 1999 reanalysis of this relationship, it was determined that ammonia toxicity for invertebrates decreases with decreasing temperature to a temperature of approximately 7°C, below which the relationship ends (U.S. EPA 1999).

The conversion procedure for acute toxicity values is illustrated here using the data for the flatworm, *Dendrocoelum lacteum*, which is the first species listed in Table 1 in the 1984/1985 criteria document and was the species chosen to illustrate the conversion procedure in Appendix 3 of the 1999 AWQC document:

Acute value (AV) = 1.40 mg unionized ammonia (UIA) or NH_3/L
Test pH = 8.20
Test Temperature = 18.0°C

Step 1.

Equation 3 in the 1999 criterion document, and the Emerson et al. (1975) equation from page 7 of this document, is used to calculate the pKa at 18 °C:

$pKa = 9.464905$

Step 2.

The AV in terms of total ammonia (TA) is calculated as:

$$[NH_3]/[NH^+_4] = 10^{(pH\text{-}pK)} = 0.0543369$$

Step 3.

The Wood (1993) equation from page 7 (Equation 2 in the 1999 AWQC document) is rearranged to obtain the acute value for TA:

$$TA = [NH_3] + [NH^+_4] = [NH_3] + [NH_3]/(10^{(pH\text{-}pKa)})$$

$$TA = [NH_3] + [NH^+_4] = [NH_3] + [NH_3]/0.0543369$$

$$= 27.1652 \text{ mg TA/L}$$

Step 4.

The AV for TA is converted to the AV for TAN (AV_t) as follows:

$AV_t/AV = (14 \text{ mg TAN/mmol}) / (17 \text{ mg TA/mmol}) = 14/17$

$AV_t = (27.1652 \text{ mg TA/L}) \times (14 \text{ mg TAN}/17 \text{ mg TA})$

$= 22.3713 \text{ mg TAN/L}$

Step 5.

The AV in terms of TAN, or AV_t, is converted from test pH 8.2 to pH 7 using the equation for describing the pH-dependence of acute values (modified from Equation 11 in the 1999 AWQC document for normalization to pH 7)[2]:

$$AV_{t,7} = \frac{AV_t}{\left(\frac{0.0114}{1 + 10^{7.204-pH}} + \frac{1.6181}{1 + 10^{pH-7.204}}\right)}$$

$AV_{t,7} = (AV_t)/(0.158673) = 140.990$ mg N/L

Step 6. (temperature adjustment for invertebrates only)

The AV in terms of TAN at pH 7, or $AV_{t,7}$, is converted from this concentration at test temperature to a standard test temperature of 20°C using the equation shown below (Equation 5 in the 1999 AWQC document)[3]:

$\log(AV_{t,7,20}) = \log(AV_{t,7}) - [-0.036(18^{\circ}C - 20^{\circ}C)]$

$= 119.451$ mg N/L

Because this is the only species in this genus for which data are in Table 1 in the 1984/1985 criteria document, 119.5 mg TAN/L is the GMAV for the genus *Dendrocoelum* in Table 3 of this update document.

---

[2] The equation provided here should be applicable from pH 6 to 9, although uncertainty might exist at the lower end of this range for certain species. Extrapolation below pH 6 is not advisable because of the increasing scatter of the data from the common regression line at lower pH, and extrapolation above pH 9 is not advisable because of inadequate knowledge about the effect of the inhibition of ammonia excretion at high pH on results of toxicity tests (Russo et al. 1988).

[3] Note: Based on the 1999 reanalysis of the relationship between temperature and ammonia toxicity, when test temperature is less than 7°C, T should be set equal to 7, to reflect the plateau of the temperature-toxicity relationship at these temperatures.

Appendix E. Conversion of Chronic Results of Toxicity Tests.

As in the previous appendix with the acute results of toxicity tests, all of the ammonia chronic values (EC_{20}s) in Appendix B of this document were first converted to TAN at test temperature and pH using the p*K*a relationship from Emerson et al. (1975). Once all the chronic values were converted to total ammonia nitrogen, these values were then adjusted to pH 7 using the pH relationship developed in the 1999 AWQC document. After the adjustment to pH 7, the TAN chronic values were further normalized to a temperature of 20°C for invertebrates only, as per the recommendations in the 1999 AWQC document. The conversion procedure is illustrated here using the data for the amphipod species *Hyalella azteca*.

Chronic value (CV) = EC_{20} of 8.207 mg TAN/L
Test pH = 8.04
Test Temperature = 25.0°C

Steps 1 through 4.

(Not required in this case as CV is already expressed in terms of TAN. For more details regarding these steps, see Appendix D).

Step 5.

The CV in terms of TAN, or CV_t, is converted from test pH 8.04 to pH 7 using the equation for describing the pH dependence of chronic values (modified from Equation 12 in the 1999 AWQC document for normalization to pH 7)[4]:

$$CV_{t,7} = \frac{CV_t}{\left(\frac{0.0278}{1 + 10^{7.688-pH}} + \frac{1.1994}{1 + 10^{pH-7.688}}\right)}$$

---

[4] See footnote 3 in Appendix D.

$CV_{t,7} = (CV_t)/(0.38855) = 21.13$ mg TAN/L

Step 6. (Temperature adjustment for invertebrates only)

The CV in terms of TAN at pH 7, or $CV_{t,7}$, is converted from this concentration at test temperature to a standard test temperature of 20°C using the equation shown below (Equation 5 in the 1999 AWQC document)[5]:

$$\log(CV_{t,7,20}) = \log(CV_{t,7}) - [-0.028(25^{\circ}C - 20^{\circ}C)]$$
$$= 29.17 \text{ mg TAN/L}$$

Because this is the only species in this genus for which data in appendix B are available, 29.17 mg TAN/L is the GMCV for the genus *Hyalella* reported in Table 4 of this update document.

---

[5] See footnote 4 in Appendix D.

Appendix F. Acute-Chronic Ratios (ACRs).

The CCC was calculated directly from chronic values (EC_{20}s) in Appendix B using the standard fifth percentile procedure provided in the 1985 Guidelines (Stephan et al. 1985). As a result, acute-chronic ratios (ACRs) are not necessary for the derivation of the new chronic criterion presented in this document. It is still worthwhile, however, for EPA to provide recommended ACRs for predicting chronic sensitivity of untested species using measured or estimated acute values for other related efforts (e.g., developing Biological Evaluations in support of National Endangered Species Act Consultations on EPA 304(a) criteria recommendations, or when an ACR(s) is allowed to derive site-specific criteria for ammonia in fresh water). Table F.1 below presents ACRs for all species with chronic values that were used in the derivation of a GMCV and for which comparable acute values were found, as well as for a few additional species of special interest, such as threatened and endangered species. All acute and chronic values were adjusted to pH 7 and to 20°C (in the case of invertebrates). For each species or genera where more than a single ACR was calculated, Species and Genus Mean Acute-Chronic Ratios (SMACRs and GMACRs, respectively) were also calculated as the geometric mean value of individual ACRs and SMACRs. (Note: in the case of a single ACR within a Genus, the ACR is the SMACR.) Additionally, taxon-specific ACRs (TSACRs) were calculated where practical and for purpose of comparison at the taxonomic level of Family and Class.

The ACRs for freshwater aquatic invertebrates range from 2.406 to 49.45 (a factor of 21; see Table F.1). Likewise, the ACRs for fish range from 3.437 to 36.53 (factor of 11). The broad range in values can probably be explained because of the different kinds of chronic tests (life-cycle, ELS, 28-d juvenile mussel or snail) and toxicological endpoints (survival, growth, or reproduction) upon which they are based. The ACR of 36.53 for fathead minnow, for example, was based on hatchability from the life-cycle test of Thurston et al. (1986), whereas the early life-stage tests with fathead minnow of Mayes et al. (1986) and Swigert and Spacie (1983) gave ACRs of 11.35 and 17.17. The range of ACRs based on chronic values from the two early life-stage tests is small, and it is perhaps not surprising that a life-cycle test gave a higher ACR than the early life-stage tests. As another example illustrating the variability among ACRs from different kinds of tests and using different toxicological endpoints, but this time comparing amongst different species of invertebrates, the ACR of 49.45 for *Lampsilis fasciola* was based on survival from a 28-day test involving two month-old juveniles (Wang et al. 2007a,b), whereas the life-cycle tests with the two species of cladocerans (*Ceriodaphnia acanthina* and *C. dubia*) are based on adverse effects on reproduction with ACRs of 2.406 (Mount 1982) and 3.924 (Nimmo et al. 1989), respectively (Table F.1).

The ACRs for bivalve mollusks in general are larger compared to other freshwater aquatic animal taxa and range from 9.028 to 49.45. The ACRs for other freshwater invertebrates range from 2.406 to 15.81. The ACRs for fishes, in contrast, are quite varied even within species or genera. For example, the ACRs for *Lepomis* sp. range from 3.437 to 28.51 despite having been based on ELS tests and using biomass or survival as the toxicological endpoint.

Figure F.1 depicts SMACRs in relation to SMAVs to determine whether there is a trend. Only the weak trend of decreasing SMACR with increasing SMAV is apparent; primarily due to the comparatively large SMACRs for freshwater bivalve mollusks.

In general TSACRs for most freshwater aquatic animals (excluding bivalve mollusks) are within the relatively small range of 5.113 to 15.81 at the Class level, and may be acceptable for use when certain taxon-specific chronic toxicity data are not available. Perhaps not surprisingly, the CCC (2.1 mg TAN/L) calculated as the quotient of the FAV of 32.99 mg TAN/L (at pH 7 and 20°C) and geometric mean ACR for the Family Unionidae (15.52) agrees well with the CCC calculated directly from available chronic data (see Appendix B and Figure 4).

Table F.1. Species, Genus and Taxon-Specific ACRs for Freshwater Aquatic Animals Exposed to Ammonia.

Table F.1. Species, Genus and Taxon-specific ACRs for Freshwater Aquatic Animals Exposed to Ammonia

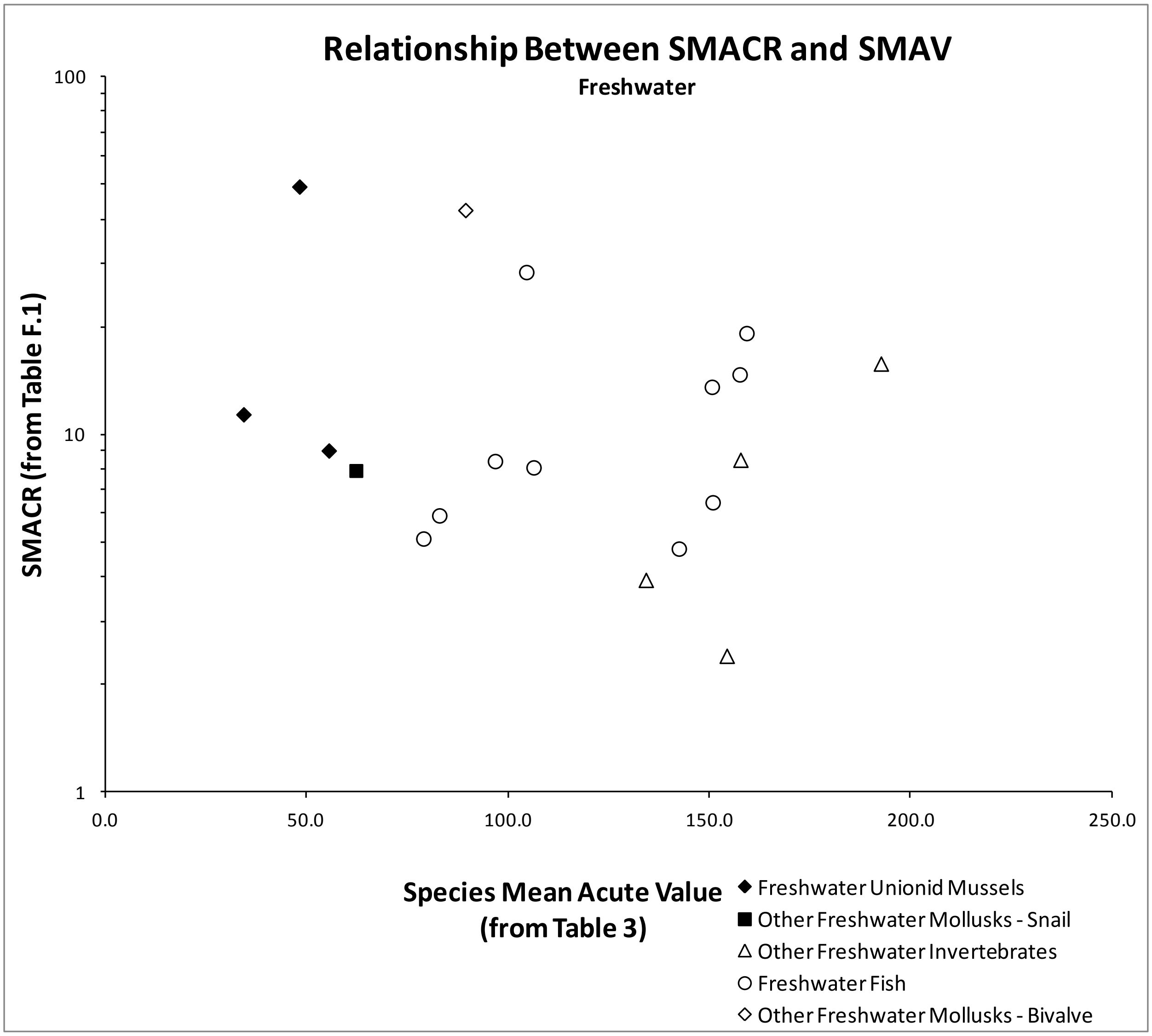
Species Scientific Name	Acute and Chronic Test Endpoint	pH	Temp	Normalized Values	Reference	ACR	SMACR	GMACR	TSACR (Family)	TSACR (Class)
Class Gastropoda (Family: Lithoglyphidae)										
Fluminicola sp.	LC50	8.25	20.2	>62.15	Besser 2011	7.940	7.940	7.940	7.940	7.940
	EC20 - Change in Length	8.22	20.1	7.828						
Class Bivalvia (Families Unionidae and Pasidiidae)										
Lampsilis fasciola	EC50	8.50	20.0	69.63	Wang et al. 2007b	49.45	49.45	21.13	15.52	25.68
	EC20 - Survival	8.20	20.0	1.408	Wang et al. 2007a					
Lampsilis siliquoidea	EC50	8.20	20.0	28.99	Wang et al. 2007a	9.028	9.028			
	EC20 - Survival	8.25	20.0	3.211	Wang et al. 2011					
Villosa iris	EC50	8.40	20.0	23.29	Wang et al. 2007b	11.40	11.40	11.40		
	EC50	8.30	20.0	68.40	Wang et al. 2007b					
	EC20 - Survival	8.20	20.0	3.501	Wang et al. 2007a					
Musculium transversum	EC50	8.10	14.6	109.0	West 1985; Arthur et al. 1987	42.50	42.50	42.50	42.50	
	EC20 - Survival	7.80	21.8	2.565	Sparks and Sandusky 1981					
Class Branchiopda (Family: Daphniidae)										
Ceriodaphnia acanthina	EC50	7.06	24.0	154.3	Mount 1982	2.406	2.406	3.073	5.113	5.113
	EC20 - Reproduction	7.15	24.5	64.10						
Ceriodaphnia dubia	EC50	7.80	25.0	152.9	Nimmo et al. 1989	3.924	3.924			
	EC20 - Reproduction	7.80	25.0	38.96						
Daphnia magna	EC50	8.50	20.0	296.9	Gersich and Hopkins 1986	8.186	8.507	8.507		
	EC20 - Reproduction	8.45	19.8	36.27	Gersich et al. 1985					
	EC50	8.34	19.7	419.1	Reinbold and Pescitelli 1982a	8.841				
	EC20 - Reproduction	7.92	20.1	47.40						
Class Malacostraca (Family: Dogielinotidae)										
Hyalella azteca	EC50	8.30	25.0	461.2	Ankley et al. 1995	15.81	15.81	15.81	15.81	15.81
	EC20 - Biomass	8.04	25.0	29.17	Borgmann 1994					

Table F.1. Species, Genus and Taxon-specific ACRs for Freshwater Aquatic Animals Exposed to Ammonia

Species Scientific Name	Acute and Chronic Test Endpoint	pH	Temp	Normalized Values	Reference	ACR	SMACR	GMACR	TSACR (Family)	TSACR (Class)
Class Actinopterygii (Families Salmonidae, Catostomidae, Cyprinidae, Ictaluridae and Centrarchidae)										
Oncorhynchus clarkii	LC50	7.81	13.1	132.3	Thurston et al. 1978	5.122	5.122	5.518	5.518	8.973
O. clarkii henshawi	EC20 - Survival	7.57	13.7	25.83	Koch et al. 1980					
Oncorhynchus mykiss	LC50	7.40	14.5	31.47	Calamari et al. 1981	9.696	5.945			
	EC20 - Survival	7.40	14.5	3.246	Calamari et al. 1977, 1981					
	LC50	7.67	7.7	40.40	Thurston et al. 1981a	3.646				
	EC20 - 5 yr Life Cycle	7.70	7.5-10.5	>11.08	Thurston et al. 1984a					
Catostomus commersoni	LC50	8.16	15.0	176.6	Reinbold and Pescitelli 1982c	14.75	14.75	14.75	14.75	
	LC50	8.14	15.4	166.3						
	EC20 - Biomass	8.32	18.6	11.62	Reinbold and Pescitelli 1982a					
Notropis topeka	LC50	8.09	13.2	147.3	Adelman et al. 2009 (EC_{20} from Appendix C)	8.437	8.437	8.437	10.96	
	EC20 - Growth Rate	8.07	12.4	17.45						
Pimephales promelas	LC50	7.76	19.0	139.3	Thurston et al. 1983, 1986	36.53	19.24	19.24		
	LC50	7.83	22.0	158.7						
	LC50	7.91	18.9	178.9						
	LC50	7.94	19.1	162.3						
	LC50	8.06	22.0	205.0						
	LC50	8.03	22.1	216.3						
	EC20 - LC Hatchability	8.00	24.2	4.784						
	LC50	8.14	22.0	141.2	Mayes et al. 1986	11.35				
	EC20 - Survival	8.00	24.8	12.43						
	LC50	7.78	25.9	117.3	Swigert and Spacie 1983	17.17				
	LC50	7.80	25.6	126.8						
	EC20 - Biomass	7.82	25.1	7.101						
Cyprinus carpio	LC50	7.72	28.0	133.9	Hasan and MacIntosh 1986	8.100	8.100	8.100		
	EC20 - Growth: Weight	7.85	23.0	16.53	Mallet and Sims 1994					
Ictalurus punctatus	LC50	7.80	25.7	97.67	Swigert and Spacie 1983	4.800	4.800	4.800	4.800	
	EC20 - Biomass	7.76	26.9	20.35						
Lepomis cyanellus	LC50	7.72	22.4	144.3	McCormick et al. 1984	12.18	6.468	13.58	13.59	
	EC20 - Biomass	7.90	22.0	11.85						
	LC50	8.28	26.2	62.07	Reinbold and Pescitelli 1982a	3.437				

Table F.1. Species, Genus and Taxon-specific ACRs for Freshwater Aquatic Animals Exposed to Ammonia										
Species Scientific Name	**Acute and Chronic Test Endpoint**	**pH**	**Temp**	**Normalized Values**	**Reference**	**ACR**	**SMACR**	**GMACR**	**TSACR (Family)**	**TSACR (Class)**
	EC20 - Survival	8.16	25.4	18.06						
Lepomis macrochirus	LC50	7.60	21.7	93.31	Smith et al. 1984	28.51	28.51			
	EC20 - Biomass	7.76	22.5	3.273						
Micropterus dolomieui	LC50 (pH 6.5)	6.53	22.3	269.2	Broderius et al. 1985	31.12	13.61	13.61		
	EC20 (pH 6.5) - Biomass	6.60	22.3	8.650						
	LC50 (pH 7.0)	7.16	22.3	144.3		14.84				
	EC20 (pH 7.0) - Biomass	7.25	22.3	9.726						
	LC50 (pH 7.5)	7.74	22.3	105.2		6.670				
	EC20 (pH 7.5) - Biomass	7.83	22.3	15.77						
	LC50 (pH 8.5)	8.71	22.3	126.0		11.14				
	EC20 (pH 8.5) - Biomass	8.68	22.3	11.31						

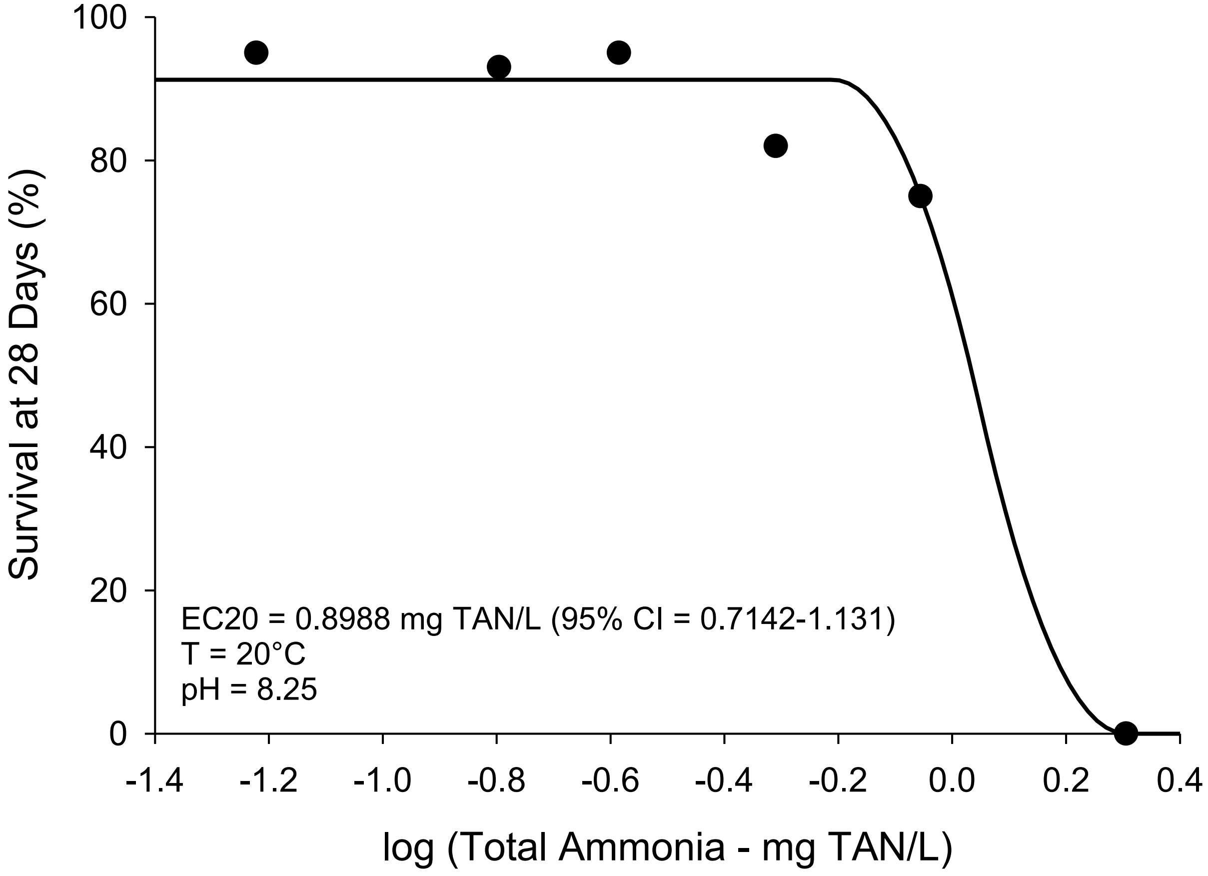
Figure F.1. SMACRs by SMAV Rank.



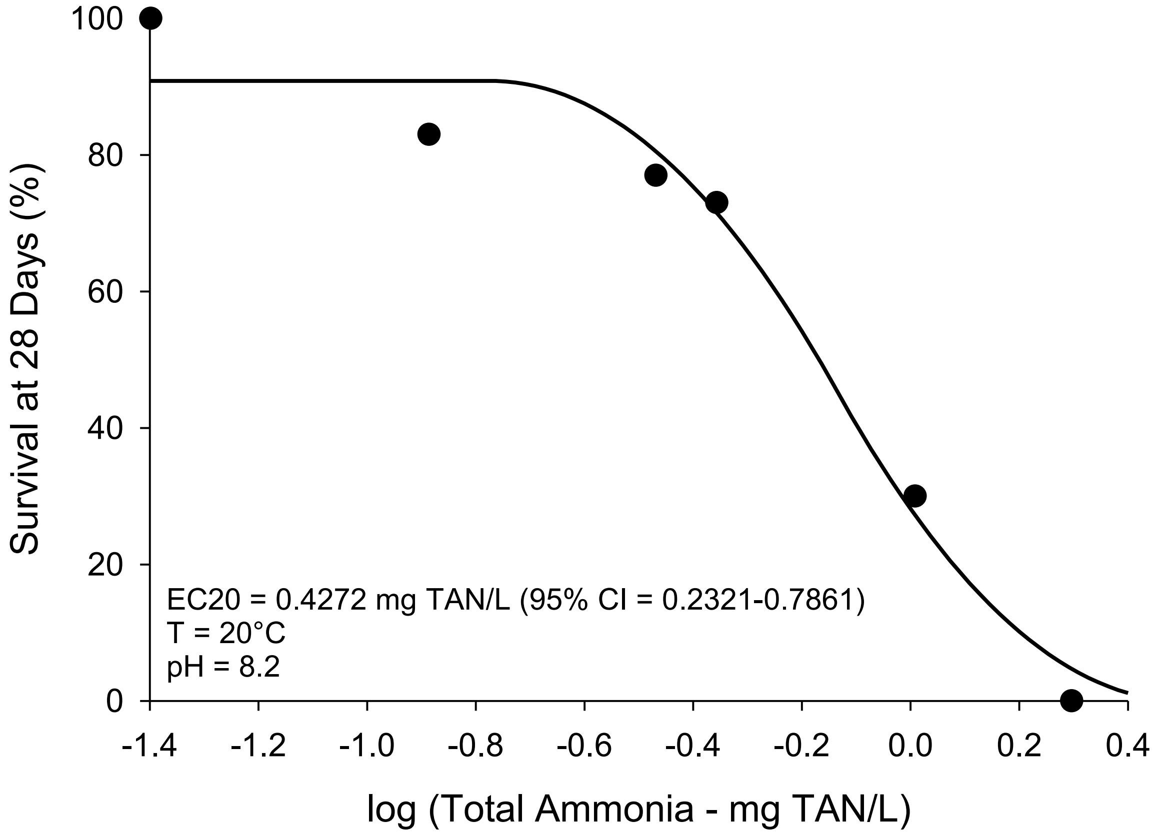
Appendix G. Results of the Regression Analyses of New Chronic Data for Unionid Mussels.

This appendix provides the figures generated using EPA's TRAP program that was used to calculate EC_{20}s for the new chronic ammonia toxicity studies conducted with unionid mussels. In the figures that follow, circles denote measured responses and solid lines denote estimated regression lines. The model-estimated EC_{20} values and corresponding 95% confidence limits are provided with each figure, as well as the pH and water temperature at which the test was conducted. Per the text on page 32 in *Chronic Toxicity to Freshwater Aquatic Animals* and as discussed in greater detail on page 56 in *Effects Characterization*, EPA decided that while 28-day survival EC_{20}s from these tests using juvenile freshwater mussels are acceptable for derivation of a chronic aquatic life criterion for ammonia, EC_{20}s based on growth responses from these tests are not. The decision not to use the growth data from these tests was based on the uncertainty in the test methods for assessing the growth endpoint and the need for additional research "to optimize feeding conditions, to conduct longer-term exposures (e.g., 90 d), and to compare growth effect to potential reproductive effect in partial life-cycle exposure" (Wang et al. 2011). Additionally, the growth response during these tests show a high degree of variability, and the test methods for assessing growth, based on substrate or water-only exposures, are currently being evaluated – see Figure below depicting the growth response of juvenile fatmucket in the 28-day tests reported in Wang et al. (2011).

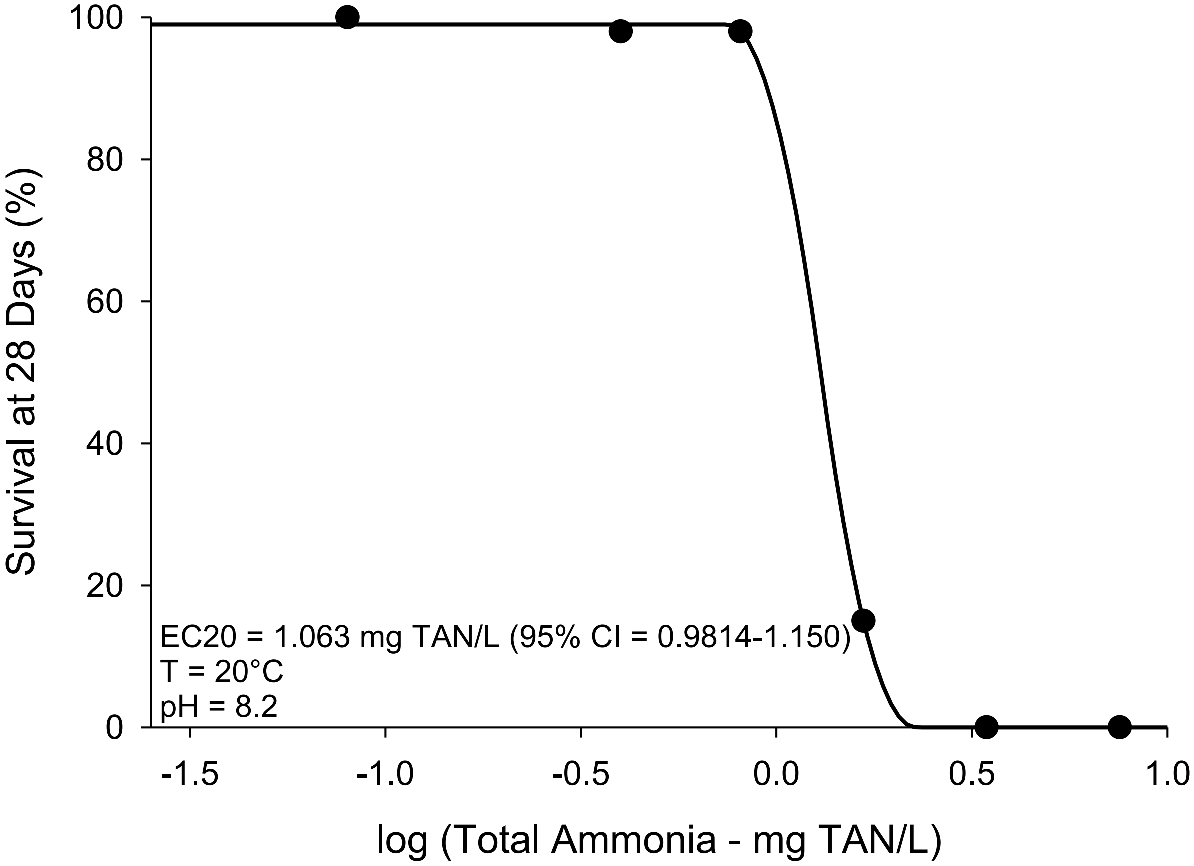
Juvenile Fatmucket, 28-Day Survival, Wang et al. 2011

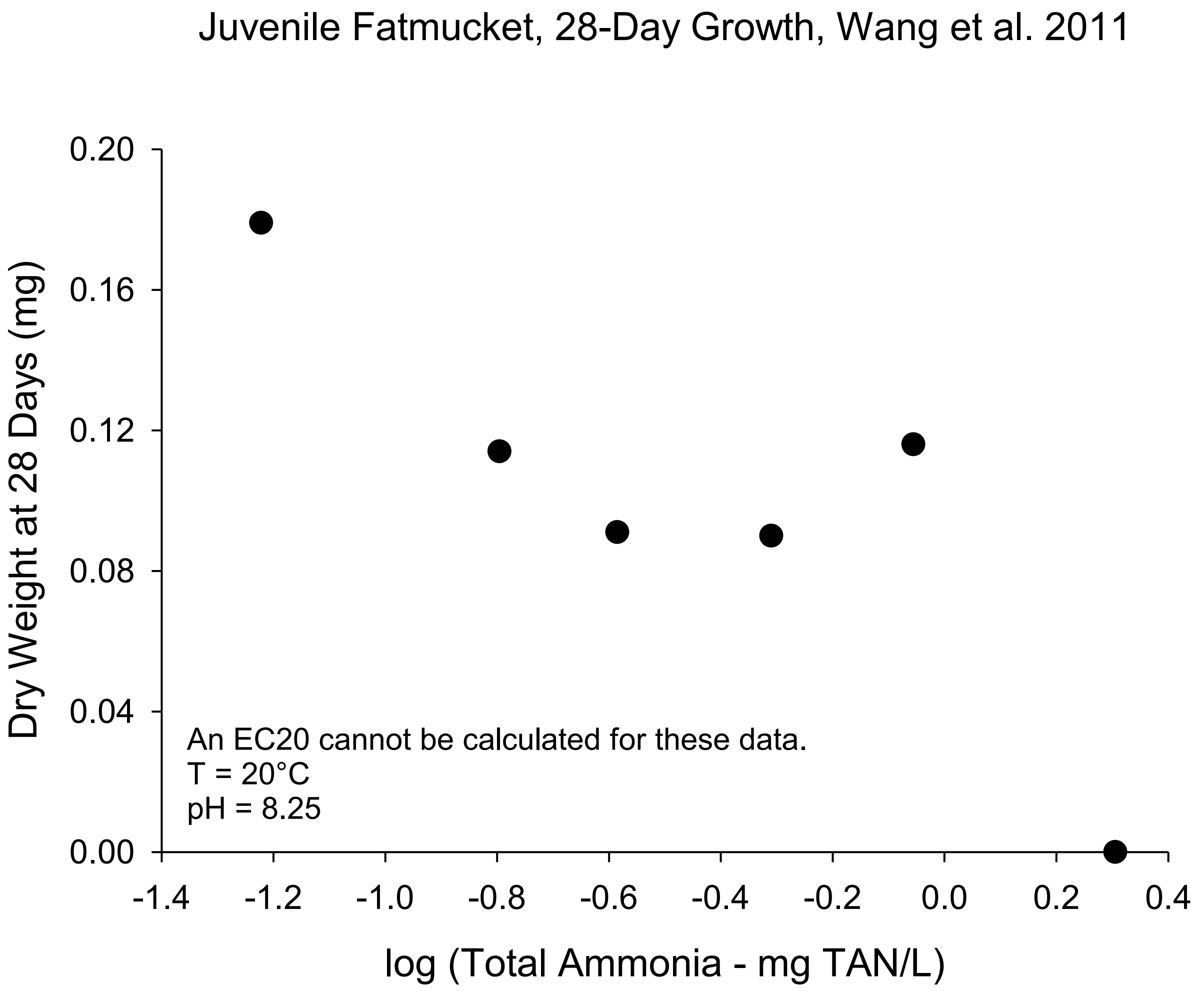


Juvenile Wavy-rayed Lampmussel, 28-Day Survival, Wang et al. 2007a



Juvenile Rainbow Mussel, 28-Day Survival, Wang et al. 2007a




Juvenile Fatmucket, 28-Day Growth, Wang et al. 2011
Dry Weight at 28 Days (mg)
0.20
0.16
0.12
0.08
0.04
0.00
An EC20 cannot be calculated for these data.
T = 20°C
pH = 8.25
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
log (Total Ammonia - mg TAN/L)

Appendix H. Detailed Descriptions of Select New Acute and Chronic Toxicity Test Data Used for Criteria Derivation.

Acute Toxicity Test Data

Venustaconcha ellipsiformis (ellipse)

As noted above, the ellipse test data was not directly used in the acute criterion calculation, but the data is described here as additional evidence supporting the determined acute criterion value. The GMAV for the ellipse is based on the 24-hr EC_{50} reported for an acute toxicity test initiated with 2-hr old glochidia of the species (Wang et al. 2007b). Glochidia were tested under static conditions at pH 8.1 and 20°C. Survival of control animals after 24 hours was 90 percent. The estimated measured EC_{50} at test temperature and pH was 4.450 mg N/L, after adjusting the reported nominal EC_{50} by multiplying by a factor of 0.89 (i.e., measured total ammonia concentrations were 89 percent of nominal concentrations for 24 hour glochidia exposures). The GMAV for this species is 23.12 mg TAN/L when adjusted to pH 7 and 20°C (Appendix A), and represents the lowest in the acute dataset (Table 3). The acute criterion of 17 mg TAN/L is considered protective of this species because the GMAV/2, a value used to estimate an effect level un-differentiable from controls (Federal Register on May 18, 1978 (43 FR 21506-18), is approximately 12 mg TAN/L for the ellipse, which is close to the current criterion value, given the variability and uncertainty in such toxicity tests.

Utterbackia imbecillis (pondshell mussel)

The GMAV for pondshell mussel of 46.93 mg TAN/L is the sixth lowest in the acute dataset (Table 3). Although this GMAV is not one of the four used in calculating the FAV, the value is composed of individual EC_{50} values ranging from a comparatively low acute value of 17.91 to 100.5 mg TAN/L (expressed as TAN and normalized to pH 7 and 20°C, Appendix A). This GMAV is based on several EC_{50}s (numbering nine in total) from three different studies (Wade et al. 1992; Keller 2000; Black 2001). This particular GMAV is based on tests with predominantly juvenile mussels of various ages, but also including a single test which employed glochidia (Appendix A). The pH and test temperature for all nine tests was relatively uniform and ranged from 7.80 to 8.35 and 24.0 to 25.1°C, respectively. Control survival exceeded 90 percent in all tests regardless of life-stage tested.

Fusconaia masoni (Atlantic pigtoe)

The GMAV for the Atlantic pigtoe represents the seventh lowest in the acute dataset, and lies just below the lowest GMAV for the most sensitive fish species, the mountain whitefish (Table 3). This GMAV is based on the 6-hr EC_{50} reported for an acute toxicity test initiated with 2-hr old glochidia of the species (Black 2001). Glochidia were tested under static conditions at pH 7.6 and 24.9°C. Survival of control animals after 6 hours was 93 percent, falling to 87 percent after 12 hours. The EC_{50} at test temperature and pH was 15.90 mg TAN/L, or 47.40 mg TAN/L when adjusted to pH 7 and 20°C (Appendix A).

Fluminicola sp. (pebblesnail)

The GMAV of 62.15 mg TAN/L for *Fluminicola* is the tenth most sensitive in the acute dataset (Table 3). As part of the study to evaluate the chronic sensitivity of pebblesnails (Gastropoda: Hydrobiidae) to ammonia via 28-day water only toxicity tests (see additional details below under Chronic Toxicity Test Data: 28-day Tests with Juvenile and Adult Pebblesnails (*Fluminicola* species), Besser (2011) reported survival of 'large' snails (i.e., mean starting shell length of 1.81 mm) after 96 hours of exposure. No mortality was observed in controls through the highest test concentration of 8.801 mg TAN/L where 32 of 40 snails (80 percent) survived. The mean pH and test temperature at this highest ammonia treatment level were 8.25 and 20.2°C, respectively. Because only 20 percent mortality occurred at this test concentration, the EC_{50} at test temperature and pH is recorded in this document as > 8.801 mg TAN/L, or >62.15 mg TAN/L when adjusted to pH 7 and 20°C (Appendix A).

Pleurocera uncialis (pagoda hornsnail)

Another non-pulmonate snail species (pagoda hornsnail) was determined to be nearly as sensitive to ammonia as pebblesnail, the pagoda hornsnail, which was ranked 12th in acute sensitivity. Goudreau et al. (1993) collected and acclimated (for six days) adult snails from Clinch River, Virginia prior to conducting a static renewal bioassay to determine a 96-hr LC_{50} for this species. The test was conducted in a walk-in experimental chamber set to a temperature of 22°C and using chlorine free laboratory dilution water at pH 8.1. Survival of adult snails in the control treatment was 100 percent. The reported LC_{50} at test temperature and pH was 11.18

mg TAN/L when expressed as total ammonia. The LC_{50} normalized to pH=7 and 20°C is 68.54 mg TAN/L (Appendix A).

Deltistes luxatis (Lost River sucker)

The endangered Lost River sucker is a freshwater fish species endemic to the Klamath Basin of northern California and southern Oregon (Appendix A). The acute toxicity of ammonia was determined for larval and juvenile Lost River sucker as reported in Saiki et al. (1999). Larval tests were initiated when fish reared from spawned eggs were 35 days old, whereas the juvenile tests were initiated after the fish reached 3-7 months old. All fish were exposed for 96 hours under flow-through conditions at pH 8.0 and 20°C. The reported LC_{50}s at test temperature and pH were 10.35 and 16.81 mg/L for larval and juvenile fish, expressed as total ammonia nitrogen (Appendix A). The LC_{50}s normalized to pH 7 and 20°C are 44.42 and 72.18 mg TAN/L, respectively (Appendix A). The GMAV for Lost River sucker is calculated as the geometric mean of the two normalized LC_{50}s, or 56.62 mg TAN/L (Table 3). Lost River sucker represents the ninth most sensitive genus in the acute dataset, and second most sensitive fish species (following mountain whitefish which was the most sensitive GMAV) and is expected to be protected by the CMC of 17 mg TAN/L.

Chronic Toxicity Test Data

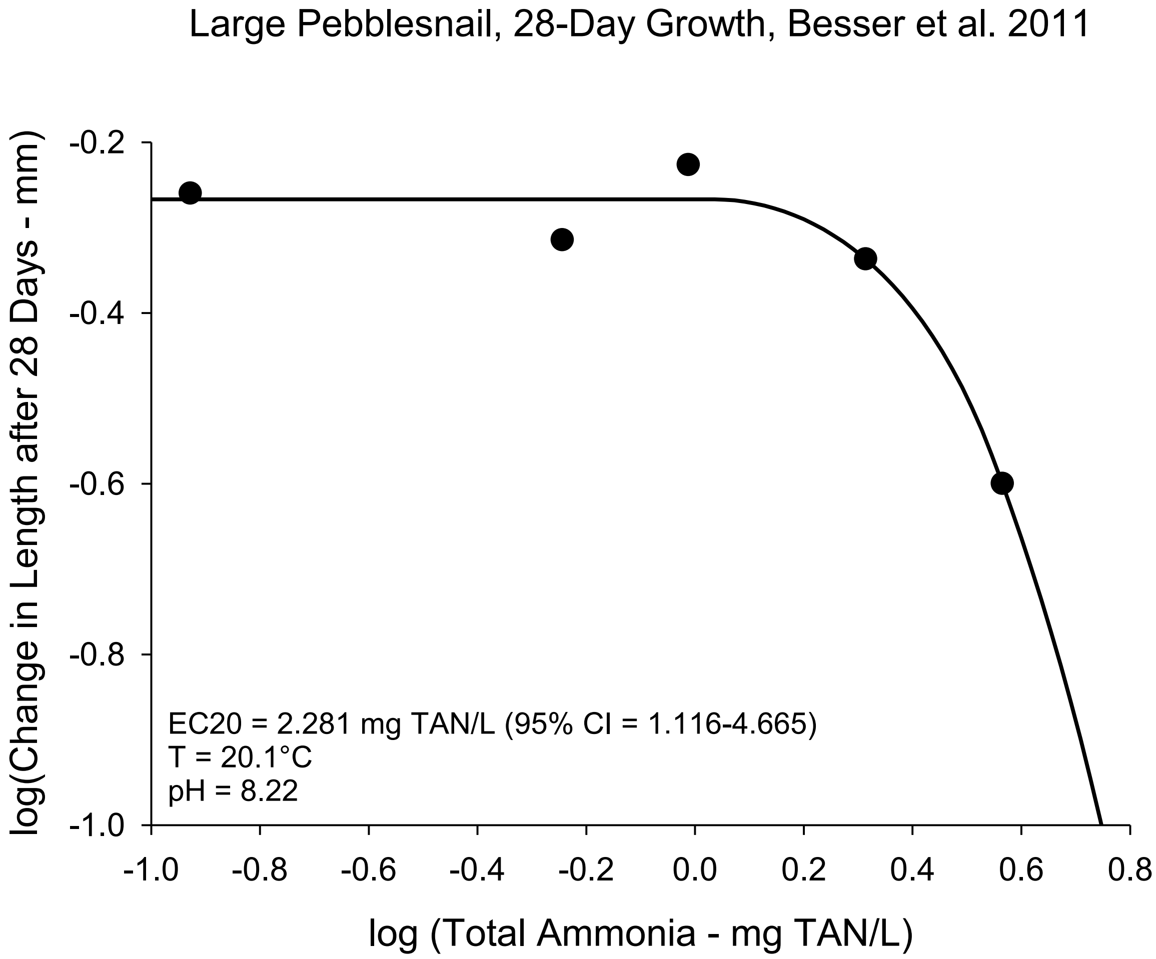
28-day Tests with Juvenile and Adult Pebblesnails (Fluminicola species)

The summary for 28-day tests recently conducted with *Fluminicola* sp. includes the results from repeat tests performed by Besser et al. in 2009 and 2010, the details of the latter of which are summarized in a memorandum to EPA in 2011 (this study referred to in this document as Besser 2011).

Test organisms used in the Besser et al. (2009) 28-day survival tests with wild-caught (Snake River, Idaho) *Fluminicola* sp. included mixed-aged adult and young-adult organisms (from 6 to 12 months). Mixed-age classes were used because the acclimation cultures produced only approximately 200 neonates for testing that were collected over a period of about four months. Despite the fact that snails in the control treatment exhibited 100 percent survival, while snails exposed to the highest ammonia concentration (7.9 mg TAN/L) exhibited 0 percent survival, extreme variation between replicates at the highest test concentrations was observed during the test, i.e., snails in replicates were either all alive or all dead in the 1.7 and 3.6 mg TAN/L treatments. Based on the mean survivals for *Fluminicola* sp., the reported survival EC_{20} for the species was estimated to be 1.02 mg TAN/L at test temperature (20.8°C) and pH (8.26), or 3.900 mg TAN/L when adjusted to pH 7 and 20°C (see Appendix C). The EC_{20} reported for the test is not considered reliable, however, due to the variability in survival among replicates in the 1.7 and 3.6 mg TAN/L test concentrations; therefore, this data was not used in the derivation of the final ammonia CCC (i.e., the all-or-none response in the replicates of these two treatments, which, when averaged and used as means instead of analyzing the replicates separately in the regression, allows estimation of an EC_{20} that would otherwise be incalculable because of the variability between treatment replicates). Thus, the upper limit CV for the test is uncertain. The value clearly is a concentration below 7.9 mg TAN/L (at test temperature and pH), but the exact concentration could not be determined at the time.

In an attempt to further define the 28-day ammonia survival effects threshold for *Fluminicola* sp., pebblesnails cultured in the laboratory at the USGS Columbia Environmental Research Center were tested in April 2010 via a similar 28-day test protocol (see Besser 2011). This 2010 test was conducted with two size classes of juvenile pebblesnails: small (mean shell length of 1.34 mm at the start of the test) and large (mean starting shell length of 1.81 mm). Both size groups were exposed in the same flow-through exposure system consisting of five ammonia concentrations (ranging from a nominal concentration of 0.5 to 8 mg N/L in 50 percent dilution series), plus a control, with four replicates of ten snails per replicate (or 40 small and 40 large snails per treatment). Mean measured TAN concentrations, pH, and temperature were maintained very close to target values throughout the test (i.e., mean measured ammonia concentrations were within 14 percent of nominal, mean treatment pH ranged from 8.18 to 8.26, and mean treatment water temperature ranged from 20.1 to 20.2°C). Survival was measured after 4 and 28 days. Survival of snails after 28 days in the small size group was lower overall (75 percent in the control and 60-68 percent in the nominal 0.5 to 2 mg TAN/L test concentration range) in relation to that of the large size group (93-100 percent in both the control and low ammonia test concentration). For both size groups, snail survival differed among test concentrations and was substantially lower than controls in the two highest ammonia concentrations (4.0 and 8.0 mg TAN/L nominal), however, due to the lower control survival of the small size group (<80 percent), the data for this group is not used quantitatively in the derivation of the final ammonia CCC and is instead presented in Appendix C as other chronic data.

Because the survival of the large size group of snails was acceptable in controls and snail length different among concentrations according to concentration-response, change in length for the large size group was analyzed further for inclusion in the derivation of the CCC. (Note: attempts to model concentration-response curves for survival in the large size group using TRAP software were not as informative because partial mortality was limited to only one treatment (i.e., 28-day survival ranged from 98 to 100 percent in the nominal 0.5, 1 and 2 mg TAN/L test concentrations, only 10 percent in the 4 mg TAN/L nominal test concentration, and zero percent at the highest nominal test concentration of 8 mg TAN/L). The growth EC_{20} for this freshwater non-pulmonate snail species calculated using EPA's TRAP (threshold sigmoid model with full convergence) is 2.281 mg TAN/L at test pH (8.22) and temperature (20.1°C), or; 7.828 mg TAN/L after adjustment to pH 7 and 20°C (see Appendix B). The TRAP output for this test is provided below to support the use of the growth-based EC_{20} for this particular species and test.



Large Pebblesnail, 28-Day Growth, Besser et al. 2011

Chronic Toxicity Tests with Juvenile Hyalella azteca

Borgmann (1994) conducted four sets of experiments on *H. azteca* using different dilution water types and life-stages of test organisms. One set of experiments consisted of tests that began with <1-week-old organisms, all of which utilized weekly renewals and dechlorinated tap water originating from Lake Ontario. Of the three tests, one lasted four weeks and the other two lasted 10 weeks, the latter of which produced data on both survival and reproduction, as described in detail in the 1999 AWQC document (U.S. EPA 1999). At the time, the results of the two 10-week tests were deemed sufficiently similar such that the results were analyzed together and subsequently used as the basis for the pH and temperature adjusted EC_{20} of <1.45 mg TAN/L (at pH 8 and temperature 25°C) reported in Table 5 of the 1999 AWQC document (U.S. EPA 1999). Since then, however, EPA has re-evaluated the results of the three tests in light of the recent extensive research that has been undertaken to elucidate the specific water ionic composition and feeding requirements necessary to ensure the health of this particular freshwater aquatic test organism for use in long-term toxicity testing. During the EPA's re-evaluation of these tests, it was concluded that while the ionic composition of the water used for testing (dechlorinated city tap water originating from Lake Ontario) was acceptable, the results of the two 10-week chronic tests should not be used for deriving AWQC for the following reasons:

- Low control survival observed after 10 weeks of exposure (only 66.3%), possibly linked to inadequate food and feeding level that was employed, particularly after the first four weeks of testing;
- Poor control reproduction observed after 10 weeks of exposure; and
- The fact that the ammonia concentrations increased substantially in critical test treatments (e.g., the 0.1 mM ammonia treatment) during the final 3 weeks of testing (weeks 7 – 10).

However, four week data for these two tests, in combination with data from the third four-week test with the same life stage, were not affected by these limitations. The measured total ammonia concentrations and mean pH (8.04) reported for the "Tap water (young)" tests in Table 1 of Borgmann (1994) reflect the analytical measurements combined from all three tests conducted with this life stage (i.e., <1 wk old *H. azteca*). Likewise, the pooled results for survival (from Figure 1a) and wet weight (from Table 4) reflect the observations (weekly for survival and after four weeks for wet weight) from the three respective tests, and thus, represent observations stemming from six test replicates per treatment when combined. Using these data up through the first four weeks of exposure, as well as the water temperature of 25°C (maintained via an incubator) at which all sets of experiments in the study were run, a 28-day EC_{20} of 29.17 mg N/L (based on biomass and normalized to pH 7 and 20°C) was calculated for *H. azteca* for the study (Appendix B). These data were deemed sufficient to derive an SMCV for the species (as an upper limit), which is subsequently used here for chronic criterion development. This decision was largely predicated on the fact that:

- The ion composition of the water used in this test was acceptable;
- The control survival for the tests up through the first four weeks was good (88.4%); and

- The feeding level during the first four weeks of testing was acceptable (as judged via the growth performance of the test organisms during this timeframe.

New Chronic Data for Non-salmonid Fish Species

Cyprinus carpio (common carp)

Mallet and Sims (1994) conducted a 28-day early life-stage test starting with eggs approximately 6 hours post-fertilization. Mean pH and temperature for the test were 7.85 and 23°C, respectively. The measured DO concentrations reported for the test ranged from 79 to 94 percent of saturation. Ammonia had no effect on hatching success at the highest concentration tested (19.6 mg TAN/L); although survival of the post-hatch stages was significantly reduced at this level compared to controls (average fry survival in the control treatment was 86 percent). Growth of fry was the most sensitive endpoint, and mean fry wet weights were inhibited at concentrations ≥10.4 mg TAN/L. Even though the number of larvae in each replicate vessel was not made uniform on hatching, at least one vessel per concentration contained an equivalent stocking density (23 to 29 carp), so the mean wet weight of carp in the one selected replicate per concentration was analyzed using regression analysis. The resulting EC_{20} value was 8.360 mg TAN/L at 23°C and pH 7.85, which is calculated to be 16.53 mg TAN/L at pH 7, with a GMCV sensitivity rank of ten (see Appendix B and Table 4).

Esox lucius (northern pike)

Harrahy et al. (2004) conducted a 52-day early life-stage test starting with newly-fertilized northern pike embryos. The mean dissolved oxygen concentration in test water ranged from 8.7 to 9.1 mg/L during the test. There was no effect of ammonia on hatching success up to 62.7 mg TAN/L, and larval survival of control fish was 100 percent. A significant reduction in larval survival and growth was observed at concentrations of total ammonia ≥30.4 and 15.1 mg TAN/L, respectively, at pH 7.62 and 8.7°C. The estimated EC_{20} value reported for biomass was 13.44 mg TAN/L, which, normalized to pH 7 to support criteria development in this document, is 20.38 mg TAN/L (Appendix B). The GMCV of 20.38 mg TAN/L for northern pike is included in Table 4 as the GMCV ranked 11th in sensitivity.

New Chronic Toxicity Data for Salmonid Species

Chronic values for two additional studies with Oncorhynchus species are included in this AWQC document. Koch et al. (1980) exposed Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*) for 103 days in an ELS test. The measured dissolved oxygen concentrations for the entire study ranged from 7.0 to 8.9 mg/L, with an overall average of 7.9 mg/L. Survival of embryos in the control treatment was 80 percent, with approximately 95 percent surviving through the fry stage, and 80 percent surviving as fingerlings up to day 94 of the test. There were no successful hatches at exposure levels of 148 mg TAN/L or higher and no significant mortality at exposure levels below 32.9 mg TAN/L. Regression analysis of the survival data using an arcsine transformation resulted in a calculated EC_{20} value of 17.89 mg TAN/L at 13.7°C and pH 7.57. The EC_{20} value is 25.83 mg N/L when adjusted to pH 7 (Appendix B).

The recent results of a 90-day ELS test using a wild strain of rainbow trout exposed to ammonia were reported by Brinkman et al. (2009). The test was initiated with newly fertilized embryos (<24 h) exposed under flow-through conditions through hatch (28 days), swim-up (15 days) and early fry development (52 days) to five concentrations of total ammonia with a control. Each treatment consisted for four replicates containing 20 embryos each (N = 100 embryos per treatment). Mean pH and temperature of test water measured among treatments was 7.75 and 11.4°C, respectively. Hatch success and survival of sac fry were similar to controls for all ammonia concentrations, resulting in an unadjusted NOEC of >16.8 mg TAN/L. Survival, growth and biomass of swim-up fry were significantly reduced at 16.8 mg TAN/L compared to controls, but unaffected at 7.44 mg N/L, resulting in a chronic value (MATC) of 11.2 mg TAN/L. The EC_{20} calculated for biomass using TRAP and normalized to pH 7 is 15.60 mg TAN/L (Appendix B).

Appendix I. Qualitative Weight-of-Evidence Test Data.

Additional 28-day Toxicity Test data for Freshwater Mussels

As part of the same study summarized above in the *Effects Analyses to Freshwater Aquatic Organisms* under *Summaries of Studies Used in Chronic Criterion Determination* (page 34), Wang et al. (2007a) also attempted to determine the effect of ammonia on growth of 2-month old juvenile rainbow mussel, fatmucket, and wavy-rayed lampmussel. The 28-day tests were conducted following the same methods (see ASTM 2006). The mean length of juvenile rainbow mussel and fatmucket exposed to the lowest ammonia concentrations tested was reduced by 13 and 12 percent compared to mean length of control animals, respectively, but increased by 7 percent for the wavy-rayed lampmussel. There was no consistent effect of ammonia, however, on either length at 28 days or change in length after 28 days for fatmucket and wavy-rayed lampmussel at test concentrations where survival was unaffected; only the 28-day test with rainbow mussel exhibited such a concentration- response for length and change in length. For the reasons explained above under the section referenced, the growth endpoint was not used from these tests to derive the chronic criterion, and instead, the reported IC_{25} (inhibition concentration) estimated for these tests are included in Appendix C. The reported growth IC_{25} for juvenile rainbow mussel, fatmucket, and wavy-rayed lampmussel from their respective 28-day tests were 0.73, 0.44, and 0.57 mg TAN/L at test pH of 8.2 and temperature 20°C. These values, when adjusted to pH 7 and 20°C, are 2.406, 1.450 and 1.878 mg TAN/L, respectively (see Appendix C).

Additional 28-day Toxicity test Data for Freshwater Snails

Besser et al. (2009), in a USGS study report completed for EPA, conducted 28-day flow-through survival and growth tests with five species of snails, including four gill-bearing (non-pulmonate) species and an air-breathing (pulmonate) species. All tests were conducted in ASTM hard water (mean hardness and alkalinity of approximately 170 and 120 mg/L as $CaCO_3$, respectively) with a pH range of 8.20-8.29 and a temperature range of 19-21°C during testing. Total ammonia nitrogen (mg TAN/L) concentrations in tests were measured weekly with the percent of nominal concentrations ranging from 83 to 101 percent. Test results were based upon the mean of the measured concentrations. For all snail exposures, the effect of ammonia on growth was not determined for test species that were of mixed ages at test initiation (as explained further below); growth, however, was not as sensitive of an endpoint as survival for at least one (*Pyrgulopsis idahoensis*) of the two snail species (*Lymnaea stagnalis* and *P. idahoensis*) where both growth and survival were measured (see Appendix C).

Fontigens aldrichi (Ozark springsnail)

As part of the original study described above, Besser et al. (2009) also determined the effect of ammonia on survival of the non-pulmonate snail *F. aldrichi*. Because *F. aldrichi* did not reproduce during culturing and acclimation, field-collected organisms of "older" (adult) mixed-ages were used for ammonia exposures. *F. aldrichi* exposed to ammonia in the 28-day test exhibited approximately 94 percent survival at 0.45 mg TAN/L, but only 50 percent at 0.83 mg TAN/L. Similar to the 2009 adult pebblesnail study, the replicates associated with the latter 0.83 mg TAN/L treatment in particular were characterized by high variability, and therefore, these data were not used quantitatively in the derivation of the final ammonia CCC. In addition, field-collected *F. aldrichi* did not reproduce in captivity and animals in the control group did not grow during testing. The reported EC_{20} for *F. aldrichi* was 0.61 mg TAN/L, or 2.332 mg TAN/L when adjusted to pH 7.0 and 20°C, and is presented as other chronic data in Appendix C.

Pyrgulopsis idahoensis (Idaho springsnail)

Two separate 28-day tests with the de-listed (from the Federal threatened and endangered species list) non-pulmonate snail species, *P. idahoensis,* were conducted which included exposing juvenile organisms that were 7-9 and 11-13 weeks post-hatch (organisms in each cohort tested as separate replicates in the same test; test identified as test #3 in the 2009 Besser et al. report), as well as a cohort of mixed-age adults for all subsequent tests (test identified as test #5 in Besser et al. 2009). The older life stages were chosen for testing because of the high control mortality demonstrated in preliminary tests using 2-3 week post-hatch *P. idahoensis.*

In the 28-day test with juveniles, snails in four of the five test concentrations exhibited ≤44.4 percent survival, whereas control survival was 100 percent; the single exception being the snails in the middle test concentration of 1.8 mg TAN/L, which demonstrated only 62.5 percent survival. The survival EC_{20} reported for the test was 0.48 mg TAN/L at 20.1°C and pH 8.25, or

1.726 mg TAN/L when adjusted to pH 7 and 20°C, however, due to the poor concentration-response relationship exhibited in this test, this EC_{20} is highly uncertain, and therefore, the data are included in Appendix C as "other data" and are not used in the derivation of the CCC.

The 28-day chronic test initiated with mixed-aged adult *P. idahoensis* (4 to 8 months of age), on the other hand, resulted in an EC_{20} reported for the test of 3.24 mg TAN/L, or 12.39 mg TAN/L when adjusted to pH 7 and 20°C (Appendix C). Comparison of the juvenile and adult *P. idahoensis* survival results indicates that juveniles are possibly the more sensitive of the two life stages; however, due to the unreliability of the juvenile data, specifically the irregular survival concentration-response relationship, such an assertion is uncertain at this time and the CVs are not used quantitatively in the derivation of the CCC.

Taylorconcha serpenticola (Bliss Rapids snail)

A non-pulmonate snail species listed under the Endangered Species Act, *Taylorconcha serpenticola,* was exposed to ammonia in 28-day flow-through toxicity tests as described above. Because *T. serpenticola* did not reproduce or grow well during culturing and acclimation, field-collected organisms of "older" (adult) mixed-ages were used. Survival of snails in the control treatment was 100 percent, whereas survival of snails exposed to concentrations up to 3.6 mg TAN/L exceeded 80 percent. Survival of snails exposed to the highest concentration tested (7.9 mg TAN/L) was reduced to only 30 percent. The survival EC_{20} reported for *T. serpenticola* in the test was 3.42 mg TAN/L at 20.8°C and pH 8.26, or 13.08 mg TAN/L at pH 7.0 and 20°C, but because these snails did not grow well preceding the test, the data are also considered "other data" and placed in Appendix C.

Pleurocera canaliculata (silty hornsnail)

EPA sponsored a study (GLEC 2011) to independently confirm the results of the 28-day juvenile and adult tests performed by the USGS, Columbia, MO laboratory (i.e., Besser et al. 2009 and Besser 2011) with non-pulmonate snails. The USGS test results indicated that specialized and Federally-listed non-pulmonate gill-bearing snails, such as the Idaho springsnail, Bliss Rapids snail and pebblesnail, are potentially: 1) sensitive to prolonged, 28-day ammonia exposure, and 2) as sensitive as ammonia-sensitive freshwater unionid mussel species to such exposure. The EPA-sponsored study involved a 28-day flow-through toxicity test using a more widely-distributed non-pulmonate snail species, *P. canaliculata.* Two other non-pulmonate snail species were also selected based on distribution and generalized habitat preference; however, *P. canaliculata* was the only one of the three wild-caught snail species that were successfully held and maintained in the laboratory for subsequent testing. Following a protocol similar to that used in the USGS studies, a 28-day toxicity test of mature, mixed-age *P. canaliculata* was conducted. The test design consisted of five ammonia test concentrations (0.9, 1.9, 3.8, 7.5, and 15 mg TAN/L, nominal) and one control, with four replicate chambers containing six snails each per test concentration (N=24 snails per treatment). Test concentrations were based on the results of a 96-hr range finding test with the species, which provided a 96-hr EC_{50} of 9.66 mg TAN/L, or approximately 88 mg N/L at 20°C and pH 7.0. The endpoint for the 28-day toxicity test was mortality or immobilization, measured daily, the results of which were used to calculate an EC_{20} (at pH 7 and 20°C) of 1.845 mg TAN/L (Appendix C). However, due to the high degree of temporal variability in the measured total ammonia concentrations, as well as the unequal response amongst replicates at the 1.9 mg TAN/L nominal test concentration, these data were not used quantitatively in the derivation of the final ammonia CCC; a 28-day ammonia survival effect concentration of <7.667 mg TAN/L was recommended as the CV for the species which supports the recent findings for the pebblesnails (1.8 mm) which were re-tested and reported to EPA via Besser (2011).

(**Note**: The calculated EC_{20} values using TRAP for *P. idahoensis*, *F. aldrichi*, and *T. serptenticola*, and the recommended 28-day ammonia survival effects concentration of <7.667 mg TAN/L for *P. canaliculata*, are deemed representative of non-pulmonate snail sensitivity in general and are included in Appendix C for the purpose of comparison.)

Lymnaea stagnalis (pulmonate pondsnail)

The effect of ammonia in a 28-day test on survival and growth of a third freshwater snail species, the air-breathing *L. stagnalis,* was also reported in Besser et al. (2009). The tests with *L. stagnalis* utilized organisms that were <1 week post-hatch due to the abundance of young produced during culturing. *L. stagnalis* exposed to ammonia in a 28-day flow-through test exhibited approximately 98 percent survival at the highest concentration tested (8.0 mg TAN/L). Because of the apparent negligible effect of ammonia on growth (i.e., the magnitude of the growth reduction was so small, 6 percent at 1.8 mg TAN/L and only 16 percent at 8 mg TAN/L), only the CV of >8.0 mg TAN/L (for survival and growth) is reported in this document for the test, or >28.76 mg TAN/L when adjusted to pH 7 and 20°C. Note: For the purposes of this document, the CV for this test species is included in Appendix C and was not used in the derivation of the CCC because of the uncertainty of this value (> 28.76 mg TAN/L) as an upper limit SMCV for the species.

Chronic Toxicity Data for Other Salmonids

A few other chronic toxicity tests produced applicable data for salmonid species that were excluded from Appendix B and subsequent SMCV and GMCV calculation because either the exposure did not include the appropriate life stage for the species, or the tests did not meet other general 1985 Guidelines requirements for use in calculating the CCC. These tests are summarized below and shown in Appendix C.

The effects of water temperature and ammonia on the swimming characteristics of brook charr (*Salvelinus fontinalis*) were investigated by Tudorache et al. (2010). Juvenile brook charr were exposed to four ammonia concentrations in de-chlorinated tap water for 96 hours at pH 9.10 and 15°C. The following swimming characteristics were measured in a 4.5 m long raceway following this exposure: gait transition speed, maximum swimming speed, tail-beat amplitude, tail-beat frequency, maximum acceleration of bursts, number of bursts, distance of bursts, and total swimming distance. The most sensitive swimming parameters (maximum swimming speed and maximum acceleration) had a reported LOEC of 0.7765 mg TAN/L, or 10.86 mg TAN/L when normalized to pH 7.

The effects of long-term exposure of ammonia on the molecular response of Atlantic salmon (*Salmo salar*) parr were investigated by Kolarevic et al. (2012). The juvenile fish were exposed for 105 days to three concentrations of total ammonia nitrogen (TAN) in a flow-through apparatus with two different feeding regimes: full and restricted. Average water temperature during the exposure was 12.1°C with a pH of 6.84. There was no effect of ammonia exposure on survival, resulting in a NOEC of 32.29 mg N/L (highest concentration tested) in the full feeding regime. When normalized to pH 7, the CV for this test is >30.64 mg TAN/L.

Beamish and Tandler (1990) exposed juvenile lake trout (*Salvelinus namaycush*) for 60 days on two different diets and observed a significant reduction in rate of weight gain when total ammonia was 6.44 mg TAN/L at pH 8.02 and temperature was 11.6°C. Food intake by fish was initially decreased at this concentration of total ammonia, but was no different from controls by the end of the test. The growth LOEC for the study, when adjusted to pH 7, was calculated to be 16.10 mg TAN/L. Note: this test was not included in the calculation of the CCC because it was not a true ELS having been initiated with juvenile fish.

Chronic Toxicity Data for Threatened and Endangered Fish Species

Meyer and Hansen (2002) conducted a 30-day toxicity test with late-stage larvae (0.059 g) of Lost River suckers (*Deltistes luxatus*) at pH 9.43. The exposure duration and pH were chosen to represent the period of combined elevated unionized ammonia concentrations and elevated pH that occur during cyanobacterial blooms in surface waters of Upper Klamath Lake, which have been shown to last for several weeks to a month. Survival decreased significantly at 1.23 and 2.27 mg TAN/L, whereas the highest NOEC for all endpoints (survival, growth, body ions, and swimming performance) was 0.64 mg TAN/L. Most deaths in the 2.27 mg TAN/L exposure occurred during the first three days of the test, while mortality of larvae in the 1.230 mg TAN/L treatment occurred gradually from days 2 to 24. The 29 percent average mortality in the 0.64 mg TAN/L treatment was all due to an unexplained complete loss of one replicate between days 5 and 7 of the exposure. Control survival was > 90 percent. The calculated LOEC of 1.230 mg TAN/L total ammonia normalized to pH 7 corresponds to a value of 25.31 mg TAN/L, substantially higher than the 2013 chronic criterion value (Appendix C).

Fairchild et al. (2005) conducted 28-day toxicity tests with early life stages of Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*), and compared the results of those tests with a test using a surrogate fish species, the fathead minnow (*Pimephales promelas*). Tests were initiated 2 days after swim-up when the larvae were feeding exogenously (or at 8-day post hatch for Colorado pikeminnow, 9-day post hatch for razorback sucker, and 4-day post-hatch for fathead minnow). Temperature, pH and dissolved oxygen over the 28-day test period averaged 19.9°C, 8.24, and 7.4 mg/L (80 percent saturation) over the course of the three studies. Control mortality was 7 percent (fathead minnows and Colorado pikeminnow) or less (3 percent, razorback sucker) on day 28. Effect concentrations based on the survival and growth endpoints of the fathead minnow and razorback sucker tests were not different; however, growth was the more sensitive endpoint for the Colorado pikeminnow test.

The 28-day growth LOEC for the Colorado pikeminnow was 8.60 mg N/L, or 29.75 mg TAN/L at pH 7, substantially greater than the 2013 chronic criterion. The 28-day survival LOEC for the razorback sucker was 13.25 mg TAN/L, or 46.58 mg TAN/L at pH 7. Both endangered fish species exhibited similar sensitivity to ammonia as the fathead minnow (LOEC of 32.71 mg TAN/L at pH=7; see Appendix C). The same can be said for the Lost River sucker, which indicates that these particular endangered fish species will be protected by the CCC value calculated in this 2013 AWQC Update.

Finally, Adelman et al. (2009) conducted both acute and chronic toxicity tests with ammonia on the endangered Topeka shiner (*Notropis topeka*) and compared those values to chronic studies with fathead minnows. All tests used a flow-through dosing apparatus and deep well water with a total hardness and alkalinity of 210-230 mg/L $CaCO_3$, and chloride concentration of 0.64-1.04 mg/L. Acute survival studies with Topeka shiner lasted 96 hours and were conducted on two different life-stages (juvenile and adult) and at two test temperatures, warm, 25°C (adult and juvenile), and cold, 13°C (juvenile only). LC_{50}s for total ammonia ranged from 18.7-21.4 mg TAN/L at 25°C and 28.9 mg TAN/L at 13°C; all acute studies were conducted at approximately pH 8. Normalized to pH 7, the 96-hr LC_{50}s were 69.59 – 88.27 mg TAN/L at 25°C and 147.3 mg TAN/L at 13°C, both substantially greater than the acute criterion value of 17 mg TAN/L, respectively (see Appendix A).

Chronic studies with Topeka shiners started with both adults and juveniles, since embryos were not available, and lasted 30 days. The results of the survival and growth studies with juvenile Topeka shiners were compared to a 30-day juvenile survival study and 32-day embryo-larval study conducted with fathead minnows in the same dilution water. The authors interpreted the results of the relationship between the comparative studies using Topeka shiners versus fathead minnows to infer what an expected result for an embryo-larval study with Topeka shiner would be. Reported MATC values (normalized to pH 8, according to USEPA 1999) were 16.95 mg TAN/L for the 30-day juvenile fathead growth test and 8.62 mg TAN/L for the 32-day embryo-larval survival and growth test. Using the relationship from the results obtained between juvenile Topeka shiners and juvenile (growth) and embryo-larval test using fathead minnows (growth and survival), a 32-day embryo-larval study with Topeka shiner might be expected to result in a chronic value that is approximately 51% more sensitive than the 30-day juvenile growth test with that species, or a chronic value of approximately 5.63 mg TAN/L (i.e., the reported 30-day MATC of 11.10 mg TAN/L at pH 8 based on growth of juvenile Topeka shiners multiplied by a factor of 0.507). Using EPA's TRAP (version 1.21a) the 32-day biomass EC_{20} for embryo-larval fathead minnow (measured from days 7-32), 30-day adult survival EC_{20} for Topeka shiner, and 30-day juvenile specific growth rate EC_{20} for Topeka shiner were 7.457, 10.85, and 6.483 mg TAN/L at test temperatures (25.5, 23.9, and 12.4°C) and pH (7.95, 7.94, and 8.07), respectively. When adjusted to pH 7, the EC_{20}s for the respective tests are 16.87 mg TAN/L for the fathead minnow (Appendix B), and 24.21 and 17.45 mg TAN/L for the Topeka shiner (Appendix C), much higher than the 2013 chronic criterion.

Chronic Toxicity Data for Amphibians

In a long term chronic study by Jofre and Karasov (1999), pre-metamorphic (Gosner stage 24-26) green frog (*Rana clamitans*) tadpoles were exposed to ammonia for 103 days under renewal conditions. Tadpoles were evaluated in two different experiments conducted in successive years. In the 1997 (repeat) experiment, survival and growth were not statistically different from controls at the highest concentration tested, or 2.2 mg TAN/L at pH 8.7 and 24°C, although only approximately 50 percent of the frogs survived at this concentration compared to the controls (98 percent survival). Survival was reduced to approximately 78 percent at 0.9416 mg TAN/L at test temperature and pH (or 7.149 mg TAN/L at pH 7). Growth, measured as total length, was no different between treatments. The frogs grew from an average total length of approximately 7.5 mm at test initiation to approximately 50 mm in all treatments. The NOEC for growth of green frog tadpoles in the study (which does not reflect an ELS or partial life cycle test) is >16.74 mg TAN/L at pH 7.

Appendix J. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development.

Appendix J. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development

Reference:	**Organism:**	**Reported or Normalized Acute Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable**	**Rationale for Omission:**
Abdalla, A.A.F. and C.D. McNabb. 1999. Acute and sublethal growth effects of unionized ammonia to Nile tilapia *Oreochromis niloticus*. In: Nitrogen production and excretion in fish. Randall D.J. and D.D. Mackinlay (Eds.), Department of Fisheries and Oceans, Vancouver, BC, Canada and Towson University, Baltimore, MD. pp. 35-48.	*Oreochromis niloticus*	Normalized LC_{50} = 87.0	Species is a resident, non-North American "invasive" species known to cause or likely to cause economic or environmental harm (see ISAC 2006). Because the species is in the Family Centrarchidae which is well represented in the current acute criteria dataset, it has been intentionally excluded from further consideration and calculation of an acute criterion.
Alonso, A. and J.A. Camargo. 2011. The freshwater planarian *Polycelis felina* as a sensitive species to assess the long-term toxicity of ammonia. Chemosphere 84: 533-537.	*Polycelis felina*	Normalized 96 h LC_{50} = 25.72	Species not resident in North America.
Ankley, G.T., M.K. Schubauer-Berigan and P.D. Monson. 1995. Influence of pH and hardness on toxicity of ammonia to the amphipod *Hyalella azteca*. Can. J. Fish. Aquat. Sci. 52(10): 2078-2083.	*Hyalella azteca*	Normalized 96 h LC_{50}s: Softwater (Lake Superior) - **25.51 (pH 6.50)** **47.35 (pH 7.49)** 233.4 (pH 8.21) Hardwater (Reconstituted-ASTM) - 232.8 (pH 6.55) 337.6 (pH 7.41) 545.5 (pH 8.45)	Ankley et al. conducted several static-renewal acute tests with *H. azteca* to determine the effect of pH and hardness on the toxicity of ammonia. For the hardness evaluation, Ankley chose three waters for testing, soft water (SW; unaltered lake Superior water), moderately hard water (MW; hardened Lake Superior water), and hard water (HW; hard reconstituted water). At the time, Ankley et al. focused only on hardness in the test waters, but the ion ratios in these three waters were not consistent. Of the three water types, only the moderately hard water (MW) that Ankley used is suitable for testing and culturing amphipods (see Appendix A for results). The SW was not suitable for testing this species because the sodium concentration was too low. Similarly, the reconstituted HW was not suitable because the bromide was too low. Bold values indicate LC_{50}s below the cutoff of 93 mg TAN/L for unused, potentially influential acute values.

Appendix J. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development

Reference:	**Organism:**	**Reported or Normalized Acute Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable**	**Rationale for Omission:**
Augspurger, T., A.E. Keller, M.C. Black, W.G. Cope and F.J. Dwyer. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. Environ. Toxicol. Chem. 22(11): 2569-2575.	*Medionidus conradicus*	Normalized 48 h LC$_{50}$ = 27.56	48-hr glochidia test. Secondary data from Keller 2000
Babu, T.R., P. Surendranath and K.V. Ramana Rao. 1987. Comparative evaluation of DDT and fenvalerate toxicity on *Penaeus indicus* (H. Milne Edwards). Mahasagar 20(4): 249-253.	*Daphnia magna*	Reported LC$_{50}$s: 60 (25 h), 32 (50 h), 20 (100 h)	pH not reported – LC$_{50}$s could not be normalized.
Belanger, S.E., D.S. Cherry, J.L. Farris, K.G. Sappington and J.J. Cairns. 1991. Sensitivity of the Asiatic clam to various biocidal control agents. J. Am. Water Works Assoc. 83(10): 79-87.	*Corbicula fluminea*	Normalized LC$_{50}$s: 23.55 (4.1 d) 64.99 (4.2 d)	Species is a resident, non-North American "invasive" species known to cause or likely to cause economic or environmental harm (see ISAC 2006). This species is the target of current eradication and control programs in various states, and because this Phylum (Mollusca) is well represented in the current acute criteria dataset, this species has been intentionally excluded from further consideration and calculation of an acute criterion.
Dehedin, A., C. Piscart and P. Marmonier. 2012. Seasonal variations of the effect of temperature on lethal and sublethal toxicities of ammonia for three common freshwater shredders. Chemopshere In press.	*Gammarus pulex*	Normalized 96h LC$_{50}$s: 36.98 49.31 49.31 69.40	Species not resident in North America. Control mortality less than 15%.
	Gammarus roeselii	Normalized 96 h LC$_{50}$s: 2.466 24.66 36.98 46.27 46.27 55.31 55.31 57.84	Species not resident in North America. Control mortality less than 15%.

Appendix J. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development			
Reference:	**Organism:**	**Reported or Normalized Acute Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable**	**Rationale for Omission:**
Dowden, B.F. and H.J. Bennett. 1965. Toxicity of selected chemicals to certain animals. J. Water Pollut. Control Fed. 37(9): 1308-1316.	*Daphnia magna*	Reported LC_{50}s: 202 (24 h), 423 (25 h), 161 (48 h), 433 (50 h), 67 (72 h), 50 (96 h), 202, 139 (100 h)	pH not reported – LC_{50}s could not be normalized.
	Lymnaea sp.	Reported LC_{50}s: 241 (24 h), 173 (48 h), 73 (72 h), 70 (96 h)	pH not reported – LC_{50}s could not be normalized.
Ewell, W.S., J.W. Gorsuch, R.O. Kringle, K.A. Robillard and R.C. Spiegel. 1986. Simultaneous evaluation of the acute effects of chemicals on seven aquatic species. Environ. Toxicol. Chem. 5(9): 831-840.	*Daphnia magna*	Reported LC_{50} in paper = >100; Reported LC_{50} in ECOTOX = >20 Normalized LC_{50} = 36.29	Insufficient controls; pH that varied from 6.5-8.5 during the exposure. LC_{50} based on a 96 h (non-standard) test duration.
Fairchild, J.F., A. Allert, J. Mizzi, R. Reisenburg and B. Waddell. 1999. Determination of a safe level of ammonia that is protective of juvenile Colorado pikeminnow in the upper Colorado River, Utah. Final Report.1998 Quick Response Program. U.S. Fish and Wildlife Service, Region 2 (Salt Lake City Office).	*Pimephales promelas*	Normalized LC_{50} = 60.12	72-hour test in well water
Hazel, R.H., C.E. Burkhead and D.G. Huggins. 1982. Development of water quality criteria for ammonia and total residual chlorine for the protection of aquatic life in two Johnson County, Kansas Streams. In: J.G. Pearson, R.B. Foster, and W.E. Bishop (Eds.), Proc. Annu. Symp. Aq. Tox., ASTM STP 766, Philadelphia, PA: 381-388.	*Etheostoma spectabile*	Normalized 96 h LC_{50}s = 83.74, 71.12	Same data as in Hazel (1979) – see *E. spectabile* in Appendix A.
Hecnar, S.J. 1995. Acute and chronic toxicity of ammonium nitrate fertilizer to amphibians from Southern Ontario. Environ. Toxicol. Chem. 14(12): 2131-2137.	*Pseudacris triseriata*	Reported values: 4-d LC_{50} = 17 4-d NOEC = 5, 4-d LOEC = 45	Formulation - ammonium nitrate fertilizer

Appendix J. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development			
Reference:	**Organism:**	**Reported or Normalized Acute Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable**	**Rationale for Omission:**
Hickey, C.W. and M.L. Vickers. 1994. Toxicity of ammonia to nine native New Zealand freshwater invertebrate species. Arch. Environ. Contam. Toxicol. 26(3): 292-298.	*Potamopyrgus antipodarum*	Normalized 96 h LC_{50}s: 33.14 29.79 38.93 36.27	Species is a resident, non-North American "invasive" species known to cause or likely to cause economic or environmental harm (see ISAC 2006). This species is the target of current eradication and control programs in various states, and because this Phylum (Mollusca) is well represented in the current acute criteria dataset, this species has been intentionally excluded from further consideration and calculation of an acute criterion.
Horne, F.R. and S. McIntosh. 1979. Factors influencing distribution of mussels in the Blanco River of Central Texas. Nautilus 94(4): 119-133.	*Cyrtonaias tampicoensis*	Normalized LC_{50} = 26.75	LC_{50} based on a 7-d (non-standard) test duration.
	Toxolasma texasensis	Normalized LC_{50} = 26.75	LC_{50} based on a 7-d (non-standard) test duration.
	Corbicula manilensis	Normalized LC_{50} = 26.75	LC_{50} based on a 7-d (non-standard) test duration.
Jofre, M.B., and W.H. Karasov. 1999. Direct effect of ammonia on three species of North American anuran amphibians. Environ.Toxicol.Chem. 18(8): 1806-1812.	*Bufo americanus*	Normalized 96 h LC_{50} = 62.85	Non-standard acute endpoint based on hatch success/ deformity.UIA calculated using Thurston et al. (1979) EPA-600/3-79-091 from measured values
	Rana clamitans	Normalized 96 h LC_{50} = 40.80	Non-standard acute endpoint based on hatch success/ deformity.UIA calculated using Thurston et al. (1979) EPA-600/3-79-091 from measured values
Jofre, M.B., M.L. Rosenshield and W.H. Karasov. 2000. Effects of PCB 126 and ammonia, alone and in combination, on green frog (*Rana clamitans*) and leopard frog (*R. pipiens*) hatching success, development, and metamorphosis. J. Iowa Acad. Sci. 107(3): 113-122.	*Rana clamitans*	Normalized 96 h LC_{50} = 49.56	Non-standard acute endpoint based on hatch success/ deformity. pH not reported; assume same as Jofre and Karasov 1999.
Kaniewska-Prus, M. 1982. The Effect of ammonia, chlorine, and chloramine toxicity on the mortality of *Daphnia magna* Straus. Pol. Arch. Hydrobiol. 29(3/4): 607-624.	*Daphnia magna*	Normalized LC_{50} = 1.980	LC_{50} based on a 24-h (non-standard) test duration.
Meyer, J.S. and J.A. Hansen. 2002. Subchronic toxicity of low dissolved oxygen concentrations, elevated pH, and elevated ammonia concentrations to Lost River suckers. Trans. Amer. Fish. Soc. 131: 656-666.	*Deltistes luxatus*	Normalized 48 h LC_{50}: 78.23	The pH for this test was reported as 9.5, which is outside of the acceptable pH range of (6.0-9.0) these criteria were meant to apply.
Morgan, W.S.G. 1979. Fish locomotor behavior patterns as a monitoring tool. J. Water Pollut. Control. Fed. 51(3): 580-589.	*Micropterus salmoides*	Normalized EC_{50} = 5.010	Acute toxicity evaluated electronically based on activity. Exposure was only 24-h (non-standard) in test duration. Concentrations were nominal.
Morgan, W.S.G. 1976. Fishing for toxicity: Biological automonitor for continuous water quality control. Effl. Water Treat. J. 16(9): 471-475.	*Micropterus salmoides*	Normalized EC_{50} = 5.010	Added nominal concentrations equivalent to 48-h LC_{50} from previous literature values, then monitored opercular rhythm activity for 24 h.

Appendix J. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development

Reference:	Organism:	Reported or Normalized Acute Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable	Rationale for Omission:
Morgan, W.S.G. and P.C. Kuhn. 1974. A method to monitor the effects of toxicants upon breathing rate of largemouth bass (*Micropterus salmoides* Lacepede). Water Res. 8(1): 67-77	*Micropterus salmoides* Lacepede	Normalized EC$_{50}$s: 110.3 (11 h), 31.32 (22 h), 110.3 (23 h), 1.556 (44 h)	Similar to Morgan (1976). This is not an actual toxicity test. Rather, it is a test of a monitoring system that relates nominal LC$_{50}$ concentrations (based on literature values), to breathing rate monitored over 24 h.
Morgan, W.S.G. 1978. The use of fish as a biological sensor for toxic comparison in potable water. Prog. Water Tech. 10: 395-398.	*Micropterus salmoides*	Normalized LC$_{50}$ = 9.091	Similar to other Morgan studies listed in this table where nominal ammonia concentrations based on literature LC$_{50}$ concentrations are added to tanks and breathing rate and activity level are monitored electronically for 24 h.
Passell, H.D., C.N. Dahm and E.J. Bedrick. 2007. Ammonia modeling for assessing potential toxicity to fish species in the Rio Grande, 1989-2002. Ecol. Appl. 17(7): 2087-2099.	*Hybognathus amarus*	Secondary data; reported LC$_{50}$ from Buhl 2002 = 1.01 mg/L unionized ammonia-N	In this study the frequency of acute ammonia exceedances were modeled by relating discharge, pH, temperature, and stream ammonia concentrations to literature LC$_{50}$ values.
Scheller, J.L. 1997. The effect of dieoffs of Asian clams (*Corbicula fluminea*) on native freshwater mussels (Unionidae). Virginia Polytechnic Institute and State University, Blacksburg, VA.	*Corbicula fluminea*	Normalized LC$_{50}$s: 6.498 (96 h) 11.57 (96 h) 14.62 (96 h)	Species is a resident, non-North American "invasive" species known to cause or likely to cause economic or environmental harm (see ISAC 2006). This species is the target of current eradication and control programs in various states, and because this Phylum (Mollusca) is well represented in the current acute criteria dataset, this species has been intentionally excluded from further consideration and calculation of an acute criterion.
	Pimephales promelas	Normalized LC$_{50}$ = 38.46	Non-standard (48 h) test duration.
Watton, A.J. and H.A. Hawkes. 1984. The acute toxicity of ammonia and copper to the gastropod *Potamopyrgus jenkinsi* (Smith). Environ. Pollut. Ser. A 36: 17-29.	*Potamopyrgus jenkinsi*	Normalized EC$_{50}$s: 40.31 and 42.06 (48 h), 27.60 and 27.17 (96 h)	Species not resident in North America.

Appendix J. Unused Acute Studies Potentially Influential for Freshwater Ammonia Criteria Development			
Reference:	**Organism:**	**Reported or Normalized Acute Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable**	**Rationale for Omission:**
Whiteman, F.W., G.T. Ankley, M.D. Kahl, D.M. Rau and M.D. Balcer. 1996. Evaluation of interstitial water as a route of exposure for ammonia in sediment tests with benthic macroinvertebrates. Environ. Toxicol. Chem. 15(5): 794-801.	*Hyalella azteca*	Normalized 96 h LC_{50}s: 10.27 (Lake Superior water) 11.06 (sediment test) 72.67 (sediment test)	Tests were fed. The results from the two sediment tests were not used because sediment toxicity tests using pore water measurements likely underestimate the toxicity of ammonia in a water-only exposure, i.e., test animals could have been exposed to the higher interstitial ammonia concentrations during the exposure[a]. The 96 h LC_{50} for *H. azteca* from water-only exposure to Lake Superior water was not used from this study because the sodium concentration in this dilution water is too low for maintaining adequate animal health – see also the results in this appendix from Ankley et al. (1995) above.

[a] For the same reason the sediment tests reported by Whiteman et al. (1996) for *H. azteca* were unused for criteria derivation, results from the sediment tests from Besser et al. (1998) were also not used. The normalized 96 h LC_{50}s for *H. azteca* from the Besser et al. (1998) sediment tests were 120.5 and 321.4 mg TAN/L at pH 6.69 and 7.56, respectively. Two other LC_{50}s generated for *H. azteca* which are also not used for criteria derivation (due to the insufficient amount of detail provided) include values of 251.5 and 262.7 mg TAN/L from Sarda (1994). Because these latter values exceed 93 mg TAN/L, they are considered non-influential data for the purpose of criteria derivation.

Appendix K. Unused Chronic Studies Potentially Influential for Freshwater Ammonia Criteria Development.

Appendix K. Unused Chronic Studies Potentially Influential for Freshwater Ammonia Criteria Development

Reference:	**Organism:**	**Reported or Normalized Chronic Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable**	**Rationale for Omission:**
El-Shafai, S.A., F.A. El-Gohary, F.A. Nasr, N.P. Vander Steen and H.J. Gijzen. 2004. Chronic ammonia toxicity to duckweed-fed tilapia (*Oreochromis niloticus*). Aquacult. 232(1-4): 117-127.	*Oreochromis niloticus*	Normalized Chronic value = 6.881 (75 d)	Test was a 35-day juvenile test; not a true fish ELS test. Species is also a resident, non-North American "invasive" species known to cause or likely to cause economic or environmental harm (see ISAC 2006).
DeGraeve, G.M., W.D. Palmer, E.L. Moore, J.J. Coyle and P.L. Markham. 1987. The effect of temperature on the acute and chronic toxicity of unionized ammonia to fathead minnows and channel catfish. Battelle, Columbus, OH.	*Ictalurus punctatus*	Normalized 30-day NOEC = 0.5628	Per the 1999 update, this 30-day test with juvenile catfish encountered some problems that precluded effective use of these data. For example, some of the test organisms were treated with acriflavine up to two days prior to the beginning of the test. In addition, the mean measured DO concentration was below 5.5 mg/L and below 60 percent of saturation in some of the treatments.
Hecnar, S.J. 1995. Acute and chronic toxicity of ammonium nitrate fertilizer to amphibians from Southern Ontario. Environ. Toxicol. Chem. 14(12): 2131-2137.	*Pseudacris triseriata*	Reported values: 100-d NOEC = 2.5, 100-d LOEC = 10	Formulation - ammonium nitrate fertilizer.
Hermanutz, R.O., S.F. Hedtke, J.W. Arthur, R.W. Andrew and K.N. Allen. 1987. Ammonia effects on macroinvertebrates and fish in outdoor experimental streams. Environ. Pollut. 47: 249-283.	*Ictalurus punctatus*	Normalized NOEC = 4.369	Survival and growth of juvenile channel catfish were evaluated via exposure to ammonia in experimental streams. Three separate tests lasted from 36 to 177 days and were started with individuals whose average weights ranged from 6 to 19 g. Average temperatures in the three tests were 17 to 21°C. Both of the longer tests showed monotonic, substantial reductions in biomass; these results are in reasonable agreement with the results of the laboratory tests. However, juveniles might not be as sensitive to ammonia toxicity as early life stages are. These results are not included because they are from a field study where ammonia concentrations were highly variable.
	Sander vitreus	Normalized NOEC = 4.182	Omitted for the same reasons as was *Ictalurus punctatus*.

Appendix K. Unused Chronic Studies Potentially Influential for Freshwater Ammonia Criteria Development			
Reference:	**Organism:**	**Reported or Normalized Chronic Value Expressed as Total Ammonia (mg TAN/L) at pH=7 and 20°C, Where Applicable**	**Rationale for Omission:**
Hickey, C.W., L.A. Golding, M.I. Martin and G.F. Croker. 1999. Chronic toxicity of ammonia to New Zealand freshwater invertebrates: A mesocosm study. Arch. Environ. Contam. Toxicol. 37:338-351.	*Deleatidium sp.* (Ephemeroptera)	Normalized 29-day EC_{25} (survival) = 3.844	Species not resident in North America. These results are not included because they are from a field study where ammonia concentrations were highly variable.
Rice, S.D. and J.E. Bailey. 1980. Survival, size, and emergence of pink salmon, *Oncorhynchus gorbuscha*, alevins after short- and long-term exposures to ammonia. Fish. Bull. 78(3):641-648.	*Oncorhynchus gorbuscha*	Normalized 61-d NOEC = 5.859	Per the 1999 update, the only chronic test began sometime after hatch and ended when the alevins emerged (i.e., at the beginning of swim-up); therefore the test did not include effects of ammonia on the growth and survival of fry after feeding started. In addition, no information was given concerning survival to the end of the test in the control or any other treatment. This test did not provide data concerning survival and is not an ELS test because it began after hatch.
Schulter, M. and J. Groeneweg. 1985. The inhibition by ammonia of population growth of the rotifer, *Brachionus rubens*, in continuous culture. Aquaculture 46: 215-220.	*Brachionus rubens*	Normalized 7-d NOEC = 3.000	Species is not resident in North America. Generally a marine Rotifera. Undescribed culture medium. NOEC based on population growth of cultures.
Smith, C.E. 1972. Effects of metabolic products on the quality of rainbow trout. Am. Fish. Trout News 17:7-8.	*Oncorhynchus mykiss*	Normalized 84-d NOEC = 2.304	This test did not provide data concerning survival and is not an ELS test because it began after hatch. The authors reported that as long as the DO concentration was maintained at 5 mg/L or greater, growth of young rainbow trout was not significantly reduced until average total ammonia concentrations reached 1.6 mg TAN/L at test pH and temperature (7.75 and 10°C, respectively).
Zischke, J.A. and J.W. Arthur. 1987. Effects of elevated ammonia levels on the fingernail clam, *Musculium transversum*, in outdoor experimental streams. Arch. Environ. Contam. Toxicol. 16(2): 225-231.	*Musculium transversum*	Normalized LOEC = 6.933 (survival)	This was a flow-through, measured mesocosm experiment performed in the field. The test concentrations varied during the length of the experiment.

Appendix L. Unused (Non-Influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development – Screened Out Studies with Code List.
(appears separately at end of appendix)

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Academy of Natural Sciences. 1960. The sensitivity of aquatic life to certain chemicals commonly found in industrial wastes. Final Report No. RG-3965 (C2R1). U.S. Public Health Service Grant, Academy of Natural Sciences, Philadelphia, PA.	5683	AF	
Alabaster, J.S., D.G. Shurben and G. Knowles. 1979. The effect of dissolved oxygen and salinity on the toxicity of ammonia to smolts of salmon, *Salmo salar* L. J. Fish Biol.15(6): 705-712 (Personal Communication Used).	406	Dur - 1d	
Alabaster, J.S., D.G. Shurben and M.J. Mallett. 1983. The acute lethal toxicity of mixtures of cyanide and ammonia to smolts of salmon, *Salmo salar* L. at low concentrations of dissolved oxygen. J. Fish Biol. 22: 215-222.	10252	Dur - 1d	
Alam, M., T.L. Frankel and M. Alam. 2006. Gill ATPase activities of silver perch, *Bidyanus bidyanus* (Mitchell), and golden perch, *Macquaria ambigua* (Richardson): Effects of environmental salt and ammonia. Aquaculture 251(1): 118-133.	84839	NonRes	
Allan, I.R.H., D.W.M. Herbert and J.S. Alabaster. 1958. A field and laboratory investigation of fish in a sewage effluent. Minist. Agric. Fish. Food, Fish. Invest. Ser. 1. 6(2): 76.	10316	AF, Det	
Alonso, A. and J.A. Camargo. 2003. Short-term toxicity to ammonia, nitrite, and nitrate to the aquatic snail *Potamopyrgus antipodarum* (Hydrobiidae, Mollusca). Bull. Environ. Contam. Toxicol. 70: 1006-1012		INV	
Alonso, A. and J.A. Camargo. 2006. Ammonia toxicity to the freshwater invertebrates *Polycelis felina* (Planariidae, Turbellaria) and *Echinogammarus echinosetosus* (Gammaridae, Crustacea). Fresenius Environ. Bull. 15(12b): 1578-1583.		NonRes	
Arillo, A., B. Uva and M. Vallarino. 1981. Renin activity in rainbow trout (*Salmo gairdneri* Rich.) and effects of environmental ammonia. Comp. Biochem. Physiol. A 68(3): 307-311.	5704	Dur - 2d	
Armstrong, D.A. 1978. Toxicity and metabolism of nitrogen compounds: Effects on survival, growth and osmoregulation of the prawn, *Macrobrachium rosenbergii*. Ph.D. Thesis, University of California, Davis, CA. (Personal Communication Used).	5620	Dur - 1d	
Bailey, H.C., C. DiGiorgio, K. Kroll, J.L. Miller, D.E. Hinton and G. Starrett. 1996. Development of procedures for identifying pesticide toxicity in ambient waters: Carbofuran, diazinon, chlorpyrifos. Environ. Toxicol. Chem. 15(6): 837-845.	16844	AF	
Ball, I.R. 1967. The relative susceptibilities of some species of fresh-water fish to poisons - I. Ammonia. Water Res. 1(11/12): 767-775.	10000	Dur	
Banerjee, S. and S. Bhattacharya. 1994. Histopathology of kidney of *Channa punctatus* exposed to chronic nonlethal level of elsan, mercury, and ammonia. Ecotoxicol. Environ. Saf. 29(3): 265-275.	13750	NonRes, Eff, UEndp	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Banerjee, S. and S. Bhattacharya. 1995. Histopathological changes induced by chronic nonlethal levels of elsan, mercury, and ammonia in the small intestine of *Channa punctatus* (Bloch). Ecotoxicol. Environ. Saf. 31(1): 62-68.	15256	NonRes, Eff, UEndp	
Banerjee, S. and S. Bhattacharya. 1997. Histopathological changes induced by chronic nonlethal levels of elsan, mercury and ammonia in the liver of *Channa punctatus* (Bloch). J. Environ. Biol. 18(2): 141-148.	18229	NonRes, Eff, UEndp	
Banerjee, T.K. and V.I. Paul. 1993. Estimation of acute toxicity of ammonium sulphate to the fresh water catfish, *Heteropneustes fossilis* II. A histopathological analysis of the epidermis. Biomed. Environ. Sci. 6(1): 45-58.	13480	NonRes, UEndp	
Batley, G.E. and S.L. Simpson. 2009. Development of guidelines for ammonia in estuarine and marine water systems. Mar. Pollut. Bull. 58(10): 1472-1476.		Dilut	Salt water
Bergerhouse, D.L. 1989. Lethal effects of elevated pH and ammonia on early life stages of several sportfish species. Ph.D. Thesis, Southern Illinois University, Carbondale, IL.	3822	UEndp, Dur - 8h	
Bergerhouse, D.L. 1992. Lethal effects of elevated pH and ammonia on early life stages of walleye. N. Am. J. Fish. Manage. 12(2): 356-366.	6903	UEndp, Dur - 8h	
Bergerhouse, D.L. 1993. Lethal effects of elevated pH and ammonia on early life stages of hybrid striped bass. J. Appl. Aquacult. 2(3/4): 81-100.	4290	UEndp, Dur - 8h	
Besser, J.M., W.G. Brumbaugh, A.L. Allert, B.C. Poulton, C.J. Schmitt and C.G. Ingersoll. 2009. Ecological impacts of lead mining on Ozark streams: Toxicity of sediment and pore water. Ecotoxicol. Environ. Saf. 72(2): 516-526.		Tox	
Bhattacharya, T., S. Bhattacharya, A.K. Ray and S. Dey. 1989. Influence of industrial pollutants on thyroid function in *Channa punctatus* (Bloch). Indian J. Exp. Biol. 27(1): 65-68.	3106	NonRes, AF, UEndp, Dur - 1d	
Biswas, J.K., D. Sarkar, P. Chakraborty, J.N. Bhakta and B.B. Jana. 2006. Density dependent ambient ammonium as the key factor for optimization of stocking density of common carp in small holding tanks. Aquaculture 261(3): 952-959.		No Dose, VarExp	Only 1 exposure concentration (naturally increased over time)
Blanco S., S. Romo, M. Fernandez-Alaez and E. Becares. 2008. Response of epiphytic algae to nutrient loading and fish density in a shallow lake: A mesocosm experiment. Hydrobiologia 600(1): 65-76.		Tox	Mesocosm; no ammonia
Boone, M.D., R.D. Semlitsch, E.E. Little and M.C. Doyle. 2007. Multiple stressors in amphibian communities: Effects of chemical contamination, bullfrogs, and fish. Ecol. Appl. 17(1): 291-301.		Tox	
Braun, M.H., S.L. Steele and S.F. Perry. 2009. The responses of zebrafish (*Danio rerio*) to high external ammonia and urea transporter inhibition: Nitrogen excretion and expression of rhesus glycoproteins and urea transporter proteins. J. Exp. Biol. 212(pt. 23): 3846-3856.		NonRes	
Brun, F.G., I. Olive, E.J. Malta, J.J. Vergara, I. Hernandez and J.L. Perez-Llorens. 2008. Increased vulnerability of *Zostera noltii* to stress caused by low light and elevated ammonium levels under phosphate deficiency. Mar. Ecol. Prog. Ser. 365: 67-75.		Tox	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Buikema, A.L., Jr., J. Cairns, Jr. and G.W. Sullivan. 1974. Evaluation of *Philodina acuticornis* (Rotifera) as bioassay organisms for heavy metals. Water Resour. Bull. 10(4): 648-661.	2019	Dur	
Burrows, R.E. 1964. Effects of accumulated excretory products on hatchery-reared salmonids. Res. Rep. No. 66. U.S. Fish Wildl. Serv., Washington, DC.	10002	Uenpd	
Cairns, J., Jr. and A. Scheier. 1959. The relationship of bluegill sunfish body size to tolerance for some common chemicals. Proc. 13th Ind. Waste Conf., Purdue Univ. Eng. Bull. 96: 243-252.	930	AF	
Cairns, J., Jr., B.R. Niederlehner and J.R. Pratt. 1990. Evaluation of joint toxicity of chlorine and ammonia to aquatic communities. Aquat. Toxicol. 16(2): 87-100.	3207	Ace, No Org	
Camargo, J.A. and I. Alonso. 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environ. Internat. 32(6): 831-849.		Sec	
Cao, T., P. Xie, L. Ni, M. Zhang and J. Xu. Carbon and nitrogen metabolism of an eutrophication tolerative macrophyte, *Potamogeton crispus*, under NH4+ stress and low light availability. Environ. Exper. Bot. In Press, Corrected Proof.		No Dose	Only 1 exposure concentration
Carey, R.O., K.W. Migliaccio and M.T. Brown. 2011. Nutrient discharges to Biscayne Bay, Florida: Trends, loads, and a pollutant index. Sci. Total. Environ. 409(3): 530-539.		No Dose	Fate
Carr, R.S., J.M. Biedenbach and M. Nipper. 2006. Influence of potentially confounding factors on sea urchin porewater toxicity tests. Arch. Environ. Contam. Toxicol. 51(4): 573-579.		Tox	
Centeno, M.D.F., G. Persoone and M.P. Goyvaerts. 1995. Cyst-based toxicity tests. IX. The potential of *Thamnocephalus platyurus* as test species in comparison with *Streptocephalus proboscideus* (Crustacea: Branchiopoda: Anostraca). Environ. Toxicol. Water Qual. 10(4): 275-282.	14017	AF, Dur - 1d	
Chetty, A.N. and K. Indira. 1994. Alterations in the tissue lipid profiles of *Lamellidens marginalis* under ambient ammonia stress. Bull. Environ. Contam. Toxicol. 53(5): 693-698.	13744	NonRes, Dur - 2d	Freshwater bivalve mollusk
Colt, J.E. 1978. The effects of ammonia on the growth of channel catfish, *Ictalurus punctatus*. Ph.D. Thesis, Univ. of California, Davis, CA.	59792	UChron, Sec	Data also published in Colt and Tchobanoglous (1978)
Corpron, K.E. and D.A. Armstrong. 1983. Removal of nitrogen by an aquatic plant, *Elodea densa*, in recirculating macrobrachium culture systems. Aquaculture 32(3/4): 347-360.	15323	UEndp, Con	Plant
Craig, G.R. 1983. Interlaboratory fish toxicity test comparison - Ammonia. Environ. Protection Service, Quality Protection Section, Water Resour. Branch, Canada.	10259	AF	
Cucchiari, E., F. Guerrini, A. Penna, C. Totti and R. Pistocchi. 2008. Effect of salinity, temperature, organic and inorganic nutrients on growth of cultured *Fibrocapsa japonica* (Raphidophyceae) from the northern Adriatic Sea. Harmful Algae 7(4): 405-414.		Tox	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Da Silva, J.M., J. Coimbra and J.M. Wilson. 2009. Ammonia sensitivity of the glass eel (*Anguilla anguilla* L.): Salinity dependence and the role of a branchial sodium/potassium adenosine triphosphatase. Environ. Toxicol. Chem. 28(1): 141-147.		NonRes	
Dabrowska, H. and H. Sikora. 1986. Acute toxicity of ammonia to common carp (*Cyprinus carpio* L.). Pol. Arch. Hydrobiol. 33(1): 121-128.	12711	Dur - 2d	
Danecker, E. 1964. The jauche poisoning of fish - An ammonia poisoning. Osterreichs Fischerei. 3/4: 55-68 (ENG TRANSL).	10305	AF, UEndp, Dur	
Daniels, S.M., M.G. Evans , C.T. Agnew and T.E.H. Allott. 2012. Ammonium release from a blanket peatland into headwater stream systems. Environ. Pollut. 163(0): 261-272.		No Dose	Fate
Daoust, P.Y. and H.W. Ferguson. 1984. The pathology of chronic ammonia toxicity in rainbow trout, *Salmo gairdneri* Richardson. J. Fish Dis. 7: 199-205.	10217	UEndp, Eff	
Dayeh, V.R., K. Schirmer and N.C. Bols. 2009. Ammonia-containing industrial effluents, lethal to rainbow trout, induce vacuolization and neutral red uptake in the rainbow trout gill cell line, RTgill-W1. Altern. Lab. Anim. 37(1): 77-87.		In Vit	
De Moor, I.J. 1984. The toxic concentration of free ammonia to *Brachionus calyciflorus* Pallas, a rotifer pest species found in high rate algal ponds (HRAP'S). J. Limnol. Soc. South Afr. 10(2): 33-36.	5433	UEndp	
Dendene, M.A., T. Rolland, M. Tremolieres and R. Carbiener. 1993. Effect of ammonium ions on the net photosynthesis of three species of elodea. Aquat. Bot. 46(3/4): 301-315.	4268	UEndp	Plant
Dey, S. and S. Bhattacharya. 1989. Ovarian damage to *Channa punctatus* after chronic exposure to low concentrations of elsan, mercury, and ammonia. Ecotoxicol. Environ. Saf. 17(2): 247-257.	446	AF, Dur - 2d	
DeYoe H.R., E.J. Buskey and F.J. Jochem. 2007. Physiological responses of *Aureoumbra lagunensis* and *Synechococcus* sp. to nitrogen addition in a mesocosm experiment. Harmful Algae 6(1): 48-55.		No Dose	Only one exposure concentration
Dhanasiri, A.K., V. Kiron, J.M. Fernandes, O. Bergh and M.D. Powell. Novel application of nitrifying bacterial consortia to ease ammonia toxicity in ornamental fish transport units: Trials with zebrafish. J. Appl. Microbiol. 111(2): 278-292.		UEndp	
Diamond, J.M., S.J. Klaine and J.B. Butcher. 2006. Implications of pulsed chemical exposures for aquatic life criteria and wastewater permit limits. Environ. Sci. Technol. 40(16): 5132-5138.	102216	No Dose, Dur, VarExp	Only 2 exposure concentrations
dos Miron, D., B. Moraes, A.G. Becker, M. Crestani, R. Spanevello, V.L. Loro and B. Baldisserotto. 2008. Ammonia and pH effects on some metabolic parameters and gill histology of silver catfish, *Rhamdia quelen* (Heptapteridae). Aquaculture 277(3-4): 192-196.		NonRes	
Dowden, B.F. and H.J. Bennett. 1965. Toxicity of selected chemicals to certain animals. J. Water Pollut. Control Fed. 37(9): 1308-1316.	915	AF	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Dowden, B.F. 1961. Cumulative toxicities of some inorganic salts to *Daphnia magna* as determined by median tolerance limits. Proc. LA. Acad. Sci. 23: 77-85.	2465	AF	
Drath, M., N. Kloft, A. Batschauer, K. Marin, J. Novak and K. Forchhammer. 2008. Ammonia triggers photodamage of photosystem II in the cyanobacterium *Synechocystis* sp. strain Pcc 6803. Plant Physiol. 147(1): 206-215.		No Dose	Only 1 or 2 exposure concentrations at a specific pH
D'Silva, C. and X.N. Verlencar. 1976. Relative toxicity of two ammonium compounds found in the waste of fertilizer plants. Mahasagar 9(1/2): 41-44.	6084	Dur - 2d	
Egea-Serrano, A., M. Tejedo and M. Torralva. 2008. Analysis of the avoidance of nitrogen fertilizers in the water column by juvenile Iberian water frog, *Pelophylax perezi* (Seoane, 1885), in laboratory conditions. Bull. Environ. Contam. Toxicol. 80(2): 178-183.	103070	NonRes, Tox, No Dose	Only one exposure concentration
Fairchild II, E.J. 1954. Effects of lowered oxygen tension on the susceptibility of *Daphnia magna* to certain inorganic salts. Ph.D. Thesis, Louisiana State Univ., LA. 134 p.		Dilut, Dur, AF	
Fairchild II, E.J. 1955. Low dissolved oxygen: Effect upon the toxicity of certain inorganic salts to the aquatic invertebrate *Daphnia magna*. In: Proc. 4th Ann. Water Symp., March 1955, Baton Rouge, LA, Eng. Expt. Stat. Bull. 51: 95-102.	115940	Dilut, Dur, AF	
Fang, J.K.H., R.S.S. Wu, A.K.Y. Chan, C.K.M. Yip and P.K.S. Shin. 2008. Influences of ammonia-nitrogen and dissolved oxygen on lysosomal integrity in green-lipped mussel *Perna viridis*: Laboratory evaluation and field validation in Victoria Harbour, Hong Kong. Mar. Pollut. Bull. 56(12): 2052-2058.		No Dose	Only one exposure concentration
Fedorov, K.Y. and Z.V. Smirnova. 1978. Dynamics of ammonia accumulation and its effect on the development of the pink salmon, *Oncorhynchus gorbuscha*, in closed circuit incubation systems. Vopr. Ikhtiol. 19(2): 320-328.	5478	UEndp	
Flagg, R.M. and L.W. Hinck. 1978. Influence of ammonia on aeromonad susceptibility in channel catfish. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 32: 415-419.	10317	UEndp	
Flis, J. 1963. Anatomicohistopathological changes induced in carp (*Cyprinus carpio* L.) by ammonia water. Part 1. Effects of toxic concentrations. Zmiany. Acta Hydrobiol. 10(1/2): 205-224.	10005	UEndp, Dur - 1d	
Foss, A., A.K. Imsland, B. Roth, E. Schram and S.O. Stefansson. 2007. Interactive effects of oxygen saturation and ammonia on growth and blood physiology in juvenile turbot. Aquaculture 271(1-4): 244-251.		No Dose	Only 2 exposure concentrations
Foss, A., A.K. Imsland, B. Roth, E. Schram and S.O. Stefansson. 2009. Effects of chronic and periodic exposure to ammonia on growth and blood physiology in juvenile turbot (*Scophthalmus maximus*). Aquaculture 296(1/2): 45-50.		NonRes	
Ge, F., Y. Xu, R. Zhu, F. Yu, M. Zhu and M. Wong. 2010. Joint action of binary mixtures of cetyltrimethyl ammonium chloride and aromatic hydrocarbons on *Chlorella vulgaris*. Ecotoxicol. Environ. Saf. 73(7): 1689-1695.		Tox	
Gohar, H.A.F. and H. El-Gindy. 1961. Tolerance of vector snails of bilharziasis and fascioliasis to some chemicals. Proc. Egypt. Acad. Sci. 16: 37-48.	115940	NonRes	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Golding, C., R. Krassoi and E. Baker. 2006. The development and application of a marine Toxicity Identification Evaluation (TIE) protocol for use with an Australian bivalve. Australas. J. Ecotoxicol. 12(1): 37-44.	108468	Tox, No Dose	Only one exposure concentration
Goncalves, A.F., I. Pascoa, J.V. Neves, J. Coimbra, M.M. Vijayan, P. Rodrigues and J.M Wilson. 2012. The inhibitory effect of environmental ammonia on *Danio rerio* LPS induced acute phase response. Dev. Comp. Immunol. 36(2): 279-288.		NonRes	
Griffis-Kyle, K.L. and M.E. Ritchie. 2007. Amphibian survival, growth and development in response to mineral nitrogen exposure and predator cues in the field: An experimental approach. Oecologia 152(4): 633-42.		Tox	
Gyore, K. and J. Olah. 1980. Ammonia tolerance of *Moina rectirostris* Leydig (Cladocera). Aquacult. Hung. (Szarvas) 2: 50-54.	5708	Dur - 1d	
Hanna, T.D. 1992. The effect of oxygen supplementation on the toxicity of ammonia (NH3) in rainbow trout *Oncorhynchus mykiss* (Richardson). M.S. Thesis, Montana State Univ., Bozeman, MT.	7823	UEndp, Dur	
Harader, R.R.J. and G.H. Allen. 1983. Ammonia toxicity to Chinook salmon Parr: Reduction in saline water. Trans. Am. Fish. Soc. 112(6): 834-837.	10510	Dur - 1d	
Healey, F.P. 1977. Ammonium and urea uptake by some freshwater algae. Can. J. Bot. 55(1): 61-69.	7486	AF, Uendp	Plant
Hedtke, J.L. and L.A. Norris. 1980. Effect of ammonium chloride on predatory consumption rates of brook trout (*Salvelinus fontinalis*) on juvenile Chinook salmon (*Oncorhynchus tshawytscha*) I. Bull. Environ. Contam. Toxicol. 24(1): 81-89.	6216	UEndp, Eff	
Hemens, J. 1966. The toxicity of ammonia solutions to the mosquito fish (*Gambusia affinis* Baird & Girard). J. Proc. Inst. Sewage Purif. 3: 265-271.	10152	Dur - 17h	
Henderson, C., Q.H. Pickering and A.E. Lemke. 1961. The effect of some organic cyanides (nitriles) on fish. Proc. 15th Ind. Waste Conf., Eng. Bull. Purdue Univ., Ser. No.106, 65(2): 120-130.	923	Tox; AF	
Herbert, D.W.M. and D.S. Shurben. 1963. A preliminary study of the effect of physical activity on the resistance of rainbow trout (*Salmo gairdnerii* Richardson) to two poisons. Ann. Appl. Biol. 52: 321-326.	8005	Dur - 1d	
Herbert, D.W.M. and D.S. Shurben. 1964. The toxicity to fish of mixtures of poisons I. Salts of ammonia and zinc. Ann. Appl. Biol. 53: 33-41.	8006	Dur - 2d	
Herbert, D.W.M. and D.S. Shurben. 1965. The susceptibility of salmonid fish to poisons under estuarine conditions – II. Ammonium chloride. Int. J. Air Water Pollut. 9(1/2): 89-91.	10318	Dur - 1d	
Herbert, D.W.M. and J.M. Vandyke. 1964. The toxicity to fish of mixtures of poisons. II. Copper-ammonia and zinc-phenol mixtures. Ann. Appl. Biol. 53(3): 415-421.	10193	Tox; Dur - 2d	
Hernandez, C., M. Martin, G. Bodega, I. Suarez, J. Perez and B. Fernandez. 1999. Response of carp central nervous system to hyperammonemic conditions: An immunocytochemical study of glutamine synthetase (GS), glial fibrillary acidic protein (GFAP) and 70 kDa heat-shock protein (HSP70). Aquat. Toxicol. 45(2/3): 195-207.	19920	UEndp, Eff	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Hiatt, R.W., J.J. Naughton and D.C. Matthews. 1953. Effects of chemicals on a schooling fish, *Kulia sandvicensis*. Biol. Bull. 104: 28-44.		NonRes	
Holland, G.A., J.E. Lasater, E.D. Neumann and W.E. Eldridge. 1960. Toxic effects of organic and inorganic pollutants on young salmon and trout. Res. Bull. No. 5. State of Washington Dept. Fish., Seattle, WA.	14397	Dur - 3d	
Hong, M., L. Chen, X. Sun, S. Gu, L. Zhang and Y. Chen. 2007. Metabolic and immune responses in Chinese mitten-handed crab (*Eriocheir sinensis*) juveniles exposed to elevated ambient ammonia. Comp. Biochem. Physiol. C 145(3): 363-369.		INV, Det	Dilution water not described; Prior exposure?
Hued, A.C., M.N. Caruso, D.A. Wunderlin and M.A. Bistoni. 2006. Field and *in vitro* evaluation of ammonia toxicity on native fish species of the central region of Argentina. Bull. Environ. Contam. Toxicol. 76(6): 984-991.		NonRes	
Hurlimann, J. and F. Schanz. 1993. The effects of artificial ammonium enhancement on riverine periphytic diatom communities. Aquat. Sci. 55(1): 40-64.	4134	No Org	Periphytic community
Ingersoll, C. 2004. Memo summarizing ammonia toxicity data for freshwater mussels generated by the USGS Columbia Environmental Research Center in 2003 and 2004. Memorandum, USGS Columbia Environmental Research Center, Columbia, MO, 13 p.		Sec	
Ingersoll, C.G., N.E. Kemble, J.L. Kunz, W.G. Brumbaugh, D.D. MacDonald and D. Smorong. 2009. Toxicity of sediment cores collected from the Astabula River in Northeastern Ohio, USA, to the amphipod *Hyalella azteca*. Arch. Environ. Contam. Toxicol. 57(2): 315-329.		SedExp	
Inman, R.C. 1974. Acute toxicity of Phos-Check (trade name) 202 and diammonium phosphate to fathead minnows. U.S. NTIS AD/A-006122. Environ. Health Lab., Kelly Air Force Base, TX.	6010	Tox	
Ip, Y.K., A.S.L. Tay, K.H. Lee and S.F. Chew. 2004. Strategies for surviving high concentrations of environmental ammonia in the swamp eel *Monopterus albus*. Physiol. Biochem. Zool. 77: 390-405.		INV	
Ip, Y.K., S.M.L. Lee, W.P. Wong and S.F. Chew. 2008. Mechanisms of and defense against acute ammonia toxicity in the aquatic Chinese soft-shelled turtle, *Pelodiscus sinensis*. Aquat. Toxicol. 86(2): 185-196.		NonRes, RouExp	Injected
Ishio, S. 1965. Behavior of fish exposed to toxic substances. In: Advances in Water Pollution Research. Jaag, O. (Ed.). Pergamon Press, NY. pp.19-40.	14092	AF, Dur - 6h, UEndp, No Org	
James, R., K. Sampath and M. Narayanan. 1993. Effect of sublethal concentrations of ammonia on food intake and growth in *Mystus vittatus*. J. Environ. Biol. 14(3): 243-248.	8994	NonRes, AF, UEndp	
Jampeetong, A. and H. Brix. Effects of NH4+ concentration on growth, morphology and NH4+ uptake kinetics of *Salvinia natans*. Ecol. Engineer. In Press, Corrected Proof.		VarExp	Concentration increased over time
Jampeetong, A., H. Brix and S. Kantawanichkul. 2012. Response of *Salvinia cucullata* to high NH4(+) concentrations at laboratory scales. Ecotoxicol. Environ. Saf. 79: 69-74.		NonRes, Con	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Jampeetong, A., H. Brix and S. Kantawanichkul. 2012. Effects of inorganic nitrogen forms on growth, morphology, nitrogen uptake capacity and nutrient allocation of four tropical aquatic macrophytes (*Salvinia cucullata*, *Ipomoea aquatica*, *Cyperus involucratus* and *Vetiveria zizanioides*). Aquatic Botany 97(1): 10-16.		NonRes, No Dose	Plant
Jensen, R.A. 1978. A simplified bioassay using finfish for estimating potential spill damage. In: Proc. Control of Hazardous Material Spills. Rockville, MD. pp. 104-108.	5773	AF, Dur - 1d	
Jha, B.K. and B.S. Jha. 1995. Urea and ammonium sulfate induced changes in the stomach of the fish *Heteropneustes fossilis*. Environ. Ecol. 13(1): 179-181.	17562	NonRes, AF, UEndp	
Joy, K.P. 1977. Ammonium sulphate as a thyroid inhibitor in the freshwater teleost *Clarias batrachus* (L.). Curr. Sci. 46(19): 671-673.	7513	NonRes, AF, UEndp	
Kawabata, Z., T. Yoshida and H. Nakagawa. 1997. Effect of ammonia on the survival of *Zacco platypus* (Temminck and Schlegel) at each developmental stage. Environ. Pollut. 95(2): 213-218.	17963	NonRes, UEndp, Dur	
Khatami, S.H., D. Pascoe and M.A. Learner. 1998. The acute toxicity of phenol and unionized ammonia, separately and together, to the ephemeropteran *Baetis rhodani* (Pictet). Environ. Pollut. 99: 379-387.	19651	NonRes, Dur - 1d	
Kim, J.K., G.P. Kraemer, C.D. Neefus, I.K. Chung and C. Yarish. 2007. Effects of temperature and ammonium on growth, pigment production and nitrogen uptake by four species of porphyra (Bangiales, Rhodophyta) native to the New England Coast. J. App. Phycol. 19(5): 431-440.		UEndp	Plant
Kirk, R.S. and J.W. Lewis. 1993. An evaluation of pollutant induced changes in the gills of rainbow trout using scanning electron microscopy. Environ. Technol. 14(6): 577-585.	4931	UEndp, Dur	
Knepp, G.L. and G.F. Arkin. 1973. Ammonia toxicity levels and nitrate tolerance of channel catfish. Prog. Fish Cult. 35(4): 221-224.	8606	Dur - 7d, Form	
Konnerup, D. and H. Brix. 2010. Nitrogen nutrition of *Canna indica*: Effects of ammonium versus nitrate on growth, biomass allocation, photosynthesis, nitrate reductase activity and N uptake rates. Aquatic Botany 92(2): 142-148.		NonRes	Plant
Krainara, T. 1988. Effects of ammonia on walking catfish, *Clarias batrachus* (Linnaeus). Abstr. M.S. Thesis, Faculty of Fisheries, Kasetsart University, Bangkok, Thailand 13:6.	17533	NonRes, AF	
Kulkarni, K.M. and S.V. Kamath. 1980. The metabolic response of *Paratelphusa jacquemontii* to some pollutants. Geobios 7(2): 70-73 (Author Communication Used).	5036	NonRes, AF, UEndp, Dur	
Kwok, K.W.H., K.M. Y Leung, G.S.G. Lui, V.K.H. Chu, P.K. S. Lam, D. Morritt, L. Maltby, T.C.M. Brock, P.J. Van den Brink, M.S.J. Warne and M. Crane. 2007. Comparison of tropical and temperate freshwater animal species' acute sensitivities to chemical: Implications for deriving safe extrapolation factors. Integr. Environ. Assess. Manag. 3(1): 49-67.		Sec	
Lang, T., G. Peters, R. Hoffmann and E. Meyer. 1987. Experimental investigations on the toxicity of ammonia: Effects on ventilation frequency, growth, epidermal mucous cells, and gill structure of rainbow trout. Dis. Aquat. Org. 3: 159-165.	4106	UEndp	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Larson J.H., P.C. Frost and G.A. Lamberti. 2008. Variable toxicity of ionic liquid-forming chemicals to *Lemna minor* and the influence of dissolved organic matter. Environ. Toxicol. Chem. 27(3): 676-681.		Tox	Plant
Lay, J.P., A. Peither, I. Juttner and K. Weiss. 1993. *In situ* pond mesocosms for ecotoxicological long-term studies. Chemosphere 26(6): 1137-1150.	7048	No Org	
Lazorchak, J.M. and M.E. Smith. 2007. Rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) 7-day survival and growth test method. Arch. Environ. Contam. Toxicol. 53(3): 397-405.	100026	Det, AF	7-day tests (S,U) with ammonia chloride; pH not reported
Lee, D.R. 1976. Development of an invertebrate bioassay to screen petroleum refinery effluents discharged into freshwater. Ph.D. Thesis, Virginia Polytechnic Inst. and State University, Blacksburg, VA.	3402	Det	This thesis appears to provide appropriate 48 h LC_{50} data for *D. pulex*, but details are lacking.
Leung, J., M. Kumar, P. Glatz and K. Kind. 2011. Impacts of unionized ammonia in digested piggery effluent on reproductive performance and longevity of *Daphnia carinata* and *Moina australiensis*. 310: 401-406.		NonRes, Efflu	
Lewis, J.W., A.N. Kay and N.S. Hanna. 1995. Responses of electric fish (family Mormyridae) to inorganic nutrients and tributyltin oxide. Chemosphere 31(7): 3753-3769.	16156	NonRes, UEndp, Dur	
Li, W.E.I., Z. Zhang and E. Jeppesen. 2008. The response of *Vallisneria spinulosa* (Hydrocharitaceae) to different loadings of ammonia and nitrate at moderate phosphorus concentration: A mesocosm approach. Freshw. Biol. 53(11): 2321-2330.		Tox	Plant
Linton, T.K., I.J. Morgan, P.J. Walsh and C.M. Wood. 1998. Chronic exposure of rainbow trout (*Oncorhynchus mykiss*) to simulated climate warming and sublethal ammonia: A year-long study of their appetite. Can. J. Fish. Aquat. Sci. 55(3): 576-586.	19144	No Dose	Only one exposure concentration
Litav, M. and Y. Lehrer. 1978. The effects of ammonium in water on *Potamogeton lucens*. Aquat. Bot. 5(2): 127-138.	7093	AF, UEndp, Dur	Plant
Lloyd, R. and D.W.M. Herbert. 1960. The influence of carbon dioxide on the toxicity of unionized ammonia to rainbow trout (*Salmo gairdnerii* Richardson). Ann. Appl. Biol. 48(2): 399-404.	10018	Dur - 8h	
Lloyd, R. and L.D. Orr. 1969. The diuretic response by rainbow trout to sublethal concentrations of ammonia. Water Res. 3(5): 335-344.	10019	Eff, UEndp, Dur - 1d	
Loong, A.M., J.Y.L. Tan, W.P. Wong, S.F. Chew and Y.K. Ip. 2007. Defense against environmental ammonia toxicity in the African lungfish, *Protopterus aethiopicus*: Bimodal breathing, skin ammonia permeability and urea synthesis. Aquat. Toxicol. 85(1): 76-86.		NonRes, No Dose	Only one exposure concentration
Loon, A.M., Y.R. Chng, S.F. Chew, W.P. Wong and Y.K. Ip. 2012. Molecular characterization and MRNA expression of carbamoyl phosphate synthetase III in the liver of the African lungish, *Protopterus annectens*, during aestivation of exposure to ammonia. J. Comp. Physiol. B. 182(3): 367-379.		NonRes	
Loppes, R. 1970. Growth inhibition by NH4+ ions in arginine-requiring mutants of *Chlamydomonas reinhardi*. Mol. Gen. Genet. 109(3): 233-240.	9619	AF, UEndp, Dur	Plant

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Magalhaes Bastos, J.A. 1954. Importance of ammonia as an ichthyotoxic substance. (Importancia da amonia como substacia ictiotoxica.). No.159, Serv. Piscicultura, Publ. Ser. 1-C, Dep. Nacl. Onbras Contra Secas, Ministerio Viacao E Onbras Publicas, Brazil. pp. 115-132.	10302	UEndp, Dur	
Malacea, I. 1966. Studies on the acclimation of fish to high concentrations of toxic substances. Arch. Hydrobiol. 65(1): 74-95 (GER) (ENG TRANSL).	10020	Dur	
Manissery, J.K. and M.N. Madhyastha. 1993. Hematological and histopathological effect of ammonia at sublethal levels on fingerlings of common carp *Cyprinus carpio*. Sci. Total Environ. (Suppl .): 913-920.	4314	Eff, UEndp	
McDonald, S.F., S.J. Hamilton, K.J. Buhl and J.F. Heisinger. 1997. Acute toxicity of fire-retardant and foam-suppressant chemicals to *Hyalella azteca* (Saussure). Environ. Toxicol. Chem. 16(7): 1370-1376.	18102	Tox	
McIntyre, M., M. Davis and A. Shawl. 2006. The effects of ammonia on the development, survival and metamorphic success of *Strombus gigas* veligers. 98th Annu. Meet. Natl. Shellfish. Assoc., Monterery, CA (ABS).		Det	Abstract only
Meador, M.R. and D.M. Carlisle. 2007. Quantifying tolerance indicator values for common stream fish species of the United States. Ecol. Indic. 7(2): 329-338.		Tox	
Melching, C.S., V. Novotny, J.B. Schilling, J. Chen and M. B. Beck. (Eds). 2006. Probabilistic evaluation of ammonia toxicity in Milwaukee's Outer Harbor. Alliance House. IWA Publishing, London, UK.		Tox	
Merkens, J.C. and K.M. Downing. 1957. The effect of tension of dissolved oxygen on the toxicity of unionized ammonia to several species of fish. Ann. Appl. Biol. 45(3): 521-527.	10021	UEndp, Dur	
Merkens, J.C. 1958. Studies on the toxicity of chlorine and chloramines to the rainbow trout. Water Waste Treat. J. 7: 150-151.	7404	UEndp, Dur	
Mitchell, S.J., Jr. 1983. Ammonia-caused gill damage in channel catfish (*Ictalurus punctatus*): Confounding effects of residual chlorine. Can. J. Fish. Aquat. Sci. 40(2): 242-247.	10543	UEndp, Dur	
Morris, J.M., E. Snyder-Conn, J.S. Foott, R.A. Holt, M.J. Suedkamp, H.M. Lease, S.J. Clearwater and J.S. Meyer. 2006. Survival of Lost River suckers (*Deltistes luxatus*) challenged with *Flavobacterium columnare* during exposure to sublethal ammonia concentrations at pH 9.5. Arch. Environ. Contam. Toxicol. 50(2): 256-263.	97379	WatQual	
Mosier, A.R. 1978. Inhibition of photosynthesis and nitrogen fixation in algae by volatile nitrogen bases. J. Environ. Qual. 7(2): 237-240.	15860	Dur	Plant
Mukherjee, S. and S. Bhattacharya. 1974. Effects of some industrial pollutants on fish brain cholinesterase activity. Environ. Physiol. Biochem. 4: 226-231.	668	Eff. Dur - 2d	
Muturi E.J., B.G. Jacob, J. Shililu and R. Novak. 2007. Laboratory studies on the effect of inorganic fertilizers on survival and development of immature *Culex quinquefasciatus* (Diptera: Culicidae). J Vector Borne Dis. 44(4): 259-65.		Dilut	Deionized water

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Nawata, C.M. and C.M. Wood. 2009. MRNA expression analysis of the physiological responses to ammonia infusion in rainbow trout. J. Comp. Physiol. B. 179(7): 799-810.		RouExp	
Nimptsch, J. and S. Pflugmacher. 2007. Ammonia triggers the promotion of oxidative stress in the aquatic macrophyte *Myriophyllum mattogrossense*. Chemosphere 66(4): 708-714.	100651	NonRes	Plant
Obiekezie, A.I. and P.O. Ajah. 1994. Chemotherapy of macrogyrodactylosis in the culture of African clariid catfishes *Clarias gariepinus* and *Heterobranchus longifiliis*. J. Aquacult. Trop. 9(3): 187-192.	16594	NonRes	
Ohmori, M., K. Ohmori and H. Strotmann. 1977. Inhibition of nitrate uptake by ammonia in a blue-green alga, *Anabaena cylindrica*. Arch. Microbiol. 114(3): 225-229.	7605	UEndp, Dur	Plant
Okelsrud, A. and R.G. Pearson. 2007. Acute and postexposure effects of ammonia toxicity on juvenile barramundi (*Lates calcarifer*). Arch. Environ. Contam. Toxicol. 53(4): 624-631.		NonRes	
Olson, K.R., and P.O. Fromm. 1971. Excretion of urea by two teleosts exposed to different concentrations of ambient ammonia. Comp. Biochem. Physiol. A 40:999-1007.	10243	Eff, AF, UEndp, Dur - 1d	
Oromi, N. D. Sanuy and M. Vilches. 2009. Effects of nitrate and ammonium on larvae of *Rana temporaria* from the Pyrenees. Bull. Environ. Contam. Toxicol. 82(5): 534-537.		NonRes	
Ortiz-Santaliestra, M. E., A. Marco, M.J. Fernandez and M. Lizana. 2006. Influence of developmental stage on sensitivity to ammonium nitrate of aquatic stages of amphibians. Environ. Toxicol. Chem. 25(1): 105-111.		NonRes	
Ortiz-Santaliestra, M. E., A. Marco, M.J. Fernandez and M. Lizana. 2007. Effects of ammonium nitrate exposure and water acidification on the dwarf newt: The protective effect of oviposition behaviour on embryonic survival. Aquat. Toxicol. 85(4): 251-257.		NonRes	
Pagliarani, A., P. Bandiera, V. Ventrella, F. Trombetti, M.P. Manuzzi, M. Pirini and A.R. Borgatti. 2008. Response of Na+-dependent ATPase activities to the contaminant ammonia nitrogen in *Tapes philippinarum*: Possible ATPase involvement in ammonium transport. Arch. Environ. Contam. Toxicol. 55(1): 49-56.		No Dose	Only 2 exposure concentrations
Palanichamy, S., S. Arunachalam and M.P. Balasubramanian. 1985. Food consumption of *Sarotherodon mossambicus* (Trewaves) exposed to sublethal concentration of diammonium phosphate. Hydrobiologia 128(3): 233-237.	11516	NonRes, AF, UEndp, Dur	
Palanisamy, R. and G. Kalaiselvi. 1992. Acute toxicity of agricultural fertilizers to fish *Labeo rohita*. Environ. Ecol. 10(4): 869-873.	8278	NonRes, AF, Dur	
Paley, R.K., I.D. Twitchen and F.B. Eddy. 1993. Ammonia, Na+, K+ and Cl- levels in rainbow trout yolk-sac fry in response to external ammonia. J. Exp. Biol.180:273-284.	7746	Eff, UEndp, Dur - 1d	
Pascoa, I., A. Fontainhas-Fernandes and J. Wilson. 2008. Ammonia tolerance in the zebrafish (*Danio rerio*): Effects of ionic strength and ontogeny: Abstracts of the Annual Main Meeting of the Society of Experimental Biology, 6th-10th July 2008, Marseille, France. Comp. Biochem. Physiol. A: Mol. Integr. Physiol. 150(3 Supp.): 106-107.		Det, INV	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Patrick, R., J. Cairns, Jr. and A. Scheier. 1968. The relative sensitivity of diatoms, snails, and fish to twenty common constituents of industrial wastes. Prog. Fish-Cult. 30(3): 137-140 (Author Communication Used) (Publ in Part As 2406).	949	AF	
Paul, V.I. and T.K. Banerjee. 1995. Acute toxicity of ammonium sulphate to the air-breathing organ of the live fish *Heteropneustes (Saccobranchus) fossilis* (Bloch). Curr. Sci. 68(8): 845-849.	19532	NonRes, UEndp, Dur	
Penaz, M. 1965. The influence of ammonia on the eggs and young of the common trout, *Salmo trutta var. fario*. Zool. Listy 14(1): 47-54.	10307	UEndp, Dur	
Phillips, B.M., B.S. Anderson, J.W. Hunt, S.L. Clark, J.P. Voorhees, R.S. Tjeerdema, J. Casteline and M. Stewart. 2009. Evaluation of phase II toxicity identification evaluation methods for freshwater whole sediment and interstitial water. Chemosphere. 74(5): 648-653.		Tox	
Puchaslski, M.A., M.E. Sather, J.T. Walker, C.M. Lehmann, D.A. Gay, J. Mathew and W.P. Robarge. 2011. Passive ammonia monitoring in the United States: Comparing three different sampling devices. J. Environ. Monit. 13(11): 3156-3167.		No Dose	Fate
Puglis H.J. and M.D. Boone. 2007. Effects of a fertilizer, an insecticide, and a pathogenic fungus on hatching and survival of bullfrog (*Rana catesbeiana*) tadpoles. Environ. Toxicol. Chem. 26(10): 2198-2201.		Tox	
Ram, R. and A.G. Sathyanesan. 1987. Effect of chronic exposure of commercial nitrogenous fertilizer, ammonium sulfate, on testicular development of a teleost *Channa punctatus* (Bloch). Indian J. Exp. Biol. 25(10): 667-670.	24	NonRes, AF, UEndp, Dur	
Ram, R.N. and A.G. Sathyanesan. 1986. Ammonium sulfate induced nuclear changes in the oocyte of the fish, *Channa punctatus* (Bl.). Bull. Environ. Contam. Toxicol. 36(6): 871-875.	11793	NonRes, AF, UEndp, Dur	
Ram, R.N. and A.G. Sathyanesan. 1986. Inclusion bodies: Formation and degeneration of the oocytes in the fish *Channa punctatus* (Bloch) in response to ammonium sulfate treatment. Ecotoxicol. Environ. Saf. 11(3): 272-276.	12428	NonRes, AF, UEndp, Dur	
Ram, R.N. and A.G. Sathyanesan. 1987. Histopathological changes in liver and thyroid of the teleost fish, *Channa punctatus* (Bloch), in response to ammonium sulfate fertilizer treatment. Ecotoxicol. Environ. Saf. 13(2): 185-190.	12684	NonRes, AF, UEndp, Dur	
Ram, R.N. and S.K. Singh. 1988. Long-term effect of ammonium sulfate fertilizer on histophysiology of adrenal in the teleost, *Channa punctatus* (Bloch). Bull. Environ. Contam. Toxicol. 41(6): 880-887.	2649	NonRes, AF, UEndp, Dur	
Ramachandran, V. 1960. Observations on the use of ammonia for the eradication of aquatic vegetation. J. Sci. Ind. Res.19C: 284-285; Chem. Abstr. 55 (1961).	626	AF, UEndp, Dur	Plant
Rani, E.F., M. Elumalal and M.P. Balasubramanian. 1998. Toxic and sublethal effects of ammonium chloride on a freshwater fish *Oreochromis mossambicus*. Water Air Soil Pollut. 104(1/2): 1-8.	19157	UChron	
Rao, V.N.R. and G. Ragothaman. 1978. Studies on *Amphora coffeaeformis* II. Inorganic and organic nitrogen and phosphorus sources for growth. Acta Bot. Indica 6(Supp I): 146-154.	5449	AF, UEndp, Dur	Plant

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Redner, B.D. and R.R. Stickney. 1979. Acclimation to ammonia by *Tilapia aurea*. Trans. Am. Fish. Soc. 108: 383-388.	2561	NonRes, Dur - 3d	
Redner, B.D., J.R. Tomasso and B.A. Simco. 1980. Short term alleviation of ammonia toxicity by environmental sodium chloride in channel catfish (*Ictalurus punctatus*). J. Tenn. Acad. Sci. 55: 54.	407	Dur - 2d	
Reichenbach-Klinke, H.H. 1967. Investigations on the influence of the ammonia content on the fish organism. Arch. Fischereiwiss. 17(2): 122-132 (GER) (ENG TRANSL).	10170	Uchron, UEndp	
Rice, S.D. and R.M. Stokes. 1975. Acute toxicity of ammonia to several developmental stages of rainbow trout, *Salmo gairdneri*. Fish. Bull. 73(1): 207-211 (Personal Communication Used).	667	Dur - 1d	
Rippon, G.D. and R.V. Hyne. 1992. Purple spotted gudgeon: Its use as a standard toxicity test animal in tropical northern Australia. Bull. Environ. Contam. Toxicol. 49(3): 471-476.	5770	NonRes, AF, Dur	
Robertson, E.L. and K. Liber. 2007. Bioassays with caged *Hyalella azteca* to determine *in situ* toxicity downstream of two Saskatchewan, Canada, uranium operations. Environ. Toxicol. Chem. 26(1): 2345-2355.		Field, Tox	
Robinette, H.R. 1976. Effects of selected sublethal levels of ammonia on the growth of channel catfish (*Ictalurus punctatus*). Prog. Fish-Cult. 38(1): 26-29.	524	Dur - 1d	
Ronan, P.J., M.P. Gaikowski, S.J. Hamilton, K.J. Buhl and C.H. Summers. 2007. Ammonia causes decreased brain monoamines in fathead minnows (*Pimephales promelas*). Brain Res. 1147:184-91.		Det, UChron	
Rubin, A.J. and G.A. Elmaraghy. 1977. Studies on the toxicity of ammonia, nitrate and their mixtures to guppy fry. Water Res. 11(10): 927-935.	7635	Sec	Other data used from an earlier report
Rushton, W. 1921. Biological notes. Salmon Trout Mag. 25: 101-117.	11164	Det, AF, UEndp, Dur	
Saha, N. and B.K. Ratha. 1994. Induction of ornithine-urea cycle in a freshwater teleost, *Heteropneustes fossilis*, exposed to high concentrations of ammonium chloride. Comp. Biochem. Physiol. B 108(3): 315-325.	16783	NonRes, UEndp	
Salin, D. and P. Williot. 1991. Acute toxicity of ammonia to Siberian sturgeon *Acipenser baeri*. In: P. Willot (Ed.), Proc.1st Symposium on Sturgeon, Bordeaux (Gironde, France), Oct.3-6, 1989: 153-167.	7491	Dur - 1d	
Samylin, A.F. 1969. Effect of ammonium carbonate on early stages of development of salmon. Uch. Zap. Leningr. Gos. Pedagog. Inst. Im. A. I. Gertsena. 422: 47-62 (RUS) (ENG TRANSL).	2606	UEndp, Dur	
Sarkar, S.K. and S.K. Konar. 1988. Dynamics of abiotic-biotic parameters of water and soil in relation to fish growth exposed to ammonium sulfate. Environ. Ecol. 6(3): 730-733.	804	UEndp, No Org	
Sarkar, S.K. 1988. Influence of ammonium sulphate on the feeding rate of fish under multivariate temperature. Comp. Physiol. Ecol. 13(1): 30-33.	3235	AF, UEndp, Dur	
Sarkar, S.K. 1991. Dynamics of aquatic ecosystem in relation to fish growth exposed to ammonium sulphate. J. Environ. Biol. 12(1): 37-43.	238	WatQual, UEndp, No Org	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Sarkar, S.K. 1991. Toxicity evaluation of urea and ammonium sulphate to *Oreochromis mossambicus* (Peters). J. Ecobiol. 3(1): 79-80.	7535	Con	
Sathyanesan, A.G., K.P. Joy and R.S. Kulkarni. 1978. Endocrine changes in fishes in response to pollutants. Q. J. Surg. Sci. 14(1/2): 67-77.	10173	Eff, AF, UEndp	
Schram, E., J.A.C. Roques, W. Abbink, T. Spanings, P. de Vries, S. Bierman, H. van de Vis and G. Flik. 2010. The impact of elevated water ammonia concentration on physiology, growth and feed intake of African catfish (*Clarisa gariepinus*). Aquaculture 306(1-4): 108-115		NonRes	
Schubauer-Berigan, M.K., P.D. Monson, C.W. West and G.T. Ankley. 1995. Influence of pH on the toxicity of ammonia to *Chironomus tentans* and *Lumbriculus variegatus*. Environ. Toxicol. Chem. 14(4): 713-717.	15119	Dur - 10d	Data rejected for *C. tentans* as indicated
Schulze-Wiehenbrauck, H. 1976. Effects of sublethal ammonia concentrations on metabolism in juvenile rainbow trout (*Salmo gairdneri* Richardson). Ber. Dtsch. Wiss. Kommn. Meeresforsch. 24:234-250.	2616	UEndp, Dur	
Shedd, T.R., M.W. Widder, M.W. Toussaint, M.C. Sunkel and E. Hull. 1999. Evaluation of the annual killifish *Nothobranchius guentheri* as a tool for rapid acute toxicity screening. Environ. Toxicol. Chem. 18(10): 2258-2261.	20487	NonRes, Dur - 1d	
Sheehan, R.J. and W.M. Lewis. 1986. Influence of pH and ammonia salts on ammonia toxicity and water balance in young channel catfish. Trans. Am. Fish. Soc. 115(6): 891-899.	12194	Dur - 1d	
Singh, S.B., S.C. Banerjee and P.C. Chakrabarti. 1967. Preliminary observations on response of young ones of Chinese carps to various physico-chemical factors of water. Proc. Nat. Acad. Sci., India 37(3B): 320-324; Biol. Abstr. 51: 5159 (1970).	2629	INV, UEndp, Dur	
Slabbert, J.L. and J.P. Maree. 1986. Evaluation of interactive toxic effects of chemicals in water using a *Tetrahymena pyriformis* toxicity screening test. Water S. A. 12(2): 57-62.	12836	AF, UEndp, Dur	
Slabbert, J.L. and W.S.G. Morgan. 1982. A Bioassay technique using *Tetrahymena pyriformis* for the rapid assessment of toxicants in water. Water Res. 16(5): 517-523.	11048	AF, UEndp, Dur	
Smart, G. 1976. The effect of ammonia exposure on gill structure of the rainbow trout (*Salmo gairdneri*). J. Fish Biol. 8: 471-475 (Author Communication Used).	2631	Eff, UEndp, Dur	
Smith, C.E. and R.G. Piper. 1975. Lesions associated with chronic exposure to ammonia. In: The pathology of fishes. Ribelin W.E. and G. Migaki (Eds.). University of Wisconsin Press, Madison, WI. pp. 497-514.	2636	Eff, UEnpd, Dur	
Smith, C.E. 1984. Hyperplastic lesions of the primitive meninx of fathead minnows, *Pimephales promelas*, induced by ammonia: Species potential for carcinogen testing. In: Use of small fish species in carcinogenicity testing. Hoover, K.L. (Ed.). Monogr. Ser. Natl. Cancer Inst. No. 65, NIH Publ. No. 84-2653, U.S. Dep. Health Human Serv., Natl. Cancer Inst., Bethesda, MD. pp. 119-125.	10254	Eff, UEndp	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Snell, T.W., B.D. Moffat, C. Janssen and G. Persoone. 1991. Acute toxicity tests using rotifers IV. Effects of cyst age, temperature, and salinity on the sensitivity of *Brachionus calyciflorus*. Ecotoxicol. Environ. Saf. 21(3): 308-317 (OECDG Data File).	9385	Sec, AF, Dur - 1d	Data provided in earlier report
Soderberg, R.W., J.B. Flynn and H.R. Schmittou. 1983. Effects of ammonia on growth and survival of rainbow trout in intensive static-water culture. Trans. Am. Fish. Soc. 112(3): 448-451.	15728	AF, UEndp, Dur	
Solomonson, L.P. 1970. Effects of ammonia and some of its derivatives on photosynthesis in the blue-green alga, *Plectonema boryanum*. Ph.D. Thesis, Univ. of Chicago, Chicago, IL.	5443	UEndp, Dur, Plant	Plant
Spadaro, D., T. Micevska and S.L. Simpson. 2008. Effect of nutrition on toxicity of contaminants to the epibenthic amphipod *Melita plumulosa*. Arch. Environ. Contam. Toxicol. 55(4): 593-602.		NonRes	
Speare, D. and S. Backman. 1988. Ammonia and nitrite waterborne toxicity of commercial rainbow trout. Can. Vet. J. 29: 666.	2958	AF, UEndp, Dur - 2d	
Spencer, P., R. Pollock and M. Dube. 2008. Effects of unionized ammonia on histological, endocrine, and whole organism endpoints in slimy sculpin (*Cottus Cognatus*). Aquat. Toxicol. 90(4): 300-309.		Det	Dilution water not described
Stanley, R.A. 1974. Toxicity of heavy metals and salts to Eurasian watermilfoil (*Myriophyllum spicatum* L.). Arch. Environ. Contam. Toxicol. 2(4): 331-341.	2262	AF	Plant
Sun, H., K. Lu, E.J.A. Minter, Y. Chen, Z. Yang and D.J.S. Montagnes. 2012. Combined effects of ammonia and microcystin on survival, growth, antioxidant responses, and lipid peroxidation of bighead carp *Hypophthalmyths nobilis* larvae. J. Hazard. Mater. 221-222: 213-219.		No Dose, INV	
Sun, H., W. Yang, Y. Chen and Z. Yang. 2011. Effect of purified microcystin on oxidative stress of silver carp *Hypophthalmyths nobilis* larvae under different ammonia concentrations. Biochem. System. Ecol. 39: 536-543.		No Dose, INV	
Suski, C.D., J. D. Kieffer, S.S. Killen and B.L. Tufts. 2007. Sub-lethal ammonia toxicity in largemouth bass. Comp. Biochem. Physiol., A: Mol. Integr. Physiol. 146(3): 381-389.		No Dose, Dur	Only 2 exposure concentrations
Tabata, K. 1962. Toxicity of ammonia to aquatic animals with reference to the effect of pH and carbonic acid. Bull. Tokai Reg. Fish. Res. Lab.(Tokai-ku Suisan Kenkyusho Kenkyu Hokoku) 34: 67-74 (ENG TRANSL).	14284	Dur - 1d	
Tarazona, J.V., M. Munoz, J.A. Ortiz, M. Nunez and J.A. Camargo. 1987. Fish mortality due to acute ammonia exposure. Aquacult. Fish. Manage. 18(2): 167-172.	12807	UEndp, Dur - 1d	
Taylor, J.E. 1973. Water quality and bioassay study from Crawford National Fish Hatchery. Trans. Nebr. Acad. Sci. 2: 176-181.	2531	UEndp, Dur - 2d	
Thomas, J.D., M. Powles and R. Lodge. 1976. The chemical ecology of *Biomphalaria glabrata*: The effects of ammonia on the growth rate of juvenile snails. Biol. Bull. 151(2): 386-397.	15962	NonRes, UEndp, Dur	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Thomas, P.C., C. Turner and D. Pascoe. 1991. An assessment of field and laboratory methods for evaluating the toxicity of ammonia to *Gammarus pulex* L. - Effects of water velocity. In: Bioindic. Environ. Manage. 6th Symposium. Jeffrey, D.W. and B. Madden (Eds.). Academic Press, London, UK. pp. 353-363.	6276	UEndp, Dur - 1d	
Thumann, M.E. 1950. The effect of ammonium salt solutions on rainbow and brook trout and some fish nutrient animals. Abh. Fischerei. Lieferung 2: 327-348.	2528	UEndp, Dur	
Tilak, K.S., K. Veeraiah and J.M.P. Raju. 2006. Toxicity and effects of ammonia, nitrite, nitrate and histopathological changes in the gill of freshwater fish *Cyprinus carpio*. J. Ecotoxicol. Environ. Monit. 16(6): 527-532.	105937	Det, AF, Dur	
Tng, Y.Y., S.F. Chew, N.L. Wee, F.K. Wong, W.P. Wong, C.Y. Tok and Y.K. Ip. 2009. Acute ammonia toxicity and the protective effects of methionine sulfoximine on the swamp eel, *Monopterus albus.* J. Exp. Zool. A Ecol. Genet. Physiol. 311(9): 676-688.		INV	
Tomasso, J.R., C.A. Goudie, B.A. Simco and K.B. Davis. 1980. Effects of environmental pH and calcium on ammonia toxicity in channel catfish. Trans. Am. Fish. Soc. 109(2): 229-234 (Personal Communication Used).	410	Dur - 1d	
Tonapi, G.T. and G. Varghese. 1984. Cardiophysiological responses of the crab, *Berytelphusa cunnicularis* (Westwood), to three common pollutants. Indian J. Exp. Biol. 22(10): 548-549.	12198	AF, UEndp, Dur	
Tonapi, G.T. and G. Varghese. 1987. Cardio-physiological responses of some selected cladocerans to three common pollutants. Arch. Hydrobiol. 110(1): 59-65.	2075	AF, UEndp, Dur	
Tsai, C.F. and J.A. McKee. 1980. Acute toxicity to goldfish of mixtures of chloramines, copper, and linear alkylate sulfonate. Trans. Am. Fish. Soc. 109(1): 132-141 (Personal Communication Used).	5619	Tox	
Twitchen, I.D. and F.B. Eddy. 1994. Effects of ammonia on sodium balance in juvenile rainbow trout *Oncorhynchus mykiss* Walbaum. Aquat. Toxicol. 30(1): 27-45.	14071	Eff, UEndp	
Twitchen, I.D. and F.B. Eddy. 1994. Sublethal effects of ammonia on freshwater fish. In: Sublethal and chronic effects of pollutants on freshwater fish. Chapter 12. Muller, R. and R. Lloyd (Eds.). Fishing News Books, London, UK. pp.135-147.	18512	Eff, UEndp, Dur - 2d	
Van Der Heide, T., A.J.P. Smolders, B.G.A. Rijkens, E.H. Van Nes, M.M. VanKatwijk and J.G.M. Roelofs. 2008. Toxicity of reduced nitrogen in eelgrass (*Zostera marina*) is highly dependent on shoot density and pH. Oecologia 158(3): 411-419.		VarExp	Substantial loss of ammonia; Plant
Van Vuren, J.H.J. 1986. The effects of toxicants on the haematology of *Labeo umbratus* (Teleostei: Cyprinidae). Comp. Biochem. Physiol. C 83(1): 155-159.	11744	NonRes, AF, UEndp, Dur	
Vedel, N.E., B. Korsgaard and F.B. Jensen. 1998. Isolated and combined exposure to ammonia and nitrite in rainbow trout (*Oncorhynchus mykiss*): Effects on electrolyte status, blood respiratory. Aquat. Toxicol. 41(4): 325-342.	19154	Eff, UEndp	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development

Citation	ECOTOX or Other Ref. No	Rejection Code(s)	Comment(s)
Vijayavel, K., E.F. Rani, C. Anbuselvam and M.P. Balasubramanian. 2006. Interactive effect of monocrotophos and ammonium chloride on the freshwater fish Oreochromis mossambicus with reference to lactate/pyruvate ratio. Pestic. Biochem. Physiol. 86(3): 157-161.	108153	Det, AF	Detail (pH, temp, etc. not reported)
Wallen, I.E., W.C. Greer and R. Lasater. 1957. Toxicity to *Gambusia affinis* of certain pure chemicals in turbid waters. Sewage Ind. Wastes 29(6): 695-711.	508	Dur, Con, UEndp	
Wang, C., S.H. Zhang, P.F. Wang, J. Hou, W. Li, and W.J. Zhang. 2008. Metabolic adaptations to ammonia-induced oxidative stress in leaves of the submerged macrophyte *Vallisneria natans* (Lour.) Hara. Aquat. Toxicol. 87(2): 88-98.		NonRes	
Ward, S., T.O.M. Augspurger, F.J. Dwyer, C. Kane and C.G. Ingersoll. 2007. Risk assessment of water quality in three North Carolina, USA, streams supporting federally endangered freshwater mussels (Unionidae). Environ. Toxicol. Chem. 26(10): 2075-2085.		Tox	
Ward, D.J., V. Perez-Landa, D.A. Spadaro, S.L. Simpson and D.F. Jolley. 2011. An assessment of three harpacticoid copepod species for use in ecotoxicological testing. Arch. Environ. Contam. Toxicol. 61(3): 414-425.		NonRes	
Water Pollution Research Board. 1961. Effects of pollution on fish: Toxicity of gas liquors. In: Water pollution research 1960, Water Pollution Research Board, Dep. of Scientific and Industrial Research, H.M. Stationery Office, London, UK. pp. 76-81.	2514	UEndp, Dur	
Water Pollution Research Board. 1968. Effects of pollution on fish: Chronic toxicity of ammonia to rainbow trout. In: Water pollution research 1967, Water Pollution Research Board, Dep. of Scientific and Industrial Research, H.M. Stationery Office, London, UK. pp. 56-65.	10185	AF, Dur - 2d, UEndp	
Watt, P.J. and R.S. Oldham. 1995. The effect of ammonium nitrate on the feeding and development of larvae of the smooth newt, *Triturus vulgaris* (L.), and on the behaviour of its food. Freshw. Biol. 33(2): 319-324.	14883	UEndp	
Wee, N.L.J., Y.Y.M. Tng, H.T. Cheng, S.M.L. Lee, S.F. Chew and Y.K. Ip. 2007. Ammonia toxicity and tolerance in the brain of the African sharptooth catfish, *Clarias gariepinus*. Aquat. Toxicol. 82(3): 204-213.		NonRes, No Dose	Only 2 exposure concentrations
Weiss, L.A. and E. Zaniboni-Filho. 2009. Survival of diploid and triploid *Rhamdia quelen* juveniles in different ammonia concentrations. Aquaculture 298(1-2): 153-156.		NonRes	
Wells, M.M. 1915. The reactions an resistance of fishes in their natural environment to salts. J. Exp. Zool. 19(3): 243-283.		Det, No Dose	
Wickins, J.F. 1976. The tolerance of warm-water prawns to recirculated water. Aquaculture 9(1): 19-37.	2320	AF, UEndp, Dur	
Wilkie, M.P., M.E. Pamenter, S. Duquette, H. Dhiyebi, N. Sangha, G. Skelton, M.D. Smith and L.T. Buck. 2011. The relationship between NMDA receptor function and the high ammonia tolerance of anoxia-tolerant goldfish. J. Exp. Biol. 214(24): 4107-4120.		Eff, UEndp	
Williams, J.E. Jr. 1948. The toxicity of some inorganic salts to game fish. M.S. Thesis, Louisiana State University, Baton Rouge, LA, 71 p.		No Org	

Appendix L. Unused (Non-influential) Acute and Chronic Studies for Freshwater Ammonia Criteria Development			
Citation	**ECOTOX or Other Ref. No**	**Rejection Code(s)**	**Comment(s)**
Woltering, D.M., J.L. Hedtke and L.J. Weber. 1978. Predator-prey interactions of fishes under the influence of ammonia. Trans. Am. Fish. Soc. 107(3): 500-504.	7218	UEndp, Dur	
Xu, Q. and R.S. Oldham. 1997. Lethal and sublethal effects of nitrogen fertilizer ammonium nitrate on common toad (*Bufo bufo*) tadpoles. Arch. Environ. Contam. Toxicol. 32(3): 298-303.	17840	AF, UEndp, Dur	
Zhang, L. and C.M. Wood. 2009. Ammonia as a stimulant to ventilation in rainbow trout *Oncorhynchus mykiss*. Respir. Physiol. Neurobiol. 168(3): 261-271.		RouExp	
Zhang, L.J., G.G. Ying, F. Chen, J.L. Zhao, L. Wang and Y.X. Fang. 2012. Development and application of whole-sediment toxicity test using immobilized freshwater microalgae *Pseudokirchneriella subcapitata*. Environ. Toxicol. Chem. 31(2): 377-386.		SedExp	Plant

Corresponding Code List

ABIOTIC FACTOR (AF)	Studies where one or both of the two abiotic factors (pH and temperature) important for ammonia criteria derivation are not reported.
ACELLULAR (Ace)	Studies of acellular organisms (protozoa) and yeast.
BACTERIA (Bact)	Studies describing only the results on bacteria.
BIOMARKER (Biom)	Studies reporting results for a biomarker having no reported association with a biologically significant adverse effect (survival, growth, or reproduction of an individual or population) and an exposure dose (or concentration).
CONTROL (Con)	Studies where control mortality is insufficient or unsatisfactory, i.e., where survival is less than 90% in acute tests or 80% in chronic tests; or where no control is used.
DETAIL (Det)	Insufficient detail regarding test methodology or statistical analysis.
DURATION (Dur)	Laboratory and field studies where duration of exposure is inappropriate (e.g., too short) for the type of test (i.e., acute or chronic), or was not reported or could not be easily estimated.
EFFLUENT (Efflu)	Studies reporting only effects of effluent, sewage, or polluted runoff where individual pollutants are not measured.
EFFECT (Eff)	Studies where the biologically significant adverse effect was not survival, growth, or reproduction of an individual or population.
ENDPOINT (UEndp)	Studies reported in ECOTOX where an endpoint (LC50, EC50, NOEC, LOEC, MATC, EC20, etc.) was not provided, where none of the concentrations tested in a chronic test were deleterious (no LOEC); or where all concentrations tested in a chronic test caused a statistically significant adverse effect (no NOEC).
FIELD (Field)	Chronic, long-term studies conducted in a field setting (stream segment, pond, etc.) where source/dilution water is not characterized for other possible contaminants.
FORMULATION (Form)	Studies where the chemical is a primary ingredient in a commercial formulation, e.g., biocide, fertilizer, etc.
INVASIVE [Harmful] (INV)	Defined in this document as a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health (see ISAC 2006).
IN VITRO (In Vit)	*In vitro* studies, including only exposure of the chemical to cell cultures and excised tissues and not related to whole organism toxicity.
LETHAL TIME (LT)	Laboratory studies reporting only lethal time to mortality, except under special conditions (no other applicable information is available for species pivotal in making a finding).
NO DOSE or CONC (No Dose or Conc)	Studies with too few concentrations to establish a dose-response, or no usable dose or concentration reported in either primary or sister article(s), except under special conditions (no other applicable information is available for species pivotal in making a finding).
NOMINAL (Nom)	Chronic studies where test concentrations were not measured.
NON-RESIDENT (NonRes)	Species that are not resident to North America, or where there is no reported evidence of their reproducing naturally in North America.
NO ORGANISM (No Org)	Laboratory and field studies where no one organism is studied (e.g., periphyton community) or where no scientific/common name is given in either a primary or sister article(s).
PURITY (Pur)	Studies where the chemical purity of the toxicant was less than 80% pure (active ingredient).
ROUTE OF EXPOSURE (RouExp)	Dietary or un-natural exposure routes for aquatic chemicals, e.g., injection, spray, inhalation.
Secondary (Sec)	Non-original data first reported elsewhere.
Sediment Exposure (SedExp)	Sediment-based toxicity test and method.
TOXICANT (Tox)	Inappropriate form of toxicant used or none identified in a laboratory or field study. Note: Inappropriate form includes mixtures.
UNACCEPTABLE CHRONIC (UChron)	Chronic studies which were not based on flow-through exposures (exception for cladocerans and other small, planktonic organisms where test water is continuously renewed), where test concentrations were not measured, or when the chronic test did not include the appropriate test duration for the organism and life-stage tested.

UNUSUAL DILUTION WATER (Dilut)	Laboratory or field studies where the dilution water contained unusual amounts or ratios of inorganic ions or was without addition of appropriate salts (i.e., distilled or de-ionized water).
VARIABLE EXPOSURE (VarExp)	Excessive variability in contaminant concentrations during the exposure period.
WATER QUALITY (WatQual)	Studies where the measured test pH is below 6 or greater than 9, where dissolved oxygen was less than 40% saturation for any length of time, or where total or dissolved organic carbon is greater than 5 mg/L.

Appendix M. 1999 Re-examination of Temperature Dependence of Ammonia Toxicity.

This section presents the temperature analysis published in the 1998 Update, followed by the re-analysis performed for the 1999 Update and reproduced here as background information. Figure and table numbers are preceded by an 'M' in this appendix, in order to distinguish them from tables and figures in the main document.

1998 Analysis of Temperature-Dependence

The 1984/1985 ammonia criteria document identified temperature as an important factor affecting the toxicity of ammonia. When expressed in terms of *unionized* ammonia, the acute toxicity of ammonia was reported in the criteria document to be inversely related to temperature for several species of fish, whereas limited data on acute ammonia toxicity to invertebrates showed no significant temperature dependence. No direct data were available concerning the temperature dependence of chronic toxicity. It was noted, however, that the differences between chronic values for salmonid fish species tested at low temperatures and chronic values for warmwater fish species tested at higher temperatures paralleled differences in acute toxicity known to be caused by temperature.

In the 1984/1985 criteria document, an average temperature relationship observed for fish was used to adjust fish acute toxicity data to a common temperature (20°C) for derivation of the CMC for *unionized* ammonia; this same relationship was used to extrapolate this CMC to other temperatures. (Invertebrate toxicity data were not adjusted, but invertebrates were sufficiently resistant to ammonia that adjustment of invertebrate data was not important in the derivation of the CMC.) This temperature relationship for fish resulted in the unionized ammonia CMC being higher at warm temperatures than at cold temperatures. Additionally, because of concerns about the validity of extrapolating the temperature relationship to high temperatures, the unionized ammonia CMC was "capped" to be no higher than its value at a temperature, called TCAP, near the upper end of the temperature range of the acute toxicity data available for warmwater and coldwater fishes. Similarly, the CCC was capped at a temperature near the upper end of the temperature range of the available chronic toxicity data.

Although the unionized ammonia criterion is lower at low temperatures, this does not result in more restrictive permit limits for ammonia because the ratio of ammonium ion to unionized ammonia increases at low temperatures, resulting in the total ammonia criterion being essentially constant at temperatures below TCAP. In practice, however, the criterion at low temperatures can be more limiting for dischargers than the criterion at high temperatures because biological treatment of ammonia is more difficult at low temperatures. Above TCAP, the constant unionized ammonia criterion results in the total ammonia criterion becoming progressively lower with increasing temperature, which can also result in restrictive discharge limitations.

Because more data are available at moderate temperatures than at lower and higher temperatures, the ammonia criterion is most uncertain for circumstances when compliance can be most difficult, either because of the low total ammonia criterion at high temperatures or because of treatment difficulties at low temperatures. This section examines the data used in the 1984/1985 criteria document and newer data to determine (1) whether the use of TCAPs should be continued and (2) whether a lower unionized criterion at low temperature is warranted. Data used include those analyzed by Erickson (1985), which are shown in Figure 2 of the 1984/1985 document, and more recent data reported by Arthur et al. (1987), DeGraeve et al. (1987), Nimmo et al. (1989), and Knoph (1992).

Data not used include those reported by the following:

1. Bianchini et al. (1996) conducted acute tests at 12 and 25°C, but one test was in fresh water, whereas the other was in salt water.
2. Diamond et al. (1993) conducted acute and chronic toxicity tests on ammonia at 12 and 20°C using several vertebrate and invertebrate species. When expressed in terms of unionized ammonia, they reported that vertebrates (i.e., fishes and amphibians) were more sensitive to ammonia at 12°C than at 20°C, whereas invertebrates were either less

sensitive or no more sensitive at 12°C, compatible with the relationships used in the 1984/1985 criteria document. However, such factors as dilution water and test duration varied between tests at different temperatures and possibly confounded the results (see Appendix 1 of the 1999 update), raising doubts about the temperature comparisons for the vertebrates and invertebrates.

Arthur et al. (1987) measured the acute toxicity of ammonia to several fish and invertebrate species at ambient temperature during different seasons of the year. For three of the five fish species (rainbow trout, channel catfish, and white sucker), the relationship of toxicity to temperature was similar to that used in the 1984/1985 criteria document. When expressed in terms of *unionized* ammonia, no clear relationship existed between temperature and toxicity for the other fish species (fathead minnow and walleye). This result for the fathead minnow is different from those of three other studies (Reinbold and Pescitelli 1982b; Thurston et al. 1983; DeGraeve et al. 1987) reporting a significant effect of temperature on the acute toxicity of unionized ammonia to the fathead minnow. For five invertebrate species, each tested over a temperature range of at least 10°C, there was no consistent relationship between temperature and unionized ammonia toxicity. An initial report of these results (West 1985) was the basis for no temperature adjustment being used for invertebrate data in the 1984/1985 criteria document. Further analysis of the Arthur (1987) data is discussed later.

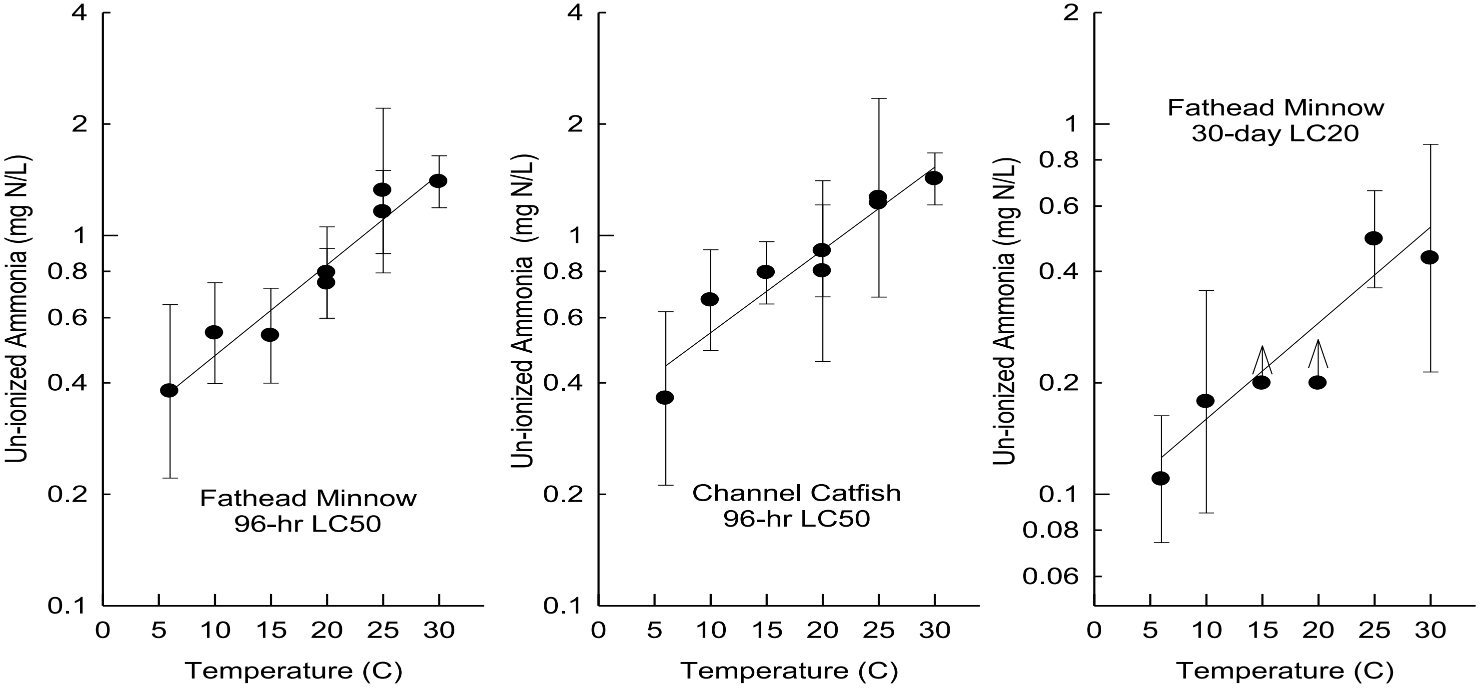
DeGraeve et al. (1987) studied the effect of temperature (from 6 to 30°C) on the toxicity of ammonia to juvenile fathead minnows and channel catfish using acute (4-day) and chronic (30-day) ammonia exposures. As shown for both fish species in Figure M.1, log(96-hr unionized ammonia LC_{50}) versus temperature was linear within the reported uncertainty in the LC_{50}s; the slopes were similar to those reported in the 1984/1985 criteria document. Problems with the channel catfish chronic tests precluded effective use of those data and the highest tested ammonia concentrations in the fathead minnow chronic tests at 15 and 20°C did not cause sufficient mortality to be useful. However, sufficient mortality did occur in the fathead minnow chronic tests at 6, 10, 25, and 30°C. Based on regression analysis of survival versus log concentration (discussed in more detail in the section concerning the CCC below), 30-day LC20s for unionized ammonia were 0.11, 0.18, 0.48, and 0.44 mg N/L at 6, 10, 25, and 30°C, respectively. This temperature dependence (Figure M.1) is similar to that for acute toxicity and that used in the 1984/1985 criteria document. The actual effect of temperature on these 30-day LC20s is probably somewhat greater, because test pH decreased with increasing temperature.

Nimmo et al. (1989) conducted acute toxicity tests on ammonia at 6 and 20°C in a well water using Johnny darters and in a river water using both Johnny darters and juvenile fathead minnows. In all three sets of tests, LC_{50}s expressed in terms of unionized ammonia were significantly higher at the warmer temperature, by factors ranging from 3.5 to 6.2.

Knoph (1992) conducted acute toxicity tests at temperatures ranging from 2 to 17°C using Atlantic salmon parr, one series of tests at $pH \approx 6.0$ and the other at $pH \approx 6.4$. In both series of tests, LC_{50}s expressed in terms of unionized ammonia increased substantially with temperature.

Even with these additional data, the shape of the temperature relationship is not completely resolved, especially for chronic toxicity. Nevertheless, the acute data for fishes overwhelmingly indicate that ammonia toxicity, expressed in terms of *unionized* ammonia, decreases with increasing temperature.

Figure M.1. The Effect of Temperature on Ammonia Toxicity in Terms of Unionized Ammonia (DeGraeve et al. 1987). Symbols denote LC_{50}s or LC_{20}s and 95% confidence limits and lines denote linear regressions of log LC versus temperature.



Most importantly, the data of DeGraeve et al. (1987) show (Figure M.1) that (a) a linear relationship of log unionized ammonia LC_{50} versus temperature applies within the reported uncertainty in the LC_{50}s over the range of 6 to 30°C and (b) temperature effects on long-term mortality are similar to those on acute mortality. For invertebrates, acute toxicity data suggest that ammonia toxicity, when expressed in terms of unionized ammonia, does not decrease, and possibly even increases, with increasing temperature. Quantifying and adjusting data for this relationship is not necessary because even at warm temperatures invertebrates are generally more resistant to acute ammonia toxicity than fishes and thus their precise sensitivities are of limited importance to the criterion. At low temperatures, they are even more resistant relative to fishes and thus their precise sensitivity is even less important to the criterion.

Based on this information, the two issues raised above were resolved as follows:

1. TCAPs will not be used in the ammonia criterion. This does not mean that the notion of high temperature exacerbating ammonia toxicity is wrong; rather, it reflects the fact that such an effect is not evident in the available data, which cover a wide temperature range.
2. A CMC, if it were expressed as unionized ammonia (rather than total ammonia, used in this document) would continue to be lower at lower temperatures, consistent with the observed temperature dependence of ammonia toxicity to the most sensitive species, i.e., fishes. Although it is possible that the temperature relationship differs among fish species and that using the same relationship for all fish species introduces some uncertainty, specifying a relationship for each fish species is not possible with current data and would also introduce considerable uncertainty.

Therefore, for a criterion expressed in terms of unionized ammonia, available data support the continued use of a generic temperature relationship similar to that in the 1984/1985 ammonia criteria document, but without TCAPs.

Figure M.2. The Effect of Temperature on Acute Ammonia Toxicity in Terms of Total Ammonia Nitrogen. Symbols denote LC$_{50}$s, solid lines denote regressions for individual datasets, and dotted lines denote pooled regressions over all datasets.

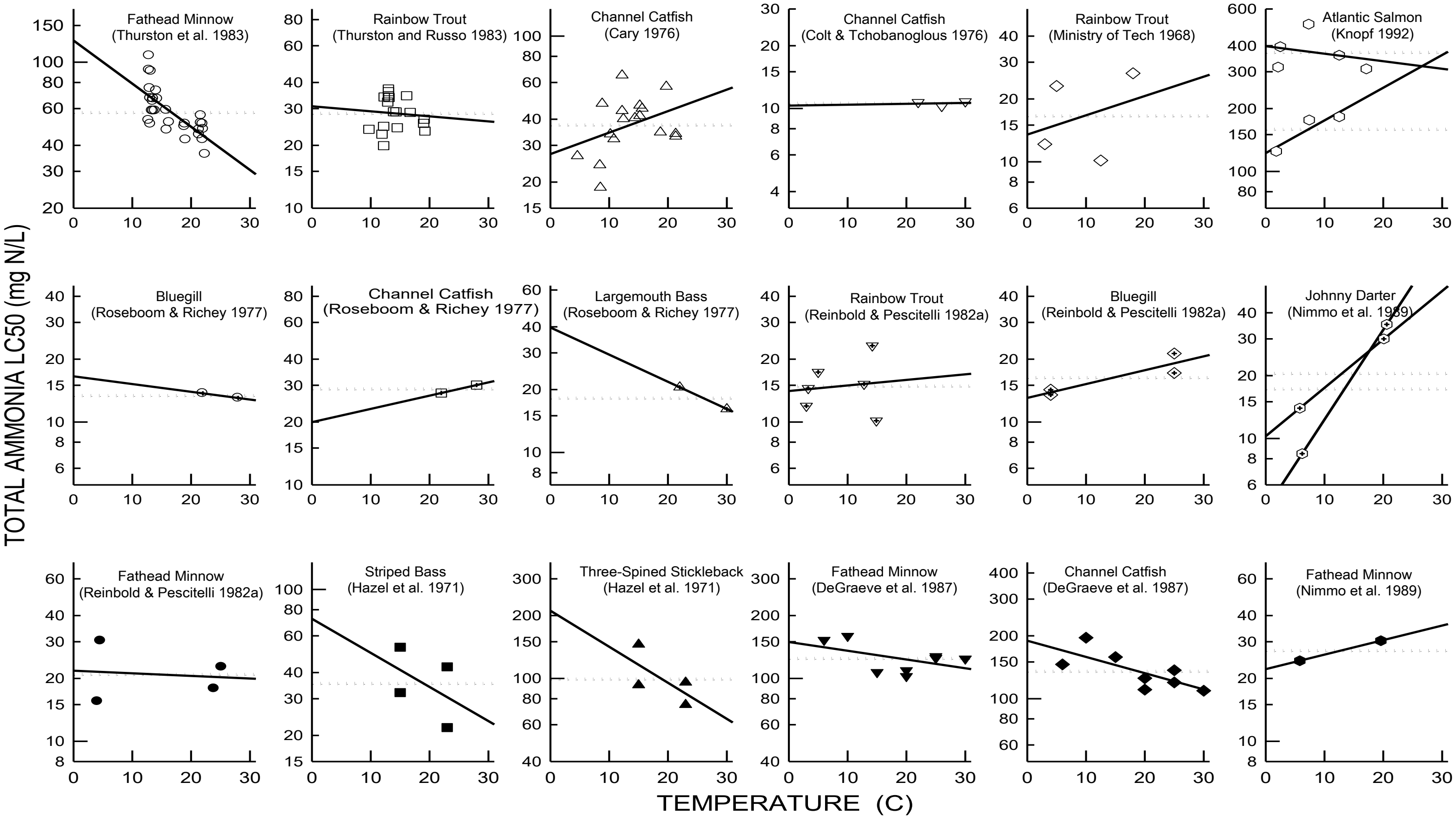
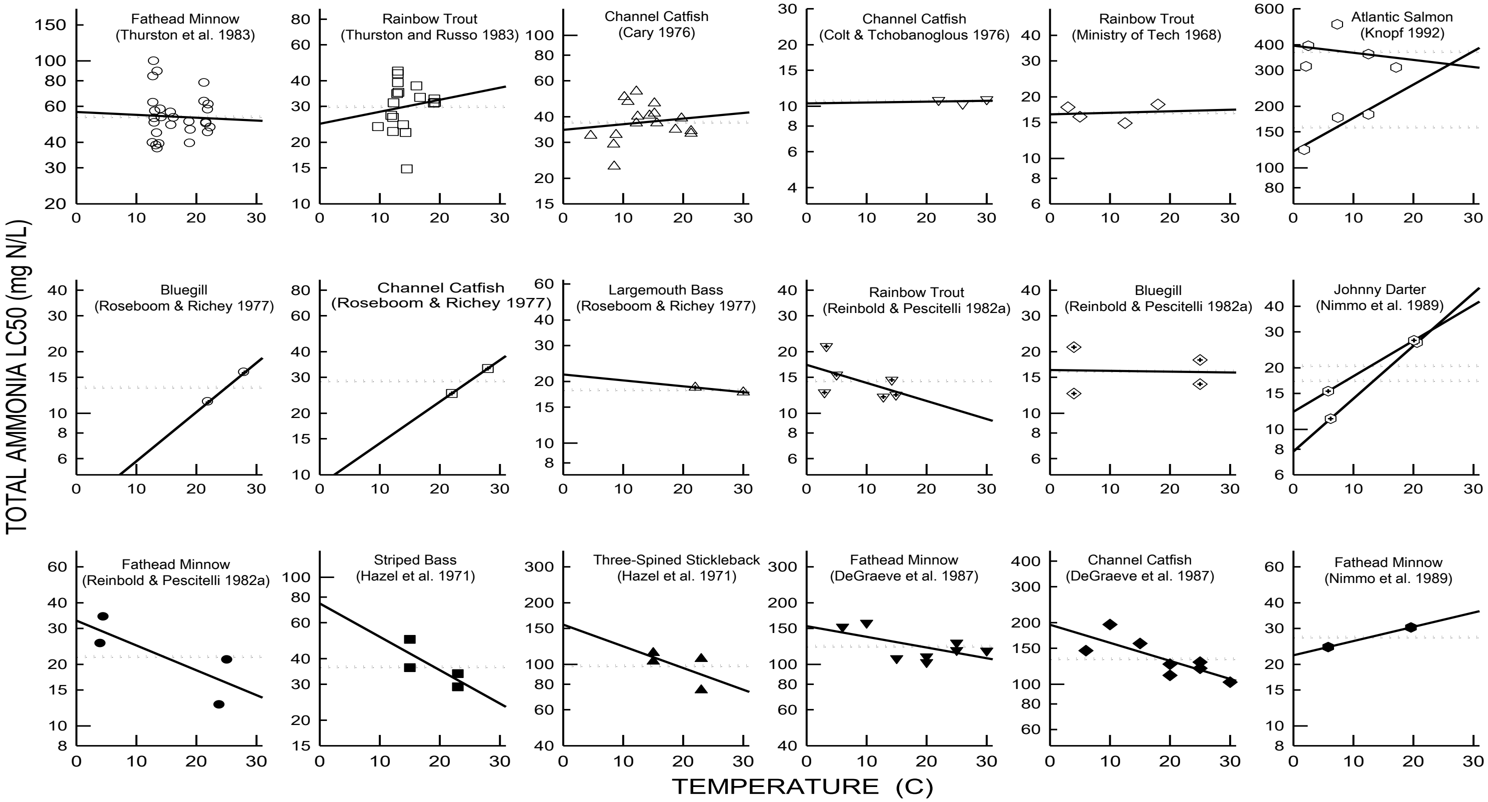


Figure M.3. The Effect of Temperature on pH-Adjusted Acute Ammonia Toxicity in Terms of Total Ammonia Nitrogen. LC$_{50}$s are adjusted to the mean pH of the dataset based on the pooled relationship of acute toxicity to pH. Symbols denote LC$_{50}$s, solid lines denote regressions for individual datasets, and dotted lines denote pooled regression over all datasets



This raised a new issue, however, because the criterion expressed in terms of total ammonia is nearly constant over all tested temperatures, and the small effect of temperature on the total ammonia criterion in the 1984/1985 criteria document is largely an artifact of conducting regression analyses in terms of unionized ammonia and is not indicative of any established, significant trend. It was thought that the expression and implementation of the ammonia criterion might have been simplified if temperature were dropped as a modifying factor, which might have been possible if ammonia toxicity is expressed in terms of total ammonia. Furthermore, permit limits and compliance are usually expressed in terms of total ammonia nitrogen, and so expressing the criterion in terms of total ammonia nitrogen would simplify its implementation by eliminating conversions to and from unionized ammonia. Because of such benefits and because there are no compelling scientific or practical reasons for expressing the criterion in terms of unionized ammonia, the freshwater toxicity data concerning temperature dependence were reanalyzed in terms of total ammonia nitrogen.

The data analyzed are from the studies included in the 1984/1985 ammonia criteria document and the studies of DeGraeve et al. (1987), Nimmo et al. (1989), and Knoph (1992). All analyses were conducted in terms of total ammonia nitrogen, either as reported by the authors or as converted by us from reported values for unionized ammonia, pH, and temperature using the speciation relationship of Emerson et al. (1975). The data are presented in Figure M.2 and show considerable diversity, with some datasets showing decreasing toxicity with increasing temperature, some showing increasing toxicity, and some showing virtually no change. There are even differences among studies using the same test species. However, in no case is the effect of temperature particularly large, being no more than a factor of 1.5 over the range of any dataset, except for the Johnny darter data of Nimmo et al. (1989). In some studies, test pH was correlated with test temperature. To reduce the confounding effect of pH, the total ammonia LC_{50} was adjusted to the mean pH of the data for the study using the pH relationship discussed in the next section of this appendix. These adjusted data are shown in Figure M.3 and also show neither large effects nor any clear consistency among or within species or studies.

For each dataset containing at least three data points, a linear regression of log LC_{50} versus temperature was conducted (Draper and Smith 1981) and the resulting regression lines are plotted as solid lines in Figures M.2 and M.3. These regressions are significant at the 0.05 level for only one dataset (the unadjusted fathead minnow data of Thurston et al. 1983); for this dataset, however, the regression is not significant when the data are adjusted for the fact that pH values were lower in the low-temperature tests than in the high-temperature tests. Slopes from regression analyses of datasets in Figure M.3 range from -0.015 to 0.013, compared to a range from 0.015 to 0.054 when expressed in terms of unionized ammonia (Erickson 1985). This narrower range of slopes in terms of total ammonia nitrogen also argues for use of total ammonia, rather than unionized ammonia, because there is less uncertainty associated with the generic relationship. For datasets with just two points, Figures M.2 and M.3 also show the slopes for comparative purposes. Based on the typical uncertainty of LC_{50}s, these slopes also would not be expected to be significant, except perhaps for the Johnny darter data of Nimmo et al. (1989).

A multiple least-squares linear regression (Draper and Smith 1981) using all datasets (with a common slope for all datasets and separate intercept for each dataset) was conducted, both with and without pH adjustment. The results of these pooled analyses are plotted as dotted lines in Figures M.2 and M.3 to show that the residual errors for the common regression line compared to the individual regression lines are not large relative to the typical uncertainty of LC_{50}s. To better show the overall fit of the common regression line, the data are also plotted together in Figure M.4 by dividing each point by the regression estimate of the LC_{50} at 20°C for its dataset. This normalization is done strictly for data display purposes because it allows all of the datasets to be overlaid without changing their temperature dependence, so that the overall scatter around the common regression line can be better examined. The data show no obvious trend, with the best-fit slope explaining only 1% of the sum of squares around the means for the pH-adjusted data and 0% for the unadjusted data. The one available chronic dataset (DeGraeve et al. 1987) also shows no significant temperature effect when expressed in terms of total ammonia nitrogen (Figure M.5) and adjusted for pH differences among the tests. (These tests and the calculation of the LC20s are discussed in detail later.)

Based on the small magnitude and the variability of the effect of temperature on total ammonia acute and chronic toxicity values for fish, the 1998 Update did not include temperature as a modifying factor for a total ammonia criterion. For invertebrates, it should be noted that the 1998 Update's assumption that temperature had no effect on the toxicity of *total* ammonia differs from the 1984/1985 criteria document's assumption that temperature has no effect on the toxicity of *unionized* ammonia. This inconsistency is resolved during the 1999 re-examination of data, to be discussed shortly, by incorporating a relationship between temperature and total ammonia toxicity to invertebrates. That relationship, however, does not affect the (1999 update) CMC because invertebrates are not among the acutely sensitive taxa.

Figure M.4. The Effect of Temperature on Normalized Acute Ammonia Toxicity in Terms of Total Ammonia Nitrogen. Data were normalized by dividing measured LC_{50}s by regression estimates of LC_{50}s at 20°C for individual datasets for Figure M.2 (top plot) and Figure M.3 (bottom plot).

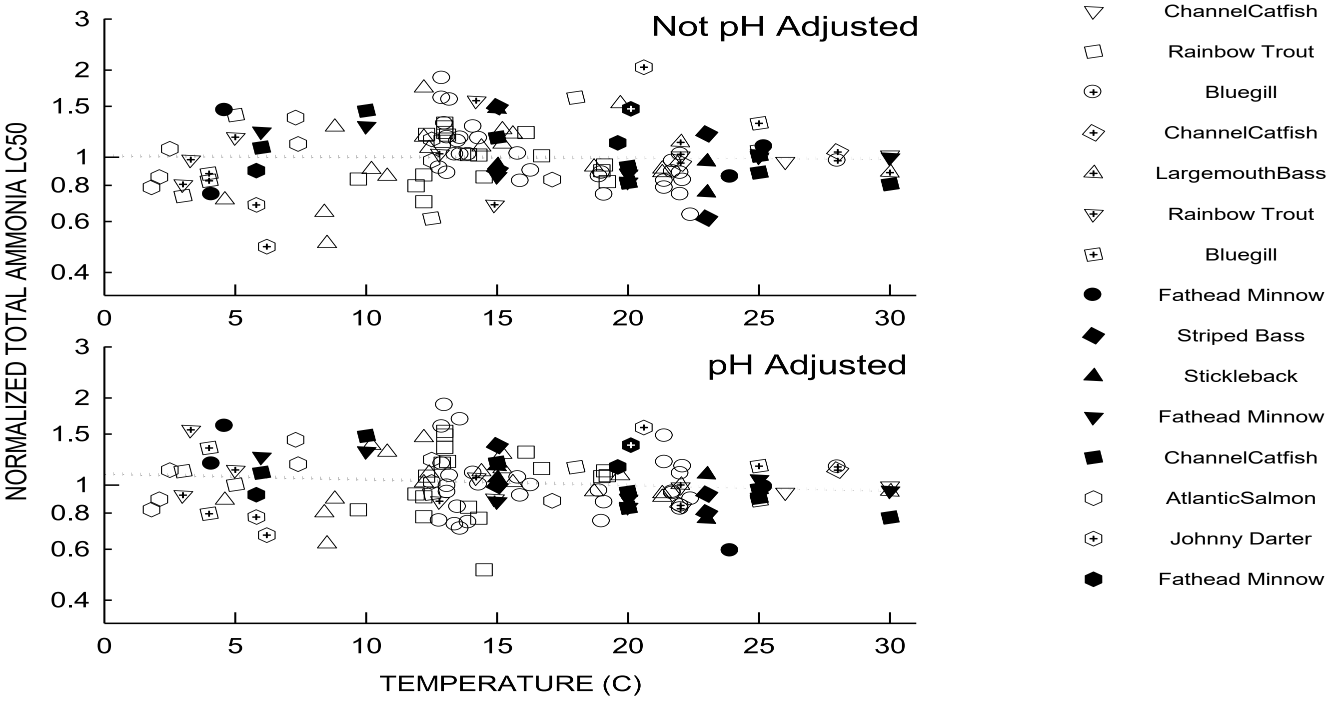
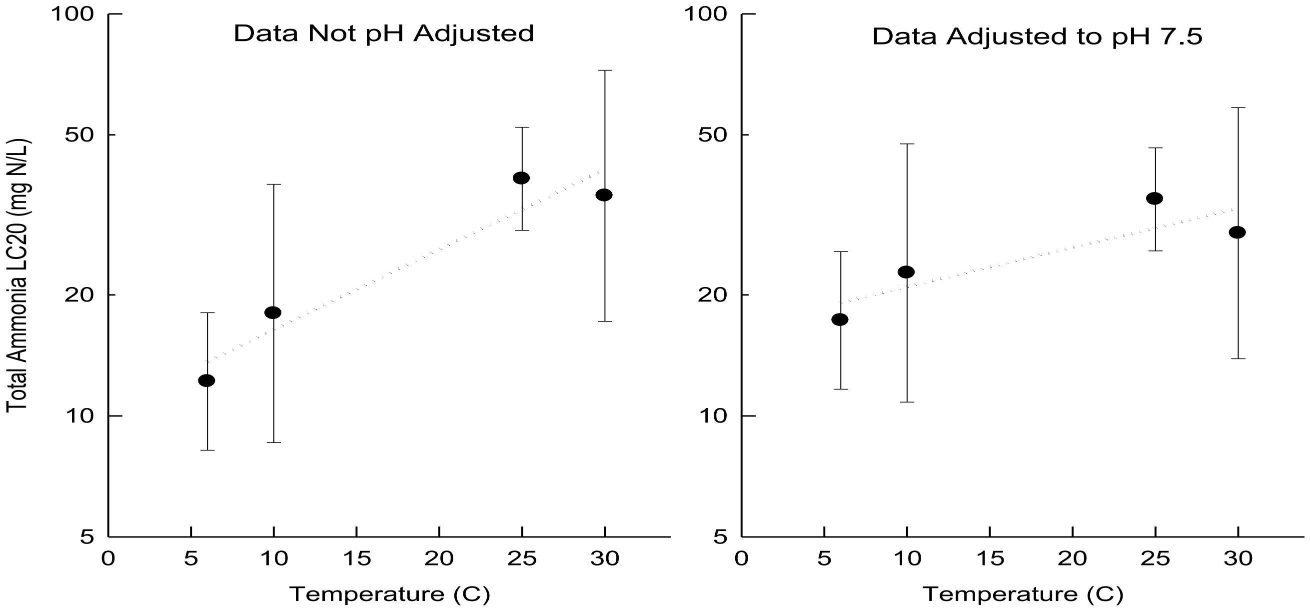


Figure M.5. The Effect of Temperature on Chronic Ammonia Lethality to Fathead Minnows in Terms of Total Ammonia Nitrogen (DeGraeve et al. 1987).
Symbols denote LC20s and 95% confidence limits and lines denote linear regressions of log LC versus temperature. Figure on left is for estimated LC_{50}s at test pH and figure on right is for LC_{50}s adjusted to pH=7.5 based on pooled relationship of chronic toxicity to pH.



The amount of uncertainty in this approach to the CMC can be demonstrated to be small by considering how the criterion would differ if total ammonia toxicity was adjusted based on the slopes in various datasets. Because the bulk of the toxicity data used in the derivation of the criterion is within a few degrees of 20°C, the temperature relationship used has very little effect on the criterion near this temperature, but rather has the greatest effect on the criterion at much higher or lower temperatures. If the average slope for the pH-adjusted acute data from Figure M.4 is used, the total ammonia CMC at 5°C would be only about 6% higher than at 20°C. The smallest and largest slopes from the acute regressions for individual species in Figure M.3 would produce a range from 40% lower to 68% higher at 5°C than at 20°C, but this greatly overstates the uncertainty because effects on a CMC derived from many datasets should not be near these extremes.

1999 Re-examination of Temperature Dependence – Acute Toxicity

The previous section, reproduced with relatively few changes from the 1998 Update, included an analysis of available data on the temperature dependence of acute ammonia toxicity to fish. These data (in Figures M.2, M.3, and M.4) consisted of 20 different data sets drawn from 11 different studies and included nine different species, four of these species being in more than one study. Data from Arthur et al. (1987) were not used in the 1998 analysis because those authors reported concerns about factors confounding temperature in their data set. Linear regression analysis of log LC_{50} (total ammonia basis) versus temperature was conducted on each data set, both with and without correcting for pH as a confounding factor. No consistent trend with temperature was observed and only one data set showed a slope different than zero at the 0.05 level of statistical significance. Therefore, a pooled linear regression analysis was conducted across all data to derive an average slope, which was very close to zero and also not statistically significant. On the basis of this analysis, the 1998 Update did not include any temperature dependence for criteria to protect fish from acute ammonia toxicity.

In response to public comment (U.S. EPA, 1999), the 1998 analysis was re-examined. This re-examination indicated that it is appropriate to handle the temperature dependencies of fish and invertebrates separately. For invertebrates, the inclusion of the Arthur et al. (1987) data in the regression analysis yields a change in the temperature dependency that is ultimately reflected in the difference between the 1999 CCC and the 1998 CCC.

In the 1998 Update, EPA did not use the Arthur et al. (1987) data because of those authors concerns that other variable factors in their tests, conducted during different seasons, might have had a potential to confound their results. In re-examining their data in response to comments, however, EPA found that most of the *fish* data from Arthur et al. showed behavior similar to that from numerous other investigators: that is, little relationship with temperature when expressed as total ammonia. Consequently, it was concluded that the other variable factors were unlikely to be confounding the results.

For fish, although the temperature dependency is unchanged from 1998, additional documentation is provided here, primarily because the apparent difference between fish acute and chronic temperature dependencies is now used in the projection of the invertebrate chronic temperature dependency.

First presented here will be more details on the regression analyses of the individual data sets conducted for the Update, plus similar analyses of the data of Arthur et al. A linear regression was conducted on each data set using the equation:

$$\log(LC50_T) = \log(LC50_{20}) + S \cdot (T - 20)$$

where $LC50_T$ is the total ammonia LC50 at temperature T, S is the slope of log LC50 versus temperature, and $LC50_{20}$ is the estimated total ammonia LC50 at 20°C. For completeness, this effort included data sets with just two points, although the regression analysis then provides a perfect fit and has no residual error, so that confidence limits, significance levels, etc. cannot be evaluated using normal methods. In such cases, the mean squared error (MSE) of data around the regression was assumed to be equal to the weighted mean residual MSE for the larger data sets, so that approximate significance levels could be determined.

Fish acute data:

Table M.1 presents the results of the regression analysis for each data set, with data adjusted to pH=8 based on the average pH relationship used in the 1998 and 1999 Updates. Plots of these relationships (except for Arthur et al. 1987) are in Figure M.3 in the previous section.

Of the 24 entries in Table M.1, nearly half (11) have very small slopes of between -0.006 and +0.006, a range which corresponds to a factor of 1.3 change or less in LC_{50} for a 20°C temperature change and is less than normal data variability. Of these 11, five have positive slopes and six have negative slopes. Of the 13 entries with steeper slopes, five have positive slopes and eight have negative slopes. Among the data sets used in the Update, only two of the regressions are statistically significant at the 0.05 level, one with a negative slope and one with a positive slope, although two other sets (for fathead minnows from DeGraeve et al. 1987 and Reinbold and Pescitelli 1982b) are close to being significant. (The level of significance for the Johnny darter data set differs from what was reported in the previous section because it consists of two different sets which were analyzed separately in the 1998 analysis, but combined here because they were not significantly different.) Of the five data sets from Arthur et al. (1987), only one is significant at the 0.05 level. For species with more than one entry, slopes vary considerably. This general lack of statistical significance and consistency precludes any reliable assessments based on these individual analyses.

The 1998 Update therefore conducted a pooled regression analysis to determine whether the combined acute toxicity data sets indicated any significant average trends with temperature. Table M.2 summarizes the mean trends determined in various pooled analyses. The first entry is the pooled analysis conducted for the 1998 Update, which included all the data in Table M.1 above except the fish data of Arthur et al. (1987). The slope from this pooled analysis was very small (-0.0023), and was not statistically significant despite the large number of data. The second entry adds the fish data of Arthur et al.; it does result in a statistically significant trend. The mean slope (-0.0058) is still small, but does amount to a 23% decrease in LC_{50} per 20°C increase in temperature. However, this slope is heavily influenced by two points with high residual ($>3\sigma$) deviations. One of these points is a test at 3.4°C by Arthur et al. (1987) with fathead minnows, which showed much greater effects of low temperature than other studies with the same species. The other point is for a test at 22.6°C by Arthur et al. (1987) with walleye, which showed very high sensitivity and was part of a set of three tests which used fish from different sources, potentially confounding the temperature effects. Without these two data, the regression has an even lower slope and is not significant at the 0.05 level (third entry in Table M.2). Overall, these analyses of the fish acute data suggest a weak overall trend of higher LC_{50}s at low temperatures, with a logLC$_{50}$ versus temperature slope in the -0.002 to -0.006 range, but of questionable statistical significance.

Table M.1. Results of Regression Analysis of logLC$_{50}$ (mg/L total ammonia nitrogen) Versus Temperature (°C) for Individual Data Sets on the Temperature Dependence of Acute Ammonia Toxicity.

Table M.1

Reference/ Species	Slope (95% CL)	logLC50$_{20}$ (95% CL)	Residual SD (r^2)	F$_{REGR}$ (α)
Thurston et al. (1983) Fathead Minnow	-0.0014 (-0.013,+0.013)	1.641 (1.582,1.700)	0.112 (<1%)	0.06 (0.81)
Thurston and Russo (1983) Rainbow Trout	+0.0059 (-0.017,+0.029)	1.350 (1.204,1.495)	0.121 (2%)	0.30 (0.59)
Cary (1976) Channel Catfish	+0.0028 (-0.008,+0.013)	1.676 (1.593,1.758)	0.093 (2%)	0.32 (0.58)
Colt and Tchobanoglous (1976) Channel Catfish	+0.0004 (-0.037,+0.038)	1.604 (1.350,1.858)	0.016 (2%)	0.02 (0.91)
Ministry of Technology (1967) Rainbow Trout	+0.0008 (-0.018,+0.019)	1.231 (1.010,1.452)	0.051 (1%)	0.03 (0.88)
Roseboom and Richey (1977) Bluegill Sunfish	+0.024 (-0.025,+0.073)	1.089 (0.803,1.375)	-	0.95 (0.33)
Roseboom and Richey (1977) Channel Catfish	+0.020 (-0.029,+0.069)	1.482 (1.196,1.768)	-	0.68 (0.41)
Roseboom and Richey (1977) Largemouth Bass	-0.0029 (-0.040,+0.034)	1.237 (0.972,1.502)	-	0.02 (0.88)
Reinbold and Pescitelli (1982b) Rainbow Trout	-0.0088 (-0.028,+0.010)	1.396 (1.159,1.632)	0.088 (29%)	1.63 (0.27)
Reinbold and Pescitelli (1982b) Bluegill Sunfish	-0.0004 (-0.027,+0.026)	1.370 (1.059,1.681)	0.128 (0%)	0.00 (0.96)
Reinbold and Pescitelli (1982b) Fathead Minnow	-0.0153 (-0.031,+0.009)	1.429 (1.243,1.615)	0.076 (89%)	16.6 (0.06)
Hazel et al. (1971) Striped Bass	-0.0163 (-0.057,+0.025)	1.274 (1.105,1.443)	0.076 (60%)	2.93 (0.23)
Hazel et al. (1971) Three-Spined Stickleback	-0.0106 (-0.053,+0.032)	1.390 (1.214,1.567)	0.081 (36%)	1.14 (0.40)
DeGraeve et al. (1987) Fathead Minnow	-0.0052 (-0.012,+0.002)	1.617 (1.563,1.670)	0.061 (36%)	3.33 (0.12)
DeGraeve et al. (1987) Channel Catfish	-0.0088 (-0.016,-0.002)	1.648 (1.595,1.701)	0.061 (62%)	9.76 (0.02)
Knopf (1992) Atlantic Salmon	-0.0035 (-0.027,+0.020)	1.715 (1.406,2.025)	0.097 (7%)	0.22 (0.067)
Knopf (1992) Atlantic Salmon	+0.0163 (-0.075,+0.108)	1.636 (0.405,2.866)	0.054 (84%)	5.18 (0.26)
Nimmo et al. (1989) Johnny Darter	+0.021 (+0.000,+0.043)	1.463 (1.248,1.678)	0.072 (90%)	18.1 (0.05)
Nimmo et al. (1989) Fathead Minnow	+0.0070 (-0.014,+0.028)	1.568 (1.353,1.782)	-	0.42 (0.52)
Arthur et al. (1987) Fathead Minnow	-0.032 (-0.059,-0.004)	1.762 (1.493,2.030)	0.105 (92%)	24.8 (0.04)

Table M.1				
Reference/ Species	**Slope (95% CL)**	**$\log LC50_{20}$ (95% CL)**	**Residual SD (r^2)**	**F_{REGR} (α)**
Arthur et al. (1987) Rainbow Trout	-0.0100 (-0.053,+0.033)	1.348 (0.937,1.758)	0.158 (16%)	0.56 (0.51)
Arthur et al. (1987) Channel Catfish	-0.0058 (-0.038,+0.027)	1.558 (1.230,1.886)	0.030 (84%)	5.15 (0.26)
Arthur et al. (1987) White Sucker	+0.0007 (-0.23,+0.25)	1.902 (1.657,2.147)	0.048 (1%)	0.01 (0.92)
Arthur et al. (1987) Walleye	-0.038 (-0.327,+0.250)	1.216 (-1.911,4.343)	0.306 (74%)	2.84 (0.34)

Table M.2. Results of Regression Analysis of log LC_{50} (mg/L total ammonia nitrogen) Versus Temperature (°C) for Pooled Data Sets on the Temperature Dependence of Acute Ammonia Toxicity to Fish.

Data Sets Pooled	**Slope (95% CL)**	**Residual SD (r^2)**	**F_{REGR} (α)**
All Data excluding Arthur et al.	-0.0023 (-0.0057,+0.0011)	0.105 (2%)	1.79 (0.18)
All Data including Arthur et al.	-0.0058 (-0.0094,-0.0022)	0.122 (8%)	10.3 (<0.01)
All Data including Arthur et al. except "Outliers"	-0.0030 (-0.0063,+0.0002))	0.105 (3%)	3.52 (0.06)
Fathead Minnow excluding Arthur et al	-0.0063 (-0.0122,-0.0005)	0.106 (11%)	4.76 (0.04)
Fathead Minnow including Arthur et al.	-0.0105 (-0.0169,-0.0049)	0.120 (25%)	13.4 (<0.01)
Fathead Minnow including Arthur et al. excl "Outlier"	-0.0073 (-0.0129,-0.0017)	0.106 (15%)	6.85 (0.01)
Rainbow Trout excluding Arthur et al.	-0.0013 (0.0122,+0.0096)	0.109 (<1%)	0.06 (0.80)
Rainbow Trout including Arthur et al.	-0.0034 (-0.0133,+0.0064)	0.115 (2%)	0.51 (0.48)
Channel Catfish excluding Arthur et al.	-0.0030 (-0.0091,+0.0031)	0.088 (4%)	1.05 (0.32)
Channel Catfish including Arthur et al.	-0.0034 (-0.088,+0.021)	0.085 (6%)	1.64 0.21)
Bluegill Sunfish	+0.0006 (-0.0172,+0.0184)	0.120 (<1%)	0.01 (0.92)

It is also useful to consider separately the overall trends for different fish species. Table M.1 includes multiple studies with fathead minnows, rainbow trout, channel catfish, and bluegill sunfish. Table M.2 includes the results of pooled analyses for each of these species, both with and without data from Arthur et al. (1987). For rainbow trout, bluegill, and channel catfish, the regressions were not statistically significant. The bluegill data indicated virtually no temperature effect, whereas weak trends similar to the pooled analyses over all data sets were suggested in the channel catfish data (slope = -0.0030 without and -0.0034 with Arthur et al. data) and rainbow trout data (slope = -0.0014 without and -0.0034 with Arthur et al. data). For fathead minnow, the pooled analyses were statistically significant and stronger, with slopes ranging from -0.0063 to -0.0105 depending on the treatment of data from Arthur et al. Such slopes for fathead minnow would result in moderate effects over a broad temperature range: a 20°C decrease in temperature would result in a 33% to 62% increase in LC_{50}. However, this species is not sensitive enough that this would affect the acute criterion values. For the species used in the acute criterion calculations, no temperature correction for acute toxicity is appropriate due to the lack of any significant trend over all data sets.

Invertebrate acute data:

Unlike fish, available acute toxicity data for invertebrates indicates that their acute sensitivity to ammonia decreases substantially with decreasing temperature. The 1998 Update noted this temperature dependence, but did not present any analysis of it because tested invertebrates were sufficiently tolerant to acute ammonia exposures that this dependence would not affect the acute ammonia criterion. The 1998 Update also noted that this temperature dependence should be a consideration in setting low temperature chronic criterion, but did not provide any specific analysis regarding this. This section will provide an analysis of available information on the temperature-dependence of invertebrate *acute* ammonia toxicity, to be used later for estimating the temperature-dependence of *chronic* ammonia toxicity.

Arthur et al. (1987) provide the only available data on the temperature dependence of acute ammonia toxicity to invertebrates. As noted earlier, these toxicity tests did not specifically test temperature effects, but rather were seasonal tests in which various chemical characteristics of the tests water varied as well as temperature. Test organisms were whatever were available in outdoor experimental streams at the time of the test, so the size, life stage, and condition of the organisms also varied. The authors of this study expressed some doubt as to how much of the effects they observed were actually due to temperature. However, for invertebrates, they did observe strong correlations of total ammonia toxicity with temperature. Confounding factors might contribute somewhat to this correlation, but temperature is still likely the primary underlying cause. If other factors were largely responsible for the apparent effects of temperature, it would be expected that strong correlations with temperature would also be evident in their fish data. However, as discussed above, the fish data usually showed much weaker effects of temperature, similar to other studies with fewer confounding factors.

These invertebrate acute data were analyzed using the same regression model and techniques as discussed above for fish. The study of Arthur et al. (1987) included data sets for nine invertebrate species, but two of these sets were not included in the analysis because they consisted of two tests at temperatures only 3°C apart. For the other species, the number of tests ranged from 2 to 6, with temperature ranges of from 9°C to 21°C. Table M.1 summarizes the regression results for the data sets of each species and for pooled analyses conducted on (a) all seven species, and (b) three species that had more than two tests and a temperature range of at least 15°C. All data were corrected to pH 8 based on the average acute pH relationship (described later). All species show substantially greater tolerance to ammonia at lower temperatures, and in most cases the significance level of the regression is better than 0.05. (As for the analysis of the fish data, when there were just two tests for a species, the significance level for the individual analysis is based on the MSE from the pooled analysis.) The slope of log LC_{50} versus temperature does not vary widely, ranging from -0.028 to -0.046 and being -0.036 for both pooled analyses. Figure M.6 provides plots of this data and the regression lines comparable to those for fish previously shown in Figures M.3 and M.4.

Again, because invertebrates are not among the species acutely sensitive to ammonia (in the 1999 update), the invertebrate acute temperature slope does not affect the formulation of the acute criterion. It will be used subsequently, however, in formulating the invertebrate *chronic* temperature slope, which ultimately will affect the formulation of the chronic criterion.

1999 Re-examination of Temperature Dependence – Chronic Toxicity

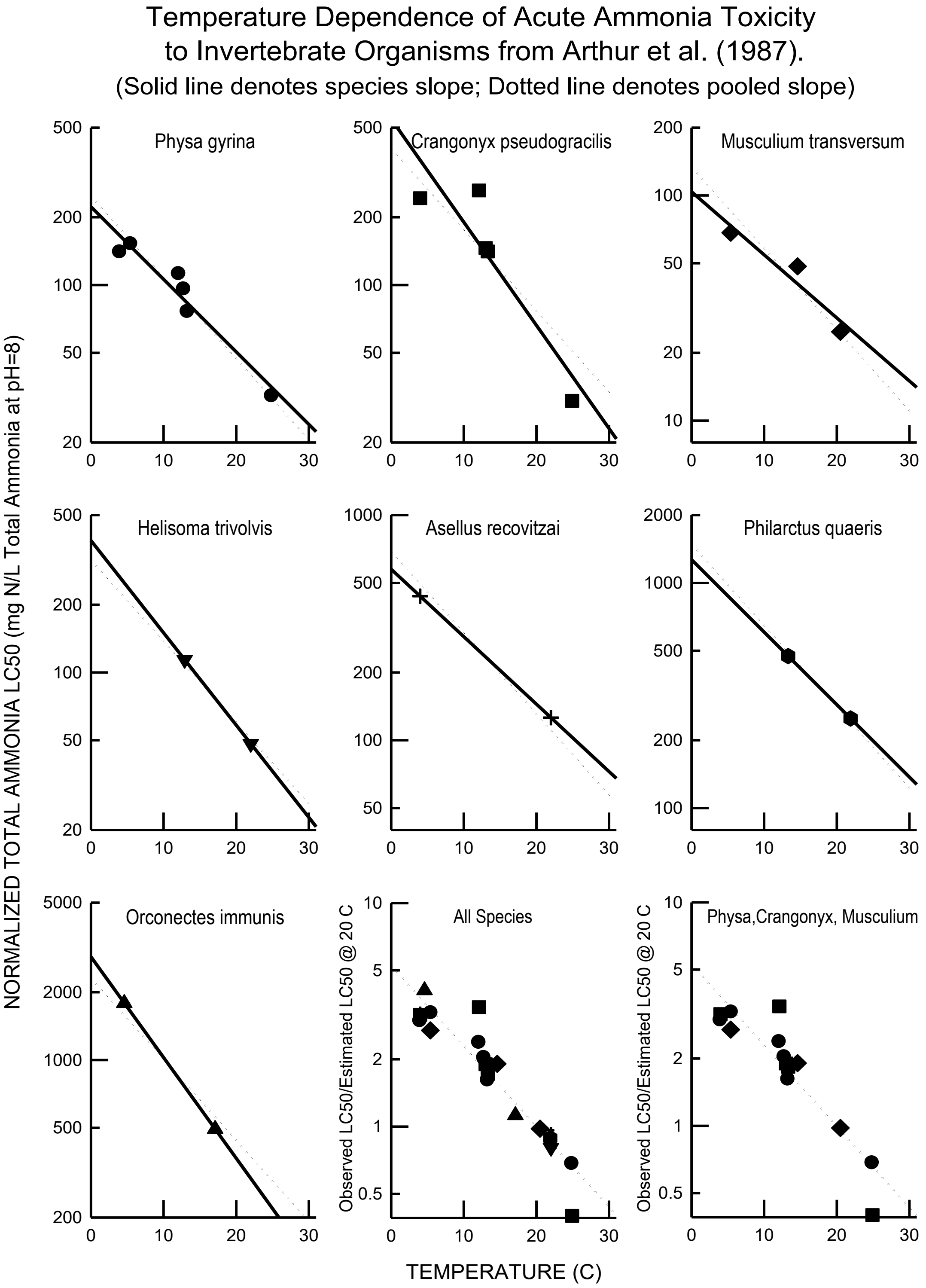
Fish chronic data

As in the 1998 Update, the only available data on the temperature dependence of chronic ammonia toxicity are from the study by DeGraeve et al. (1987) on survival of juvenile fathead minnows during 30-day exposures to ammonia at temperatures ranging from 6°C to 30°C. In contrast to acute toxicity, which for fathead minnows showed sensitivity to be slightly *reduced* at low temperatures, this data on chronic toxicity suggested *greater* sensitivity at low temperatures. However, this trend was small, at least once the confounding effect of pH was corrected for, and not statistically significant. Based on this analysis, the 1998 Update treated effect concentrations for chronic ammonia toxicity to fish as it did for acute toxicity: as being invariant with temperature. However, the 1998 Update also noted that, if seasonal variations in temperature cause a shift in what endpoints the criterion should be based on, the chronic criterion could have a seasonal temperature dependence even if effect concentrations for specific chronic endpoints do not vary with temperature (This is discussed in the 1999 AQWC document under the section named Seasonality of Chronic Toxicity Endpoints).

This section will provide more details regarding the analysis of the chronic toxicity data from DeGraeve et al. (1987), and a comparison of its temperature dependence to that of acute toxicity in the same study. Figure M.5 showed the temperature dependence of acute and chronic effect concentrations from this study.

An important issue in this analysis is the confounding effect of pH on the apparent effect of temperature, because pH increased with decreasing temperature in these chronic exposures. To examine what the effect of temperature is, the effect concentrations should be adjusted to a common pH using an equation that accounts for the effect of pH. A critical question then is what pH equation to use, because no study exists for the effect of pH on this particular chronic endpoint (juvenile 30-day survival), or on the interaction of pH and temperature effects. The 1998 Update used the pH relationship derived for the chronic criterion. Of the pH relationships available, that one is probably most appropriate, but entails some uncertainty. To evaluate how conclusions about temperature effects will vary if the true pH relationship is different, this analysis will also use the pH relationship for acute toxicity to fathead minnows from Thurston et al. (1983). This relationship likely represents an extreme possibility; i.e., it assumes that chronic toxicity pH relationships are the same acute ones, contrary to what is indicated by available chronic studies.

Figure M.6. Temperature Dependence of Acute Ammonia Toxicity to Invertebrate Organisms from Arthur et al. (1987).



Using the pooled chronic pH relationship (presented later in this document), slope=0.010, significance=0.13, and r^2=0.76. Using the fathead minnow acute pH relationship, slope=0.0053, significance=0.32, and r^2=0.45. In neither case is the regression statistically significant at the 5 percent level, due to the amount and variability of the data. Nevertheless, it should be noted that, in both cases, the chronic data show an upward trend with temperature, in contrast to that observed for acute toxicity. Even under the extreme assumption that these data have a pH relationship similar to acute toxicity, the slope is 0.005, and is twice this under the assumption that these data follow the chronic pH relationship. Thus, even if fathead minnows show increased *acute* tolerance to ammonia at low temperatures, a similar assumption for *chronic* toxicity is contraindicated.

The difference between acute and chronic temperature relationships can be better assessed by looking at acute-chronic ratios. Figure M.7 shows the temperature dependence of the ratio of the acute LC_{50} to the chronic LC_{20}. The chronic LC_{20}s used for the ACRs were normalized via the above two alternative pH relationships, while the acute LC_{50}s were normalized only using the acute pH relationship. The results show that for either pH normalization alternative, the ACRs are substantially higher at lower temperatures than at higher temperatures. If the chronic data are pH-normalized using the chronic pH relationship, the regression is significant at the 0.05 level, with a slope of -0.0155. If normalized using the acute pH relationship, the slope is less (-0.0110), but even with this extreme assumption, there is only a 13 percent probability that the regression slope arose by chance.

It is not surprising that acute-chronic ratios are higher at low temperature. Temperature can affect toxicity in a variety of ways, one of which is simply to slow down responses. This is evident in some reports on the effect of temperature on ammonia toxicity. For example, for the rainbow trout data from Ministry of Technology (1967), there was little effect of temperature on total ammonia LC_{50}s at 96 hours, but at shorter durations LC_{50}s increased with decreasing temperature. The overall impact on the temperature dependence of LC_{50}s and ACRs will depend on the duration of the acute toxicity test and on the speed of action of acute ammonia toxicity in the species of concern. However, temperature is likely to affect ammonia toxicity in multiple ways, some of which would alter acute and chronic toxicity similarly. Nonetheless, to some degree the ratio of effect concentrations at different durations is expected to increase at lower

Figure 1. Temperature Dependence of Acute Ammonia Toxicity to Invertebrate Organisms from Arthur et al. (1987)

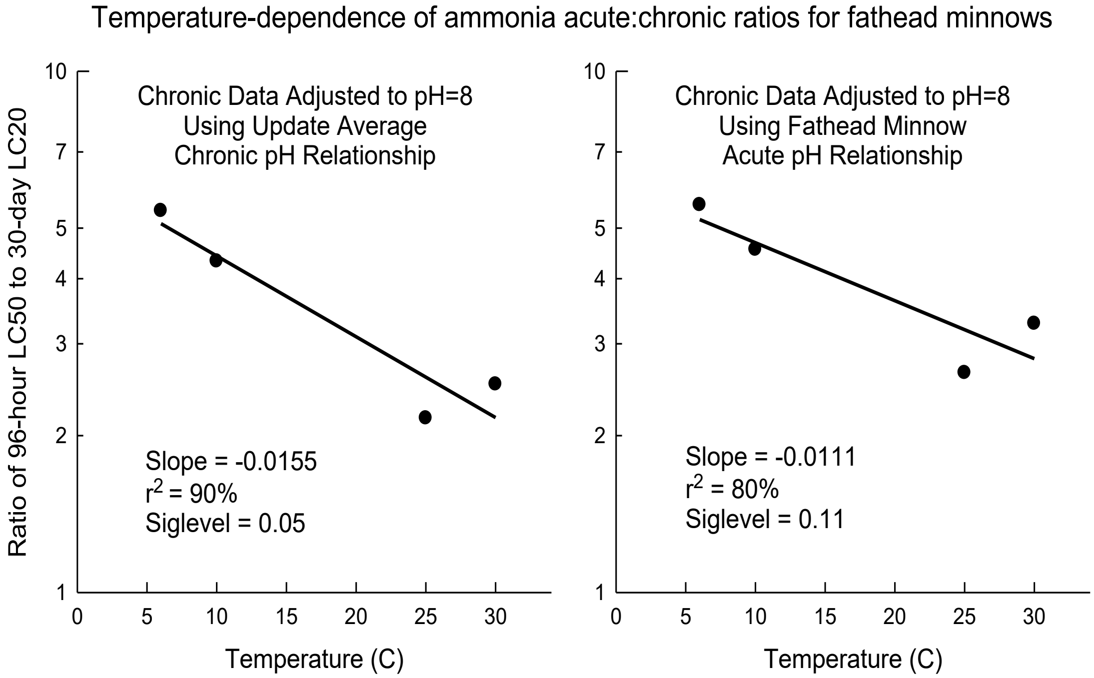
(Solid line denotes species slope; Dotted line denotes pooled slope)

Figure 1. Temperature Dependence of Acute Ammonia Toxicity to Invertebrate Organisms from Arthur et al. (1987)

(Solid line denotes species slope; Dotted line denotes pooled slope)

temperatures. This expectation, as well as empirical evidence, argues against the direct application of acute temperature relationships to chronic toxicity.

Figure M.7. Temperature-Dependence of Ammonia ACRs for Fathead Minnows.
(The choice of reference condition, pH=8 here versus pH=7.5 in Figure M.5, has no effect on slope or significance.)



Invertebrate chronic projections

No data are available on the effect of temperature on chronic ammonia toxicity to invertebrates. Because invertebrates are much more acutely tolerant at low temperatures than at high temperatures, it is likely that their chronic toxicity would also show some temperature dependence. However, as discussed above, there is reason to expect acute and chronic toxicity to vary somewhat differently with temperature, with acute-chronic ratios increasing at low temperature, especially for organisms for which acute ammonia toxicity is not especially fast, which is the case for invertebrates (Thurston et al. 1984b). The observed trend in the fathead minnow ACRs provides support for this expectation.

The critical question then becomes, how much of the acute temperature slope for invertebrates should be assumed to apply to chronic toxicity? If this slope is predominantly due to temperature-induced delays of acute toxicity, chronic toxicity might have very little slope. If this slope is not at all due to such delays, then all the slope should be applied to chronic toxicity.

One option for an objective mathematical prediction of the invertebrate chronic slope is to assume that the difference between acute and chronic slopes will be the same for fish and invertebrates, potentially implying that the effect of temperature on the kinetics of toxicity is roughly the same for fish and invertebrates. In this case the invertebrate chronic slope would be the difference between -0.036, the average invertebrate acute slope, and -0.016, the observed slope for fish acute-chronic ratios. This would yield an invertebrate chronic slope of -0.020. This correction still applies most of the acute slope to chronic toxicity, but recognizes that the chronic slope should probably be less steep.

It is recognized that few data are available to define the Figure M.7 fish ACR slope, and that the assumption the invertebrate ACR slope would equal the fish ACR slope is quite uncertain despite having some theoretical underpinning in the kinetics of toxicity. Consequently a second option is to equate the invertebrate chronic slope to the invertebrate acute slope (-0.036) minus one-half the fish ACR slope (-0.016/2). This splits the difference between no correction and full correction for the fish ACR slope, resulting in an invertebrate chronic slope of -0.028.

A third, related option is suggested from the appearance of data in the last two plots in Figure M.6, plots of “All Species” and “Physa, Crangonyx, Musculium”. These plots suggest a steeper invertebrate acute slope at higher temperatures than at very low temperature. At greater than 10°C, these data also comfortably fit a slope of -0.044. If such a slope were used to fit those data, however, a concentration plateau would need to be imposed between 5 and 10°C to avoid over-estimating the acute effect concentrations measured near 5°C. If the invertebrate chronic slope is obtained by subtracting the full value of the fish ACR slope (-0.016), this would yield the same invertebrate chronic slope, -0.028, as the option in the previous paragraph. In this case, however, concentrations would be capped between 5 and 10°C in order to reflect the implied attenuation of slope at low temperature relative to higher temperatures.

EPA selected this third option, a compromise between the first two options, for defining the invertebrate chronic temperature slope in formulating the CCC, discussed later. This provides a good fit to the available information.

Appendix N. Site-Specific Criteria for Ammonia.

Recalculation Procedure for Site-specific Criteria Derivation

The water quality standards (WQS) regulation at 40 CFR § 131.11(b)(1)(ii) provides states with the opportunity to adopt water quality criteria that are "…modified to reflect site-specific conditions." As with any criteria, site-specific criteria must be based on a sound scientific rationale in order to protect the designated use and are subject to review and approval or disapproval by EPA.

The recalculation procedure for site-specific criteria derivation is intended to allow site-specific criteria that differ from national criteria recommendations (i.e., concentrations that are higher or lower than national recommendations) where there are demonstrated differences in sensitivity between the aquatic species that occur at the site and those that were used to derive the national criteria recommendations. The national dataset may contain aquatic species that are sensitive to a particular pollutant, but these or comparably sensitive species might not occur at the site (e.g., freshwater mussels are included in the national ammonia dataset but may not be present at a particular site). On the other hand, a species that is critical at the site might be sensitive to the pollutant and require site-specific criteria that are lower than the national recommended criteria.

In the case of ammonia, where a state demonstrates that mussels are not present on a site-specific basis, the recalculation procedure may be used to remove the mussel species from the national criteria dataset to better represent the species present at the site. For example, many of the commonly occurring freshwater bivalves (e.g., pea clam) are more closely related to the non-unionid fingernail clam *Musculium* (which is the fourth most sensitive genus in the national dataset for the chronic criterion) than to the unionid mussels *Lampsilis* and *Villosa* (which are the two most sensitive genera in the national dataset for the chronic criterion). At sites where all bivalves present are more closely related to *Musculium* than to *Lampsilis* and *Villosa* (i.e., where unionid mussels are not present at the site), the recalculation procedure may be used to remove *Lampsilis* and *Villosa* from the dataset because they would not be representative of the species present at the site. With removal of *Lampsilis* and *Villosa* from the national dataset, the recalculation procedure could result in criteria (and associated water quality-based effluent limits (WQBELs) based on such criteria) with higher concentrations than EPA's recommendations but that are still protective of the designated use. The retention of *Musculium* in the dataset would represent the other non-unionid bivalves present at the site, so the non-unionid bivalves would still be protected if *Lampsilis* and *Villosa* were removed from the chronic dataset. However, at sites where both unionid and non-unionid bivalves are present, all three bivalves in the national chronic dataset (i.e., *Lampsilis*, *Villosa*, and *Musculium*) would be retained because they would represent the species present at the site. The recalculation procedure describes how to compare the taxonomy of species present at the site with the taxonomy of species in the national dataset.

The number of tested genera (N) in the criteria calculations must be updated where genera such as *Lampsilis* and *Villosa* are removed from the dataset. For example, if only the two unionid mussels are removed from the dataset for the national chronic ammonia criterion, N would be reduced from 16 genera in the national dataset to 14 genera in the site-specific dataset, and this would affect the site-specific criteria values.

Freshwater snails represent another sensitive freshwater species group for which acute and chronic toxicity data exist and are used in criteria derivation. Because freshwater snails tend to be more ubiquitous in the environment, however, the existing data for these animals are not likely to be deleted from the datasets in a criteria recalculation.

As with any criteria, states choosing to utilize the recalculation procedure should ensure that their site-specific criteria "…provide for the attainment and maintenance of the water quality standards of downstream waters." 40 CFR § 131.10(b). In addition, states should consider how they will demonstrate that mussels are not present at the site before selecting this approach. For additional information on the recalculation procedure, see EPA's *Water Quality Standards Handbook* at http://www.epa.gov/wqshandbook.

Acute Criterion Magnitude Recalculation for Ammonia

Unionid Mussels Present and Oncorhynchus species Absent

Where *Oncorhynchus* species are absent, EPA does not lower its acute criteria for ammonia below the 5th percentile in order to protect the commercially and recreationally important adult rainbow trout, but instead, retains all tested species in the Order Salmoniformes as tested surrogate species representing untested freshwater fish resident in the U.S. from another Order. The lowest GMAV for a freshwater fish (vertebrate species) is 51.93 mg TAN/L for *Prosopium* (Table 3). Therefore, in this case, the CMC equals the lower of: a) 0.7249 times the temperature adjusted lowest invertebrate GMAV (e.g., 17 mg TAN/L at pH 7.0 and 20º C), or (b) 0.7249 times the lowest freshwater fish GMAV (e.g., 38 mg TAN/L at pH 7.0), according to the following temperature relationship:

$$CMC = 0.7249 \times MIN\left(51.93, 23.12 \times 10^{0.036\times(20-T)}\right)$$

Thus, the CMC increases with decreasing temperature as a result of increased invertebrate insensitivity until it reaches a plateau of 37.65 mg TAN/L at 10.2°C and below (51.93 mg TAN/L x 0.7249), where the most sensitive taxa switches to the temperature invariant fish genus *Prosopium* (Tables 5b and N.1; see also *Oncorhynchus* absent line in Figure 5a). Note: while the mountain whitefish (*Prosopium williamsoni*) is a species in the same family as *Oncorhynchus* sp. (i.e., Family: Salmonidae), it is also an appropriately sensitive surrogate species amongst all freshwater fish in the Class Actinopterygii.

The CMC where *Oncorhynchus* sp. are absent extrapolated across both temperature and pH is as follows:

$$CMC = 0.7249 \times \left(\frac{0.0114}{1+10^{7.204-pH}} + \frac{1.6181}{1+10^{pH-7.204}}\right) \times MIN\left(51.93, 23.12 \times 10^{0.036\times(20-T)}\right)$$

When a threatened or endangered species occurs at a site and sufficient data indicate that it is sensitive at 1-hour average concentrations below the CMC, it is appropriate to consider deriving a site-specific criterion. It should be noted that the dataset used to derive these new ammonia criteria included some threatened or endangered species, none of which were the most sensitive of the species tested. Extrapolated values across a range of temperatures and pH values are presented in Table N.1.

Unionid Mussels Absent and Oncorhynchus spp. Present

If a state can demonstrate that unionid mussels are not present at a site, a site-specific criteria can be calculated for waters with mussels absent. It is important to recognize that for site-specific criteria derived where unionid mussels are absent, the commercially and recreationally important adult rainbow trout (*Oncorhynchus mykiss*) is the most acutely sensitive species. Thus, when *Oncorhynchus* spp. are present, the acute criterion cannot exceed 24 mg TAN/L (the SMAV for adult rainbow trout 48.21 mg TAN/L divided by two – see also *Acute Criterion Calculation* section in this document).

At pH 7, the temperature relationship is expressed as follows:

$$CMC = MIN\left(24.10, \left(45.05 \times 10^{0.036 \times (20-T)}\right)\right)$$

Where 24.10 mg TAN/L is one half the SMAV of 48.21 mg TAN/L for adult rainbow trout, and 45.05 is 0.7249 (the CMC divided by the lowest GMAV in the complete acute dataset) multiplied by 62.15 mg TAN/L, the GMAV of the temperature dependent pebblesnail (*Fluminicola* sp.), the most sensitive non-mussel invertebrate (Table N.2).

At temperatures 0 - 27.5°C, the CMC with mussels absent and *Oncorhynchus* spp. present is 24.10 mg TAN/L, because adult rainbow trout remain the most sensitive species group in this temperature range. At temperatures greater than 27.5°C, however, the GMAV for *Fluminicola* species (62.15 mg TAN/L) becomes the most sensitive GMAV because invertebrates are increasingly more acutely-sensitive to ammonia as temperature increases, and thus, the CMC equals that of the mussels absent, *Oncorhynchus* sp. absent temperature relationship (Figure N.1). Consistent with the approach followed with the unionid mussels present, *Oncorhynchus* species absent CMC calculation in the *Acute Criterion Calculations* section of this document, the site-specific criteria should 1) retains all tested species in the Order Salmoniformes as tested surrogate species representing untested freshwater fish resident in the U.S. from another Order; and 2) maintains the SSD relationship from the complete acute dataset (i.e., CMC is equal to the lowest GMAV times 0.7249).

The CMC, where mussels are absent and *Oncorhynchus* spp. are present, extrapolated across both temperature and pH is as follows (extrapolated values provided Table N.3):

$$CMC = MIN\left(\left(\frac{0.275}{1+10^{7.204-pH}} + \frac{39}{1+10^{pH-7.204}}\right), \left(0.7249 \times \left(\frac{0.0114}{1+10^{7.204-pH}} + \frac{1.6181}{1+10^{pH-7.204}}\right) \times 62.15 \times 10^{0.036 \times (20-T)}\right)\right)$$

Unionid Mussels Absent and Oncorhynchus spp. Absent

If both unionid mussels and *Oncorhynchus spp.* are absent, the CMC calculated using the Guidelines algorithm is 30.25 mg TAN/L at pH 7 and 20°C and is based on the four most sensitive GMAVs in the following rank order: mountain whitefish, Lost River sucker, pebblesnail, and golden shiner (see Table N.2). The ratio of the mussels absent and *Oncorhynchus* spp. absent CMC to the most sensitive GMAV (i.e., mountain whitefish; *Prosopium* sp.) is 0.5825, or 30.25 mg TAN/L divided by 51.93 mg TAN/L. However, this would result in a more protective criterion than when *Oncorhynchus* spp. are absent but mussels are present (see *Acute Criterion Calculations*). Because the unionid mussels absent and *Oncorhynchus* spp. absent CMC cannot be more protective than the unionid mussels present and *Oncorhynchus* spp. absent CMC, the CMC to lowest GMAV ratio of 0.7249 from the complete acute dataset is multiplied by 51.93 mg TAN/L for *Prosopium* sp., the lowest GMAV in the unionid mussels absent dataset, resulting in a calculated CMC of 37.65 mg TAN/L at pH 7 and 20°C. This is equivalent to the maximum plateau CMC when mussels are present and *Oncorhynchus* spp. are absent at temperatures of 10.2°C and below (compare in Figures 5a and N.1).

At pH 7, the temperature relationship is expressed as follows:

$$CMC = 0.7249\ \times MIN\left(51.93, \left(62.15 \times 10^{0.036\times(20-T)}\right)\right)$$

At temperatures between 0-22.1°C the CMC with unionid mussels and *Oncorhynchus* spp. absent is 37.65 mg TAN/L. At temperatures greater than 22.1°C, the temperature dependent pebblesnail (*Fluminicola* sp.) becomes the most sensitive GMAV, and the CMC decreases with increasing temperature (Figure N.1).

The CMC, where both unionid mussels and *Oncorhynchus* spp. are absent, extrapolated across both temperature and pH is as follows (extrapolated values provided Table N.4):

$$CMC = 0.7249\ \times \left(\frac{0.0114}{1+10^{7.204-pH}} + \frac{1.6181}{1+10^{pH-7.204}}\right) \times\ MIN\ \left(51.93, \left(62.15\ \times\ 10^{0.036\times(20-T)}\right)\right)$$

A summary of the acute criterion recalculations for all four mussel and Salmonid present and absent combinations at pH 7 and 20°C is included in Table N.5.

Chronic Criterion Magnitude Recalculation for Ammonia

Unionid Mussels Absent, Early Life Stage (ELS) Protection Necessary

When unionid mussels are present, the CCC is the same regardless of whether early life stages (ELS) of fish genera require protection. This is because unionid mussels represent the two most sensitive genera in the chronic dataset, and at pH 7, the CCC at the invertebrate temperature plateau of 7°C is 4.363 mg TAN/L, which is lower than the GMCV for *Lepomis*, the most sensitive fish genera, multiplied by the CCC to lowest GMCV ratio (or 6.920 mg TAN/L x 0.8876 = 6.142 mg TAN/L – see *Chronic Criterion Calculations* for additional details).

When unionid mussels are absent and fish ELS require protection, however, the CCC is 6.508 mg TAN/L at pH 7 and 20°C (Tables N.6, N.7). The lowest GMCV is 6.920 mg TAN/L for the temperature invariant vertebrate genus *Lepomis*, and the most sensitive invertebrate GMCV is 7.547 mg TAN/L for *Musculium* (Table N.6). The ratio of the CCC to the most sensitive GMCV (*Lepomis* sp.) when unionid mussels are absent is 0.9405, or 6.508 mg TAN/L divided by 6.920 mg TAN/L. At pH 7 and 20°C, the CCC when mussels are absent and ELS protection is required is expressed as follows:

$$CCC = 0.9405 \times MIN\left(6.920, \left(7.547 \times 10^{0.028\times(20-T)}\right)\right)$$

This function remains constant at a CCC equal to 6.508 mg TAN/L at 0-21.3°C because the most sensitive GMCV is for the temperature invariant genera *Lepomis* (Figure N.2; Table N.6). At temperatures greater than 21.3°C, the GMCV for the invertebrate *Musculium* (i.e., 7.547 mg TAN/L) becomes the most sensitive, and the CCC decreases with increasing temperature (Figure N.2).

When unionid mussels are absent and ELS protection is required, the thirty-day average concentration of ammonia nitrogen (in mg TAN/L) does not exceed, more than once every three years on the average, the CCC calculated using the following equation:

$$CCC = 0.9405 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times MIN\left(6.920, \left(7.547 \times 10^{0.028\times(20-T)}\right)\right)$$

Recalculated chronic criterion concentrations for the mussels absent, fish ELS protection necessary scenario across a range of temperatures and pH values are provided in Table N.8.

Unionid Mussels Absent, Early Life Stage (ELS) Protection Not Necessary

One approach for setting a chronic criterion for mussels absent and *fish ELS absent* is to modify the criterion for mussels absent and *fish ELS present*. The four most sensitive genera for the criterion to be modified are *Lepomis* (ELS), *Musculium*, *Fluminicola*, and *Pimephales* (ELS), which had yielded a criterion of 6.508 mg TAN/L at pH 7.0 and 20º C, or 0.9405 x the lowest GMCV (*Lepomis*). Since the *Lepomis* GMCV, 6.920 mg TAN/L, is based on ELS sensitivity, consider that with ELS absent this value would increase to its juvenile and adult GMCV of 21.3 mg TAN/L (from U.S. EPA 1999, page 75 GMCVs, translated from pH 8 to pH 7). In this case, *Musculium*, with GMCV 7.547 mg TAN/L, would now be the most sensitive genus in the dataset, such that at pH 7 and 20ºC the criterion could be calculated as 0.9405 x 7.547 = 7.098 mg TAN/L. Because *Musculium* remains the most sensitive genus throughout the full range of temperatures, the criterion follows the invertebrate temperature relationship, increasing with decreasing temperature until it reaches its maximum at the built-in 7ºC plateau, which is 16.41 mg TAN/L at pH 7, fully protective of the lowest juvenile-adult fish GMCV, that for *Lepomis*, 21.3 mg TAN/L shown above.

Mussels absent ELS protection not required at pH 7

$$CCC = 0.9405 \times \left(7.547 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

Overall

$$CCC = 0.9405 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times \left(7.547 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

Recalculated chronic criterion concentrations for the mussels absent, fish ELS protection not required scenario across a range of temperatures and pH values are provided in Table N.9. A summary of the chronic criterion recalculations for all four mussel and fish ELS present and absent combinations at pH 7 and 20°C is included in Table N.7.

Table N.1. Temperature and pH-Dependent Values of the CMC (Acute Criterion Magnitude) – Unionid Mussels Present, *Oncorhynchus* Absent.

	Temperature (°C)																				
pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	**17**	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	3.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7.0	6.4	5.9	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	6.0	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.3	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2.0	1.8	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.74	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

Table N.2. Acute Data Without Mussels: Comparison of the Four Taxa Used to Calculate the FAV and CMC in the 1999 AWQC and this Updated 2013 AWQC Excluding Data for Freshwater Unionid Mussels.

1999 Draft Update Acute Criterion (CMC) Magnitude (Salmonids [*Oncorhynchus* spp.] present)			**2013 Final Acute Criterion (CMC) Magnitude excluding Mussels (Salmonids [*Oncorhynchus* spp.] absent)**	
Species	**GMAV pH 8.0, T=25°C (mg TAN/L)**	**GMAV pH 7.0, T=20°C (mg TAN/L)**	**Species**	**GMAV pH 7.0, T=20°C (mg TAN/L)**
Oncorhynchus sp. (salmonids), includes: *O. aquabonita, O. clarkii, O. gorbuscha, O. kisutch*, O. mykiss**, and *O. tshawytscha**	21.95	99.15	Golden shiner, *Notemigonus crysoleucas*	63.02
Orangethroat darter, *Etheostoma spectabile*	17.96	74.25	Pebblesnail, *Fluminicola* sp.	62.15
Golden shiner, *Notemigonus crysoleucas*	14.67	63.02	Lost River sucker, *Deltistes luxatus**	56.62
Mountain whitefish, *Prosopium williamsoni*	12.11	51.93	Mountain whitefish, *Prosopium williamsoni*	51.93
FAV	11.23	48.21	FAV	76
CMC	5.6	**24**	**CMC**	**38****

*Federally-listed as endangered or threatened species

**CMC Excluding mussels, with Oncorhynchus present is 24 mg TAN/L to protect the recreationally and commercially important species Rainbow Trout. When Oncorhynchus is absent, the CMC is based on the mountain whitefish and is calculated by the ratio of the CMC to the lowest GMAV in the complete acute dataset (0.7249) times the lowest GMAV in the dataset excluding mussels (51.93 mg TAN/L for mountain whitefish) which results in a CMC of 37.65 mg TAN/L at pH 7 and 20°C.

Table N.3. Temperature and pH-Dependent Values of the CMC (Acute Criterion Magnitude) – Unionid Mussels Absent and *Oncorhynchus* Present.

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	33	33	33	33	33	33	33	33	33	33	33	33	31	29	27
6.6	31	31	31	31	31	31	31	31	31	31	31	31	31	31	30	28	26
6.7	30	30	30	30	30	30	30	30	30	30	30	30	30	30	29	26	24
6.8	28	28	28	28	28	28	28	28	28	28	28	28	28	28	27	25	23
6.9	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25	23	21
7.0	24	24	24	24	24	24	**24**	24	24	24	24	24	24	24	23	21	20
7.1	22	22	22	22	22	22	22	22	22	22	22	22	22	22	21	19	18
7.2	20	20	20	20	20	20	20	20	20	20	20	20	20	20	19	17	16
7.3	18	18	18	18	18	18	18	18	18	18	18	18	18	18	17	16	14
7.4	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	14	13
7.5	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	12	11
7.6	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	10	9.3
7.7	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.3	8.6	7.9
7.8	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	7.8	7.2	6.6
7.9	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.5	6.0	5.5
8.0	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.4	5.0	4.6
8.1	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.5	4.1	3.8
8.2	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.7	3.4	3.1
8.3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.0	2.8	2.6
8.4	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.3	2.1
8.5	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	1.9	1.8
8.6	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.6	1.4
8.7	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.2
8.8	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.0
8.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.92	0.85
9.0	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.85	0.78	0.72

Table N.4. Temperature and pH-Dependent Values of the CMC (Acute Criterion Magnitude) – Unionid Mussels Absent and *Oncorhynchus* Absent.

	Temperature (°C)																
pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	51	51	51	51	51	51	51	51	48	44	40	37	34	31	29	27
6.6	49	49	49	49	49	49	49	49	49	46	42	39	36	33	30	28	26
6.7	46	46	46	46	46	46	46	46	46	43	40	37	34	31	29	26	24
6.8	44	44	44	44	44	44	44	44	44	41	38	35	32	29	27	25	23
6.9	41	41	41	41	41	41	41	41	41	38	35	32	30	27	25	23	21
7.0	38	38	38	38	38	38	**<u>38</u>**	38	38	35	32	30	27	25	23	21	20
7.1	34	34	34	34	34	34	34	34	34	32	29	27	25	23	21	19	18
7.2	31	31	31	31	31	31	31	31	31	29	26	24	22	21	19	17	16
7.3	27	27	27	27	27	27	27	27	27	26	23	22	20	18	17	16	14
7.4	24	24	24	24	24	24	24	24	24	22	21	19	17	16	15	14	13
7.5	21	21	21	21	21	21	21	21	21	19	18	16	15	14	13	12	11
7.6	18	18	18	18	18	18	18	18	18	17	15	14	13	12	11	10	9.3
7.7	15	15	15	15	15	15	15	15	15	14	13	12	11	10	9.3	8.6	7.9
7.8	13	13	13	13	13	13	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6
7.9	11	11	11	11	11	11	11	11	11	9.9	9.1	8.4	7.7	7.1	6.5	6.0	5.5
8.0	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.2	7.5	6.9	6.4	5.9	5.4	5.0	4.6
8.1	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	6.8	6.2	5.7	5.3	4.9	4.5	4.1	3.8
8.2	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.6	5.1	4.7	4.4	4.0	3.7	3.4	3.1
8.3	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6
8.4	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	3.8	3.4	3.2	3.0	2.7	2.5	2.3	2.1
8.5	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.1	2.9	2.6	2.4	2.2	2.1	1.9	1.8
8.6	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4
8.7	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.2
8.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0
8.9	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.92	0.85
9.0	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.2	1.1	1.0	0.93	0.85	0.78	0.72

Table N.5. 2013 Acute Criterion Recalculations for Site-specific Criteria.

Acute Criterion Duration (1 hr average) at pH 7 and 20°C (mg TAN/L)	**Acute Criterion Magnitude (CMC) Oncorhynchus spp. (Rainbow Trout) Present**	**Acute Criterion Magnitude (CMC) Oncorhynchus spp. (Rainbow Trout) Absent**
Mussels Present	17	17
Mussels Absent	24	38
Frequency: Criteria values not to be exceeded more than once in three years.		

Table N.6. Chronic Dataset Without Mussels: Comparison of the Four Taxa used to Calculate the CCC in the 1999 AWQC and this Updated 2013 AWQC Excluding Data for Freshwater Unionid Mussels.

1999 Draft Update Chronic Criterion (CCC) Magnitude			**2013 Final Chronic Criterion (CCC) Magnitude excluding mussels**	
Species	**GMCV pH 8.0, T=25°C (mg TAN/L)**	**GMCV pH 7.0, T=20°C (mg TAN/L)**	**Species**	**GMCV pH 7.0, T=20°C (mg TAN/L)**
Fathead minnow, *Pimephales promelas*	3.09	7.503	Fathead minnow, *Pimephales promelas*	9.187
Lepomis sp. (Centrarchidae), includes: Bluegill sunfish, *L. macrochirus*, and Green sunfish, *L. cyanellus*	2.85	6.92	Pebblesnail, *Fluminicola* sp.	7.828
Long fingernailclam, *Musculium transversum*	<2.26	7.547	Long fingernailclam, *Musculium transversum*	7.547
Amphipod, *Hyalella azteca*	<1.45	4.865	*Lepomis* sp. (Centrarchidae), includes: Bluegill, *L. macrochirus* and Green sunfish, *L. cyanellus*	6.920
CCC	1.2	**4.5***	**CCC**	**6.5**

*Based on data renormalized to pH 7.0 and T 20°C

NMED Exhibit 61

Table N.7. Chronic Criterion Recalculations for Site-Specific Criteria.

Chronic Criterion Duration (30-day average) at pH 7 and 20°C (mg TAN/L)	**Chronic Criterion Magnitude (CCC) Fish ELS Present**	**Chronic Criterion Magnitude (CCC) Fish ELS Absent**
Mussels Present	1.9	1.9
Mussels Absent	6.5	7.1
Not to exceed 2.5 times the CCC as a 4-day average within the 30-day averaging period.		
Frequency: Criteria values not to be exceeded more than once in three years.		

Table N.8. Temperature and pH-Dependent Values of the CCC (Chronic Criterion Magnitude) – Mussels Absent and Early Life Stage (ELS) Protection Necessary.

Temperature (°C)

pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.0	6.6	6.2	5.8	5.4	5.1	4.8	4.5	4.2
6.6	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	6.9	6.5	6.1	5.7	5.4	5.0	4.7	4.4	4.1
6.7	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	6.8	6.4	6.0	5.6	5.3	4.9	4.6	4.3	4.1
6.8	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.6	6.2	5.8	5.5	5.1	4.8	4.5	4.2	4.0
6.9	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9
7.0	6.5	6.5	6.5	6.5	6.5	6.5	6.5	**6.5**	6.2	5.8	5.5	5.1	4.8	4.5	4.2	4.0	3.7
7.1	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.0	5.6	5.3	4.9	4.6	4.3	4.1	3.8	3.6
7.2	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4
7.3	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.4	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2
7.4	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0
7.5	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8
7.6	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.2	3.9	3.7	3.5	3.2	3.0	2.9	2.7	2.5
7.7	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.3
7.8	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0
7.9	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8
8.0	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.6	2.4	2.3	2.1	2.0	1.9	1.7	1.6	1.5
8.1	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3
8.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1
8.3	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.96
8.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.2	1.1	1.1	0.99	0.93	0.87	0.81
8.5	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.0	0.95	0.89	0.83	0.78	0.73	0.69
8.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.97	0.91	0.85	0.80	0.75	0.70	0.66	0.62	0.58
8.7	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.82	0.77	0.72	0.68	0.64	0.60	0.56	0.52	0.49
8.8	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.70	0.65	0.61	0.58	0.54	0.51	0.47	0.44	0.42
8.9	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.60	0.56	0.52	0.49	0.46	0.43	0.41	0.38	0.36
9.0	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31

Table N.9. Temperature and pH-Dependent Values of the CCC (Chronic Criterion Magnitude) – Mussels Absent and Early Life Stage (ELS) Protection not Necessary.

Temperature (°C)

pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	19	17	16	15	14	13	13	12	11	10	9.7	9.1	8.5	8.0	7.5	7.0	6.6	6.2	5.8	5.4	5.1	4.8	4.5	4.2
6.6	18	17	16	15	14	13	12	12	11	10	9.6	9.0	8.4	7.9	7.4	6.9	6.5	6.1	5.7	5.4	5.0	4.7	4.4	4.1
6.7	18	17	16	15	14	13	12	11	11	10	9.4	8.8	8.3	7.7	7.3	6.8	6.4	6.0	5.6	5.3	4.9	4.6	4.3	4.1
6.8	17	16	15	14	14	13	12	11	10	9.8	9.2	8.6	8.1	7.6	7.1	6.7	6.2	5.8	5.5	5.1	4.8	4.5	4.2	4.0
6.9	17	16	15	14	13	12	12	11	10	9.5	8.9	8.4	7.8	7.4	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9
7.0	16	15	14	14	13	12	11	10	9.8	9.2	8.6	8.1	7.6	**7.1**	6.7	6.2	5.9	5.5	5.1	4.8	4.5	4.2	4.0	3.7
7.1	16	15	14	13	12	11	11	10	9.4	8.8	8.3	7.7	7.3	6.8	6.4	6.0	5.6	5.3	4.9	4.6	4.3	4.1	3.8	3.6
7.2	15	14	13	12	12	11	10	9.5	9.0	8.4	7.9	7.4	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4
7.3	14	13	12	12	11	10	9.6	9.0	8.4	7.9	7.4	6.9	6.5	6.1	5.7	5.4	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2
7.4	13	12	12	11	10	9.5	9.0	8.4	7.9	7.4	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0
7.5	12	11	11	10	9.4	8.8	8.2	7.7	7.2	6.8	6.4	6.0	5.6	5.2	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8
7.6	11	10	10	9.1	8.5	8.0	7.5	7.0	6.6	6.2	5.8	5.4	5.1	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3.0	2.9	2.7	2.5
7.7	9.9	9.3	8.7	8.1	7.7	7.2	6.8	6.3	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.3
7.8	8.8	8.3	7.8	7.3	6.8	6.4	6.0	5.6	5.3	5.0	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0
7.9	7.8	7.3	6.8	6.4	6.0	5.6	5.3	5.0	4.6	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8
8.0	6.8	6.3	6.0	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.6	3.3	3.1	2.9	2.7	2.6	2.4	2.3	2.1	2.0	1.9	1.7	1.6	1.5
8.1	5.8	5.5	5.1	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3
8.2	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1
8.3	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.96
8.4	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99	0.92	0.87	0.81
8.5	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.83	0.78	0.73	0.69
8.6	2.6	2.4	2.2	2.1	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.85	0.80	0.75	0.70	0.66	0.62	0.58
8.7	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.93	0.88	0.82	0.77	0.72	0.68	0.63	0.60	0.56	0.52	0.49
8.8	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.96	0.90	0.85	0.79	0.74	0.70	0.65	0.61	0.58	0.54	0.51	0.47	0.44	0.42
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.82	0.77	0.72	0.68	0.64	0.60	0.56	0.52	0.49	0.46	0.43	0.40	0.38	0.36
9.0	1.4	1.3	1.2	1.1	1.0	0.98	0.92	0.86	0.81	0.76	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31

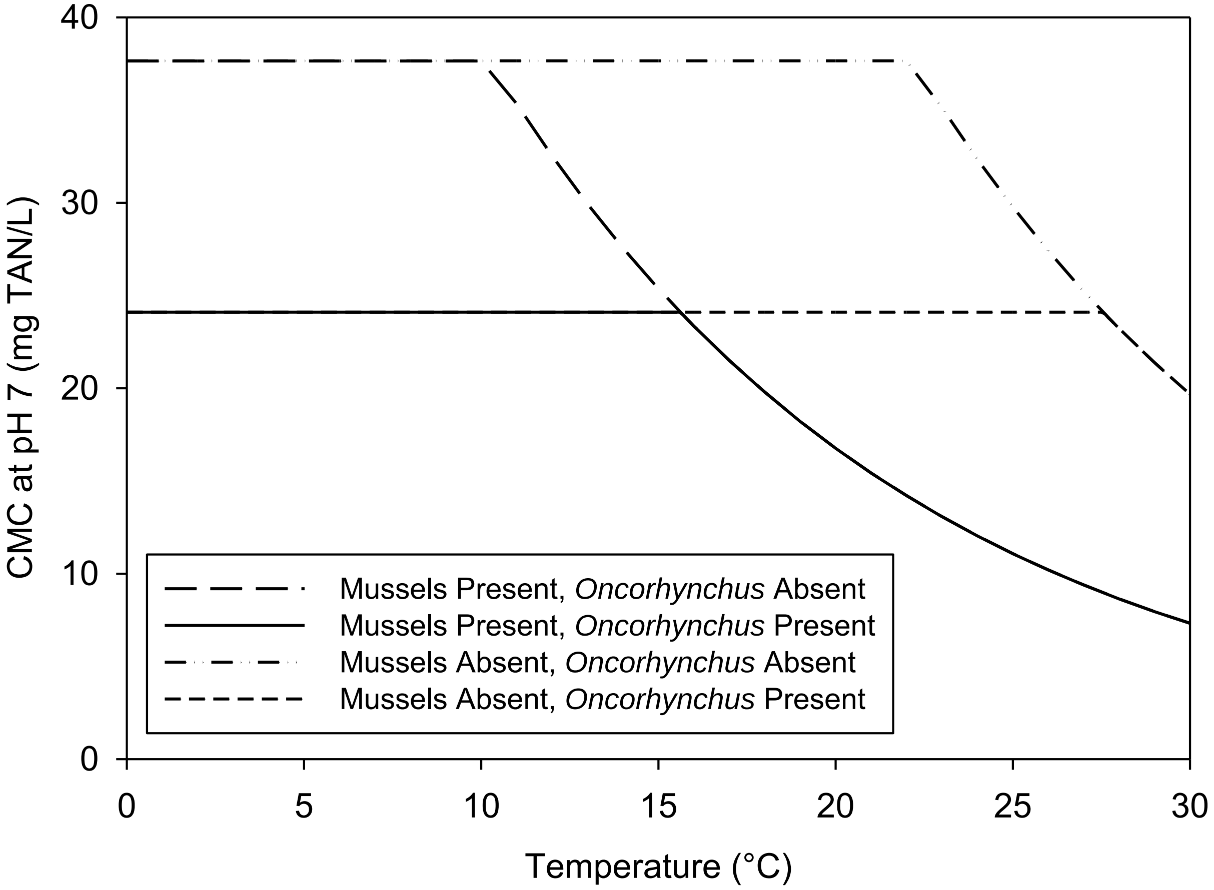


Figure N.1. Comparison of the 2013 CMC Extrapolated Across a Temperature Gradient at pH 7 Accounting for the Presence or Absence of Unionid Mussels and the Presence or Absence of *Oncorhynchus*.

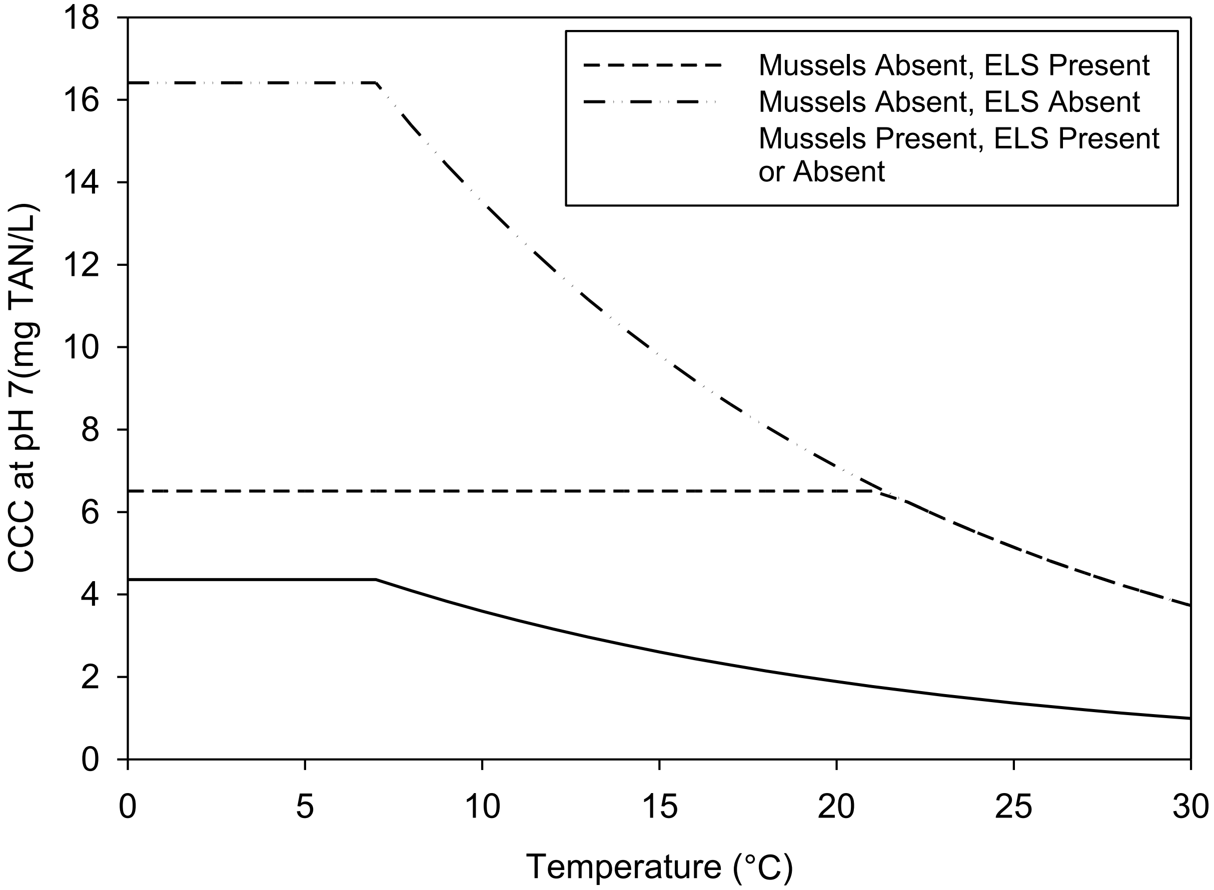


Figure N.2. Comparison of the 2013 CCC Extrapolated Across a Temperature Gradient at pH 7 Accounting for the Presence or Absence of Mussels and/or the Need for Early Life Stage (ELS) Protection of Fish Species.

DUANE A. SMITH
EXECUTIVE DIRECTOR

1957

BRAD HENRY
GOVERNOR

STATE OF OKLAHOMA
WATER RESOURCES BOARD
www.owrb.ok.gov

August 11, 2008

Ms. Denise Keehner
U.S. EPA Headquarters
Ariel Rios Building
1200 Pennsylvania Ave., N.W.
Mail Code: 4305T
Washington, D.C. 20460

Dear Ms. Keehner:

It has been my pleasure to work with you and your staff over the last several months to clarify many fundamental Water Quality Standards issues we have wrestled with in recent years. Whether these issues arose through ASIWPCA, WQS Managers Meetings, WQS Workgroup Meetings or the WQS Academy, it has been both enlightening and encouraging to explore them with you.

Would it be possible for you to forward to me in writing the results of some of these discussions to share with my staff and state colleagues? As an example, we've framed the question of "existing uses" with the following questions:

What are existing uses?
When determining an existing use, are there situations where a state should describe existing uses more specifically than designated uses?
How should a state determine the existing use for a water body?
What is the difference between an existing use and a designated use?
Can a state adopt the existing use as its designated use?

We have discussed other foundational issues as well and I would be most interested in affirming my understanding of the outcomes of these discussions that reflect our common understanding.

Thanks again for all your time and effort on the critically important work of WQS. As always feel free to call me with any questions at (405) 530-8800.

Sincerely,

Derek Smithee, Chief
Water Quality Programs Division

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
WATER

September 5, 2008

Mr. Derek Smithee
State of Oklahoma
Water Resources Board
3800 N. Classen Blvd.
Oklahoma City, OK 73118

Dear Mr. Smithee:

Thank you for your letter of August 11, 2008. I also appreciate the discussions we have had with states at ASIWPCA meetings, WQS Managers Meetings, WQS Workgroup meetings, and the WQS Academy. You asked if we could forward you in writing the results of these discussions to share with your staff and colleagues. Our office is happy to provide you with answers to your specific questions that reflect common understanding throughout EPA Regional Offices in the enclosed attachment.

If you have any questions please feel free to contact me at 202-566-1566 or Jim Keating at 202-566-0383.

Sincerely,
Denise Keehner 9/23/08

Denise Keehner, Director
Standards and Health Protection Division

Enclosures

Attachment

1) ***What are existing uses?***

EPA's regulations define existing uses as "...those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards."[1,2] Existing uses are relevant to two provisions in the Federal regulation – 40 C.F.R. § 131.10(g), designated uses, and 40 C.F.R. § 131.12(a)(1), antidegradation. Overall, these provisions:

- ☐ Prohibit removal of a designated use that would also remove an existing use.[3]
- ☐ Require the maintenance and protection of existing instream water uses and the level of water quality necessary to protect existing uses when implementing a state's or tribe's antidegradation policy.[4]

EPA considers the phrase "existing uses are those uses actually attained" to mean the use and water quality necessary to support the use that have been achieved in the waterbody on or after November 28, 1975. Waterbody uses relate to a distinct purpose (e.g., recreation, public water supply) or function (e.g., supporting an aquatic ecosystem). EPA's regulations, relating to the protection of existing uses, require states and tribes to maintain and protect these uses, not specific water quality parameters which may have achieved levels more protective than necessary to support these uses.[5]

In nearly all cases, a waterbody will have achieved some degree of use related to aquatic life, wildlife, and human activity on or after November 28, 1975. States and tribes are not bound by their designated use classification categories when describing existing uses. In some cases, the use(s) and water quality actually achieved may be less protective than the designated use(s) assigned to the waterbody. For example, while the water quality since November 28, 1975 may never have been sufficient to support the diverse aquatic community associated with the waterbody's designated use, it is likely that the water quality in the waterbody supports or has supported some less diverse community of organisms. When such uses have been achieved on or after November 28, 1975, EPA considers the uses reflecting the degree of aquatic life, wildlife, and human activity achieved to be "existing" uses.

---

[1] 40 C.F.R. § 131.3(e).

[2] November 28, 1975 is the date EPA promulgated the initial Federal water quality standards regulations related to existing uses. 40 C.F.R. 55334 (Nov. 28, 1975).

[3] 40 C.F.R. § 131.10(g).

[4] 40 C.F.R. § 131.12(a)(1).

[5] In the 1982 preamble to the proposed rule for the current WQS regulations, EPA stated that the first tier of antidegradation applies to uses, not specific parameters. For example, if a stream actually achieved a warm water fishery use and achieved a dissolved oxygen level of 7.0 mg/L, under the existing use regulation the state would only be required to maintain the dissolved oxygen levels sufficient to support the warm water fishery existing use (e.g. 5.0 mg/L if that is sufficient to support the existing warmwater fishery use). 47 Fed. Reg.49,234, 49,238 (col. 3)(Oct. 29, 1982).

A waterbody may have multiple existing uses. When evaluating the uses actually achieved along a continuum, the existing uses of a waterbody are the "highest degree of uses" and water quality necessary to support those uses, that have been achieved since November 28, 1975, independent of the designated use. "Highest degree of uses" generally means the degree of use closest to those supported by minimally impacted conditions, which usually is associated with the highest level of water quality. In the paragraph above, if this less diverse community is the highest degree of aquatic life use that has been achieved since 1975, this would be the existing aquatic life use.

EPA's existing use regulations ensure that the waterbody's highest degree of uses and the necessary levels of water quality actually achieved on or after November 28, 1975 will be maintained and protected consistent with the overall objective of the Clean Water Act (CWA) to restore and maintain the physical, chemical, and biological integrity of the nation's waters.[6] Thus, 40 C.F.R. §§ 131.10(g) and 131.12(a)(1) define the absolute "floor" or minimum use and necessary level of water quality achieved that must be maintained and protected in a waterbody.[7] In the above example, where a state is designating its uses or revising its designated uses, the state or tribe must ensure that the resulting water quality will not jeopardize the less diverse aquatic community (and thus the existing use).

The regulation at 40 C.F.R. § 131.10(g) prohibiting removal of an existing use is not intended to apply to a situation where the state or tribe wishes to remove a use where the removal would result in improving the condition of a waterbody, i.e., facilitates attainment of a use closer to those supported by minimally impacted conditions.[8] The intent of the regulation is to further the objectives of the CWA "to restore and maintain the chemical, physical, and biological integrity" of the nations waters (CWA section 101(a)), not to prevent actions that make the waterbody more like its minimally impacted condition. For example, if a pollution tolerant aquatic community is replaced by a more diverse aquatic community as a result of improving water quality, loss of the pollution tolerant community is a necessary step towards restoring a waterbody to its minimally impacted condition and is not a removal of an existing use. Similarly, if a state or tribe stocks trout (a coldwater species) into a natural warmwater fishery, the existing use provision would not prevent removal of that stocked trout fishery use because a natural warmwater fishery is closer to the minimally impacted condition.

Existing use determinations should be made on a site-specific. If a state or tribe can show that removing a designated use will not remove an existing use and the state or tribe can show that there are factors precluding the attainment of this designated use, the state/tribe must then determine and designate the highest attainable use.

2) ***When determining an existing use, are there situations where a state or tribe should describe existing uses more specifically than designated uses?***

---

[6] CWA section 101(a).

[7] See the preamble to EPA's WQS regulations at 48 Fed. Reg. 51,500, 51,403, col. 2 (Nov. 8, 1983).

[8] See 40 C.F.R. § 131.10(h). States or tribes may remove existing uses where the state or tribe is adding a use requiring more stringent criteria..

Yes. While there are some situations where it would be reasonable to describe existing uses of a waterbody using the same broad categories employed for designating uses, a state or tribe should describe existing uses more specifically where necessary to meet the intent of the existing use requirements. It would be consistent with the intent of the regulation for a state or tribe to more specifically describe its existing use, for example, where necessary to maintain and protect unique attributes of a waterbody that are not adequately described using a broadly defined designated use category. Examples 1 (CSO-impacted waters) and 2 (mining-impacted waters) provided in the next question, demonstrate the importance of describing the existing use (and the water quality necessary to support this existing use) in a specific manner so that the uses and the water quality improvements achieved since 1975 can be maintained and protected.

States and tribes must consider existing uses prior to removing or revising a designated use and in the context of its antidegradation requirements.[9] The Federal regulations do not require states and tribes to specify both existing uses and designated uses for each waterbody in their water quality standards; however a state or tribe may do so if it chooses.[10]

3) ***How should a state or tribe determine the existing use for a waterbody?***

A state or tribe should determine existing uses on a site-specific basis to ensure it has identified the highest degree of uses and water quality necessary to support the uses that have been achieved since November 28, 1975. When describing existing uses, states and tribes should articulate not only the use(s) that has been achieved, but also the water quality supporting the specific use(s) that has been achieved. Examples 1 (CSO-impacted) and 2 (mining-impacted) below illustrate this point. For aquatic life, states and tribes should consider the available biological data as an indicator of both water quality and the actual use, in conjunction with any available chemical water quality data.

Although EPA interprets the definition of "existing use" to require consideration of the available data and information on both actual use and water quality, all the necessary data may not be available. In these circumstances, a state or tribe may choose, in implementing its water quality standards program, to determine an existing use based on the strength of evidence that a use has actually been achieved or the strength of evidence that water quality supporting a use has been achieved. In other words, where data may be limited or inconclusive, EPA expects states and tribes to consider the quantity, quality, and reliability of the different types of available data to describe the existing use as accurately and completely as possible and to resolve any apparent discrepancies based upon that evaluation. As an example, a state is considering removing a primary contact recreation use and is therefore evaluating the existing use. While it has information that people are swimming in a waterbody, it does not have any data to determine the level of water quality that has been achieved on or after November 28, 1975. In this case, the state has two

---

[9] 40 C.F.R. §§ 131.10(g) and 131.12(a)(1).

[10] EPA notes that 40 C.F.R. § 131.10(i) requires states and tribes to "revise its standards to reflect the uses actually being attained."

choices regarding the existing recreation use. If there is no reason to believe that there has ever been a water quality problem (e.g., no nearby sources of bacteria), then it would be reasonable for the state or tribe to determine that primary contact recreation is the existing use. However, if there is reason to believe a nearby source may have been limiting the water quality since November 28, 1975, the state should conduct a use attainability analysis to determine if primary contact recreation is attainable or not. If primary contact recreation is deemed attainable, the state must retain primary contact recreation use as the designated use, even if it is unclear whether that use is existing. If a primary contact recreation use is not attainable, then the state or tribe must designate the highest attainable recreation use.[11]

In a 1985 Antidegradation Questions and Answers document, EPA said "An existing use can be established by demonstrating that fishing, swimming, or other uses have actually occurred since November 28, 1975 or that the water quality is suitable to allow such uses to occur (unless there are physical problems which prevent the use regardless of water quality.)" While this approach allows states to make an existing use determination where it only has information on one or the other type of information, some have interpreted this statement as obligating states to ignore one set of information where both types are available. EPA has found that, in practice, taking into account all the available information results in a more accurate articulation of the existing uses. In addition, the 1985 policy was stated under the assumption that states and tribes would likely describe existing uses in the same terms or categories employed for designated uses. However, during the time since issuing those Qs and As, EPA has seen increasingly complex issues arise regarding the implementation of the existing use provisions of the Federal water quality standards regulations. It has become apparent that using the same designated use categories to describe existing uses may be insufficiently detailed to accurately describe the existing use.

Under the clarification that states and tribes are not bound to describing their existing uses with the same categories employed for designated uses, the following summarizes how states and tribes should determine existing uses.

1. Where a use (i.e., some degree of use related to aquatic life, wildlife, and human activity) has actually been achieved on or after November 28, 1975, the existing use is the highest degree of use *and* the water quality that has been achieved and is necessary to support the use (see examples 1 and 2); and

2. Where the water quality achieved was sufficient to support a use on or after November 28, 1975, but the use (i.e., some degree of use related to aquatic life, wildlife, and human activity) has not occurred, the federal regulations provide states and tribes the discretion to determining whether or not this is an existing use. In this case, however, it would be reasonable to presume the use is attainable and that a state or tribe would need to explain the factors unrelated to water quality (e.g. human caused conditions that cannot be remedied, hydrologic modifications) that

---

[11] 40 C.F.R. §§ 131.10(a) – (k).

are limiting the attainment of the use before it can be removed (see examples 3 and 4).

It is appropriate to describe the existing uses of a waterbody in terms of both actual use and water quality because doing so provides the most comprehensive means of describing the baseline conditions that must be protected. In identifying an existing use, it is important to have a high degree of confidence because a state or tribe may not remove an existing use when revising designated uses, regardless of whether the existing use remains attainable. This is also important because EPA's antidegradation provisions require any CWA authorization of a discharge or activity that may result in a discharge to protect the existing use.[12]

A specific example given in the 1985 Antidegradation Qs and As was one of shellfish harvesting. In the example, shellfish are thriving, but it is not clear whether people were actually harvesting the shellfish. In 1985, EPA said that shellfish harvesting is the existing use because to say "otherwise would be to say that the only time an aquatic protection use 'exists' is if someone succeeds in catching fish." (Appendix G Water Quality Standards Handbook). EPA's regulations provide states and tribes the discretion to determine whether or not shellfish harvesting is the existing use in this example. While in the example there was actual evidence of aquatic life (healthy shellfish), there was no evidence of shellfish harvesting. Under EPA's current interpretation, the state or tribe is not *required* to deem shellfish harvesting is an existing use in this situation. A state or tribe may determine that the existing use is an aquatic life use that supports healthy shellfish but that "harvesting" is not part of the "existing use" since there is no evidence of actual harvesting. On the other hand, if shellfish harvesting has not been documented but the evidence shows that the water quality to support harvesting has been achieved and the shellfish present are (or were) suitable for consumption, a state or tribe may determine the existing use is shellfish harvesting or shellfish suitable for consumption. Example 3 below further discusses that if water quality supports harvesting, a shellfish harvesting use is considered attainable (whether or not the state/tribe has determined it is an existing use) and should not be removed, even if no harvesting has actually occurred, unless the state can demonstrate otherwise based on one of the 131.10(g) factors.

For example, if shellfish harvesting has not been documented but the evidence shows that the water quality achieved and presence of shellfish suitable for consumption support harvesting, a state or tribe could determine the existing use is shellfish harvesting or shellfish suitable for consumption. Please see examples 3 (shellfish harvesting) and 4 (public water supply) for further discussion.

Example 1

People occasionally recreate in a waterbody impacted by combined sewer overflows (CSOs). While water quality may be sufficient to support full primary contact recreation most of the time (i.e., the ambient bacterial densities in the waterbody meet the bacteria water quality criteria), the number of indicator bacteria is likely to exceed the water

---

[12] 40 C.F.R. § 131.12(a)(1).

quality criteria established to support primary contact recreation during heavy rainfall events that trigger CSO events. If the CSOs have existed before November 28, 1975, what is the existing use related to recreation for this scenario?

In this example, water quality data may show that bacteria levels fluctuated above and below the state/tribal criterion for the protection of primary contact recreation and that exceedances correlated with the occurrence of CSO events. In addition, data regarding the type, timing, and frequency of recreation may show that some recreation (swimming or kayaking) occurs regularly in the waterbody even after a CSO discharge when the bacteria levels make it unsafe for primary contact recreation.

Based on the available data for this example, the existing use may be described as a primary contact recreation use at times not affected by CSOs and high risk recreation at times of CSO overflows (because there is a higher risk of getting sick from pathogens than in a water that supports a primary contact recreation use all the time). This existing use describes the absolute "floor" or minimum use and necessary level of water quality achieved for this waterbody that may not be removed when changing designated uses. In addition, the existing use must be protected in the context of antidegradation when authorizing a discharge or activity, under the CWA, that is required to meet water quality standards (WQS). The WQS existing use regulations, therefore, would not allow designated use changes or CWA authorized discharges/activities that would, for example, lower the water quality in a manner that would reduce the level of protection to recreators achieved by the existing use. Once the state/tribe has determined that changing the designated use will not remove an existing use, the state or tribe must conduct a use attainability analysis (UAA) if it wishes to change its currently designated recreational use to one that would require less stringent criteria.

Example 2

Hard rock mining has affected a mountain stream since before November 28, 1975, eliminating trout and other native fish, as well as impairing the benthic invertebrate community, within 20 stream miles of the mining district. Between 1990 and 2000, the State undertook a major remediation effort which resulted in a significant reduction in most metal concentrations. However, concentrations of cadmium and zinc (year round) remain well above the State's acute and chronic numeric criteria adopted to protect the trout stream use classification. The State found that with the significant reduction in most metals, the benthic invertebrate community fully recovered and the trout and other native fish returned to the remediated segment. Yet, the State also found that the number of fish per acre was still less than those at similar reference sites and the length/weight index showed these trout were not in as good of condition as those in the reference streams. Despite the inferior condition of the trout, the lower species numbers, and the fact that the water quality was exceeding some of the criteria adopted to protect a trout fishery use classification, the return of the trout was enough to encourage the public to fish and thus establish a successful trout fishing use.

In this example, the existing use (i.e., highest degree of aquatic life use and water quality necessary to support the use that has been achieved since November 28, 1975) may be described as a trout fishery in waters with high levels of cadmium and zinc concentrations. In this example, it is likely that maintaining the water quality improvements for the most limiting water quality parameters (cadmium and zinc) is especially important to maintain the existing use because changes to these parameters are likely to correlate with changes in the trout population.

Example 3

A waterbody has a healthy shellfish community that is propagating and thriving in a biologically suitable habitat and the water quality is sufficient to support both this healthy shellfish community and shellfish consumption by humans. However, there is not available information indicating that shellfish have been harvested since November 28, 1975. Because the water quality is sufficient to fully support a healthy shellfish community and a shellfish community actually exists, the existing use may be described as "a healthy shellfish community" or, as discussed earlier, the state or tribe may choose to determine shellfish harvesting is the existing use by weighing the evidence on water quality sufficient to support the use and evidence of actual use, and relying on one to a greater extent than the other. If the available data are lacking or inconclusive on whether shellfish are actually being harvested and consumed, a state or tribe may determine the existing use based on a reasonable judgment.

Shellfish harvesting is a CWA 101(a)(2) use. Therefore, if a state or tribe is considering removing a designated shellfish harvesting use, under 40 C.F.R. § 131.10(j)(2), it must conduct a UAA to demonstrate that shellfish harvesting is not feasible to attain due to one of the six factors in 40 C.F.R. § 131.10(g), keeping in mind that it cannot adopt a use that would lower the water quality in such a way that the water would no longer support the existing use. If the water quality is sufficient to support shellfish harvesting, it may be difficult to demonstrate that the use is not feasible to attain, even if no harvesting has or is occurring. However, 40 C.F.R. § 131.10(g) does provide for situations where factors other than water quality affect the attainability of a use. Any proposed use change must go through a public process consistent with state/tribal law and EPA's public participation requirements.[13]

Example 4

Since November 28, 1975, a particular waterbody has met the human health criteria necessary for a waterbody to be used as a source of public water supply. However, there has never been a drinking water intake because the waterbody has never been used as a source of drinking water. Is public water supply an existing use for this scenario?

As stated above, EPA expects states and tribes to look at the available data and information on both water quality and actual use to determine if it is an existing use. If data are clear that the water quality was sufficient to support a public water supply (PWS)

---

[13] 40 C.F.R. §§ 131.10(e) and 131.20(b).

use, but no PWS use actually occurred since there was no PWS intake, then the Federal regulations do not *require* that the state or tribe find that there is an existing public water supply use. EPA recognizes that when states/tribes initially designated uses they may have designated certain waters or all state/tribal waters for public water supply use even though state, tribal, and local governments have never actually used these waters as public water supply sources since November 28, 1975. However, as discussed earlier, states and tribes may choose, in implementing their water quality standards programs, to determine that a public water supply use is an existing use based on the strength of evidence that a use is actually occurring or the strength of evidence that water quality supports a potential use. For example, if a use has never occurred in or on the waterbody since November 28, 1975, but the water quality at the time of evaluation would support such a use, a state or tribe may determine that this use is an existing use because maintaining the water quality will preserve its use in the future. In addition, where data are unavailable or inconclusive, a state or tribe has the discretion to determine whether or not there is an existing public water supply use based on best professional judgment.

4) ***What is the difference between an existing use and a designated use?***

In 1998, EPA stated that "Designated uses focus on the attainable condition while existing uses focus on the past or present condition."[14]Existing uses are a description of the highest degree of uses and water quality necessary to support the uses that have been achieved at any time since November 28, 1975.[15] The existing use identifies a minimum use and level of water quality that must be maintained to protect uses that have already been attained (*i.e*, the "floor").[16] A designated uses, on the other hand, expresses the state/tribal objectives (i.e., the highest attainable uses) for a waterbody or set of waterbodies. The designated use may or may not have actually been attained in the waterbody.[17] In implementing the regulations, it is important to consider both the distinction and linkage between designated and existing uses. The following is a somewhat simplified example to illustrate how they relate to one another:

Blue Lake is a relatively small, natural lake. It is fed by tributary streams and has an outlet stream that connects it to a larger watershed. Beginning in the 1960s, Blue Lake served as a summer retreat and was surrounded by small summer homes with onsite septic systems. Over time, as popularity for the vacation spot increased, the area became incorporated into a larger urban area. The resulting urban nonpoint source pollution, hydrologic modifications to the watershed (increased impervious surfaces), and failure of onsite septic systems caused high nutrient and sediment loadings, organic enrichment, and low dissolved oxygen (DO) levels in Blue Lake. This led to an increase in nuisance algae blooms and loss of submerged aquatic vegetation. The State conducted a biological assessment in 1974 which documented poor water quality and that the aquatic community

---

[14] 1998 Advance Notice of Proposed Rulemaking on the Water Quality Standards Regulation. 63 FR 36,742, 36, 748 (col. 3) (July 8, 1998).

[15] 40 C.F.R. § 131.3(e).

[16] See the preamble to EPA's WQS regulations at 48 Fed. Reg. 51,500, 51,403, (col. 2) (November 8, 1983).

[17] 40 C.F.R. § 131.3(f).

was comprised of low numbers of tolerant invertebrate and fish species. Based on this information, the State designated a limited warmwater aquatic life use for Blue Lake.

During the 1980s and 1990s, the community reduced pollutant loadings to Blue Lake and water quality and biological conditions improved. Although pollutant loadings from urban stormwater remained, connecting the homes to community water and sewer lines significantly reduced the organic enrichment and nutrient loadings to Blue Lake. State monitoring data showed an increase in water clarity, reduced algal turbidity, reduced chlorophyll *a,* and reduced nutrients. Biological assessment data showed a return of expected submerged aquatic vegetation and an improved invertebrate community (rating as a fair quality aquatic community). This information documented the improved condition and helped the State define the existing use (much improved from the limited warmwater aquatic life designated use). However, the fish community still lacked a variety of species expected for this type of lake and water quality still did not meet the criteria for the state's designated warmwater aquatic life use.

In response to the improved conditions, the identified existing use, and the remaining stressors, the State conducted a use attainability analysis (UAA) in 2005 to determine the highest attainable use that should be designated. The UAA demonstrated that implementing a stormwater management program would likely result in attainment of the warmwater aquatic life designated use, although it would take several years. The State expects the projected improved water quality levels to support a good quality aquatic community. Despite the number of years it might take to see improvements, the State determined that a warmwater aquatic life use (and not a limited warmwater aquatic life use) was the appropriate long term objective and revised its water quality standards to adopt the new designated use.

Although it is important to recognize that the regulatory roles and requirements for existing and designated uses differ, decisions about each are not made in isolation. In this example, the aquatic community assessments not only helped to identify improvements in the existing condition but also helped to identify the stressors limiting attainment of a higher use. Information about the limiting stressors, then, was used to evaluate whether or not the expected condition would be attainable. As illustrated here, there is a link between existing and designated uses, and information about the existing condition can be used to inform attainability decisions.

5) ***Can a state or tribe adopt the existing use as its designated use?***

In 1998, EPA stated that "Designated uses focus on the attainable condition while existing uses focus on the past or present condition." EPA's regulations at 40 C.F.R. § 131.10 links these uses in a manner which intends to ensure that States and Tribes designate appropriate water uses, reflecting both the exiting and attainable uses of each waterbody.[18] A state or tribe may adopt an existing use as the designated use where it is the highest attainable use. However, where it is not, states and tribes must consider designating uses based on the

---

[18] 1998 Advance Notice of Proposed Rulemaking on the Water Quality Standards Regulation. 63 FR 36,742, 36, 748 (col. 3) (July 8, 1998).

potential of a waterbody to attain a use, and not simply base the use designation on what has been attained, (i.e. the existing use).[19]

---

[19] 40 C.F.R. §§ 131.2 and 131.10.

State of New Mexico
Water Quality Management Plan
& Continuing Planning Process

Appendix C

Hydrology Protocol

for the

Determination of Uses Supported by
Ephemeral, Intermittent, and Perennial Waters

1912

Originally Approved May 2011
Approved Revision October 23, 2020

This page intentionally left blank.

EXECUTIVE SUMMARY

The *Hydrology Protocol* provides a methodology for distinguishing among ephemeral, intermittent and perennial streams and rivers in New Mexico. The results of the *Hydrology Protocol* may also aid in the designation of appropriate designated uses supported by those waterbodies as a result of flow regime. New Mexico's water quality standards (*Standards for Interstate and Intrastate Surface Waters*, 20.6.4 NMAC) set distinct protections for unclassified ephemeral, intermittent and perennial waters (*see* 20.6.4.97 to 99 NMAC) and also identify many classified waters by their hydrology, e.g. "perennial tributaries to" or "perennial reaches of" (*see* 20.6.4.101 to 899 NMAC). Hydrological determinations are key to assuring that the appropriate designated uses and water quality criteria are applied to a particular waterbody.

The *Hydrology Protocol* was specifically developed to generate documentation of the aquatic life and recreation uses supported by the hydrology of a given stream or river. This information can then be used to provide technical support for a Use Attainability Analysis (UAA). Under particular circumstances, the use of the *Hydrology Protocol* can be used for the expedited UAA process (20.6.4.15(C) NMAC), which facilitates the efficient application of the limited aquatic life and secondary contact uses to ephemeral waters, where appropriate, prior to undergoing the full administrative rule-making process. However, the *Hydrology Protocol* cannot be used in place of the UAA.

SWQB or any other party may conduct a *Hydrology Protocol* survey as part of a UAA in accordance with UAA requirements found under 40 CFR 131.10, 20.6.4.15 NMAC and the State's approved Water Quality Management Plan/Continuing Planning Process (WQMP/CPP), therefore the user/evaluator may be a member of SWQB, another regulatory agency, a contractor, or a member of the public.

The information gained from the protocol can also be used to identify unclassified waters within an otherwise classified standards segment. The details of these specific applications are described in Section II of *New Mexico's Water Quality Management Plan and Continuing Planning Process*, to which this *Hydrology Protocol* is an appendix. Other applications where a determination of stream hydrology is necessary are possible but results of the *Hydrology Protocol* must be evaluated cautiously within the specific decision framework of the study.

The protocol relies on hydrological, geomorphic and biological indicators related to the persistence of water and is organized into two levels of evaluations: Level 1 and Level 2. Data gathered during the Level 1 Evaluation should, in most cases, provide enough information to give a clear indication of the hydrological status of the stream. The "*Hydrology Determination Field Sheets,"* a.k.a. "*Field Sheets,*" was developed to record the information collected through application of the *Hydrology Protocol* and may be used to support the UAA process. The Level 1 Evaluation Field Sheets provide some of the necessary information needed in a Use Attainability Analysis to demonstrate a stream is ephemeral, intermittent or perennial. Attainment of a specific Clean Water Act Section 101(a)(2) aquatic life and recreational use may not be feasible due to the factor identified in 40 CFR 131.10(g)(2): *natural, ephemeral, intermittent, or low flow conditions or water levels prevent the attainment of the use*. The data obtained through a Hydrology Protocol survey provides some of the information that would be necessary to demonstrate that attainment is not achievable but, is only one of the elements required under a UAA to demonstrate the evidence to support changing a designated use.

In certain instances, additional data and supporting information are necessary to determine the hydrological condition of the stream. The methods described as part of the Level 2 Evaluation may be conducted if the Level 1 Evaluation is inconclusive (i.e. the score falls within a gray zone, see Section 2, Table 5). The Level 2 Evaluation relies on more intense and focused data collection efforts and provides the evaluator with additional data and observations to make a final hydrological determination. The Level 2 Evaluation may be used for either an expedited or regular UAA as documentation to support the proper standards classification of a given stream.

Regardless of whether a Level 1 or Level 2 Evaluation is performed, the SWQB encourages the evaluator to gather as much information as possible to make an accurate assessment of the stream. Recommendations are provided in the protocol, but other data not included in these recommendations may be gathered as well.

Table of Contents

I. INTRODUCTION

Streams are drainage features that may exhibit ephemeral, intermittent or perennial characteristics or change from ephemeral to intermittent and intermittent to perennial along a gradient or continuum—sometimes with no single distinct point demarcating these transitions. Nevertheless, all stream systems are characterized by interactions among hydrological, biological, and geomorphic (physical) processes. According to Maidment (1993), *Streamflow* can be described as flowing surface water along a defined natural channel generated by a combination of:

- *Stormflow* – streamflow resulting from the relatively rapid runoff of precipitation from the land as interflow (rapid, unsaturated, subsurface flow), overland flow, or saturated flow from raised, near surface water tables close to the stream.
- *Baseflow* – return flow from sustained groundwater discharge into the channel.
- Contributions of discharge from upstream tributaries as stormflow or baseflow.
- Contributions of discharge from point source dischargers and irrigation return flows.

The *Hydrology Protocol* uses attributes of hydrological, biological and geomorphic processes to produce a quantitative score. The score is then used to characterize the stream as "ephemeral," "intermittent," or "perennial". The term "stream", as it pertains to the *Hydrology Protocol*, refers to a wadable, lotic water body (typically 1st, 2nd, or 3rd Strahler stream order) and the term "river" refers to a non-wadable, lotic water body (generally 4th Strahler stream order or higher). Throughout this document the terms are interchangeable with one another as the same process and procedures are used regardless of whether the channel is wadable or not.

II. DEFINITIONS

The *Hydrology Protocol* is based on the definitions of "ephemeral," "intermittent" and "perennial" adopted by the WQCC in 20.6.4.7 NMAC as follows:

> ***"Ephemeral"*** *when used to describe a surface water of the state means the water body contains water briefly only in direct response to precipitation; its bed is always above the water table of the adjacent region.*
>
> ***"Intermittent"*** *when used to describe a surface water of the state means the water body contains water for extended periods only at certain times of the year, such as when it receives seasonal flow from springs or melting snow.*
>
> ***"Perennial"*** *when used to describe a surface water of the state means the water body typically contains water throughout the year and rarely experiences dry periods.*

III. HYDROLOGY DETERMINATION AND RATING FORM

A. General Information

There are two levels of evaluation for the *Hydrology Protocol* (HP). Data gathered during the Level 1 Evaluation should, in most cases, provide enough information to give a clear indication of the hydrological status of the stream. However, a more in-depth Level 2 Evaluation may be used to gather more information and data for more complex borderline cases. The *Field Sheets* are used to record the information and data collected through application of the HP.

For waterbodies where an HP is being conducted with the intent to remove a designated use that is not an existing use, as defined under 40 CFR 131.3 and 20.6.4.7(E)(3) NMAC, a UAA must be prepared. Third-party UAAs conducted in accordance with 20.6.4.15(D) NMAC, must have a workplan, approved by the Department, prior to conducting an HP UAA.

Although the HP is used as supporting evidence in a UAA, it is beyond the scope of this document to provide guidance on preparing a UAA.

B. User/Evaluator Experience

In order to distinguish ephemeral streams and rivers from non-ephemeral ones or intermittent streams and rivers from perennial ones using the information presented in this protocol, the evaluator should have experience making geomorphic, hydrological, and biological observations in New Mexico or in the semi-arid climate of the southwestern U.S.

The *Hydrology Protocol* was designed to provide the necessary supporting documentation for a UAA based on natural hydrologic flow conditions. In accordance with 20.6.4.15 NMAC, NMED or any other party may conduct a UAA, therefore the User/Evaluator for the *Hydrology Protocol* may be a member of NMED, another regulatory agency, a contractor, and/or a member of the public. It should be noted that only the Department can submit an expedited UAA using the *Hydrology Protocol* for EPA's technical review and approval, as described under 20.6.4.15(C) NMAC.

C. Drought Conditions

Spatial and temporal variations in stream attributes occur in stream systems. These variations can affect persistence and volume of streamflow. The changes to the system's flow regime can be related to seasonal precipitation and evapotranspiration patterns, as well as influenced by recent weather and interannual climate variability.

Local drought and weather data should be reviewed prior to evaluating flow conditions in the field. Perennial streams will have water in their channels year-round in the absence of drought conditions. Therefore, it is *strongly* recommended that field evaluations be conducted outside of drought conditions whenever possible.

Drought conditions, for the purposes of this *Hydrology Protocol*, are defined as any time the Standardized Precipitation Index (SPI) is less than -1.5, indicating severely to extremely dry conditions as described by the National Drought Mitigation Center (NDMC 1995). The 12-month SPI will be used to determine drought conditions and noted on the *Field Sheets*. The 12-month SPI should be verified through other sources such as the Standardized Precipitation Evapotranspiration Index (Beguería, et al. 2014) or the United States Drought Monitor to ensure that extreme or exceptional drought conditions are not indicated for the survey location.

The 12-month SPI was chosen for use in the *Hydrology Protocol* because SPIs of this time-scale can be linked to groundwater-surface water fluctuations and reservoir storage, it can provide an early warning of drought, and it can help assess drought severity. The SPI calculation for any location in New Mexico is based on 10 climate regions of New Mexico and long-term precipitation records (both rainfall and snowpack), and has available archived maps dating back to 1996. The 12-month SPI value for a particular stream is included as another piece of evidence to be evaluated before making a final stream determination. If the evaluator believes that extreme conditions such as severe drought or abnormal precipitation are influencing the overall rating, he may want to postpone a final decision until another evaluation can take place during more normal conditions.

D. Recent Rainfall Activity

Recent (generally considered to be within 48 hours) rainfall or snowmelt can also influence scoring; therefore, it is *strongly* recommended that field evaluations be conducted at least 48 hours after the last known major rainfall or snowmelt. Field observations regarding the presence or absence of recent high flows should be made and documented on the *Field Sheets* to supplement any available local rain gauge data and to determine if field observations were made at least 48 hours following a precipitation or runoff event. To reduce this source of variability, the Level 1 Field Evaluation should occur during stable baseflow conditions which will vary by region and elevation of the sample reach but are typically between late May and mid-July (to avoid snowmelt) or mid-September and early November (to avoid monsoons). The protocol and scoring mechanism were designed with redundancy (i.e. multiple indicators) to allow for defensible scoring even within 48 hours after a recent rainfall or during drought conditions. Nevertheless, performing field evaluations during or after severe conditions, such as floods or drought, is not optimal nor is it recommended.

E. Scoring

The *Field Sheets* are used to record the score for each attribute and determine the total numeric score for the sample reach under investigation. The *Field Sheets* specifically request information regarding: date, project, evaluator, site, Assessment Unit (AU), 12-month SPI value, latitude/longitude, as well as any other pertinent observations (such as indications of recent rain events). Additional notes for the Field Sheets should include the most recent precipitation date and amount from the closest rain gage, if available, and evidence of any anthropogenic influences and modifications. The *Field Sheets* are an official record, so all pertinent observations should be recorded on it.

In order to assess the natural variability encountered when making hydrological determinations in the field, a four-tiered, weighted scale was developed for evaluating and scoring each hydrological attribute. The scores that are applied to sets of geomorphic, hydrological and biological attributes are: poor, weak, moderate, and strong. *Moderate* scores are intended as an approximate qualitative midpoint between the two extremes of *Poor* and *Strong*. The score ranges were developed to better assess the often gradual and variable transitions of streams from ephemeral to non-ephemeral. The remaining qualitative description of *Weak* represents gradations that will often be observed in the field. Definitions of poor, weak, moderate and strong are provided in **Table 1**. These definitions are intended as guidelines and the evaluator must select the most appropriate category based upon experience and observations of the sample reach under review, its watershed, and physiographic region.

The quantitative score given to each attribute reflects the evaluator's qualitative assessment of the characteristic along the sample reach. These category range within each of the characteristics allows the evaluator flexibility in assessing variable features or attributes. In addition, the incremental category gradients reduce the variability of range in scores between different evaluators. There may be circumstances where intermediary scores between the categories presented for each indicator are appropriate. In those cases, document the rationale for the intermediary score on the *Field Sheets*.

Table 1. Guide to Scoring Categories

Category	Description
Strong	The characteristic* is easily observable (i.e. observed within less than one minute of searching).
Moderate	The characteristic is present and observable with minimal (i.e. one or two minutes) searching.
Weak	The characteristic is present, but you have to search intensely (i.e., ten or more minutes) to find it.
Poor	The characteristic is not observed.

*****geomorphic, hydrological or biological

F. Level 1 Evaluation: Data Collection for the Hydrology Determination of NM Streams and Rivers

1. Level 1 Office Procedures

The following information should be gathered and reviewed prior to conducting field work for a Level 1 Field Evaluation. It is important to gather as much physical and geographic information as possible by conducting reconnaissance on the stream reach prior to going out to the study site to save time, money and other resources and identify any risks or concerns.

Geographical Information System (GIS) and Remote Sensing Tools

The following is a non-exhaustive list of suggested coverages and resources that can help identify and generate informative maps of the field of study area. In addition, the aerial photographs, GIS coverages and resources listed below can be used to calculate sinuosity prior to field work (see *Indicator* #1.7 (Sinuosity) for more information).

Useful resources include:

- Google Earth
- SWQB Mapper (https://gis.web.env.nm.gov/oem/?map=swqb)
- GIS software (ArcMAP, QGIS, etc.)

Useful coverages that can be added to a GIS project include (Note, not all information listed here will be available for every stream.):

- SWQB water quality stations
- SWQB assessment units
- National Hydrography Dataset (NHD) streams
- Southwest Regional Gap Analysis (http://swregap.nmsu.edu/default.htm)
- Office of the State Engineer (OSE) data
- The United States Geological Survey (USGS) quadrangle maps
- Aerial photographs
- National Hydrography Dataset
- Digital Geologic Map of NM
- National Land Cover Dataset
- Bureau of Land Management (BLM) Land Status
- United States Department of Agriculture (USDA) or Natural Resources Conservation Service (NRCS) soil survey
- Omernik Ecoregions
- NM Roads

Streamflow

Historic or recent flow data from gages such as those managed by the USGS, OSE or Los Alamos National Laboratory (LANL) should be used to make hydrological determinations. Streamgage data, if available, may clearly indicate ephemeral, intermittent, or perennial flow patterns for the available period of record and will facilitate the scoring of Indicator #1.1 *Water in Channel*.

Useful resources include:

- USGS Current Water Data for New Mexico: https://waterdata.usgs.gov/nm/nwis/rt
- OSE Real-Time Water Measurement Information System: http://meas.ose.state.nm.us/
- Los Alamos Area Environmental Data (Intellus): https://www.intellusnm.com

Drought Conditions

The following resources will help determine drought conditions and recent rainfall activity. At a minimum, the 12-month Standardized Precipitation Index (SPI) should be recorded on the *field sheets* along with the date and source the SPI was evaluated. Note, not all information listed here will be available for every stream:

- Historic or recent flow data (known sources include SWQB, OSE, USGS, or localized sources such as Los Alamos National Laboratory for waters on the Pajarito Plateau)
- Standardized Precipitation Index (SPI)
    - https://hprcc.unl.edu/maps.php?map=ACISClimateMaps
- Standardized Precipitation Evapotranspiration Index (SPEI)
    - http://spei.csic.es/index.html
- Rain gauge stations within the County
- Airport/regional climate data
- The National Weather Service:
    - https://w2.weather.gov/climate/index.php?wfo=abq
- https://w2.weather.gov/climate/xmacis.php?wfo=abqhttps://water.weather.gov/ahps/United States Drought Monitor https://droughtmonitor.unl.edu/
- PRISM Climate Data:
    - http://www.prism.oregonstate.edu/mtd

Refer to *Drought Conditions* and *Recent Rainfall Activity* on pages 6-7 for more information.

Stream Segment Identification and Sample Reach Selection

This protocol describes a method for assessing geomorphic, hydrological, and biological indicators of stream flow duration. However, flow characteristics often vary along the length of a stream, resulting in gradual transitions in flow duration. Choosing the sample reach on which to conduct an assessment can influence the resulting conclusion about flow duration. Before a determination of hydrology can be made for a stream the appropriate sample reach, within the larger stream segment to which the UAA will apply, must be identified.

For SWQB stream segments are termed **assessment units** (**AUs**). AUs are river or stream reaches defined by various factors such as hydrologic or watershed boundaries, geology, topography, incoming tributaries, surrounding land use/land management, water quality standards, etc. AUs are designed to represent waters with assumed homogeneous water quality (WERF 2007). AUs in New Mexico average 10 miles in length and are typically no more than 25 miles in length. A **sample reach**, as used in this protocol, is a length of stream (40 times the average stream bankfull width or 160 meters, whichever is larger) that is chosen to represent a uniform set of physical, chemical, and biological conditions within an AU. It is the principal sampling unit for collecting hydrological, geomorphic and biological data using this protocol. Below are several factors to look for when determining the homogeneity of the AU and the representativeness of the sample reach:

- Are there significant tributaries (2nd order or higher) entering along the reach?
- Are there any changes in geology?
- Are there any dramatic shifts in land use?
- Is there a dramatic change in slope?
- Are there changes in riparian vegetation type and amount?
- Are there any point sources discharging into the reach?
- Are there any irrigation return flows discharging into the reach?

Many of these questions may be evaluated using maps and remote sensing products (e.g. Google Earth), however field reconnaissance along the length of the AU – to evaluate potential gradients in stream hydrology and to select representative sample reach(es) for hydrologic evaluation – should also be conducted.

The sample reach(es) selected for evaluation with the Hydrology Protocol should be as representative as possible of the natural characteristics of the AU. For example, if the stream is mostly vegetated, the sample reach should be located along an area of the channel that is mostly vegetated as opposed to an area that has no vegetation or is sparsely vegetated. It is the responsibility of the assessor(s) to verify and document the homogeneity of the AU and representativeness of the sample reach. SWQB typically defines a representative sample reach for conducting data collection as 40 times the average stream width or 160 meters, whichever is larger. If there are questions regarding the homogeneity of an AU (i.e., you answered "yes" to any of the questions above) then a hydrology evaluation should be performed on multiple sample reaches to identify potential transition point(s) between flow categories and accurately characterize the AU. One approach may be to examine air photos or satellite imagery and identify those areas with the greatest vegetation as potential study reaches with the greatest likelihood for "perennial" characteristics. Using the tools and resources described above may be helpful in confirming characteristics on the ground should an AU need to be re-evaluated.

2. Level 1 Field Procedures

In order to distinguish between ephemeral, intermittent, and perennial streams and rivers using the information presented in this protocol, the field evaluator should have experience making geomorphic, hydrological, and biological observations in New Mexico or the semi-arid region of the southwestern U.S. Field evaluations should be performed at least 48 hours after the last known major rainfall or snowmelt event. In addition, it is *strongly* recommended that field evaluations be conducted outside of drought conditions whenever possible.

Field Equipment and Supplies

- Copy of *Hydrology Protocol* and associated *Field Sheets*.
- Site maps and satellite imagery (1:250 scale if possible)
- Global Positioning System (GPS) – used to determine latitude and longitude
- Clipboard/pencils/sharpies
- Two Metric Rulers
- Two Measuring Tapes
- Survey rod
- Bank pins
- Laser Level/Rod Eyes/Clinometer
- Compass (if not available as part of GPS unit)
- Camera – used to photograph and document site features
- Shovel or Soil Auger
- D-frame dip net/white sorting tray (optional) Munsell
- Soil color chart (optional)
- Long piece of string (optional)
- Mechanical tally counter (optional)
- Sand-gauge card (optional)

Sample Reach Selection

Before selecting a location for the survey, note the character of the stream while driving to the site to verify that the reach is representative of the AU being characterized. This initial examination allows the evaluator to study the nature of the channel, observe characteristics of the watershed, and observe characteristics that indicate what source of water (stormflow, or base flow plus tributary/point source discharges, if present) may predominantly or solely contribute to flow in the AU. These initial observations also aid in determining the magnitude (poor, weak, moderate or strong) of specific parameters. In addition, the assessor can identify if the sample reach is generally uniform (i.e. "representative") or if it should be assessed as two or more distinct reaches. Hydrology evaluations must not be made at one point without first walking up and down the channel for at least 160 meters.

Ideally, the visual examination would be from the stream origin to the downstream confluence with a larger stream or until a change in characteristics such as slope or geology is observed, but this is usually not feasible or practical. Furthermore, property access issues may arise on privately held property. Make sure the site is easily and safely accessible. If the site is on private property get the land owner’s approval before conducting an evaluation.

Upon finding a representative area to conduct the survey, document the latitude and longitude (origination and termination) extent of the survey reach on the *Field Sheets*, the length of the survey area should be no less than 160 meters.

Photodocumentation

It is important to explain the rationale behind any conclusions reached using this protocol and sometimes photos are just the medium in which to do that. It is essential to take several photos of the sample reach, AU and/or watershed, as appropriate, to document the environmental conditions and any disturbances or modifications that are relevant to making a final hydrology determination. Multiple and varied photos will help evaluate and verify the homogeneity of the AU as well as the representativeness of the sample reach when and if a UAA is reviewed by NMED, EPA and the WQCC. Photos that document the evaluation attributes (e.g. riparian vegetation, benthic macroinvertebrates, etc.) are also encouraged and provide excellent supporting documentation for any conclusions reached.

The assessor should include a detailed description of each photo on the *Field Sheets*, including date, description of the photo (e.g. left bank, right bank, upstream, downstream, etc.), and GPS coordinates (if different from site location), and attach the photos to the *Field Sheets* to officially document the conditions at the time of the evaluation and to support any conclusions that were reached using this protocol.

3. Level 1 Scoring

Hydrological determinations are accomplished by evaluating 14 different attributes of the sample reach and assigning a numeric score to each attribute following the four–tiered, weighted scale described in Section 1 Scoring and summarized in Table 1. Total scores reflect the persistence of water with higher scores indicating intermittent and perennial systems. **Please see Section 2 – Guidance for Overall Score Interpretation for more details.**

4. Level 1 Indicators

1.1. Water in Channel

It is necessary to distinguish stormwater inflow (resulting from precipitation within the past 48 hours) from baseflow. Flow observations preferably should be taken at least 48 hours after the last substantial rainfall or runoff event. Local weather data and drought information should be reviewed before evaluating flow conditions. Perennial systems will have water in their channels year-round in the absence of drought conditions. Therefore, it is recommended that field evaluations be conducted outside of drought conditions whenever possible. Drought conditions are defined as any time the Standard Precipitation Index (SPI) is less than -1.5, indicating severely to extremely dry conditions (NDMC 1995). The 12-month SPI should be recorded on the *Field Sheets* to indicate climatic conditions at the time of sampling, and confirmed through other sources such as the Standardized Precipitation Evapotranspiration Index (Beguería, et al. 2014) or the United States Drought Monitor to ensure that extreme conditions are not indicated for the survey location.

Evidence of recent high flows should be noted on the *Field Sheets*. Such evidence includes moist or wet sediment on plants or debris and organic drift lines at or above bankfull or in the active floodplain. Artificial (i.e. point-source) discharges should also be noted on form. Site inspections should result in visually discernible stream flows as evidence of base flow contribution between rain events, even in low flow conditions. If base flows are present during a site inspection that is more than 48 hours after a major rainfall or runoff event, the sample reach is either perennial or intermittent. However, intermittent reaches do not always have water in them. A good rule of thumb for differentiating ephemeral reaches from intermittent ones is if they have water in them during the dry season or during a drought. Look for water in pool areas in the streambed. The presence or types of plants as well as saturated sediment underneath rocks located within the channel are also good indications of the presence of water during the dry season or during a drought.

If the stream is visited during the dry season (typically defined in NM as **late May to mid-July** and **mid-September to early November**, but also varies by region and elevation of the stream) and base flows are not evident, the stream may be ephemeral or intermittent. If there is no flowing water within 48 hours of a rain or runoff event, then the stream is more than likely ephemeral. The prerequisite for a stream to be determined as ephemeral is that there must be no evidence of base flows in the stream banks.

Strong – Flow is evident throughout the sample reach. Moving water is seen in riffle areas but may not be as evident throughout the runs.

Moderate – Water is present in the channel but flow is barely discernable in areas of greatest gradient change (i.e. riffles) or floating object is necessary to observe flow.

Weak – Dry channel with standing pools. There is some evidence of base flows (e.g. riparian vegetation growing along channel, saturated sediment under rocks, etc)

Poor – Dry channel. Dry under rocks and debris. No evidence of base flows was found.

If available, historic or recent flow data from streamgages such as those managed by the USGS, OSE, or LANL may clearly indicate ephemeral, intermittent, or perennial flow patterns for the available period of record and will facilitate the scoring of Indicator #1.1 *Water in Channel*.

1.2. Fish (qualitative observations)

In most cases, fish are indicators of perennial systems, since fish will rarely inhabit an intermittent stream. Fluctuating water levels of intermittent streams provide unstable and stressful habitat conditions for fish communities. When looking for fish, all available habitats should be observed, including pools, riffles, root clumps, and other obstructions (to greatly reduce surface glare, the use of polarized sunglasses is recommended). In small streams, the majority of species usually inhabit pools and runs. Fish should be easily observed within a minute or two. Also, fish will seek cover once alerted to your presence, so be sure to look for them slightly ahead of where you are walking. Check several areas along the sample reach, especially underneath undercut banks.

Strong - Found easily and consistently throughout the sample reach.
Moderate - Found with little difficulty but not consistently throughout the sample reach.
Weak - Takes 10 or more minutes of extensive searching to find.
Poor - Fish are not present (after 10 or more minutes of searching).

1.3. Benthic Macroinvertebrates (qualitative observations)

The larval stages of many aquatic insects are good indicators that a stream is perennial because a continuous aquatic habitat is required for these species to mature. Turn over the rocks and other large substrate found in areas of visible flowing water, (i.e. riffles) and scan the undersides for benthic macroinvertebrates. Also observe the newly disturbed area where the rock once was for signs of movement. This method may be more suitable for mountainous areas where riffles predominate. For lower gradient systems and other areas of slow moving water, benthic macroinvertebrates may be located in a variety of habitats including root wads, undercut banks, pools, leaf-packs, and submerged aquatic vegetation. Note that some benthic macroinvertebrates will make small debris/sand cases, which can be covered with periphyton and easily confused for excess debris picked up from the substrate. The use of a small net to sample a variety of habitats including water under overhanging banks or roots, accumulations of organic debris (e.g. leaves) and the substrate may be helpful.

In DRY channels, focus the search on the sandy channel margins for mussel and aquatic snail shells, any remaining pools for macroinvertebrates, and under cobbles and other larger bed materials for caddisfly casings. Casings of emergent mayflies or stoneflies may be observed on dry cobbles or on stream-side vegetation.

Strong - Found easily and consistently throughout the sample reach.
Moderate - Found with little difficulty but not consistently throughout the sample reach.
Weak - Takes 10 or more minutes of extensive searching to find.
Poor - Benthic macroinvertebrates are not present (after 10 or more minutes of searching).

1.4. Presence of Filamentous Algae and Periphyton (qualitative observations)

These forms of algae are attached to the streambed substrate and require an aquatic environment to persist. They are visible as a pigmented mass or film, or sometimes hairlike growths on submerged surfaces of rocks, logs, plants and any other structures within the channel. Periphyton growth is influenced by chemical disturbances such as increased nutrient (nitrogen or phosphorus) inputs and physical disturbances such as increased sunlight to the stream from riparian zone disturbances.

Strong - Found easily and consistently throughout the sample reach.
Moderate - Found with little difficulty but not consistently throughout the sample reach.
Weak - Takes 10 or more minutes of extensive searching to find.
Poor - Filamentous algae and/or periphyton are not present (after 10 or more minutes of searching).

1.5. Differences in Vegetation

As a rule, only perennial and intermittent systems can support riparian areas that serve the entire suite of riparian ecological functions. Ephemeral streams generally do not possess the hydrological conditions that allow true riparian vegetation to grow. Although water flows down ephemeral channels periodically, the water table does not occur sufficiently close to the soil surface to allow water loving vegetation to access the greater quantity of water they need to grow. Vegetation growing along ephemeral watercourses may occur in greater densities or grow more vigorously than vegetation in the adjacent uplands, but generally there are no dramatic compositional differences between the two. Even along those ephemeral channels where vegetation composition differs somewhat from the adjacent uplands, that vegetation does not require as much soil moisture as true riparian plants.

Note if vegetation is absent or altered due to man-made activities on the Level 1 *Field Sheet*

Strong – Dramatic compositional differences in vegetation are present between the riparian corridor and the adjacent uplands. A distinct riparian vegetation corridor exists along the entire sample reach – riparian, aquatic, or wetland species dominate the length of the reach.
Moderate – A distinct riparian vegetation corridor exists along part of the sample reach. Compositional species difference between upland and riparian corridor. Riparian
vegetation is interspersed with upland vegetation along the length of the reach.
Weak – Vegetation growing along the sample reach may occur in greater densities or grow more vigorously than in the adjacent uplands, but there are minimal compositional differences between the two.
Poor – No compositional or density differences in vegetation are present between the banks and the adjacent uplands. Vegetation growing along the riparian area does not occur in greater density or grow more vigorously than in the adjacent uplands.

1.6. Absence of Rooted Upland Plants in Streambed

This attribute relates flow to the absence of rooted plants, since flow will often act as a deterrent to plant establishment by removing seeds or preventing aeration to roots. Cases where rooted upland plants are present in the streambed may indicate ephemeral or intermittent flow. Focus should be on the presence of plants in the bed or thalweg and plants growing on any part of the bank should not be considered. Note, however, there will be exceptions to this attribute. For example, rooted plants can be found in shaded perennial streams with moderate flow but in all cases these plants will be water tolerant (i.e. obligate and/or facultative wetland plants).

Additionally, in some situations (e.g., high gradient sand bedded streams located within flashy watersheds) highly erosive flows and/or depth of scour in response to extreme rainfall events may limit the presence of rooted vegetation. Under these circumstances the assessor may use

professional judgment in selecting the appropriate scoring criteria, and should document on the

Field Sheets and with photos those factors that explain any alternative scoring methodology.

Strong – Rooted upland plants are absent within the streambed/thalweg.
Moderate – There are a few rooted upland plants present within the streambed/thalweg.
Weak – Rooted upland plants are consistently dispersed throughout the streambed/thalweg.
Poor – Rooted upland plants are prevalent within the streambed/thalweg.

*** If the sample reach being evaluated has a score ≤ 2 up to this point, the reach is determined to be ephemeral. If the reach being evaluated has a score≥ 18 at this point, the reach is determined to be perennial. You can STOP the evaluation. However, if the reach has a score between 2 and 18 you should continue the Level 1 Evaluation.***

1.7. Sinuosity

Sinuosity is a measure of a channel's "crookedness." Sinuosity is the result of the stream naturally dissipating its flow forces. Intermittent systems don't have a constant flow regime and, as a result, exhibit substantially less sinuous channel morphology. While ranking, take into consideration the size of the stream (e.g. 1st, 2nd, 3rd order, etc.), which may also influence the stream sinuosity. Sinuosity is best measured using aerial photography (Rosgen 1996).

Examples of sinuosity are provided in Figure 1. To calculate sinuosity using an aerial photograph, measure the stream length and related valley length for at least two meander wavelengths. A meander wavelength is the distance of one meander, or bend, along the down- valley axis of the stream. Divide the *stream* length (SL) by the *valley* length (VL) (Figure 2). If aerial photos are not available, sinuosity can be measured using a GPS's trip computer function to measure channel length and valley length. The higher the ratio (SL/VL), the more sinuous the stream.

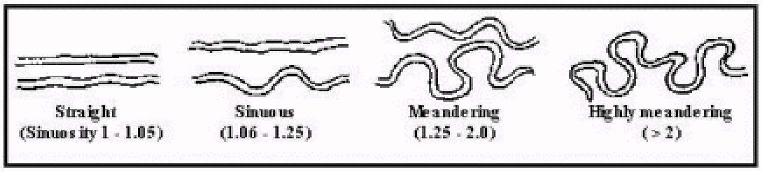


Figure 1. Examples of Stream Sinuosity (NCDWQ 2005)

In some surface waters (e.g., mountain stream settings or areas of complex and varied geology) channel sinuosity may be more reflective of external morphological factors, rather than the presence or absence of stream flow. Under these circumstances the assessor may use professional judgment in selecting the appropriate scoring criteria, and should document on the Level 1 *Field Sheets* and with photos those factors that explain any alternative scoring methodology.

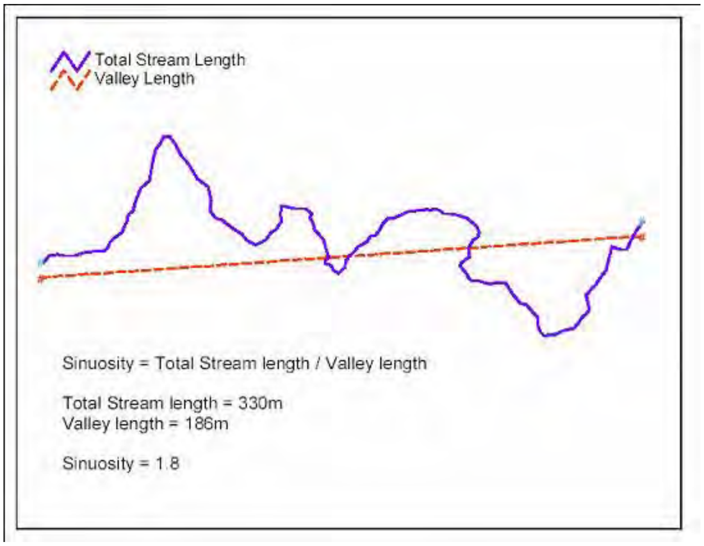


Figure 2. Stream Sinuosity (NCDWQ 2005)

******Note method used to determine sinuosity on the Field Sheets******

Strong – Stream sinuosity ratio is greater than 1.4. Stream has numerous, closely-spaced bends, few straight sections.

Moderate – Stream sinuosity ratio is between 1.4 and 1.2. Stream has good sinuosity with some straight sections.

Weak – Stream sinuosity ratio is between 1.2 and 1.0. Stream has very few bends and mostly straight sections.

Poor – Stream sinuosity ratio is equal to 1.0. Stream is completely straight with no bends.

1.8. Floodplain and Channel Dimensions

The relative importance of many fluvial processes in arid regions, especially the magnitude and frequency of their operation, differs considerably from more humid regions. As a result, channel forms also differ considerably from humid regions. Although one of the difficulties of characterizing dryland ephemeral streams is their enormous variability in form, they tend to be more incised with confined channels relative to intermittent and perennial streams (Knight et al. 1999).

When determining the vertical confinement of the stream, it is important to distinguish whether the flats adjacent to the channel are a frequent and active floodplain, terraces (abandoned floodplain), or are well outside of the flood-prone area. The ratio of the flood-prone area width to the bankfull, or active, channel width is used to determine the vertical confinement of the stream (Rosgen 1994). A larger ratio corresponds to a wide, active floodplain and a minimally confined channel, whereas a smaller ratio corresponds to a narrow or absent floodplain and a noticeably confined channel (*see scoring and "note" below*).

The flood-prone area width is measured at the elevation that corresponds to twice the maximum depth of the bankfull channel as taken from the established bankfull stage (Figure 3). The bankfull, or active, channel is defined as that which is filled with moderate sized flood events that would typically occur every one or two years and do not usually inundate the floodplain. Bankfull levels can be identified by:

- The presence of a floodplain at the elevation of initial flooding,
- The elevation associated with the *highest* depositional features,
- An obvious slope break that differentiates the channel from a relatively flat floodplain terrace higher than the channel,
- A transition from exposed sediments to terrestrial vegetation,
- Moss growth on rocks along the banks,
- Evidence of recent flooding,
- Presence of drift material caught on overhanging vegetation, and
- Transition from flood- and scour-tolerant vegetation to that which is relatively intolerant.

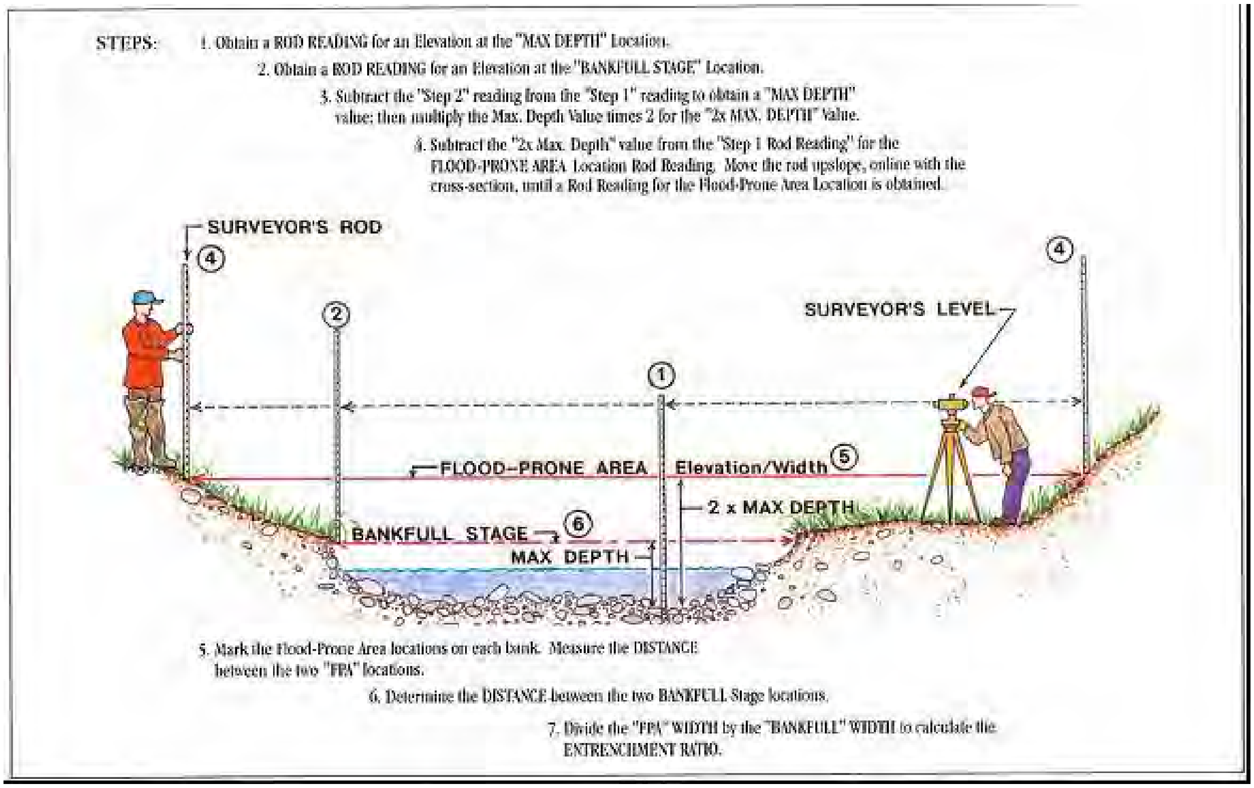
Field Protocol:

The evaluator(s) should start by selecting a location for the purpose of obtaining bankfull data. In general, the easiest location to measure bankfull channel width is within the narrowest segment of the sample reach. Deflectors such as rocks, logs, or unusual constrictions that make a stream especially narrow should be avoided.

1. Once a location is chosen, obtain a *rod reading* for an elevation at the "max depth" location by having one person hold a survey rod at the max depth location (thalweg) and a second person on the terrace adjacent to the stream using a clinometer and a meter stick or ski pole with one meter marked on it (if available, a surveyor's level can be used instead of a clinometer). Hold the clinometer at the one-meter mark on the ski pole, look through the clinometer holding it at zero, and read the height on the survey rod at the "max depth" location (Refer to **Figure 3**). Record the "max depth" *rod reading* on *Level 1 Field Sheets*.
2. Identify the bankfull stage using the indicators described above. Obtain a *rod reading* for an elevation at the "bankfull stage" location using the methods described in Step #1. Record the "bankfull stage" *rod reading* on Level 1 *Field Sheets*.
3. Subtract the "bankfull stage" reading from the "max depth" reading to obtain a maximum depth value. Multiply the maximum depth value by 2 for the "2x Max.

Depth" value. Record the "2x Max. Depth" value on Level 1 *Field Sheets*.

4. Subtract the "2x Max Depth" value from the "max depth" *rod reading* for the "flood- prone area" location *rod reading*. Move the rod upslope, online with the cross-section, until a rod reading for the "flood-prone area" location is obtained.
5. Mark the flood-prone area (FPA) locations on each bank. Measure the distance between the two FPA locations. Record the **FPA Width** on Level 1 *Field Sheets*.
6. Measure the distance between the two Bankfull Stage locations. Record the **Bankfull Width** on Level 1 *Field Sheets*.
7. Divide the FPA Width by the Bankfull Width to calculate the Floodplain to Channel Ratio. Record the calculated ratio on Level 1 *Field Sheets*. <u>The Floodplain to Channel Ratio is used to score the stream for this indicator</u>.



STEPS: 1. Obtain a ROD READING for an Elevation at the "MAX DEPTH" Location.
2. Obtain a ROD READING for an Elevation at the "BANKFULL STAGE" Location.
3. Subtract the "Step 2" reading from the "Step 1" reading to obtain a "MAX DEPTH" value; then multiply the Max. Depth Value times 2 for the "2x MAX. DEPTH" Value.
4. Subtract the "2x Max. Depth" value from the "Step 1 Rod Reading" for the FLOOD-PRONE AREA Location Rod Reading. Move the rod upslope, online with the cross-section, until a Rod Reading for the Flood-Prone Area Location is obtained.
5. Mark the Flood-Prone Area locations on each bank. Measure the DISTANCE between the two "FPA" locations.
6. Determine the DISTANCE between the two BANKFULL Stage locations.
7. Divide the "FPA" WIDTH by the "BANKFULL" WIDTH to calculate the ENTRENCHMENT RATIO.

Figure 3. Determining a Flood-Prone Area elevation/width (Rosgen 1996)

In some surface waters (e.g., mountain stream settings or areas of complex and varied geology) the degree of channel confinement may be more reflective of external morphological factors rather than the presence or absence of stream flow. Under these circumstances the assessor may use professional judgment in selecting the appropriate survey location and scoring criteria and should document on the Level 1 *Field Sheets* and with photos those factors that explain the resulting 'representative' scores.

******Alternative methods for determining the Floodplain to Active Channel Ratio should be described and recorded on the Field Sheets******

Strong - Ratio > 2.5*. Stream is minimally confined with a wide, active floodplain.

Moderate - Ratio between 1.2 and 2.5. Stream is moderately confined. Floodplain is present but may only be active during larger storm events.

Weak - Ratio < 1.2. Stream is incised with a noticeably confined channel. Floodplain is narrow or absent and disconnected from the channel during most storm events.

*NOTE**:** a larger ratio corresponds to a wide, active floodplain and a minimally confined channel, while a smaller ratio corresponds to a narrow or absent floodplain and a noticeably confined channel. If the channel is dry and bankfull stage cannot be determined, score this indicator based on your observations using the following scoring system:

Strong = stream is not incised/confined. Wide, active floodplain is connected to the channel.

Moderate = stream is moderately incised/confined. Flood-prone area width is narrow. Floodplain adjacent to the channel may be connected during large floods or represented by abandoned terraces.

Weak = stream is undeniably incised/confined. Flats adjacent to the stream are well outside of the flood-prone area.

1.9. In-channel Structure -- Riffle-Pool Sequences

A repeating sequence of riffle/pool (riffle/run in lower gradient systems, ripple/pool in sand bed systems, or step/pool in higher gradient systems) can be observed readily in perennial systems. Riffle-run (or ripple-run) sequences in low gradient systems are often created by in-channel woody structures such as roots and woody debris. When present, these characteristics can be observed even in a dry channel by closely examining the local profile of the channel. A riffle is a zone with relatively high channel slope gradient, shallow water, and high flow velocity and turbulence. In smaller streams, riffles are defined as areas of a distinct change in gradient where flowing water can be observed. The bottom substrate material in riffles contains the largest sedimentary particles that are moved by bankfull flow (bedload). A pool is a zone with relatively low channel slope gradient, deep water, and low velocity and turbulence. Fine textured sediments generally dominate the bottom substrate material in pools. Along the sample reach, take notice of the frequency between the riffles and pools.

Strong - Demonstrated by a frequent number of riffles followed by pools along the entire sample reach. There is an obvious transition between riffles and pools.

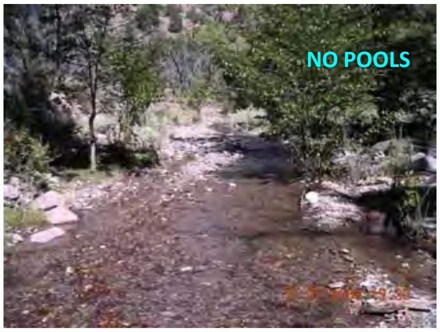
Moderate - Represented by a less frequent number of riffles and pools. Distinguishing the transition between riffles and pools is difficult.

Weak - Mostly has areas of pools or of riffles.

Poor - No riffles or pools observed.

Example of “**Strong**” Score – San Francisco River

Example of “**Moderate**” Score – Santa Fe River



Example of “**Weak**” Score – Mineral Creek

Example of “**Poor**” Score – Arroyo Chamiso

*** If the sample reach being evaluated has a score ≤ 5 at this point, the reach is determined to be ephemeral. If the reach being evaluated has a score ≥ 21 at this point, the reach is determined to be perennial. You can STOP the evaluation. However, if the reach has a score between 5 and 21 you should continue the Level 1 Evaluation.***

1.10. Particle size or Stream Substrate Sorting

This feature can be examined in two ways. The first is to determine if the sediment texture in the bottom of the channel is similar to the texture outside the channel. If this is the case, then there is evidence that erosive forces have not been active enough to down cut the channel and support an intermittent or perennial system. Sediment in the bed of ephemeral channels typically have the same or comparable texture (i.e. particle size) as areas close to but not in the channel. Accelerated stormflow resulting from human activities may produce deep, well-developed ephemeral or intermittent channels which have little or no coarse bottom materials indicative of upstream erosion and downstream transport. The bottom substrate of non-ephemeral systems often has accumulations of coarse sand and larger particles.

The second way this feature can be examined is to look at the distribution of the particles in the substrate in the channel. In lower-gradient, sand-bed streams one may need to look for size variations among sand grains – for instance, coarse versus fine sand. Note, however, the usefulness of this attribute may vary among ecoregions. For instance, in the plateaus or tablelands the variability in the size of substrate particles will probably be less than in the mountains.

Examples of Methods used to determine particle size and gradation:

- Sand Gauge Reference Card (best for sand dominated systems)
- Standard Sieve Analyses
- Wire Screen Method
- Pebble Count Method:
    - EPA's EMAP Pebble Count
    - Wolman Pebble Count
    - Zig Zag Pebble Count
    - USFS Pebble Count Sampling Frame

For whatever method is chosen, repeat procedure for an area close to but not in the channel for comparison purposes. Step outside the bankfull width or above the bank onto the floodplain or first terrace and repeat the procedure used in the bankfull channel. Avoid areas of dense vegetation and soil accumulation. Beware of cactus, snakes, and other hazards when "blindly" picking up particles outside of the channel or even in dry streambeds. For pebble counts, the objective is to measure at least 50 pebbles in the channel and 50 pebbles in areas close to but not in the channel for accurate distributional representations and comparisons.

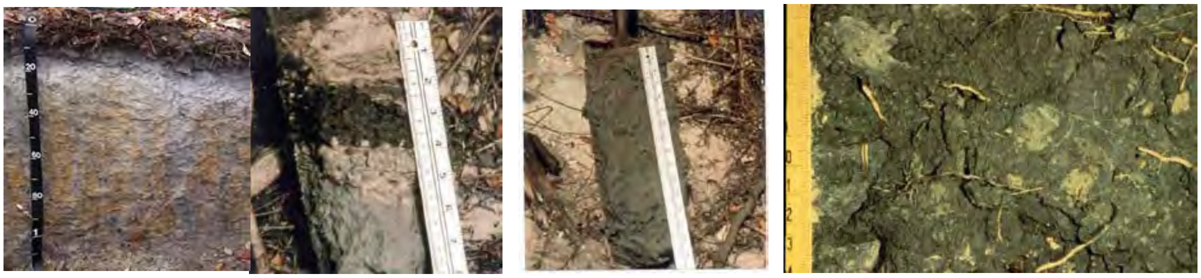
Strong - Particle sizes in the channel are noticeably different from particle sizes outside the channel in the flood-prone area. There is a clear distribution of various sized substrates in the channel with finer particles accumulating in the pools, and larger particles accumulating in the riffles/runs.

Moderate - Particle sizes in the channel are moderately similar to particle sizes outside the channel in the flood-prone area. Various sized substrates are present in the channel and are represented by a higher ratio of larger particles (gravel/cobble).

Weak - Particle sizes in the channel are similar or comparable to particle sizes outside the channel in the flood-prone area. Substrate sorting is not readily observed in the channel.

1.11. Hydric Soils

One of the most reliable methods for differentiating between ephemeral and non-ephemeral stream types during drier conditions requires investigation of the stream bank (i.e. from the stream bed to the top of the bank). Ephemeral streams usually have poor channel development and lack groundwater-induced base flows that normally result in hydric soils dominating the banks of intermittent and perennial streams. The presence of hydric soil indicators above the elevation of the channel bottom in floodplain soils adjacent to the channel indicates the presence of a seasonal high water table that can provide a critical period of base flow. Non-ephemeral stream banks typically are dominated by soils with hydric indicators, such as visually confirmed oxidized rhizospheres, a matrix of gray or black soils, and reducing conditions confirmed by a redox meter. The presence of hydric soils should be determined through visual observations, pungent odors, clay, etc. Additional information on field indicators of hydric soils is available from the Natural Resources Conservation Service at https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/hydric/. There are also special considerations regarding the determination of hydric soils in arid regions. The United States Army Corps of Engineers (USACE) Wetlands Regulatory Assistance Program has divided New Mexico into three regions (Arid West, Western Mountains, and Great Plains). A regional map and regional supplements to the Corps of Engineers Wetland Delineation Manual are available at: https://www.usace.army.mil/Missions/Civil-Works/Regulatory-Program-and-Permits/reg_supp.



Examples of Hydric Soils in the Arid West – U.S. Army Corps of Engineers
(photos found at: http://www.usace.army.mil/CECW/Documents/cecwo/reg/trel08-28.pdf)

Note that hydric soil indicators may be poorly developed at the seasonal high-water table elevation in young, coarse textured, alluvial soil materials with low concentrations of clay, iron, and manganese, or floodplain soils where moving water fails to become reduced.

Present – Hydric soils are found within the sample reach.
Absent – Hydric soils are not found within the sample reach.

1.12. Sediment on Plants or Debris

The transportation and processing of sediment is a main function of streams. Therefore, evidence of sediment on plants or other debris in the channel may be an important indicator of recent high flows. Note that sediment production in stable, vegetated watersheds is considerably less than in disturbed watersheds. Are plants in the channel, on the streambank, or in the floodplain covered with sediment? Look for silt/sand accumulating in thin layers on debris or rooted aquatic vegetation in the runs and pools. Be aware of upstream land-disturbing construction activities, which may contribute greater amounts of sediments to the channel and can confound this indicator. Note these activities on the *Field Sheets* if these confounding factors are present.

Strong – Sediment found readily on plants and debris within the channel, on the streambank, and within the floodplain throughout the length of the sample reach.
Moderate – Sediment found on plants or debris within the channel although not prevalent along the sample reach. Mostly accumulated on plants and debris in pools.
Weak – Sediment on plants and debris is isolated in small amounts along the sample reach.
Poor – No sediment is present on plants or debris.

****Refer to Section 2 Overall Score Interpretation, for guidance on overall Level 1 score interpretation****

Level 1 Supplemental Indicators

The following indicators do not occur consistently throughout New Mexico, which may be the reason why they were not statistically significant between waterbody types. Regardless, when they occur they are useful indicators in the determination of perenniality. Record the score on the Level 1 *Field Sheets* and include the score when calculating the total points.

1.13. Seeps and Springs

Seeps: Seeps have water dripping or slowly flowing out from the ground or from the side of a hill or incised streambank. Springs: Look for “mushy” or very wet, black decomposing leaf litter nearby in small depressions or in the channel. Springs and seeps often are present at grade controls and headcuts. The presence of this indicator suggests that groundwater is a source of streamflow except during a period of drought. Score this category based on the presence or absence of these features observed within the sample reach.

Present – Seeps and/or springs present in reach.
Absent – Seeps and/or springs were not present in reach

1.14. Iron Oxidizing Bacteria/Fungi

These features are often (although not exclusively) associated with groundwater. Iron oxidizing bacteria/fungi derive energy by oxidizing iron, originating from groundwater, in the ferrous form (Fe^{2+}) to the ferric form (Fe^{3+}). In large amounts, iron-oxidizing bacteria/fungi discolor the substrate giving it a red, rust-colored appearance. In small amounts, it can be observed as an oily sheen on the water’s surface. This indicates that the stream water is derived from a groundwater source, and these features are most commonly seen in standing water on the ground’s surface or in slow moving creeks and streams. Filmy deposits on the surface or banks of a stream are often associated with the greasy "rainbow" appearance of iron oxidizing bacteria. This is a naturally occurring phenomenon where there is iron in the groundwater. However, a sudden or unusual occurrence may indicate a petroleum product release from an underground fuel storage tank. One way to differentiate iron-oxidizing bacteria from oil releases is to trail a small stick or leaf through the film. If the film breaks up into small islands or clusters, it is most likely bacterial in origin. However, if the film swirls back together, it is most likely a petroleum discharge.

Present – Iron-oxidizing bacteria/fungi present in reach.
Absent – Iron-oxidizing bacteria/fungi not present in reach.

Oily sheen on water's surface due to iron-oxidizing bacteria
(photos found at:
http://www.arlingtonva.us/departments/EnvironmentalServices/epo/EnvironmentalServicesEpoDr.aspx)

Iron-oxidizing bacteria in seepage spring at La Plata River, Farmington, NM

****Refer to Section 2 Overall Score Interpretation, for guidance on overall Level 1 score interpretation****

G. Level 2 Evaluation: Borderline Determinations

If, after conducting a Level 1 Evaluation, a hydrological determination cannot be made because more information is required, then a Level 2 Evaluation should be conducted between mid-August and mid-November to coincide with SWQB's biological index period.

1. Level 2 Office Procedures

Refer to the results of the **Level 1 Evaluation**. If this step was not completed in the Level 1 Evaluation or cannot be located then refer to *Drought Conditions* and *Recent Rainfall Activity* and the *Level 1 Office Procedures*, particularly *Stream Segment Identification and Sample Reach Selection*, for more information.

Additional Supporting Information
Additional supporting information may not be scored but can be used to support a Level 2 hydrological determination. Unfortunately, not all information listed here will be available for every assessment unit. Additional supporting information includes, but is not limited to:

Observation of flow:

Observation of flow under certain seasonal or hydrological conditions can directly support classifying a sample reach as perennial. Reaches with flow during the dry season or periods of drought are likely perennial. Although the presence of flow during a drought indicates perennial conditions, care must be taken in evaluating the upper limits of perenniality because some perennial systems may only contain isolated pools of water or be dry during periods of drought.

Thermograph Data:

- Historic or recent SWQB thermograph data may provide some insight on flow during certain seasonal or hydrological conditions
- Do thermograph and/or streamflow data (or lack thereof) warrant the use of equipment to estimate the onset and cessation of flow? (See *Indicator #2.1* below)

Key biological indicators:

As discussed below, the presence of aquatic organisms whose life cycle requires residency in flowing water for extended periods (especially those one year or greater) is a strong indication that a sample reach is perennial. If a reach is recognized as borderline, a qualified aquatic biologist or environmental scientist should evaluate the presence and abundance of such macroinvertebrates and vertebrates species before making a final hydrological determination.

- Current and/or historic fisheries data may be found at:
  - Natural Heritage New Mexico (https://nhnm.unm.edu/)
  - Museum of SW Biology (http://www.msb.unm.edu/index.html)
  - Sublette, James E. et al. 1990. *The Fishes of New Mexico – First Edition.* University of New Mexico Press. 393 p.
- SWQB Fisheries Data are available upon request by contacting the Surface Water Quality Bureau (505-827-0187 or https://www.env.nm.gov/surface-water-quality/).

Other information that may be considered:

- Groundwater contour maps and/or nearby, local well logs.
- Information provided by a long-term resident and/or local professional who has observed the stream during various seasons and hydrological conditions.
- Review of historic information such as aerial photography.
- Professional judgment may be used in conjunction with the total score and supporting information in making the final determination.

2. **Level 2 Field Procedures**

In order to distinguish between ephemeral, intermittent, and perennial streams and rivers using the information presented in this protocol, the field evaluator should have experience making geomorphic, hydrological, and biological observations in New Mexico or the semi-arid region of the southwestern U.S. Field evaluations should be performed at least 48 hours after the last known major rainfall event or snowmelt. In addition, it is *strongly* recommended that field evaluations be conducted outside of drought conditions whenever possible. Drought conditions, for the purposes of this *Hydrology Protocol*, are defined as any time the 12-month SPI is less than -1.5, indicating severely to extremely dry conditions (NDMC 1995).

Refer to the results of the **Level 1 Evaluation**. If this step was not completed in the Level 1 Evaluation or cannot be located then refer to the *Level 1 Field Procedures*, specifically *Sample Reach Selection* and *Photodocumentation,* for more information.

Level 2 Field Equipment and Supplies

Copy of *Hydrology Protocol* and associated *Field Sheets*
*Thermograph Deployment/Upload/Retrieval Field Sheet
*Fish Sampling Field Data Sheet
Site maps and aerial photographs (1:250 scale if possible)
Global Positioning System (GPS) –
  used to determine latitude and longitude
Camera and Compass –
  used to photograph and document site features
Clipboard/pencils/sharpies
Measuring tape
Survey flags for transect locations
Survey rod
Bank pins
Level
Shovel or Soil Auger
Thermographs with caps and tags
Zip ties/bailing wire
Hammer & T-post driver
Rebar & T-posts (various lengths)
Flagging
Wire/tie cutters
Kicknet (18 inch; 500µm net size)
Forceps
Sieve (500µm mesh)
Buckets –
  to help sort macroinvertebrates
Sample containers (500-mL or 1-L)
Ethanol
Ethanol-proof sample labels
Ethanol-proof pen
Timepiece
Backpack electrofisher & accessories
Seine net
Buckets & aerators
Dip & aquarium nets
Voucher kit & formalin
Field guide
Collection permits
Measuring Board
One battery per site –
  for electrofisher + back-up

*See the SWQB SOP webpage at https://www.env.nm.gov/surface-water-quality/sop for the current version

3. **Level 2 Indicators**

2.1. Water in Channel (OPTIONAL)

Observation of flow under certain seasonal or hydrological conditions can directly support classifying a sample reach as perennial. Reaches with flow during the dry season or periods of drought are likely perennial. The longer the period from the last substantial rainfall the stronger the presence of flow supports the perennial determination. Although the presence of flow during a drought indicates perennial conditions, care must be taken in evaluating the upper limits of perenniality because some perennial systems may only contain isolated pools of water or be dry during periods of drought.

If available, historic or recent flow data from streamgages such as those managed by the USGS, OSE or LANL may clearly indicate ephemeral, intermittent, or perennial flow patterns for the available period of record and will facilitate the scoring of this indicator. If streamgage data are not available, temperature sensors (or electrical resistance sensors or pressure transducers) can be used to estimate the onset and cessation of flow (Constanz et al. 2001; Lawler 2002; Blasch et al. 2002). Periods of flow are characterized by those sections of the thermograph where the amplitude of the diel temperature signal is visibly dampened (Constanz et al. 2001). When the in-stream temperature data are compared graphically to the temperature data from a nearby site out of streamflow where little dampening has occurred, a flow signal is easily identifiable.

Strong – The water sensor is decidedly different from the air sensor. The streamflow signal is easily identifiable and occurs throughout the entire time of deployment (i.e. water sensor has a diel signal that is visibly dampened compared to air sensor throughout the deployment).

Moderate – The water sensor differs from the air sensor. A flow signal is identifiable during the majority of time; however, there are short periods of time when the water sensor has a diel signal that is comparable to the air sensor indicating periods of drying.

Weak – The water sensor differs somewhat from the air sensor. A flow signal is identifiable during certain days or weeks; however, there are long periods of time when the water and air sensors have similar diel signals (i.e. no dampening) indicating dry periods.

Poor – There are no substantial differences between the water and air sensors. The two thermographs are visibly comparable to one another indicating little to no water in the channel.

**If using an electrical resistance sensor or pressure transducer, use the following ratings:

Strong – The streamflow signal is easily identifiable and occurs throughout the entire time of deployment

Moderate – A streamflow signal is identifiable during the majority of time; however, there are short periods of time when the sensor indicates periods of drying.

Weak – A streamflow signal is identifiable during certain weeks or months; however, there are long periods of time when the sensor indicates a dry channel.

Poor – There is no sustained streamflow signal from the sensor (flow signal is only for very brief periods of time – on the timescale of days – indicating a flow response due to storm events). Or there is no discernible streamflow signal.

2.2. Hyporheic Zone/Groundwater Table

Hyporheic zone: Even when there is no visible flow above the channel bottom, there may likely be slow groundwater discharge into and downstream flow in the **hyporheic zone**. The hyporheic zone is the subsurface interface beneath and adjacent to a stream or river where surface water and shallow groundwater mix. It may be recognized by the accumulation of coarse textured sediments in the bottom of the channel that may be up to 2-3 ft deep in small streams. The saturated sediment in the hyporheic zone exchanges water, nutrients, and fauna with surface flowing waters. Consequently, the hyporheic zone is the site of groundwater discharge to the stream channel, downstream flow, and biological and chemical activity associated with aquatic functions of the stream.

Indicators of a hyporheic zone can be observed by digging a bore hole in the streambed when site conditions are conducive to manually digging a bore hole. Water standing in the bore hole or saturated sediment within the bore hole indicates the presence of a hyporheic zone. If conditions are not conducive to boring a hole in the streambed, one can look under rocks. Saturated or moist sediment underneath rocks located within the channel indicates the presence of a hyporheic zone.

Groundwater Table: The presence of a seasonal high water table or groundwater discharge (i.e. seeps or springs) from the bank, above the elevation of the channel bottom, indicates a relatively reliable source of base flow to a stream. When site conditions are conducive to manually digging a bore hole, indicators of a current water table can be observed by digging a bore hole in the adjacent floodplain approximately two feet away from the streambed. The presence of water standing in the hole above the elevation of the channel bottom after waiting for at least 30 minutes (longer for clayey soils) indicates the presence of a high groundwater table.

Strong – Considerable base flow is present. Hyporheic zone and/or groundwater table is readily observable throughout sample reach.

Moderate – Some base flow is present. Hyporheic zone and/or groundwater table is present, but not abundant throughout sample reach.

Weak – Water is standing in pools and the hyporheic zone is saturated, but there is not visible flow above the channel bottom. Indicators of groundwater discharge are present but require considerable time to locate.

Poor – Little to no water in the channel. No indication of a high groundwater table or hyporheic zone.

2.3. Bivalves

Clams cannot survive outside of water, thus one should examine the streambed or look for them where plants are growing in the streambed. Also, look for empty shells washed up on the bank. Some bivalves can be pea-sized or smaller. Since clams require a fairly constant aquatic environment in order to survive, the search for bivalves can be conducted while looking for other benthic macroinvertebrates. A small net may be useful.

Present – Bivalves are found within the sample reach.

Absent – Bivalves are not found within the sample reach.

2.4. Amphibians

Salamanders and tadpoles can be found under rocks, on streambanks and on the bottom of the stream channel. They may also appear in the benthic sample. Frogs will alert you of their presence by jumping into the water for cover. Frogs and tadpoles typically inhabit the shallow, slower moving waters of the pools and near the sides of the bank. Amphibian eggs, also included as an indicator, can be located on the bottom of rocks and in or on other submerged debris. They are usually observed in gelatinous clumps or strings of eggs.

Present – Amphibians are found within the sample reach.
Absent – Amphibians are not found within the sample reach.

Any collection and identification of aquatic species should be performed by a qualified aquatic biologist, environmental scientist, or other professional.

2.5. Benthic Macroinvertebrates (quantitative observations)

The larval stages of many aquatic insects are good indicators that a stream is perennial because a continuous aquatic habitat is required for these species to mature. The Arid West Water Quality Research Project has published a final report on *Aquatic Communities of Ephemeral Stream Ecosystems* (AWWQRR 2006) that may be a useful supplement to this protocol. In addition, SWQB scientists have been looking for the presence of long-lived aquatic species as reliable determinants for perennial channels, North Carolina's Division of Water Quality has developed a list of benthic macroinvertebrate taxa that are perennial stream indicators (NCDWQ 2010) and West Virginia's Department of Environmental Protection maintains a list of macroinvertebrate species that have an extended aquatic life stage (WVDEP – Watershed Assessment Branch, (304) 926-0495). Further information on life histories of specific macroinvertebrates found through the application of this protocol can be researched, if necessary.

Examples of Methods and Equipment used to collect Benthic Macroinvertebrates:

- EPA's EMAP Protocol
- SWQB's Benthic Macroinvertebrate SOP
- Kick Net
- D-Frame Dip Net
- Rectangular Dip Net
- Surber Sampler
- Hess Sampler
- Approaches:
    - Targeted Riffle
    - Reach-Wide, Multi-Habitat
        - top/bottom of riffle, undercut banks, pools/runs, snags/roots/logs

The goal is to collect as many different kinds of aquatic macroinvertebrates from as many different habitats as necessary to ensure an accurate site assessment. Be aware that each habitat type has different sampling protocols, and some have a greater diversity of organisms than others (**Table 2**). If you have many habitats from which to choose, consider sampling from those with the most diversity. If your stream has a rocky bottom, sample at two separate riffle areas and at one other habitat. If your stream has a soft bottom or does not have riffles, collect samples at submerged logs, snags or undercut banks.

Table 2. Relative diversity of various habitat types

Habitat Type	Stream Type	Habitat
Riffles	Rocky bottom	Most diverse
Undercut banks Snags,	Rocky, soft bottoms	↓
tree roots, logs	Rocky, soft bottoms	Least diverse

Strong – More than one taxa of benthic macroinvertebrate that requires water for their entire life cycle (rheophilic taxa) are present as later instar larvae. Overall there is a balanced distribution of taxa. A list of benthic organisms that indicate perennial features are listed in **Tables 3 and 4**.

Moderate – Only one rheophilic taxon was found in the sample, however sample is diverse. Overall there is a balanced distribution of taxa.

Weak – Rheophilic taxa are not present in the sample; however other types of benthic macroinvertebrates are present. Both diversity and abundance are low or not distributed evenly.

Poor – Benthic macroinvertebrates are not present.

Table 3. Ephemeroptera, Plecoptera, and Trichoptera (EPT) perennial indicator taxa

	Ephemeroptera (Mayflies)	**Plecoptera (Stoneflies)**	**Trichoptera (Caddisflies)**
Family:	Caenidae Ephemerellidae Ephemeridae Heptageniidae	Peltoperlidae Perlidae Perlodidae	Hydropsychidae Lepidostomatidae Molannidae Odontoceridae Philopotamidae Polycentropodidae Psychomyiidae Rhyacophilidae

Table 4. Additional indicators of perennial features

	Megaloptera	**Odonata**	**Diptera**	**Coleoptera**	**Mollusca**
Family:	Corydalidae Sialidae	Aeshnidae Calopterygidae Cordulegastridae Gomphidae	Ptychopteridae	Psephenidae Elmidae	Unionidae Ancylidae Pleuroceridae
Family & *Genus*:			Tipulidae *Tipula* sp.	Dryopidae *Helichus* sp.	

2.6. Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa

The larval stages of many species of these three orders require a period of at least a year, submerged in a constantly flowing aquatic environment before reaching maturity and therefore are commonly associated with perennial systems. Studies conducted by North Carolina State University have found that benthic samples collected in intermittent systems frequently display crustaceans (crayfish, isopods, and amphipods) as the dominant order (NCDWQ 2005). In sample reaches with more perennial characteristics, EPT taxa were collected. In highly urbanized areas, these indicators may be absent due to degradation and, therefore, may not be appropriate to evaluate perennial or intermittent flow conditions. These lists should be carefully evaluated (family or genus level ID) since some genera, such as the *Baetis* mayflies for example, are very short-lived in their aquatic life stages.

Present – EPT taxa are found within the sample reach.
Absent – EPT taxa are not found within the sample reach.

Any collection and identification of aquatic species should be performed by a qualified aquatic biologist, environmental scientist, or other professional.

2.7. Fish (quantitative observations)

Fluctuating water levels of intermittent systems provide unstable and stressful habitat conditions for fish communities. When looking for fish, all available habitats should be observed, including pools, riffles, root clumps, and other obstructions (to greatly reduce surface glare, the use of polarized sunglasses is recommended). In small streams, the majority of species usually inhabit pools and runs. Check several areas along the sample reach, especially underneath undercut banks. In most cases, fish are indicators of perennial systems, since fish will rarely inhabit an intermittent stream.

Fish should be collected, measured, and classified to verify if fish are present in a water body and to help confirm the appropriate hydrological determination. Best professional judgment should be exercised to determine sampling methodology (e.g. shocking, seining, etc.) and to ensure that safety concerns are addressed.

Strong – Fish are present in all habitats (riffles, pools, runs, root clumps, undercut banks, etc.). Multiple age classes are present and evenly represented. Large-bodied fish may be present.

Moderate – Fish are evident in fewer numbers with one age class dominating. Some habitat is not occupied. Large-bodied fish may be present.

Weak – Fish are not readily visible, require 10 or more minutes to locate, and are typically found within one habitat type (e.g. pools, runs). Very sparse.

Poor – Fish are not found within the sample reach.

IV. OVERALL SCORE INTERPRETATION

The final determination of whether a stream is ephemeral, intermittent, or perennial is based on a variety of information including the total score, supporting information, and professional judgment. The use of the Level 1 Evaluation should, in most cases, provide enough information to accurately distinguish between ephemeral, intermittent, and perennial systems. Scores should reflect the persistence of water with higher scores indicating intermittent and perennial systems. However, if a stream is recognized as borderline (i.e. gray zone – see **Table 5**) or if observations are made during a severe or extreme drought (12-month SPI value less than -1.5), then a Level 2 Evaluation that relies on more intensive and focused data collection can be used to make a final hydrological determination or to verify the Level 1 evaluation.

For a Level 1 Evaluation a minimum total score of 9.0 is set as a guideline to distinguish ephemeral channels from non-ephemeral ones unless there are aquatic macroinvertebrates and/or fish, in which case at least one of the Clean Water Act Section 101(a)(2) objectives is attainable and the stream is at least intermittent. In addition, a Level 1 score greater than 22.0 distinguishes perennial streams from non-perennial streams. SWQB recognizes that there is inherent variability in nature, therefore Level 1 scores between 9 and 12 may be ephemeral but will be recognized as intermittent until further data collection and analysis through a Level 2 evaluation or detailed UAA can more clearly determine that the stream is ephemeral. Similarly, Level 1 scores between 19 and 22 may be intermittent but will be recognized as perennial until further data collection and analysis indicate that the stream is intermittent. **Table 5** summarizes interpretation of Level 1 scoring. In most instances, the use of a Level 1 Evaluation should be sufficient to make a final hydrological determination. A hydrological determination does not change the designated use for a waterbody without the completion of a UAA in accordance with 40 CFR 131.10, 20.6.4.15 NMAC and the State's approved Water Quality Management Plan/Continuing Planning Process (WQMP/CPP). **If after conducting Level 1 Evaluation, a hydrological determination <u>cannot be made</u> because more information is required, then a Level 2 Evaluation which uses more intensive data collection can be conducted.**

Table 5. Summary of Level 1 Score Interpretation

Waterbody Type	Level 1 Total Score	Hydrology Determination
Ephemeral	**Less than 9.0***	**Stream is ephemeral**
≥ 9.0 and < 12.0		Stream is recognized as intermittent until further analysis indicates that the stream is ephemeral
Intermittent	**≥ 12.0 and ≤ 19.0**	**Stream is intermittent**
> 19.0 and ≤ 22.0		Stream is recognized as perennial until further analysis indicates that the stream is intermittent
Perennial	**Greater than 22.0**	**Stream is perennial**

* If there are aquatic macroinvertebrates and/or fish the stream is at least intermittent.

If a sample reach is recognized as borderline (within the gray zones), reaches upstream and downstream of the study area should be assessed to better evaluate the changes in stream classifications along a channel. Additional supporting information can be used to help make the final determination. This supporting information may include, but is not limited to:

Observation of flow: Observation of flow under certain seasonal or hydrological conditions can directly support classifying a stream reach as intermittent or perennial. Conditions supporting a perennial stream classification include:

Stream reaches with flow during the dry season or periods of drought are likely perennial. The longer the period from the last substantial rainfall the stronger the presence of flow supports the perennial stream determination. Although the presence of flow during a drought indicates perennial conditions, care must be taken in evaluating the upper limits of perenniality because some perennial streams may only contain isolated pools of water or be dry during periods of drought.

Key biological indicators: As discussed in the Level 2 Evaluation, the presence of aquatic organisms whose life cycle requires residency in flowing water for extended periods (especially those one year or greater) is a strong indication that a stream reach is perennial. If a stream or river is recognized as borderline, a qualified aquatic biologist/environmental scientist should evaluate the presence and abundance of such macroinvertebrate and vertebrate species before determining the final stream classification.

Other additional supporting information that may be considered:

- Groundwater contour maps or nearby, local well logs.
- Information provided by a long-term resident and/or local professional who has observed the stream during the various seasons and hydrological conditions.
- Review of historic information such as aerial photography.
- Professional judgment may be used in conjunction with the total score and supporting information in making the final determination.

The total score can be affected by seasonal or hydrological conditions as well as man-made impacts such as irrigation diversions or livestock impoundments associated with activities in the watershed. For example, a sample reach may score lower in drought conditions due to the lack of biological and/or certain hydrological indicators. However, a reach may score higher on certain indicators such as drift lines and alluvial deposits if directly below a stormwater outfall. The final hydrological determination should take these factors into account.

The *Hydrology Protocol* is considered to be an evolving, living document. Current thresholds are based on data collected by SWQB during the 2008 and 2009 field seasons from 57 stream reaches throughout the state of New Mexico. An analysis of these data was performed to determine which indicators clearly differentiated the three types of streams and to identify threshold values for scoring. In the event that new data indicate the threshold values used in this protocol are not appropriate and/or if new standards are adopted, SWQB will review the protocol, the related threshold values and differentiating scores. Revisions to the protocol will be proposed to the WQCC as needed in accordance with the process for updating the Water Quality Management Plan/Continuing Planning Process.

V. LITERATURE CITED

Arid West Water Quality Research Project. (2006). *Aquatic Communities of Ephemeral Stream Ecosystems* [PDF file]. Pima County Regional Wastewater Reclamation Department. Pima, Arizona. Retrieved from https://webcms.pima.gov.

Beguería, S., Vicente-Serrano, S.M., Fergus Reig, Borja Latorre. (2014). Standardized Precipitation Evapotranspiration Index (SPEI) revisited: parameter fitting, evapotranspiration models, kernel weighting, tools, datasets and drought monitoring. *International Journal of Climatology*, 34, 3001-3023.

Beguería, S., Vicente-Serrano, S.M., Fergus Reig, Borja Latorre. (2018). Standardized Precipitation Evapotranspiration Index (SPEI). Spanish National Research Council. Madrid, Spain. Retrieved at http://spei.csic.es/index.html.

Blasch, K., T.P.A. Ferre, A.H. Christensen, and J.P. Hoffmann. (2002). New field method to determine streamflow timing using electrical resistance sensors. *Vadose Zone Journal,* 1, 289-299.

Constantz, J., D. Stonestrom, A.E. Stewart, R. Niswonger, and T.R. Smith. (2001). Analysis of streambed temperatures in ephemeral channels to determine streamflow frequency and duration. *Water Resources Journal,* 37, 329-340.

Lawler, D. (2002). *Using Streambed Temperature Sensors to Monitor Flow Events in the San Pedro River, Southeast Arizona and North-Central Sonora, Mexico* (Master's Thesis). University of Arizona, Tucson, AZ. 68 p.

Levick, L., D. Goodrich, M. Hernandez, D. Semmens, J. Stromberg, R. Leidy, M. Apodaca, D. P. Guertin, M. Tluczek, and W. Kepner. (2007). Southwest Region Threatened, Endangered, and At-Risk Species Workshop: Managing Within Highly Variable Environments Hydrology and Ecology of Intermittent and Dry Wash Ecosystems USDA-ARS EPA/600/R-07/142, ARS/218464. US Department of Agriculture, Tucson, AZ. 20 p.

Linenfelser, B. (2007). *Evaluating waterbody assessment and listing processes: Integration of monitoring and evaluative techniques*. Water Environment Research Foundation (WERF). Alexandria, VA. 94 p.

Knight, K., T. Moody, W. Odem, and M. Wirtanen. (1999). *Stream Channel Morphology in New Mexico: Regional Relationships*. Department of Civil and Environmental Engineering, Northern Arizona University, Flagstaff, AZ. 53 p.

Maidment, D.R. (1993). *Handbook of Hydrology*. McGraw-Hill, Inc. New York. 1424 p.

National Drought Mitigation Center (NDMC). (1995). The Standardized Precipitation Index (SPI). School of Natural Resources, University of Nebraska – Lincoln. Retrieved at https://drought.unl.edu/droughtmonitoring/SPI/MapInterpretation.aspx

New Mexico Administrative Code (NMAC). (2007). *State of New Mexico Standards for Interstate and Intrastate Surface Waters. 20.6.4*. New Mexico Water Quality Control Commission. As amended through August 1, 2007.

North Carolina Division of Water Quality (NCDWQ). (2005). *Identification methods for the origins of intermittent and perennial streams. Version 3.1*. North Carolina Department of Environment and Natural Resources, Division of Water Quality. Raleigh, NC. 40 p.

North Carolina Division of Water Quality (NCDWQ). (2010). *Methodology for Identification of Intermittent and Perennial Streams and their Origins, Version 4.11*. North Carolina Department of Environment and Natural Resources, Division of Water Quality. Raleigh, NC. 43 p.

Rosgen, D.L. (1994). A classification of natural rivers. *Catena* 22, 169-199.

Rosgen, D.L. (1996). *Applied river morphology*. Wildland Hydrology. Pagosa Springs, Colorado. 378 p.

II. SURFACE WATER QUALITY STANDARDS

A. Extent of Authority

New Mexico's Standards for Interstate and Intrastate Surface Waters (20.6.4 NMAC) establish surface WQS that consist of designated uses for surface waters of the State, the water quality criteria necessary to protect the designated uses, and an Antidegradation Policy. These standards are not applicable to tribal waters within the exterior boundaries of a tribe or those lands to which the tribe has incorporated into federal trust. Section 518 of the CWA authorizes EPA to treat eligible Indian tribes with reservations in a similar manner to states (TAS) for administering each of the principal CWA regulatory programs. Therefore, protection of these waters is administered under the individual tribe's WQS as approved by EPA or by EPA for those tribes that have not received TAS under Section 518(e) of the CWA. The State of New Mexico does not have jurisdiction to adopt or impose WQS for tribal waters within NM's borders.

B. Objective

The Standards for Interstate and Intrastate Surface Waters state the following objective:

> *The State of New Mexico is required under the New Mexico Water Quality Act … and the federal Clean Water Act … to adopt water quality standards that protect the public health or welfare, enhance the quality of water, and are consistent with and serve the purposes of the New Mexico Water Quality Act and the federal Clean Water Act. It is the objective of the federal Clean Water Act to restore and maintain the chemical, physical, and biological integrity of the nation's waters, including those in New Mexico. This part is consistent with Section 101(a)(2) of the federal Clean Water Act, which declares that it is the national goal that wherever attainable, an interim goal of water quality that provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983. Agricultural, municipal, domestic and industrial water supply are other essential uses of New Mexico's surface water; however, water contaminants resulting from these activities will not be permitted to lower the quality of surface waters of the state below that required for protection and propagation of fish, shellfish and wildlife and recreation in and on the water, where practicable.* (20.6.4.6(B) NMAC).

C. Components of New Mexico's Surface Water Quality Standards

The federal WQS regulation (40 CFR 131) establishes the requirements for states and tribes to review, revise and adopt WQS. It also establishes the procedures for EPA to review, approve, disapprove and promulgate WQS pursuant to Section 303 (c) of the CWA. As such, WQS are designed to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act. New Mexico's WQS (20.6.4 NMAC), as required under the CWA, define water quality goals by designating uses for surface waters of the State, setting criteria to protect those uses, and establishing an Antidegradation Policy and implementation plan to preserve water quality. Each of these components is described in more detail below.

NMED Exhibit 64

Designated Uses

In accordance with 40 CFR 131.10, the State is required to specify goals and expectations for how each water body is used. The system for designating these uses is through development of surface WQS. Numeric criteria are adopted to protect each designated use. It is through the designation of a use for a specific waterbody that water quality protections are implemented.

Designated uses include fish culture, public water supply, industrial water supply, domestic water supply, irrigation and irrigation storage, primary contact, secondary contact, livestock watering, wildlife habitat, and several aquatic life subcategories. The full list of designated uses is specified in 20.6.4.900 NMAC.

Within each river basin, waters are divided into individual "segments" for classification and standard-setting purposes (20.6.4.101 through 20.6.4.899 NMAC). Most of the state's perennial water segments and many non-perennial segments have designated uses listed under 20.6.4.101 to 899 NMAC. All other "non-classified" waters are assigned default designated uses under 20.6.4.98 to 99 NMAC; however, some waters that have been characterized through a use attainability analysis have designated uses specified under 20.6.4.97 NMAC.

Water Quality Criteria

Water quality criteria are established to sustain and protect designated uses of surface waters of the State. States typically adopt both narrative criteria (e.g., general criteria that describe the desired condition of a surface water) and numeric criteria (e.g., maximum allowable pollutant concentration in a surface water).

The State of New Mexico has adopted narrative, or general, criteria under 20.6.4.13 NMAC. General criteria apply to all surface waters of the state and declare that:

> *"…surface waters of the State shall be free of any water contaminant in such quantity and of such duration as may, with reasonable probability, injure human health, animal or plant life or property, or unreasonably interfere with the public welfare or the use of property."*

As identified under Subsections A to M of 20.6.4.13 NMAC, New Mexico's general criteria include: bottom deposits and suspended or settleable solids; floating solids, oil and grease; color; organoleptic quality (odor and taste of fish and water); plant nutrients; toxic pollutants; radioactivity; pathogens; temperature; turbidity; total dissolved solids (TDS); dissolved gases; and biological integrity.

Numeric criteria are specific quantitative limits for pollutants established to protect specific designated uses and specific WQS segments. Use-specific numeric criteria are provided in 20.6.4.900 NMAC and apply to all waters with the applicable designated uses, unless otherwise specified in 20.6.4.101 through 20.6.4.899 NMAC as segment-specific criteria. The WQS also include numeric "human health-organism only" criteria established to protect human health when aquatic organisms are consumed from waters containing pollutants.

Antidegradation Policy

New Mexico's Antidegradation Policy, which is based on requirements in 40 CFR 131.12, describes how waters are to be protected from degradation (Subsection A of 20.6.4.8 NMAC). At a minimum, the policy protects existing instream uses. Water quality that exceeds the levels necessary to support the propagation of fish, shellfish, and wildlife, and recreation in and on the water is to be maintained unless the WQCC finds that allowing lower water quality is necessary to accommodate important economic and social development. Waters designated as Outstanding National Resource Waters (ONRWs) are to receive the highest level of antidegradation protection. Designated ONRWs are listed in 20.6.4.9 NMAC.

D. Process for Establishing and Updating Water Quality Standards

[As required by 40 CFR 130.5(b)(6) for CPP]

General Process for Establishing or Revising Water Quality Standards

Under the State's WQA, NMSA 1978, Section 74-6-2(H), the duties and powers of the WQCC include adoption of standards for surface and groundwaters of the state. Anyone may propose new or revised standards to the WQCC at any time in accordance with the rulemaking procedures for the WQCC (20.1.6 NMAC) and the State's WQS (20.6.4 NMAC). These regulations specify requirements for pre-hearing procedures and petitions for regulatory changes, hearing notices, hearing participation, post-hearing actions and appeals. It is recognized that notification and engagement of the public prior to petition is vital to the rule-making process and, therefore, additional requirements have been identified under this WQMP/CPP to encourage participation, allow effective presentation of evidence and points of view, allow participants an opportunity to submit information, and assure that hearings are conducted in a fair and equitable manner. For all proposed changes to the State's WQS, the WQCC bases its decision on evidence presented at the public hearing.

The process to adopt new or amended surface WQS conforms to requirements under numerous federal and state acts including, but not limited to, the CWA (33 U.S.C. § 1251 *et seq)*, the Endangered Species Act (16 U.S.C. §1531 *et seq*), the Civil Rights Act (18 U.S.C. § 241 *et seq*), the Americans with Disabilities Act (42 U.S.C. 12101 *et seq*), the Freedom of Information Act 5 U.S.C. § 552, the WQA (NMSA 1978, Section 74-6-4), the New Mexico State Rules Act (NMSA 1978, Section 14-4-1), and the New Mexico Open Meetings Act (NMSA 1978, Section 10-15-1).

New or amended WQS codified under 20.6.4 NMAC, as adopted by the WQCC, are filed with the State Records Center pursuant to the regulatory provisions under the State's WQA (NMSA 1978, Section 74-6-1 *et seq.*) and the State Rules Act (NMSA 1978, Section 14-4-1 *et seq.*), and in accordance with the State's regulations for rules filed under 1.24.1 NMAC. The new or amended standards become effective for state purposes thirty (30) days after filing.

New or revised surface WQS adopted by the WQCC are certified by the State Attorney General as being duly adopted pursuant to state laws and then submitted by the WQCC to the EPA Region

6 Administrator. In accordance with the CWA Section 303(c)(3), the EPA Administrator must determine, within sixty days of submission, if the new or amended WQS meet the requirements of the CWA. If the Administrator determines that any such revised or new standard is not consistent with the applicable requirements of the CWA, the Administrator shall notify the State and specify the changes to meet such requirements no later than the ninetieth day after the date of submission. If the State does not remedy the deficiencies, EPA will publish proposed regulations and promulgate a standard to supersede the disapproved State standard.

Establishing or Revising Water Quality Standards through the Triennial Review

Section 303(c)(1) of the CWA requires the State to hold public hearings for the purpose of reviewing WQS including standards that do not include the uses specified in section 101(a)(2) of the Clean Water Act and, as appropriate, amend and adopt standards at least once every three years. This review is referred to as a "Triennial Review." The WQCC conducts a Triennial Review of the State's surface WQS as required by Section 303(c)(1) of the CWA and 20.6.4.10 NMAC. NMED is delegated the responsibility for organizing and presenting the Triennial Review at the required intervals. The general process for establishing or revising water quality standards described above are followed for Triennial Review proceedings.

Establishing or Revising a Designated Use through a Use Attainability Analysis

The process for establishing or revising a designated use occurs through the development of a Use Attainability Analysis (UAA). The UAA is a scientific study that assesses the factors affecting the attainment of a designated use. In accordance with 20.6.4.15 NMAC, the UAA is required to be conducted before a designated use specified in Section 101 (a)(2) of the CWA may be removed or changed to a subcategory requiring less stringent criteria. The uses specified in Section 101(a)(2) of the CWA "provides for the protection and propagation of fish, shellfish, and wildlife, and provides for recreation in and on the water." The established designated uses meeting this goal in the State's WQS include the wildlife habitat use, the primary and secondary contact use, and all aquatic life use subcategories except the limited aquatic life use.

In order for a state to designate a use, or remove a use that is not an existing use, the UAA must demonstrate that attainment of the use is not feasible based on one of the factors identified at 40 CFR 131.10(g):

(1) Naturally occurring pollutant concentrations prevent the attainment of the use; or

(2) Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met; or

(3) Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or

(4) Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or

(5) Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or

(6) Controls more stringent than those required by sections 301(b) and 306 [technology-based effluent limitations] of the Act would result in substantial and widespread economic and social impact.

A UAA may be conducted by the Department or, in accordance with Subsection D of 20.6.4.15 NMAC, by any person who submits notice to the Department with intent to conduct a UAA. A UAA must rely on a scientifically defensible method and the result, should it support a designated use change under one of the six factors under 40 CFR 131.10(g), must undergo the same administrative review and hearing process as that for the Triennial Review.

Prior to commencement of any investigation, third-parties seeking to conduct a UAA, shall submit a work plan to the Department and EPA for review. Upon approval of the work plan by the Department, the proponent may then conduct the UAA. Upon completion, data, findings and conclusions will be submitted to the Department and either the proponent or the Department may proceed with the administrative review and hearing process for the designated use change. As with the Triennial Review process, the change shall not be considered effective for State purposes until approved by the WQCC and published with an effective date in the New Mexico Register. For CWA purposes, the designated use change shall only be considered effective following EPA review and approval process described above.

For a designated use change that is being proposed based on evidences of the natural, ephemeral, intermittent or low flow conditions as identified under 40 CFR 131.10(g)(2), the *Hydrology Protocol* method under Appendix C of this WQMP/CPP is recommended. The *Hydrology Protocol* was designed as a multi-parameter evaluation to determine the natural hydrologic conditions of a waterbody and the associated designated uses that should be attainable. For studies investigating a possible designated use change due to hydrologic conditions under 40 CFR 131.10(g)(2), consideration must be taken for any supplemental flows attributed to permitted effluent discharges.

Existing uses, defined in the WQS as "a use actually attained in a surface water of the state on or after November 28, 1975, whether or not it is a designated use", may not be removed regardless of the outcome of a UAA unless a use with more stringent criteria is added. (40 CFR 131.10(h) and Subsection A of 20.6.4.15 NMAC).

Establishing or Revising a Designated Use using the *Hydrology Protocol*

There are three primary types of hydrologic conditions defined under the WQS in New Mexico, each of which has established designated uses for protections under Section 101(a)(2) of the CWA. These include listed ephemeral waters (20.6.4.97 NMAC), general intermittent waters (20.6.4.98 NMAC), and general perennial waters (20.6.4.99 NMAC). In addition, the State's WQS also identify many classified waters by their hydrology, e.g., "perennial tributaries to" or "perennial reaches of" (20.6.4.101 to 899 NMAC).

NMED Exhibit 64

The *Hydrology Protocol,* attached as Appendix C, is primarily used to provide scientific technical support for a designated use change through a UAA based on natural, ephemeral, intermittent or low flow conditions or water levels that prevent the attainment of the designated use. Since the *Hydrology Protocol* is done in support of a UAA, it can be conducted either by the Department, or by an entity other than the Department. If an entity other than the Department conducts this type of analysis, a UAA workplan for the use of the *Hydrology Protocol* must be submitted to the Department for review and approval in accordance with Subsection D of 20.6.4.15 NMAC before proceeding with the survey.

For waterbodies that are classified under 20.6.4.101 to 899 NMAC, the State asserts protections for these waters under the classified segment. A survey using the *Hydrology Protocol* can be used to confirm or delineate segment-specific hydrological regimes that may or may not lead to a revision to the State's WQS. For example, numerous classified segments in the WQS include only perennial waters, without specifically identifying which reaches are perennial (e.g., "perennial reaches of…", "perennial tributaries to…"). In such cases, the *Hydrology Protocol* can be used to determine whether a waterbody in whole, or a segment of the waterbody is perennial and therefore included in the classified segment, or non-perennial and therefore subject to the designated uses and criteria for general non-perennial waters in 20.6.4.98 NMAC. Such determinations do not require a UAA or a hearing because they do not change the designated uses or criteria but merely allow for the applicable uses to be properly identified. However, if a revision to incorporate the results of the *Hydrology Protocol* survey are needed to further refine, delineate or re-classify a waterbody under 20.6.4.101 to 899 NMAC this must be done through the UAA process.

For waterbodies that are perennial but have not been classified under 20.6.4.101 to 899 NMAC, the State asserts perennial protections for these waters under 20.6.4.99 NMAC. A survey using the *Hydrology Protocol* may be used to verify the hydrological regime for these unclassified perennial waters. A revision to incorporate the results of the *Hydrology Protocol* survey to classify a waterbody under 20.6.4.101 to 899 NMAC is done through the UAA process.

For the waterbodies in the State that are non-perennial but have not undergone an in-depth investigation to determine the hydrologic regime (i.e., intermittent, ephemeral), the State asserts intermittent protections for these waters under 20.6.4.98 NMAC, consistent with the goals in Section 101(a)(2) of the CWA. If the results of the *Hydrology Protocol* survey indicate that the waterbody is in fact intermittent, no further action is required because it is protected, by default, under 20.6.4.98 NMAC for intermittent waters.

For those cases in which the results of the *Hydrology Protocol* survey demonstrate that an unclassified non-perennial waterbody is ephemeral, designated uses that are not existing uses may only be changed if a UAA is conducted according to 40 CFR 131.10(g) and 20.6.4.15 NMAC in order for the State to assert protections for the ephemeral waterbody under 20.6.4.97 NMAC.

In some cases, an expedited UAA process outlined under Subsection C of 20.6.4.15 NMAC and illustrated in Figures II-1 and II-2 may be pursued. The expedited UAA process is not applicable for entities other than the Department. However, this does not preclude third-parties from developing and executing a workplan for the use of the *Hydrology Protocol* and submitting the UAA to the Department for use in the expedited process. The expedited UAA process facilitates the efficient application of the limited aquatic life and secondary contact uses to ephemeral waters where appropriate. As described under Subsection C of 20.6.4.15 NMAC, it is the Departments' role and responsibility to post the use attainability analysis on its water quality standards website, notify its interested parties of a 30-day public comment period, submit to EPA and if given technical approval, petition and testify regarding the standards changes before the WQCC periodically.

The *Hydrology Protocol* can also be used to support other factors under 40 CFR 131.10(g), such as those attributed to hydrological modifications, and provide additional evidence that "it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use." 40 CFR 131.10(g)(4).

Persons or entities proposing to conduct a UAA using the *Hydrology Protocol* must submit a UAA workplan for the use of the *Hydrology Protocol* to the SWQB for review and approval before proceeding (Subsection D of 20.6.4.15 NMAC). Such an approach will help ensure that the *Hydrology Protocol* and UAA process proceed smoothly, without delay, and that the study will comply with applicable statutes and rules.

Figure II-1. The *Hydrology Protocol* can be used to evaluate an unclassified water, an unnamed waterbody within a classified segment, or a classified waterbody. This flow chart depicts the primary pathways to determining or amending the applicable water quality standards based on the *Hydrology Protocol* results.

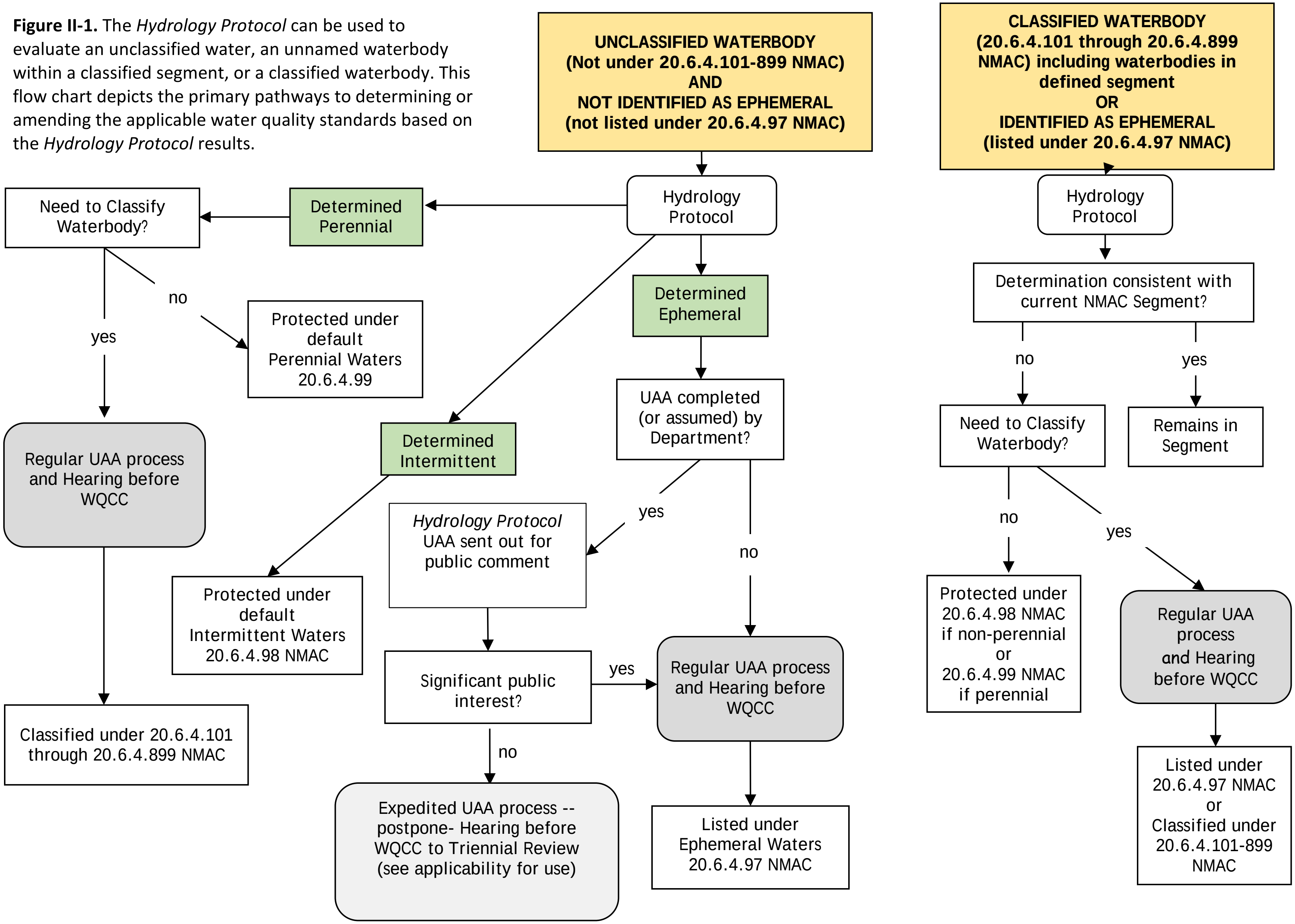
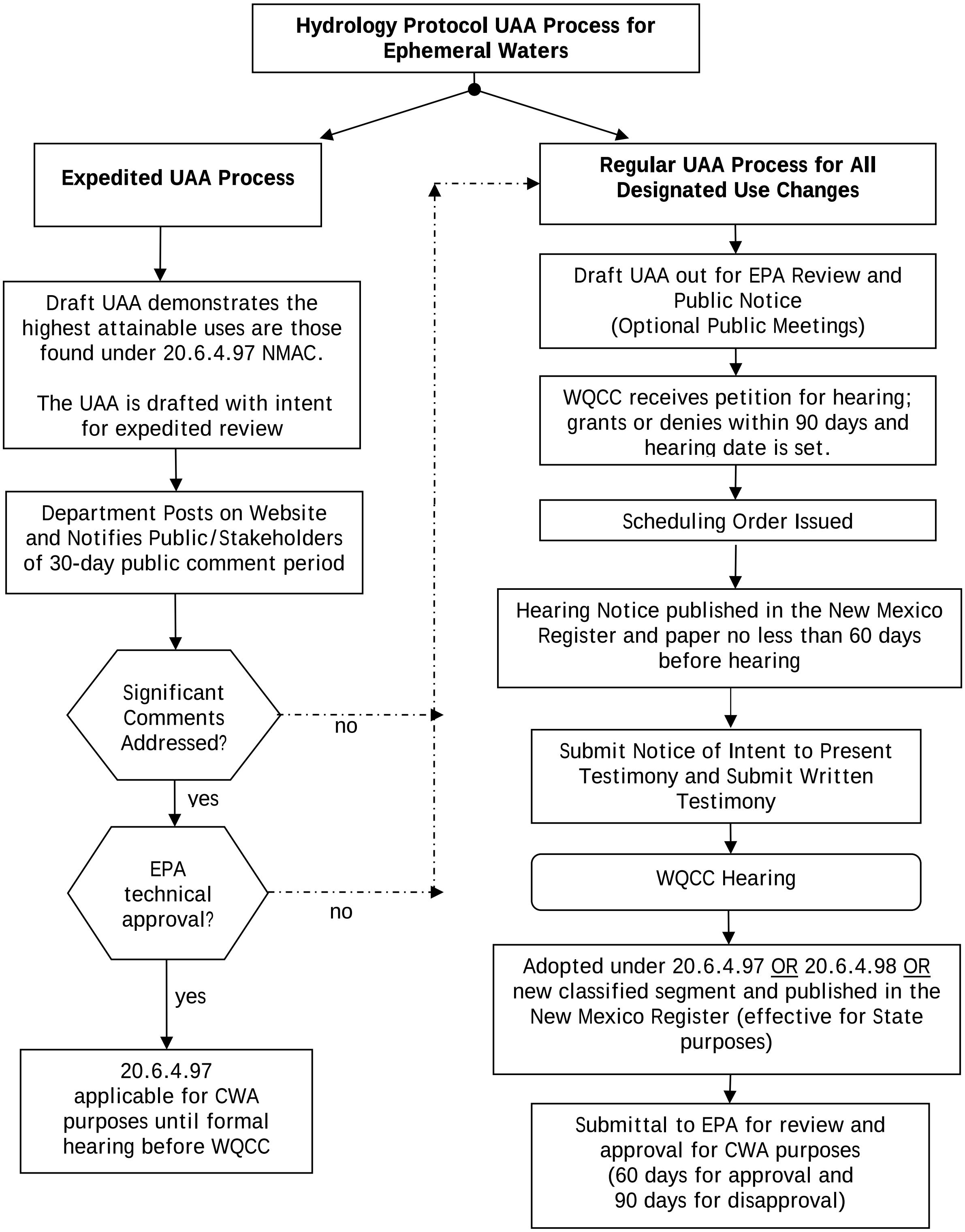


Figure II-2. Flow chart compares the expedited UAA process for an ephemeral stream determined through a hydrology protocol with the UAA process.



Establishing or Revising a Site-Specific Standard

In accordance with 20.6.4.10 NMAC, there are circumstances such as species sensitivity; site specific physical, chemical or biological conditions that alter bioaccumulation of a chemical; or natural background concentrations that exceed a particular numeric criterion for an established designated use that warrants inclusion or updating due to site specific conditions. The commission may adopt site-specific numeric criteria based on relevant site-specific conditions pertaining to those conditions listed under 20.6.4.10(D)(1).

Any person may petition the commission to adopt site-specific criteria, giving a thorough explanation of the rational for the proposal that justifies the proposed criteria and relying on scientifically defensible methods that demonstrate the site-specific criteria fully protects the designated use, such as those listed under Subsection D(4) of 20.6.4.10 NMAC. In the same process for establishing or revising designated uses for waterbodies, establishing site-specific standards requires the petitioner (the State or other party) to submit demonstration of the supporting evidence for the standard. The process to petition for a site-specific criteria is a rulemaking under 20.6.4 NMAC and requires adherence to rulemaking processes by the WQCC under 20.1.6 NMAC.

Process for Establishing or Revising a Temporary Standard

When a waterbody has been determined to have the appropriate designated use, but specific limiting conditions prevent the attainment of that use in the short-term, the WQCC may adopt a temporary standard. A temporary standard is a time-limited designated use and criterion for a specific pollutant(s) or water quality parameter(s) that reflects the highest attainable condition during the term of the temporary standard. A temporary standard is a change in a designated use, and therefore, must be adopted by the WQCC and EPA under rule-making procedures, just as with any other water quality standard amendment. A temporary standard may be granted if the petitioner can meet the applicability and demonstration requirements identified under 20.6.4.10(F) NMAC. .

Water Quality Standards for Wetlands

Wetlands in New Mexico are protected as “surface waters of the state.” However, wetland-specific designated uses and criteria associated with those uses have not been developed. Wetlands designated and protected as ONRWs are identified in the *Maps and List of Wetlands Within United States Forest Service Wilderness Areas Designated as Outstanding National Resource Waters* (Subsection D(3)(h) of 20.6.4.9 NMAC). Other wetlands not identified as ONRWs and not identified as a classified water in sections 20.6.4.101 through 20.6.4.899 NMAC are protected through the designated uses identified in 20.6.4.98 and 20.6.4.99 NMAC, depending on their hydrology.

SWQB is working toward increasing wetlands protection through monitoring and strengthening WQS that pertain to the State’s wetlands resources. To achieve these goals the SWQB is currently:

- developing a Rapid Assessment Methodology for New Mexico (NMRAM) for a range of environments and wetland types;
- mapping wetland resources in New Mexico; and,
- ranking the condition of existing wetlands.

SWQB will utilize the information gathered from the monitoring effort to propose wetland-specific state WQS to the WQCC. This information and data will also be used to assess the effectiveness of wetland restoration and mitigation activities.

E. Process for Assuring Adequate Implementation of Water Quality Standards

[As required by 40 CFR 130.5(b)(6) for CPP]

NMED, acting under the authority delegated by the WQCC, implements the WQS by establishing and maintaining controls on the discharge of point source and non-point source pollutants to surface waters of the state. This occurs through ongoing monitoring and assessment of water quality to the State's approved WQS (*see* Section III of this WQMP/CPP); evaluation of proposed discharges in accordance with the Implementation Plan described at Subsection B of 20.6.4.8 NMAC and the State's *Antidegradation Policy Implementation Procedure* (Appendix A of this WQMP/CPP); establishment of controls on point source pollutant discharges as described under Section V of this WQMP/CPP; and through Best Management Practices (BMPs) applied to nonpoint sources of pollution, as outlined under the State's Nonpoint Source Management Program (NPSMP) and Section VII of this WQMP/CPP. Violations of the WQS are enforceable through civil and/or criminal actions pursuant to the WQA at NMSA 1978, Section 74-6-10.

B. **Bacteriological Surveys**: The monthly geometric mean shall be used in assessing attainment of criteria when a minimum of five samples is collected in a 30-day period.

C. **Sampling Procedures**:

(1) Streams: Stream monitoring stations below discharges shall be located a sufficient distance downstream to ensure adequate vertical and lateral mixing.

(2) Lakes: Sampling stations in lakes shall be located at least 250 feet from a discharge.

(3) Lakes: Except for the restriction specified in Paragraph (2) of this subsection, lake sampling stations shall be located at any site where the attainment of a water quality [~~standard~~] criterion is to be assessed. Water quality measurements taken at intervals in the entire water column at a sampling station shall be averaged for the epilimnion, or in the absence of an epilimnion, for the upper one-third of the water column of the lake to determine attainment of criteria, except that attainment of criteria for toxic pollutants shall be assessed during periods of complete vertical mixing, e.g., during spring or fall turnover, or by taking depth-integrated composite samples of the water column.

215. The Commission adopts the Department's proposal to replace "standard" with "criterion" for the reasons given in section 12.E.

D. Acute toxicity of effluent to aquatic life shall be determined using the procedures specified in U.S. environmental protection agency "methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms" (5th Ed., 2002, EPA 821-R-02-012), or latest edition thereof if adopted by EPA at 40 CFR Part 136, which is incorporated herein by reference. Acute toxicities of substances shall be determined using at least two species tested in whole effluent and a series of effluent dilutions. Acute toxicity due to discharges shall not occur within the wastewater mixing zone in any surface water of the state with an existing or designated use.

216. The Commission adopts the Department's proposal to correct the name of the document cited.

E. Chronic toxicity of effluent or ambient surface waters of the state to aquatic life shall be determined using the procedures specified in U.S. environmental protection agency "Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms" (4th Ed., 2002, EPA 821-R-02-013), or latest edition thereof if adopted by EPA at 40 CFR Part 136, which is incorporated herein by reference. Chronic toxicities of substances shall be determined using at least two species tested in ambient surface water or whole effluent and a series of effluent dilutions. Chronic toxicity due to discharges shall not occur at the critical low flow, or any flow greater than the critical low flow, in any surface water of the state with an existing or designated aquatic life use more than once every three years.
[20.6.4.14 NMAC - Rp 20 NMAC 6.1.1106, 10-12-00; Rn, 20.6.4.13 NMAC, 05-23-05, A, 05-23-05]

20.6.4.15 USE ATTAINABILITY ANALYSIS:

A. A use attainability analysis is a scientific study [~~that shall be~~] conducted [~~only~~] for the purpose of assessing the factors affecting the attainment of a use. Whenever a use attainability analysis is conducted, it shall be subject to the requirements and limitations set forth in 40 CFR Part 131, Water Quality Standards; specifically, Subsections 131.3(g), 131.10(g), 131.10(h) and 131.10(j) shall be applicable.

217. The Commission adopts the Department's proposal to change the first sentence to describe a UAA rather than restrict when a UAA may be conducted to more accurately reflect the intent of the section.

218. The federal regulations cited in the last clause concern the removal or non-designation of section 101(a)(2) "fishable/swimmable" uses; this section has the same focus. To remove or exclude a section 101(a)(2) use from a particular water body, a UAA must demonstrate that the use is not attainable.

219. This demonstration is not required for other types of changes to the Standards, e.g., removing designated uses such as irrigation or industrial water supply, retaining a use with less stringent criteria, or adjusting the criteria associated with uses in Section 900. While these other types of changes must be justified, they are not subject to the UAA requirement of this section.

220. The Commission does not adopt Amigos Bravos' proposal to add references to sections 131.20(a) and (c) in Section A because it is not supported by substantial evidence in the record and would place a considerable burden on NMED. Section 131.20(a) requires a triennial review of the water quality standards, including a review of new information pertaining to water bodies whose designated uses do not include section 101(a)(2) uses. It neither requires a UAA nor sets UAA requirements. Section 131.20(c) requires States to submit the results of the triennial review to EPA, but does not set any requirements relating to conducting a UAA. If any person or entity wishes to conduct a re-examination and revise a UAA, they are free to do so under existing regulations.

(1) [~~Any person who proposes to classify, or reclassify to a designated use with less stringent criteria, a surface water of the state with designated uses that do not include the uses specified in Section 101(a)(2) of the federal Clean Water Act must conduct~~] The commission may remove a designated use specified in Section 101(a)(2) of the federal Clean Water Act or adopt subcategories of a Section 101(a)(2) use requiring less stringent criteria only if a use attainability analysis demonstrates that attaining the use is not feasible because of a factor listed in 40 CFR 131.10(g). Section 101(a)(2) uses, which refer to the protection and propagation of fish, shellfish and wildlife and recreation in and on the water, are also specified in Subsection B of 20.6.4.6 NMAC.

221. The Commission adopts the Department's proposal to clarify when a UAA is required and what it must demonstrate because it clarifies the two scenarios that require a UAA

for a particular water body: (1) removing a section 101(a)(2) use; and (2) adopting subcategories of a section 101(a)(2) use with less stringent criteria. 40 CFR 131.10(j) states, in essence, that section 101(a)(2) uses cannot be removed or omitted unless they are unattainable, and the UAA is the tool to demonstrate that a use is unattainable.

222. In New Mexico, primary contact and all aquatic life use subcategories except limited aquatic life constitute section 101(a)(2) uses.

223. The Commission adopts the Department's proposal to add the phrase "which refer to the protection and propagation of fish, shellfish and wildlife and recreation in and on the water" to enhance readability for readers not familiar with section 101(a)(2) uses.

224. The Commission adopts the Department's proposal to clarify the Commission's responsibility in the UAA process because it identifies the Commission as the entity authorized to change a designated use, rather than the person making a proposal. This language also parallels 40 CFR 131.10.

225. The Commission adopts the Department's proposal to remove the reference to the undefined term "classify" because the UAA requirement applies to all surface waters of the state, both classified and unclassified.

226. "Classified water of the state" is a defined term in section 7 which refers to the waters identified in sections 101-899. Designated uses and criteria also apply to the unclassified waters identified in sections 97-99.

227. The Commission adopts the Department's proposal to clarify the factors which must be established in a UAA to prove that a use is not feasible because section 15 should provide clear direction on this point. The EPA identifies the referenced factors in 40 CFR 131.10(g).

(2) A designated use cannot be removed if it is an existing use unless a use requiring more stringent criteria is designated.

228. The Commission adopts the Department's proposal to add the phrase "unless a use requiring more stringent criteria is designated" because the federal regulations at 40 CFR 131.10(h) allows this exception.

229. For example, it is appropriate to remove "fish culture" as a designated use when a hatchery is no longer operating because no criteria are specifically applied to the fish culture use. The use can be removed so long as an aquatic life use is designated, because the criteria applicable to aquatic life uses are more stringent than the criteria applicable to the fish culture use.

[~~(3) A use attainability analysis or an equivalent study approved by the department and the regional administrator must be conducted to remove any non existing designated use from any classified waters of the state.~~]

230. The Commission adopts the Department's proposal to delete this paragraph as no longer necessary. Paragraph (1) already specifies when a UAA is needed, paragraph (2) prohibits the removal of existing uses, and revised subsection C (formerly subsection E) requires input from the Department and EPA when a UAA is conducted by another party.

231. The Commission does not adopt Amigos Bravos' proposal for section (3) because Amigos Bravos proposes to restate a portion of 40 CFR 131.20(a) in the Standards, which is unnecessary and misplaced. The Department reviews these waters during the triennial review when it solicits comments and proposals on the entirety of 20.6.4 NMAC, as required by federal law.

232. Moreover, the proposal concerns only review of additional information, not the preparation of a new UAA. If such a provision were added to the Standards, it should be placed in section 10(A), which governs the triennial review process.

B. [~~Physical, chemical and biological evaluations of surface waters of the state other than lakes and reservoirs for purposes of use attainability analyses or equivalent studies shall be conducted according to the procedures outlined in the "technical support manual: waterbody surveys and assessments for conducting use attainability analyses," United States environmental protection agency, office of water, regulations and standards, Washington, D.C., November 1983, or latest edition thereof, which is incorporated herein by reference, or an alternative equivalent study methodology approved by the department.~~

~~**C.** Physical, chemical and biological evaluations of lakes and reservoirs for purposes of use attainability analyses or equivalent studies shall be conducted according to the procedures outlined in the "technical support manual: waterbody surveys and assessments for conducting use attainability analyses, volume III: lake systems," United States environmental protection agency, office of water, regulations and standards, Washington, D.C., November 1984, or latest edition thereof, which is incorporated herein by reference, or an alternative equivalent study methodology approved by the department.~~

~~**D.** A use attainability analysis or equivalent study should include:~~

~~**(1)** identification of existing uses of the surface water of the state to be reviewed that have existed since 1975;~~

~~(2) an evaluation of the best water quality attained in the surface water of the state to be reviewed that has existed since 1975;~~

~~(3) an analysis of appropriate factors demonstrating that attaining the designated use is not feasible because of the condition listed in 40 CFR Part 131.10(g);~~

~~(4) a physical evaluation of the surface water of the state to be reviewed to identify factors that impair attainment of designated uses and to determine which designated uses are feasible to attain in such surface water of the state;~~

~~(5) an evaluation of the water chemistry of the surface water of the state to be reviewed to identify chemical constituents that impair the designated uses that are feasible to attain in such water; and~~

~~(6) an evaluation of the aquatic and terrestrial biota utilizing the surface water of the state to determine resident species and which species could potentially exist in such water if physical and chemical factors impairing a designated use are corrected.~~] A use attainability analysis shall assess the physical, chemical, biological, economic or other factors affecting the attainment of a use. The analysis shall rely on scientifically defensible methods such as the methods described in the following documents:

(1) Technical support manual: waterbody surveys and assessments for conducting use attainability analyses, volume I (November 1983) and volume III (November 1984) or latest editions, United States environmental protection agency, office of water, regulations and standards, Washington, D.C., for the evaluation of aquatic life or wildlife uses;

(2) The department's hydrology protocol, latest edition, approved by the commission, for identifying ephemeral and intermittent waters; or

(3) Interim economic guidance for water quality standards – workbook, March 1995, United States environmental protection agency, office of water, Washington, D.C. for evaluating economic impacts.

233. The Commission adopts the Department's proposal to redraft subsections B, C and D to provide simpler and more accurate guidance.

234. A UAA must assess the factors affecting the attainment of a use. Because those factors vary by situation, the deleted sections would be appropriate for only some UAAs. For example, subsection D required that every UAA contain an evaluation of the best water quality attained in the water body, even though that information may not be relevant for determining whether an ephemeral stream will support fish populations. Subsections B and C referenced EPA's Technical Support Manuals which may be used to evaluate aquatic life uses, but are not applicable to recreational and other uses.

235. The revised language replaces these specific references with a general requirement that the methods must be scientifically defensible. The identified methods are illustrative only. This approach allows flexibility without compromising quality.

236. The identified methods include the Department's Hydrology Protocol. The Department will develop the protocol as a tool to distinguish between different types of waters, using a combination of hydrological, geomorphic, and biological characteristics.

237. The protocol will include a numerical rating system to produce an objective, practical scoring mechanism for determining stream hydrology. If field characteristics are not sufficient to make this determination, the Department will incorporate other information, such as long-term flow data and observations by local stakeholders and professionals.

238. The Department will present the protocol to the Commission for its consideration and approval in a separate process.

C. If a use attainability analysis based on the department's hydrology protocol (latest edition), approved by the commission, demonstrates to the satisfaction of the department that Section 101(a)(2) uses are not feasible in an ephemeral water body, the department shall post the use attainability analysis on its water quality standards website and notify its interested parties list of a 30-day public comment period. After reviewing any comments received, the department may proceed by submitting the use attainability analysis and response to comments to region 6 EPA for technical approval. If technical approval is granted, the water shall be subject to 20.6.4.97 NMAC. The use attainability analysis, the technical approval, and the applicability of 20.6.4.97 NMAC to the water shall be posted on the department's water quality standards website. The department shall periodically petition the commission to list ephemeral waters under Subsection C of 20.6.4.97 NMAC and to incorporate changes to classified segments as appropriate.

239. The Commission adopts the Department's proposed process for authorizing the application of section 97 to ephemeral waters between rulemaking proceedings to provide for an expedited application of the Commission-approved section 97 uses and criteria, include adequate safeguards to prevent the inappropriate downgrading of a water, and meet EPA's requirements.

240. The process is similar to section 13.F, which establishes a process for deriving and implementing criteria for toxic pollutants not identified in the Standards.

241. UAAs must be complete and thorough. Most UAAs for ephemeral waters are expected to be straightforward; the process will expeditiously apply the appropriate criteria, avoiding inappropriate impairment listings on the CWA 303(d)/305(b) List of Assessed Waters and undue requirements on dischargers.

242. The Department must periodically petition the Commission to formally list the affected waters in section 97(C) of the Standards. "Periodically" means, at a minimum, during the triennial review. In some cases, the water or portion thereof may have been included in a classified segment, so the petition would seek to amend the classified segment as well, as reflected in the phrase "and to incorporate changes to classified segments as appropriate."

243. The process contains several safeguards against inappropriately downgrading a water. First, the Commission must approve the hydrology protocol. Second, the Department must prepare a UAA. Third, the public may comment on the UAA, and the Department must respond to comments. Fourth, the EPA must grant technical approval of the UAA. Finally, the Commission must agree to list the water in section 97(C).

244. While this process has the potential to be more expeditious than the regular UAA approach, it does not relegate the Commission to a rubber-stamp role. The Commission will retain its full authority under the WQA, and its disapproval of a petition to list a water under section 97(C) would restore the original criteria.

245. The Commission does not adopt Amigos Bravos' proposal to require public notice and to allow for a public comment period in Section C because the Department has already incorporated a public comment period into its section 15.C proposal.

[~~E~~]D. Use attainability analysis conducted by an entity other than the department. Any person may submit notice to the department stating [~~that they intend~~] the intent to conduct a use attainability analysis [~~or equivalent study~~]. The proponent shall develop a work plan to conduct the use attainability analysis [~~or equivalent study~~] and shall submit the work plan to the department and [~~the regional~~] region 6 EPA [~~staff~~] for review and comment. The work plan [~~should~~] shall identify the scope of data currently available and [~~proposed~~] the scope of data to be gathered, the factors affecting use attainment that will be analyzed and [~~must contain~~] provisions for public notice and consultation with appropriate state and federal agencies. [~~A copy of the notice and the work plan must be submitted concurrently to the commission.~~] Upon approval of the work plan by the department, the proponent shall conduct the use attainability analysis [~~or equivalent study~~] in accordance with the approved work plan. The cost of such analysis [~~or equivalent study~~] shall be the responsibility of the proponent. Upon completion of the use attainability analysis [~~or equivalent study~~], the proponent shall submit the data, findings and conclusions to the department. [~~and the commission.~~
~~F. If the department determines that the analysis or equivalent study was conducted in accordance with the approved work plan and the findings and conclusions are based upon sound scientific rationale, and demonstrates that it is not feasible to attain the designated use, the~~] The department or the proponent may [~~request~~] petition the commission to [~~initiate rulemaking proceedings to~~] modify the designated use [~~for the surface water of the state that was reviewed~~] if the conclusions of the analysis support such action.

246. The Commission adopts the Department's proposal to add a header to clarify that the subsection pertains to UAAs conducted by an entity other than the Department.

247. The Commission adopts the Department's proposal to delete "or equivalent study" because the term is not necessary. Any study is a UAA if conducted "for the purpose of assessing the factors affecting the attainment of a use" as described in subsection A.

248. The Commission adopts the Department's proposal to delete the requirement to submit the notice of intent or UAA findings to the Commission because the UAA need only be submitted to the Commission when a petition is presented to amend the Standards.

249. The Commission adopts the Department's proposal to combine and simplify subsections E and F because revised subsection A stipulates that a UAA must demonstrate that "attaining the use is not feasible because of a factor listed in 40 CFR 131.10(g)", and revised subsection B requires that the UAA must be based on scientifically defensible methods. These requirements need not be repeated here.

250. NMED's proposal is consistent with the WQA, CWA and with 40 C.F.R. § 131.10, and is a process which is similar to those consistently endorsed and approved by EPA. The WQA broadly authorizes the WQCC to "assign responsibility for administering its regulations to constituent agencies." NMSA 74-6-4(F).

251. This authority to delegate responsibility for administering regulations authorizes the WQCC to assign responsibility to NMED to implement the expedited UAA process under NMAC 20.6.4.15, which is ultimately subject to technical approval by EPA and final approval by the WQCC.

252. NMED's stated that it will work with stakeholders in a separate process to develop an appropriate hydrology protocol and that expedited hydrology protocol-based UAAs will be available on a local, regional, or watershed basis.

253. Requiring a separate UAA for every water body unable to meet fishable/swimmable standards would be a much more burdensome process, for NMED and those individuals who will be depending on these UAAs. Regional and categorical UAAs are permitted by the EPA, as evidenced by the implementation of a regional/state-wide UAA in Arizona.

254. In commenting on the provisions adopted in New Mexico's last triennial review, the EPA "recommend[ed] that New Mexico develop a comprehensive or categorical UAA." (EPA Review of Revisions to New Mexico's Standard's for Interstate and Intrastate Surface Waters, 20.6.4 at 41 (Dec. 29, 2006)).

255. Water quality standards currently permit regional UAAs because the regulations do not specify that a UAA has to be done for one particular water. Including a provision in the regulations that explicitly allows regional or categorical UAAs is consistent with NMED's understanding of the water quality standards.

20.6.4.52 PECOS RIVER BASIN – In order to protect existing and designated uses, it is a goal of the state of New Mexico to prevent increases in TDS in the Pecos river above the following benchmark values, which are expressed as flow-weighted, annual average concentrations, at three USGS gaging stations: at Santa Rosa 500 mg/L; near Artesia 2,700 mg/L; and near Malaga 3,600 mg/L. The benchmark values serve to guide state action. They are adopted pursuant to the New Mexico Water Quality Act, not the Clean Water Act.
[20.6.4.52 NMAC – N, XX-XX-XX]

256. The Commission adopts the Department's proposed benchmark values for salinity in the Pecos River Basin because it provides a valuable tool for tracking a critical water quality characteristic in this important watershed.

257. The lower Pecos River is subject to high salinity concentrations that present challenges for designated uses such as irrigation and public water supply. TDS concentrations vary depending on flow conditions, with higher concentrations at lower flows. The salinity increases as one moves downstream from Santa Rosa. At the USGS gaging station near Artesia, the median and maximum TDS concentrations are 4,785 and 18,000 mg/L. These values far exceed optimum concentrations for irrigation and drinking water. The data illustrate both the general magnitude of the concentrations and their variability. Water managers must take these factors into account when determining how to satisfy demands in the basin.

258. Segments 201, 202, 206, 207, 211 and 216 currently specify TDS criteria ranging from 3,000 to 20,000 mg/L for the Pecos River and some tributaries upstream of Santa Rosa. These criteria apply at flows of 50 cfs or greater. The criteria are consistent with the observed higher concentrations along the river. The expected high concentrations that periodically occur, therefore, do not result in exceedances. However, if significant new saline discharges were proposed in the lower basin, the existing criteria may not be effective in preventing degradation.

United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Criteria and Standards Division
Washington, DC 20460

EPA 440/5-86-008
August 1988

Water

EPA

Ambient Water Quality Criteria for

Aluminum - 1988

NMED Exhibit 66

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

ALUMINUM

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL RESEARCH LABORATORY
DULUTH, MINNESOTA

NMED Exhibit 66

NOTICES

This document has been reviewed by the Criteria and Standards Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, and approved for publication.

This document is available to the public through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

NTIS Number - PB88 245 998

FOREWORD

Section 304(a)(1) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of proposed criteria based upon consideration of comments received from other Federal agencies, State agencies, special interest groups, and individual scientists. Criteria contained in this document replace any previously published EPA aquatic life criteria for the same pollutant(s).

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific stream uses are adopted by a State as water quality standards under section 303, they become enforceable maximum acceptable pollutant concentrations in ambient waters within that State. Water quality criteria adopted in State water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations States might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. It is not until their adoption as part of State water quality standards that criteria become regulatory.

Guidance to assist States in the modification of criteria presented in this document, in the development of water quality standards, and in other water-related programs of this Agency has been developed by EPA.

Martha G. Prothro AUG 23 1988

Martha G. Prothro
Director
Office of Water Regulations and Standards

NMED Exhibit 66

ACKNOWLEDGMENTS

Larry T. Brooke
(contributor)
University of Wisconsin-Superior
Superior, Wisconsin

Charles E. Stephan
(document coordinator)
Environmental Research Laboratory
Duluth, Minnesota

CONTENTS

TABLES

Introduction

The chemistry of aluminum in surface water is complex because of five properties (Campbell et al. 1983; Hem 1968a,b; Hem and Roberson 1967; Hsu 1968; Roberson and Hem 1969; Smith and Hem 1972). First, it is amphoteric: it is more soluble in acidic solutions and in basic solutions than in circumneutral solutions. Second, such ions as chloride, fluoride, nitrate, phosphate, and sulfate form soluble complexes with aluminum. Third, it can form strong complexes with fulvic and humic acids. Fourth, hydroxide ions can connect aluminum ions to form soluble and insoluble polymers. Fifth, under at least some conditions, solutions of aluminum in water approach chemical equilibrium rather slowly. This document addresses the toxicity of aluminum to freshwater organisms in waters in which the pH is between 6.5 and 9.0, because the water quality criterion for pH (U.S. EPA 1976) states that a pH range of 6.5 to 9.0 appears to adequately protect freshwater fishes and bottom-dwelling invertebrate fish food organisms from effects of the hydrogen ion. At a pH between 6.5 and 9.0 in fresh water, aluminum occurs predominantly as monomeric, dimeric, and polymeric hydroxides and as complexes with humic acids, phosphate, sulfate, and less common anions. This document does not contain information concerning the effect of aluminum on saltwater species because adequate data and resources were not available.

Several investigators have speculated about the toxic form of aluminum. Freeman and Everhart (1971) found that the toxicity of aluminum increased as pH increased from 6.8 to 8.99. They concluded that soluble aluminum was the toxic form. Hunter et al. (1980) observed the same relationship with rainbow trout over a pH range of 7.0 to 9.0. However, the opposite relationship resulted in a study with rainbow trout by Call (1984) and in studies with the fathead minnow by Boyd (1979), Call (1984), and Kimball (Manuscript). The tests conducted by Freeman and Everhart (1971), Hunter et al. (1980), and Kimball (Manuscript) were all renewal or flow-through and showed the lowest acute values, whereas the other tests were static. In addition, because the polymerization of aluminum hydroxide is a relatively slow process, the chemical form of aluminum might have differed from test to test due to the amount of time the aluminum was in stock and test solutions.

Driscoll et al. (1980) worked with postlarvae of brook trout and white suckers under slightly acidic conditions and concluded that only inorganic forms of aluminum were toxic to fish. Hunter et al. (1980) reported that the toxicity of test solutions was directly related to the concentration of aluminum that passed through a 0.45 μm membrane filter. In a study of the toxicity of "labile" aluminum to a green alga, Chlorella pyrenoidosa, Helliwell et al. (1983) found that maximum toxicity occurred in the pH range of 5.8 to 6.2. This is near the pH of minimum solubility of aluminum and maximum concentration of $Al(OH)_2^+$. They found that the toxicity of aluminum decreased as pH increased or decreased from about 6.0, and they speculated that the monovalent hydroxide is the most toxic form. Seip et al. (1984) stated that "the simple hydroxides ($Al(OH)^{+2}$ and $Al(OH)_2^+$) are regarded as the most dangerous forms while organically bound Al and polymeric forms are less toxic or essentially harmless."

In dilute aluminum solutions, formation of particles and the large insoluble polynuclear complexes known as floc is primarily a function of the concentrations of organic acids and the hydroxide ion (Snodgrass et al. 1984). Time for particle formation varies from < 1 min. to several days (Snodgrass et al. 1984) depending upon the source of aluminum, the pH, and the presence of electrolytes and organic acids. When particles form aggregates large enough to become visible, the floc is whitish and tends to settle. Mats have been reported blanketing a stream bed (Hunter et al. 1980). Laboratory studies conducted at alkaline pHs have reported floc in the exposure chambers (Brooke 1985; Call 1984; Lamb and Bailey 1981; Zarini et al. 1983). The floc did not appear to affect most aquatic species. However, the swimming ability of Daphnia magna was impeded by "fibers" of flocculated aluminum trailing from the carapaces, and the movements and perhaps feeding of midges was affected, ultimately resulting in death (Lamb and Bailey 1981). Bottom-dwelling organisms might be impacted more by aluminum floc in the field than in the laboratory.

Aluminum floc might coprecipitate nutrients, suspended material, and microorganisms. Removal of phosphorus from water has been observed in laboratory studies (Matheson 1975; Minzoni 1984; Peterson et al. 1974) and in a lake (Knapp and Soltero 1983). Turbidity due to clay has been removed from pond waters using aluminum sulfate (Boyd 1979). Unz and Davis (1975) speculated that aluminum floc might coalesce bacteria and concentrate organic matter in effluents, thus assisting the biological sorption of nutrients. Aluminum sulfate has been used to flocculate algae from water (McGarry 1970; Minzoni 1984; Zarini et al. 1983).

An understanding of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereafter referred to as the Guidelines, and the response to public comment (U.S. EPA 1985a) is necessary in order to understand the following text, tables, and calculations. Results of such intermediate calculations as Species Mean Acute Values are given to four significant figures to prevent roundoff error in subsequent calculations, not to reflect the precision of the value. Unless otherwise noted, all concentrations of aluminum in water reported herein from toxicity and bioconcentration tests are expected to be essentially equivalent to acid-soluble aluminum concentrations. All concentrations are expressed as aluminum, not as the chemical tested. The latest comprehensive literature search for information for this document was conducted in July, 1986; some more recent information was included.

Acute Toxicity to Aquatic Animals

The earliest study of the toxicity of aluminum to aquatic life was performed by Thomas (1915) using mummichogs acclimated to fresh water. His report lacks detail and it is unclear whether the aluminum sulfate was anhydrous or hydrated. Assuming that the anhydrous form was used, the calculated concentrations of aluminum where all of the fish died in 1.5 and 5 days were 2,200 and 1,100 µg/l, respectively. More recent tests with fish showing similar sensitivities to aluminum (Tables 1 and 6) were conducted with brook trout with a 96-hr LC50 of 3,600 µg/L (Decker and Menendez 1974), rainbow trout with a 72-hr LC50 of 5,200 µg/L (Freeman and Everhart 1971), and common carp with a 48-hr LC50 of 4,000 µg/L (Muramoto 1981). Other fish species tested were more resistant to aluminum.

The range of concentrations of aluminum that was acutely toxic to freshwater invertebrate species was about the same as the range of concentrations that was toxic to fish. The lowest acute values for invertebrates are 1,900 µg/L (McCauley et al. 1986) and 3,690 µg/L (Call 1984) for ceriodaphnids, whereas the highest acute value is 55,500 µg/L in a test with a snail (Call 1984). No data are available concerning the effect of pH on toxicity of aluminum to invertebrates.

Species Mean Acute Values (Table 1) were calculated as geometric means of the available acute values, and then Genus Mean Acute Values (Table 3) were calculated as geometric means of the available Species Mean Acute Values. Several species tested were not exposed to aluminum concentrations high enough to allow calculation of an LC50. Although these were ranked in Table 3 according to the highest concentration used in the test, this does not imply a true ranking of sensitivities. The freshwater Final Acute Value for aluminum at a pH between 6.5 and 9.0 was calculated to be 1,496 μg/L using the procedure described in the Guidelines and the Genus Mean Acute Values in Table 3. Because acute values are available for only fourteen genera, the FAV is about one-half the acute value for the most sensitive genus.

Chronic Toxicity to Aquatic Animals

Chronic toxicity values for aluminum have been determined with three freshwater species (Table 2). McCauley et al. (1986) found that 2,600 μg/L reduced survival and reproduction of *Ceriodaphnia dubia* by 23% and 92%, respectively. An aluminum concentration of 1,400 μg/L reduced survival by 11%, but increased reproduction. Although survival increased at concentrations above 2,600 μg/L, no reproduction occurred. In a life-cycle test with *Daphnia magna*, survival was the same at 540 μg/L as in the control treatment, but was reduced about 29% at 1,020 μg/L (Kimball, Manuscript). Reproduction was about the same at 1,020 μg/L as in the control treatment. Biesinger and Christensen (1972) obtained a 21-day LC50 of 1,400 μg/L with *D. magna* (Table 6). They estimated that 320 μg/L would reduce reproduction by 16%, but the concentrations of aluminum were not measured in the test solutions.

Kimball (Manuscript) reported the results of an early life-stage test with fathead minnows. An aluminum concentration of 4,700 μg/L reduced weight by 11.4%, whereas 2,300 μg/L reduced weight by 7.1%. Survival at both concentrations was as good or better than in the control treatment. These chronic tests indicate that, of the three species tested, the invertebrates are more sensitive to aluminum than the vertebrate.

The three available acute-chronic ratios for aluminum are 0.9958 with Ceriodaphnia dubia, 51.27 with Daphnia magna, and 10.64 with the fathead minnow (Table 2). These values follow the common pattern that acutely sensitive species have lower acute-chronic ratios (Table 3). The Final Acute-Chronic Ratio is meant to apply to acutely sensitive species, and, therefore, should be close to 0.9958. However, according to the Guidelines, the Final Acute-Chronic Ratio cannot be less than 2, because a ratio lower than 2 would result in the Final Chronic Value exceeding the Criterion Maximum Concentration. Thus the Final Chronic Value for aluminum is equal to the Criterion Maximum Concentration of 748.0 µg/L for fresh water at a pH between 6.5 and 9.0 (Table 3).

Data in Table 6 concerning the toxicity of aluminum to brook trout and striped bass show that the Final Chronic Value should be lowered to 87 µg/L to protect these two important species. Cleveland et al. (Manuscript) found that 169 µg/L caused a 24% reduction in the weight of young brook trout in a 60-day test, whereas 88 µg/L caused a 4% reduction in weight. In a 7-day test, 174.4 µg/L killed 58% of the exposed striped bass, whereas 87.2 µg/L did not kill any of the exposed organisms (Buckler et al., Manuscript). Both of these tests were conducted at a pH of 6.5 to 6.6.

Toxicity to Aquatic Plants

Single-celled plants were more sensitive to aluminum than the other plants tested (Table 4). Growth of the diatom, Cyclotella meneghiniana, was inhibited at 810 µg/L, and the species died at 6,480 µg/L (Rao and Subramanian 1982). The green alga, Selenastrum capricornutum, was about as sensitive to aluminum as the diatom. Effects were found at concentrations ranging from 460 µg/L (Call 1984) to 990 µg/L (Peterson et al. 1974). Among multicellular plants, root weight of Eurasian watermilfoil was significantly decreased at 2,500 µg/L, but duckweed was not affected at 45,700 µg/L (Table 4). A Final Plant Value, as defined in the Guidelines, cannot be obtained because no test in which the concentrations of aluminum were measured and the endpoint was biologically important has been conducted with an important aquatic plant species.

Bioaccumulation

Cleveland et al. (1986) found that young brook trout contained more aluminum after exposure for 15 days than after exposure for 30 days, and the bioconcentration factors ranged from 50 to 231. No U.S. FDA action level or other maximum acceptable concentration in tissue, as defined in the Guidelines, is available for aluminum, and, therefore, no Final Residue Value can be calculated.

Other Data

Additional data on the lethal and sublethal effects of aluminum on freshwater species are presented in Table 6. Bringmann and Kuhn (1959a,b) found that Scenedesmus quadricauda was more resistant to aluminum in river water than Chlorella pyrenoidosa. They did not find any toxic effects on Daphnia magna during a 48-h exposure to 1,000,000 µg/L. Toxicity might have been reduced by naturally occurring ligands in the river water.

Birge and coworkers reported that 50% of the embryos and fry of the narrow-mouthed toad, goldfish, largemouth bass, and rainbow trout were killed or deformed by exposure to aluminum concentrations of 50, 150, 170, and 560 µg/L, respectively (Table 6). Freeman and Everhart (1971) obtained an LC50 of 513 µg/L with rainbow trout fingerlings, but these and other investigators also obtained much higher LC50s with embryos, fry, and fingerlings of rainbow trout. Freeman (1973) studied the growth of rainbow trout after exposure to aluminum for 4.7 to 45 days. Growth was reduced by 5,200 $\mu g/L$ when pH was 7.0, 8.0, or 9.0. Normal growth resumed within two weeks in control water.

Unused Data

Many data on the effects of aluminum on freshwater organisms were not used because the pH of the dilution water used in the tests was less than 6.5 (Anderson 1948; Baker and Schofield 1982; Brown 1981,1983; Brown et al. 1983; Buckler et al., Manuscript; Clark and LaZerte 1985; Cleveland et al. 1986; Cook and Haney 1985; Dickson 1983; Driscoll et al. 1980; Eddy and Talbot 1983; Gunn and Keller 1984; Gunn and Noakes 1986; Havas and Hutchinson 1982,1983; Hunn et al. 1987; Jones 1940; Ogilvie and Stechey 1983; Orr et al. 1986; Schindler and Turner 1982; Schofield and Trojnar 1980; Staurnes et al. 1984; Tease and Coler 1984; van Dam et al. 1981; Witters et al. 1984). Data were also not used if the studies were conducted with species that are not resident in North America.

Burrows (1977), Chapman et al. (1968), Doudoroff and Katz (1953), Howells et al. (1983), Kaiser (1980), McKee and Wolf (1963), Odonnell et al. (1984), Phillips and Russo (1978), and Thompson et al. (1972) compiled data from other sources. Test results (e.g., Helliwell et al. 1983) were not used when it was likely that they would have been substantially different if they had been reported in terms of acid-soluble aluminum. Data were not used when aluminum was a component of an effluent or a mixture (Buckler et al., Manuscript; Guthrie et al. 1977; Hall et al. 1985; Hamilton-Taylor et al. 1984; Havas and Hutchinson 1982; Jay and Muncy 1979; Markarian et al. 1980).

Becker and Keller (1983), Marquis (1982), and Stearns et al. (1978) were not used because the results were not adequately presented or could not be interpreted. Data were not used when only enzymes were exposed (e.g., Christensen 1971/72; Christensen and Tucker 1976). Tests conducted by McCauley et al. (1986) at higher pHs were not used because the organisms were not acclimated to the dilution water before the beginning of the test. Control mortality was too high in many tests reported by Buckler et al. (Manuscript).

Reports of the concentrations of aluminum in wild aquatic organisms (e.g., Ecological Analysts, Inc. 1984; Elwood et al. 1976; Wren et al. 1983) were not used when the number of measurements of the concentration of aluminum in water was too small. Reports of other field studies were not used when they either lacked adequate measurements of aluminum concentrations in the water or reported no specific adverse effects (Berg and Burns 1985; Brumbaugh and Kane 1985; Buergel and Soltero 1983; Gibbons et al. 1984; Knapp and Soltero 1983; Sonnichsen 1978; van Coillie and Rousseau 1974; Zarini et al. 1983).

Summary

Acute tests have been conducted on aluminum at pH between 6.5 and 9.0 with freshwater species in fourteen genera. In many tests, less than 50% of the organisms were affected at the highest concentration tested. Both ceriodaphnids and brook trout were affected at concentrations below 4,000 μg/L, whereas some other fish and invertebrate species were not affected by 45,000 μg/L. Some researchers found that the acute toxicity of aluminum increased with pH, whereas others found the opposite to be true. Three studies have been conducted on the chronic toxicity of aluminum to aquatic animals. The chronic values for *Daphnia magna*, *Ceriodaphnia dubia*, and the fathead minnow were 742.2, 1,908, and 3,288 $\mu g/L$, respectively. The diatom, *Cyclotella meneghiniana*, and the green alga, *Selenastrum capricornutum*, were affected by concentrations of aluminum in the range of 400 to 900 $\mu g/L$. Bioconcentration factors from 50 to 231 were obtained in tests with young brook trout. At a pH of 6.5 to 6.6, 169 $\mu g/L$ caused a 24% reduction in the growth of young brook trout, and 174 $\mu g/L$ killed 58% of the exposed striped bass.

National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably, when the pH is between 6.5 and 9.0, if the four-day average concentration of aluminum does not exceed 87 $\mu g/L$ more than once every three years on the average and if the one-hour average concentration does not exceed 750 $\mu g/L$ more than once every three years on the average.

Implementation

Because of the variety of forms of aluminum in ambient water and the lack of definitive information about their relative toxicities to freshwater species, no available analytical measurement is known to be ideal for expressing aquatic life criteria for aluminum. Previous aquatic life criteria for metals and metalloids (U.S. EPA 1980) were expressed in terms of the total recoverable measurement (U.S. EPA 1983a), but newer criteria for metals and metalloids have been expressed in terms of the acid-soluble measurement (U.S. EPA 1985b). Acid-soluble aluminum (operationally defined as the aluminum that passes through a 0.45 µm membrane filter after the sample has been acidified to a pH between 1.5 and 2.0 with nitric acid) is probably the best measurement at the present for the following reasons:

1. This measurement is compatible with nearly all available data concerning toxicity of aluminum to, and bioaccumulation of aluminum by, aquatic organisms. It is expected that the results of tests used in the derivation of the criteria would not have changed substantially if they had been reported in terms of acid-soluble aluminum.
2. On samples of ambient water, measurement of acid-soluble aluminum will probably measure all forms of aluminum that are toxic to aquatic life or can be readily converted to toxic forms under natural conditions. In addition, this measurement probably will not measure several forms, such as aluminum that is occluded in minerals, clays, and sand or is strongly sorbed to particulate matter, that are not toxic and are not likely to become toxic under natural conditions. Although this measurement (and many others) will measure soluble complexed forms of aluminum, such as the EDTA complex of aluminum, that probably have low toxicities to aquatic life, concentrations of these forms probably are negligible in most ambient water.
3. Although water quality criteria apply to ambient water, the measurement used to express criteria is likely to be used to measure aluminum in aqueous effluents. Measurement of acid-soluble aluminum is expected to be applicable to effluents because it will measure precipitates, such as carbonate and hydroxide precipitates of aluminum, that might exist in an effluent and dissolve when the effluent is diluted with receiving water. If desired, dilution of effluent with receiving water before measurement of acid-soluble aluminum might be used to determine whether the receiving

water can decrease the concentration of acid-soluble aluminum because of sorption.

4. The acid-soluble measurement is expected to be useful for most metals and metalloids, thus minimizing the number of samples and procedures that are necessary.
5. The acid-soluble measurement does not require filtration of the sample at the time of collection, as does the dissolved measurement.
6. The only treatment required at the time of collection is preservation by acidification to a pH between 1.5 and 2.0, similar to that required for the total recoverable measurement.
7. Durations of 10 minutes to 24 hours between acidification and filtration of most samples of ambient water probably will not affect the result substantially.
8. Ambient waters have much higher buffer intensities at a pH between 1.5 and 2.0 than they do at a pH between 4 and 9 (Stumm and Morgan 1981).
9. Differences in pH within the range of 1.5 to 2.0 probably will not affect the result substantially.
10. The acid-soluble measurement does not require a digestion step, as does the total recoverable measurement.
11. After acidification and filtration of the sample to isolate the acid-soluble aluminum, the analysis can be performed using either atomic absorption spectrophotometric or ICP-atomic emission spectrometric analysis (U.S. EPA 1983a), as with the total recoverable measurement.

Thus, expressing aquatic life criteria for aluminum in terms of the acid-soluble measurement has both toxicological and practical advantages. The U.S. EPA is considering development and approval of a method for a measurement such as acid-soluble.

The 0.45 μm membrane filter is the usual basis for an operational definition of "dissolved," at least in part because filters with smaller holes often clog rapidly when natural water samples are filtered. Some particulate and colloidal material, however, might pass through a 0.45 μm filter. The intent of the acid-soluble measurement is to measure the concentrations of metals and metalloids that are in true solution in a sample that has been appropriately acidified. Therefore, material that does not pass through a filter with smaller holes, such as a 0.1 μm membrane filter, should not be considered acid-soluble even if it passes through a 0.45 μm membrane filter. Optional filtration of appropriately acidified water samples through 0.1 μm membrane filters should be considered whenever the concentration of aluminum that passes through a 0.45 μm membrane filter in an acidified water sample exceeds a limit specified in terms of acid-soluble aluminum.

Metals and metalloids might be measured using the total recoverable method (U.S. EPA 1983a). This would have two major impacts because this method includes a digestion procedure. First, certain species of some metals and metalloids cannot be measured because the total recoverable method cannot distinguish between individual oxidation states. Second, in some cases these criteria would be overly protective when based on the total recoverable method because the digestion procedure will probably dissolve some aluminum that is not toxic and cannot be converted to a toxic form under natural conditions. This could be a major problem in ambient waters that contain suspended clay. Because no measurement is known to be ideal for expressing aquatic life criteria for aluminum or for measuring aluminum in ambient water or aqueous effluents, measurement of both acid-soluble aluminum and total recoverable aluminum in ambient water or effluent or both might be useful. For example, there might be cause for concern when total recoverable aluminum is much above an applicable limit, even though acid-soluble aluminum is below the limit.

In addition, metals and metalloids might be measured using the dissolved method, but this would also have several impacts. First, in many toxicity tests on aluminum the test organisms were exposed to both dissolved and undissolved aluminum. If only the dissolved aluminum had been measured, the acute and chronic values would be lower than if acid-soluble or total recoverable aluminum had been measured. Therefore, water quality criteria expressed as dissolved aluminum would be lower than criteria expressed as acid-soluble or total recoverable aluminum. Second, not enough data are available concerning the toxicity of dissolved aluminum to allow derivation of a criterion based on dissolved aluminum. Third, whatever analytical method is specified for measuring aluminum in ambient surface water will probably also be used to monitor effluents. If effluents are monitored by measuring only the dissolved metals and metalloids, carbonate and hydroxide precipitates of metals would not be measured. Such precipitates might dissolve, due to dilution or change in pH or both, when the effluent is mixed with receiving water. Fourth, measurement of dissolved aluminum requires filtration of the sample at the time of collection. For these reasons, it is recommended that aquatic life criteria for aluminum not be expressed as dissolved aluminum.

As discussed in the Water Quality Standards Regulation (U.S. EPA 1983b) and the Foreword to this document, a water quality criterion for aquatic life has regulatory impact only after it has been adopted in a State water quality standard. Such a standard specifies a criterion for a pollutant that is consistent with a particular designated use. With the concurrence of the U.S. EPA, States designate one or more uses for each body of water or segment thereof and adopt criteria that are consistent with the use(s) (U.S. EPA

1983c,1987). In each standard a State may adopt the national criterion, if one exists, or, if adequately justified, a site-specific criterion. (If the site is an entire State, the site-specific criterion is also a State-specific criterion.)

Site-specific criteria may include not only site-specific criterion concentrations (U.S. EPA 1983c), but also site-specific, and possibly pollutant-specific, durations of averaging periods and frequencies of allowed excursions (U.S. EPA 1985c). The averaging periods of "one hour" and "four days" were selected by the U.S. EPA on the basis of data concerning how rapidly some aquatic species react to increases in the concentrations of some pollutants, and "three years" is the Agency's best scientific judgment of the average amount of time aquatic ecosystems should be provided between excursions (Stephan et al. 1985; U.S. EPA 1985c). However, various species and ecosystems react and recover at greatly differing rates. Therefore, if adequate justification is provided, site-specific and/or pollutant-specific concentrations, durations, and frequencies may be higher or lower than those given in national water quality criteria for aquatic life.

Use of criteria, which have been adopted in State water quality standards, for developing water quality-based permit limits and for designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Although dynamic models are preferred for the application of these criteria (U.S. EPA 1985c), limited data or other considerations might require the use of a steady-state model (U.S. EPA 1986). Guidance on mixing zones and the design of monitoring programs is also available (U.S. EPA 1985c,1987).

Table 1. Acute Toxicity of Aluminum to Aquatic Animals

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	pH	LC50 or EC50 (µg/L)[b]	Species Mean Acute Value (µg/L)	Reference
				FRESHWATER SPECIES			
Planarian (adult), *Dugesia tigrina*	S, M	Aluminum chloride	47.4	7 48	>23,000[c]	>23,000	Brooke et al. 1985
Snail (adult), *Physa* sp	S, M	Aluminum chloride	47 4	7 46	55,500[d]	-	Call 1984
Snail (adult), *Physa* sp.	S, M	Aluminum chloride	47.4	6 59	>23,400	-	Call 1984
Snail (adult), *Physa* sp.	S, M	Aluminum chloride	47.4	7 55	30,600	-	Call 1984
Snail (adult), *Physa* sp.	S, M	Aluminum chloride	47.4	8 17	>24,700	30,600	Call 1984
Cladoceran (<16 hr), *Ceriodaphnia dubia*	S, M	Aluminum chloride	50 0	7 4	1,900	1,900	McCauley et al 1986
Cladoceran (< 24 hr), *Ceriodaphnia* sp	S, M	Aluminum chloride	47 4	7 68	3,690	3,690	Call 1984
Cladoceran, *Daphnia magna*	S, U	Aluminum chloride	45 3	6 5-7 5	3,900[e]	-	Biesinger and Christensen 1972
Cladoceran, *Daphnia magna*	S, M	Aluminum chloride	45 4	7 61	>25,300	-	Brooke et al 1985
Cladoceran, *Daphnia magna*	S, M	Aluminum sulfate	220[f]	7.05	38,200	38,200	Kimball, Manuscript
Amphipod (adult), *Gammarus pseudolimnaeus*	S, M	Aluminum chloride	47 4	7 53	22,000	22,000	Call 1984

Table I. (continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	pH	LC50 or EC50 (µg/L)[b]	Species Mean Acute Value (µg/L)	Reference
Stonefly (nymph), *Acroneuria* sp.	S, M	Aluminum chloride	47.4	7 46	>22,600	>22,600	Call 1984
Midge (larva), *Tanytarsus dissimilis*	S, U	Aluminum sulfate	17.43	7 71- 6 85	>79,900	>79,900	Lamb and Bailey 1981
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	S, M	Sodium aluminate	28.0	7 0	>40,000	>40,000	Peterson et al 1974
Rainbow trout (juvenile), *Salmo gairdneri*	S, M	Aluminum chloride	47 4	7 46	8,600[d]	-	Call 1984
Rainbow trout (juvenile), *Salmo gairdneri*	S, M	Aluminum chloride	47.4	6 59	7,400	-	Call 1984
Rainbow trout (juvenile), *Salmo gairdneri*	S, M	Aluminum chloride	47.4	7 31	14,600	-	Call 1984
Rainbow trout (juvenile), *Salmo gairdneri*	S, M	Aluminum chloride	47 4	8 17	>24,700[e]	10,390	Call 1984
Brook trout (juvenile), *Salvelinus fontinalis*	F, M	Aluminum sulfate	-	6 5	3,600	3,600	Decker and Menendez 1974
Fathead minnow (adult), *Pimephales promelas*	S, U	Aluminum sulfate	-	7 6	>18,900	-	Boyd 1979

Table 1. (continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	pH	LC50 or EC50 (µg/L)[b]	Species Mean Acute Value (µg/L)	Reference
Fathead minnow (juvenile), *Pimephales promelas*	S, M	Aluminum chloride	47.4	7.61	>48,200	-	Call 1984
Fathead minnow (juvenile), *Pimephales promelas*	S, M	Aluminum chloride	47.4	8.05	>49,800	-	Call 1984
Fathead minnow (juvenile), *Pimephales promelas*	F, M	Aluminum sulfate	220[f]	7.34	35,000	35,000	Kimball, Manuscript
Channel catfish (juvenile), *Ictalurus punctatus*	S, M	Aluminum chloride	47.4	7.54	>47,900	>47,900	Call 1984
Green sunfish (juvenile), *Lepomis cyanellus*	S, M	Aluminum chloride	47.4	7.55	>50,000	>50,000	Call 1984
Yellow perch (juvenile), *Perca flavescens*	S, M	Aluminum chloride	47.4	7.55	>49,800	>49,800	Call 1984

---

[a] S = static; R = renewal; F = flow-through, M = measured; U = unmeasured.

[b] Concentration of aluminum, not the chemical

[c] 48-hr test.

[d] Aluminum chloride was added to Lake Superior water, the pH was adjusted, and the solution was aerated for 18 days prior to addition of test organisms, not used in calculations

[e] Not used in calculations

[f] From Smith et al (1976)

Table 2. Chronic Toxicity of Aluminum to Aquatic Animals

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	pH	Limits (µg/L)[b]	Chronic Value (µg/L)	Reference
			FRESHWATER SPECIES				
Cladoceran, *Ceriodaphnia dubia*	LC	Aluminum chloride	50	7.15	1,400- 2,600	1,908	McCauley et al. 1986
Cladoceran, *Daphnia magna*	LC	Aluminum sulfate	220[c]	8.30	540- 1,020	742.2	Kimball, Manuscript
Fathead minnow, *Pimephales promelas*	ELS	Aluminum sulfate	220[c]	7.24- 8.15	2,300- 4,700	3,288	Kimball, Manuscript

---

[a] LC = life-cycle or partial life-cycle; ELS = early life-stage.

[b] Measured concentrations of aluminum.

[c] From Smith et al. (1976).

Table 2. (continued)

Acute-Chronic Ratio

Species	Hardness (mg/L as $CaCO_3$)	pH	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
Cladoceran, *Ceriodaphnia dubia*	50	7.15- 7.4	1,900	1,908	0.9958
Cladoceran, *Daphnia magna*	220	7.05- 8.30	38,200	742.2	51.47
Fathead minnow, *Pimephales promelas*	220	7.24- 8.15	35,000	3,288	10.64

Table 3. Ranked Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank[a]	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)[b]	Species Mean Acute-Chronic Ratio[c]
14	>79,900	Midge, *Tanytarsus dissimilis*	>79,900	-
13	>50,000	Green sunfish, *Lepomis cyanellus*	>50,000	-
12	>49,800	Yellow perch, *Perca flavescens*	>49,800	-
11	>47,900	Channel catfish, *Ictalurus punctatus*	>47,900	-
10	>40,000	Chinook salmon, *Oncorhynchus tshawytscha*	>40,000	-
9	38,200	Cladoceran, *Daphnia magna*	38,200	51 47
8	35,000	Fathead minnow, *Pimephales promelas*	35,000	10 64
7	30,600	Snail, *Physa* sp.	30,600	-
6	>23,000	Planarian, *Dugesia tigrina*	>23,000	-
5	>22,600	Stonefly, *Acroneuria* sp	>22,600	-
4	22,000	Amphipod, *Gammarus pseudolimnaeus*	22,000	-
3	10,390	Rainbow trout, *Salmo gairdneri*	10,390	-

NMED Exhibit 66

Table 3. (continued)

Rank[a]	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)[b]	Species Mean Acute-Chronic Ratio[c]
2	3,600	Brook trout, *Salvelinus fontinalis*	3,600	-
1	2,648	Cladoceran, *Ceriodaphnia dubia*	1,900	0 9958
		Cladoceran, *Ceriodaphnia* sp	3,690	-

---

[a] Ranked from most resistant to most sensitive based on Genus Mean Acute Value Inclusion of "greater than" values does not necessarily imply a true ranking, but does allow use of all genera for which data are available so that the Final Acute Value is not unnecessarily lowered.

[b] From Table 1

[c] From Table 2

Fresh water (pH between 6 5 and 9 0)

Final Acute Value = 1,496 µg/L

Criterion Maximum Concentration = (1,496 µg/L) / 2 = 748 0 µg/L

Final Acute-Chronic Ratio = 2 (see text)

Final Chronic Value = (1,496 µg/L) / 2 = 748 0 µg/L

Final Chronic Value = 87 µg/L (lowered to protect brook trout and striped bass, see text)

NMED Exhibit 66

Table 4. Toxicity of Aluminum to Aquatic Plants

Species	Chemical	pH	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
FRESHWATER SPECIES							
Diatom, *Cyclotella meneghiniana*	Aluminum chloride	7.9	-	8	Inhibited growth algistatic algicidal	810 3,240 6,480	Rao and Subramanian 1982
Green alga, *Selenastrum capricornutum*	Sodium aluminate	7.0	15	14	Reduced cell counts and dry weight	990-1,320	Peterson et al. 1974
Green alga, *Selenastrum capricornutum*	Aluminum chloride	7.6	14.9	4	EC50 (biomass)	570	Call 1984
Green alga, *Selenastrum capricornutum*	Aluminum chloride	8.2	14.9	4	EC50 (biomass)	460	Call 1984
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	-	32	EC50 (root weight)	2,500	Stanley 1974
Duckweed, *Lemna minor*	Aluminum chloride	7.6	14.9	4	Reduced frond production	>45,700	Call 1984
Duckweed, *Lemna minor*	Aluminum chloride	8.2	14.9	4	Reduced frond production	>45,700	Call 1984

---

[a] Concentration of aluminum, not the chemical.

NMED Exhibit 66

Table 5. Bioaccumulation of Aluminum by Aquatic Organisms

Species	Chemical	Concentration in Water (µg/L)[a]	Hardness (mg/L as $CaCO_3$)	pH	Tissue	Duration	BCF or BAF[b]	Reference
Brook trout (eyed embryo), *Salvelinus fontinalis*	Aluminum sulfate	242	13	7 24	Whole body	Post-hatch: 15 days 30 days	 147 50	Cleveland et al 1986
Brook trout (37 days), *Salvelinus fontinalis*	Aluminum sulfate	242	14	7 35	Whole body	15 days 30 days	231 136	Cleveland et al. 1986

---

[a] Measured concentration of aluminum.

[b] Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of aluminum in water and in tissue

Table 6. Other Data on Effects of Aluminum on Aquatic Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Concentration (µg/L)[a]	Reference
				FRESHWATER SPECIES			
Green alga, *Chlorella vulgaris*	Aluminum chloride	-	<7.0	3-4 mo	Inhibited growth	4,000	De Jong 1965
Green alga, *Chlorella vulgaris*	Aluminum sulfate	-	-	30 days	Reduced maximum growth	<163,000	Becker and Keller 1973
Green alga, *Scenedesmus quadricauda*	Aluminum chloride	-	7.5-7.8	96 hr	Incipient inhibition (river water)	1,500-2,000	Bringmann and Kuhn 1959a,b
Planktonic communities	Aluminum sulfate	-	6.1-6.9	1 hr	Decreased phosphate uptake and photosynthesis	50	Nelewajko and Paul 1985
Protozoan, *Microregma heterostoma*	Aluminum chloride	-	7.5-7.8	28 hr	Incipient inhibition (river water)	12,000	Bringmann and Kuhn 1959b
Protozoan, *Chilomonas paramecium*	Aluminum chloride	-	5.5-7.4	3 hr	Some survival	110	Ruthven and Cairns 1973
Protozoan, *Peranema trichoporum*	Aluminum chloride	-	5.5-6.5	3 hr	Some survival	62,600	Ruthven and Cairns 1973
Protozoan, *Tetrahymena pyriformis*	Aluminum chloride	-	5.5-6.5	3 hr	Some survival	110	Ruthven and Cairns 1973
Protozoan, *Euglena gracilis*	Aluminum chloride	-	6.0-7.0	3 hr	Some survival	111,800	Ruthven and Cairns 1973
Cladoceran (mature), *Daphnia catawba*	Aluminum chloride	8.07	6.5	72 hr	Reduced survival	1,020	Havas and Likens 1985b

Table 6. (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Concentration ($\mu g/L$)[a]	Reference
Cladoceran, *Daphnia magna*	Aluminum sulfate	-	-	16 hr	Incipient immobilization	21,450	Anderson 1944
Cladoceran, *Daphnia magna*	Ammonium aluminum sulfate	-	-	16 hr	Incipient immobilization	21,620	Anderson 1944
Cladoceran, *Daphnia magna*	Potassium aluminum sulfate	-	-	16 hr	Incipient immobilization	21,530	Anderson 1944
Cladoceran, *Daphnia magna*	Aluminum chloride	-	7.5	48 hr	Non-toxic (river water)	1,000,000	Bringmann and Kuhn 1959a
Cladoceran, *Daphnia magna*	Aluminum chloride	45.3	6.5-7.5	21 days	EC16 (reduced reproduction)	320	Biesinger and Christensen 1972
Cladoceran, *Daphnia magna*	Aluminum chloride	45.3	6.5-7.5	21 days	LC50	1,400	Biesinger and Christensen 1972
Cladoceran, *Daphnia magna*	Sodium aluminate	27.0	7.0	96 hr	Mortality	>40,000	Peterson et al. 1974
Cladoceran, *Daphnia magna*	Aluminum chloride	8.26	6.5	48 hr	Mortality	320	Havas 1985, Havas and Likens 1985a
Cladoceran, *Daphnia magna*	Aluminum chloride	-	6.5	48 hr	Loss of sodium	1,020	Havas and Likens 1985a
Cladoceran, *Daphnia magna*	Aluminum chloride	8.26	6.5	24 hr	BCF = 18,000 BCF = 9,600 BCF = 11,000	20 320 1,020	Havas 1985
Cladoceran, *Daphnia magna*	Aluminum chloride	33.35	6.5	24 hr	BCF = 18,000 BCF = 14,700	20 1,020	Havas 1985

Table 6. (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Concentration (µg/L)[a]	Reference
Cladoceran, *Daphnia magna*	Aluminum sulfate	220[b]	7 05	48 hr	EC50 (fed)	38,200	Kimball, Manuscript
Crayfish, *Orconectes virilis*	Aluminum chloride	11 0	7 0	2 hr	Calcium uptake unaffected	200	Malley and Chang 1985
Aquatic beetle (adult), *Tropistermus lateralis nimbatus*	Aluminum chloride	-	7 0	14 days	Changed the fat body	200	Wooldridge and Wooldridge 1969
Midge (larva), *Tanytarsus dissimilis*	Aluminum sulfate	17.43	6 63	55 days	37% dead	832	Lamb and Bailey 1981
Rainbow trout (fingerling), *Salmo gairdneri*	Aluminum chloride	46 8	8.02	32 days	50% dead	5,230	Freeman and Everhart 1971
		28 3	8 48	7 5 days	50% dead	5,140	
		28.3	8 99	3 days	50% dead	5,200	
		56 6	6.64	44 days	50% dead	513	
		56 6	6 80	39 days	50% dead	5,140	
Rainbow trout (embryo), *Salmo gairdneri*	Aluminum chloride	-	7.0-9 0	Fertilization to hatch	No reduced fertility	5,200	Everhart and Freeman 1973
Rainbow trout (embryo, larva), *Salmo gairdneri*	Aluminum chloride	104 (92-110)	7.4	28 days	EC50 (death and deformity)	560	Birge 1978, Birge et al 1978,1980,1981
Rainbow trout (juvenile), *Salmo gairdneri*	Aluminum sulfate	25	7.0	10 days	0% dead	200,000	Hunter et al 1980
			8 0	96 hr	40% dead	50,000	
			8 5	42 hr	100% dead	50,000	
			9 0	42 hr	100% dead	50,000	
Rainbow trout (embryo, larva), *Salmo gairdneri*	Aluminum sulfate	14 3	6 5	8 days	No effect	1,000	Holtze 1983
			7 2		No effect	1,000	

NMED Exhibit 66

Table 6. (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Concentration (µg/L)[a]	Reference
Rainbow trout (eyed embryo), <u>Salmo gairdneri</u>	Aluminum sulfate	14.3	6.5 7.2	8 days	14.2% dead 21.6% dead	1,000 1,000	Holtze 1983
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	Aluminum sulfate	-	6.5	11 days	Increased ventilation rate	75	Neville 1985
Brook trout (eyed embryo), <u>Salvelinus fontinalis</u>	Aluminum sulfate	13	7.2	To 30 days post-hatch	Reduced some behaviors	242	Cleveland et al. 1986
Brook trout (37 days), <u>Salvelinus fontinalis</u>	Aluminum sulfate	14	7.3	30 days	Reduced some behaviors	242	Cleveland et al. 1986
Brook trout (eyed embryo), <u>Salvelinus fontinalis</u>	Aluminum sulfate	<1	7.8	To hatch	Did not decrease % hatch	283	Hunn et al. 1987
Brook trout (larva), <u>Salvelinus fontinalis</u>	Aluminum sulfate	<1	7.8	60 days	Reduced growth and some behaviors	283	Hunn et al. 1987
Brook trout (embryo, larva), <u>Salvelinus fontinalis</u>	Aluminum sulfate	12.3	6.5-6.6	60 days	48% dead 3% dead 24% reduction in weight 4% reduction in weight	350 169 169 88	Cleveland et al. Manuscript
Goldfish (60-90 mm), <u>Carassius auratus</u>	Aluminum potassium sulfate	-	6.8	4 days	Reduced survival time	5,700	Ellis 1937
Goldfish (juvenile), <u>Carassius auratus</u>	Aluminum sulfate	64-80	6.6-7.4	7 days	0% dead	50,000	Sanborn 1945

NMED Exhibit 66

Table 6. (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Concentration (µg/L)[a]	Reference
Goldfish (embryo, larva), *Carassius auratus*	Aluminum chloride	195	7.4	7 days	EC50 (death and deformity)	150	Birge 1978
Common carp (juvenile), *Cyprinus carpio*	Aluminum chloride	-	6.5	48 hr	30% dead	4,000	Muramoto 1981
			6.6		10% dead	4,000	
Fathead minnow (adult), *Pimephales promelas*	Aluminum chloride	-	-	-	50% reduction of acetylcholinesterase activity	18,000	Olson and Christensen 1980
Fathead minnow (juvenile), *Pimephales promelas*	Aluminum sulfate	220[b]	7.3	8 days	LC50 (fed)	22,400	Kimball, Manuscript
Largemouth bass (juvenile), *Micropterus salmoides*	Aluminum sulfate	64-80	6.6-7.4	7 days	0% dead	50,000	Sanborn 1945
Mummichog (adult), *Fundulus heteroclitus*	Aluminum sulfate	-	-	36 hr	100% dead	2,210[c]	Thomas 1915
				120 hr	100% dead	1,100[c]	
Mosquitofish (adult female), *Gambusia affinis*	Aluminum chloride	-	4.3-7.7	4 days	LC50 (high turbidity)	26,900 18,500	Wallen et al. 1957
Threespine stickleback (adult), *Gasterosteus aculeatus*	Aluminum nitrate	-	>7.0	10 days	No toxicity	70	Jones 1939
Striped bass (159 days), *Morone saxatilis*	Aluminum sulfate	-	6.5	7 days	0% dead	390	Buckler et al., Manuscript
			7.2		0% dead	390	
Striped bass (195 days), *Morone saxatilis*	Aluminum sulfate	-	6.5	7 days	0% dead	390	Buckler et al., Manuscript
			7.2		0% dead	390	

Table 6. (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	pH	Duration	Effect	Concentration (µg/L)[a]	Reference
Striped bass (160 days), *Morone saxatilis*	Aluminum sulfate	-	6.5	7 days	0% dead	87.2	Buckler et al., Manuscript
			6.5		58% dead	174.4	
			7.2		2% dead	174.4	
			7.2		100% dead	348.8	
Largemouth bass (embryo, larva), *Micropterus salmoides*	Aluminum chloride	93-105	7.2-7.8	8 days	EC50 (death and deformity)	170	Birge et al. 1978
Narrow-mouthed toad (embryo, larva), *Gastrophryne carolinensis*	Aluminum chloride	195	7.4	7 days	EC50 (death) and deformity)	50	Birge 1978, Birge et al. 1979
Marbled salamander (embryo, larva), *Ambystoma opacum*	Aluminum chloride	93-105	7.2-7.8	8 days	EC50 (death and deformity)	2,280	Birge et al. 1978

---

[a] Concentration of aluminum, not the chemical

[b] From Smith et al. (1976)

[c] If the aluminum sulfate is assumed to be anhydrous.

REFERENCES

Anderson, B.G. 1944. The toxicity thresholds of various substances found in industrial wastes as determined by the use of Daphnia magna. Sewage Works J. 16:1156-1165.

Anderson, B.G. 1948. The apparent thresholds of toxicity to Daphnia magna for chlorides of various metals when added to Lake Erie water. Trans. Am. Fish. Soc. 78:96-113.

Baker, J.P. and C.L. Schofield. 1982. Aluminum toxicity to fish in acidic waters. Water Air Soil Pollut. 18:289-309.

Becker, A.J., Jr. and E.C. Keller, Jr. 1973. The effects of iron and sulfate compounds on the growth of Chlorella. Proc. W. Va. Acad. Sci. 45:127-135.

Becker, A.J., Jr. and E.C. Keller, Jr. 1983. Metabolic responses of the crayfish Procambarus clarkii to reduced pH and elevated aluminum concentration. Am. Zool. 23:888.

Berg, D.J. and T.A. Burns. 1985. The distribution of aluminum in the tissues of three fish species. J. Freshwater Ecol. 3:113-120.

Biesinger, K.E. and G.M. Christensen. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of Daphnia magna. J. Fish. Res. Board Can. 29:1691-1700.

Birge, W.J. 1978. Aquatic toxicology of trace elements in coal and fly ash. In: Energy and environmental stress in aquatic systems. Thorp, J.H. and J.W. Gibbons (Eds.). CONF-771114. National Technical Information Service, Springfield, VA. pp. 219-240.

Birge, W.J., J.E. Hudson, J.A. Black and A.G. Westerman. 1978. Embryo-larval bioassays on inorganic coal elements and in situ biomonitoring of coal-waste effluents. In: Surface mining and fish/wildlife needs in the eastern United States. Samuel, D.E., J.R. Stauffer, C.H. Hocutt and W.T. Mason (Eds.). PB-298353 or FWS/OBS-78/81. National Technical Information Service, Springfield, VA. pp. 97-104.

Birge, W.J., J.A. Black and A.G. Westerman. 1979. Evaluation of aquatic pollutants using fish and amphibian eggs as bioassay organisms. In: Animals as monitors of environmental pollutants. Nielson, S.W., G. Migaki and D.G. Scarrelli (Eds.). National Academy of Sciences, Washington, DC. pp. 108-118.

Birge, W.J., J.A. Black, A.G. Westerman and J.E. Hudson. 1980. Aquatic toxicity tests on inorganic elements occurring in oil shale. In: Oil shale symposium: Sampling, analysis and quality assurance. Gale, C. (Ed.). PB80-221435 or EPA-600/9-80-022. National Technical Information Service, Springfield, VA. pp. 519-534.

Birge, W.J., J.A. Black and B.A. Ramey. 1981. The reproductive toxicology of aquatic contaminants. In: Hazard assessment of chemicals: Current developments. Vol. 1. Saxena, J. and F. Fisher (Eds.). Academic Press, New York, NY. pp. 59-115.

Boyd, C.E. 1979. Aluminum sulfate (alum) for precipitating clay turbidity from fish ponds. Trans. Am. Fish. Soc. 108:307-313.

Bringmann, G. and R. Kuhn. 1959a. The toxic effects of waste water on aquatic bacteria, algae, and small crustaceans. Gesundh.-Ing. 80:115-120.

Bringmann, G. and R. Kuhn. 1959b. Water toxicology studies with protozoans as test organisms. Gesundh.-Ing. 80:239-242.

Brooke, L. 1985. University of Wisconsin-Superior, Superior, WI. (Memorandum to C. Stephan, U.S. EPA, Duluth, MN. July 25.)

Brown, D.J.A. 1981. The effects of various cations on the survival of brown trout, Salmo trutta at low pHs. J. Fish Biol. 18:31-40.

Brown, D.J.A. 1983. Effect of calcium and aluminum concentrations on the survival of brown trout (Salmo trutta) at low pH. Bull. Environ. Contam. Toxicol. 30:582-587.

Brown, T.E., A.W. Morley, N.T. Sanderson and R.D. Tait. 1983. Report on a large fish kill resulting from natural acid water conditions in Australia. J. Fish Biol. 22:335-350.

Brumbaugh, W.G. and D.A. Kane. 1985. Variability of aluminum concentrations in organs and whole bodies of smallmouth bass (Micropterus dolomieui). Environ. Sci. Technol. 19:828-831.

Buckler, D.R., P.M. Mehrle, L. Cleveland and F.J. Dwyer. Manuscript. Influence of pH on the toxicity of aluminium and other inorganic contaminants to east coast striped bass. Columbia National Fisheries Research Laboratory, Columbia, MO.

Buergel, D.M. and R.A. Soltero. 1983. The distribution and accumulation of aluminum in rainbow trout following a whole-lake alum treatment. J. Freshwater Ecol. 2:37-44.

Burrows, W.D. 1977. Aquatic aluminum: Chemistry, toxicology, and environmental prevalence. Crit. Rev. Environ. Control 7:167-216.

Call, D.J. 1984. University of Wisconsin-Superior, Superior, WI. (Memorandum to C. Stephan, U.S. EPA, Duluth, MN. November 27.)

Campbell, P.G.C., M. Bisson, R. Bougie, A. Tessier and J. Villeneuve. 1983. Speciation of aluminum in acidic freshwaters. Anal. Chem. 55:2246-2252.

Chapman, W.H., H.L. Fisher and M.W. Pratt. 1968. Concentration factors of chemical elements in edible aquatic organisms. UCRL-50564. National Technical Information Service, Springfield, VA.

Christensen, G.M. 1971/72. Effects of metal cations and other chemicals upon the in vitro activity of two enzymes in the blood plasma of the white sucker, <u>Catostomus</u> <u>commersoni</u> (Lacepede). Chem.-Biol. Interact. 4:351-361.

Christensen, G.M. and J.H. Tucker. 1976. Effects of selected water toxicants on the in vitro activity of fish carbonic anhydrase. Chem.-Biol. Interact. 13:181-192.

Clark, K.L. and B.D. LaZerte. 1985. A laboratory study of the effects of aluminum and pH on amphibian eggs and tadpoles. Can. J. Fish. Aquat. Sci. 42:1544-1551.

Cleveland, L., E.E. Little, S.J. Hamilton, D.R. Buckler and J.B. Hunn. 1986. Interactive toxicity of aluminum and acidity to early life stages of brook trout. Trans. Am. Fish. Soc. 115:610-620.

Cleveland, L., E.E. Little, R.H. Wiedmeyer and D.R. Buckler. Manuscript. Chronic no-observed-effect concentrations of aluminum for brook trout exposed in dilute acid water. National Fisheries Contaminant Research Center, Columbia, MO.

Cook, W. and J. Haney. 1984. The acute effects of aluminum and acidity upon nine stream insects. Technical Report. Water Resource Research Center, University of New Hampshire, Durham, NH.

Decker, C. and R. Menendez. 1974. Acute toxicity of iron and aluminum to brook trout. Proc. W. Va. Acad. Sci. 46:159-167.

De Jong, L.E.D.D. 1965. Tolerance of Chlorella vulgaris for metallic and non-metallic ions. Antonie Leeuwenhoek J. Microbiol. 31:301-313.

Dickson, W. 1983. Liming toxicity of aluminum to fish. Vatten 39:400-404.

Doudoroff, P. and M. Katz. 1953. Critical review of literature on the toxicity of industrial wastes and their components to fish. II. The metals, as salts. Sewage Ind. Wastes 25:802-839.

Driscoll, C.T., Jr., J.P. Baker, J.J. Bisogni, Jr. and C.L. Schofield. 1980. Effect of aluminium speciation on fish in dilute acidified waters. Nature 284:161-164.

Ecological Analysts, Inc. 1984. Study on metals in food fish near the abandoned Vienna fly ash disposal area. PB84-178441. National Technical Information Service, Springfield, VA.

Eddy, F.B. and C. Talbot. 1983. Formation of the perivitelline fluid in Atlantic salmon eggs (Salmo salar) in fresh water and in solutions of metal ions. Comp. Biochem. Physiol. 75C:1-4.

Ellis, M.M. 1937. Detection and measurement of stream pollution. Bull. Bur. Fish. 48:365-437.

Elwood, J.W., S.G. Hildebrand and J.J. Beauchamp. 1976. Contribution of gut contents to the concentration and body burden of elements in Tipula spp. from a spring-fed stream. J. Fish. Res. Board Can. 33:1930-1938.

Everhart, W.H. and R.A. Freeman. 1973. Effects of chemical variations in aquatic environments. Volume II. Toxic effects of aqueous aluminum to rainbow trout. EPA-R3-73-011b. National Technical Information Service, Springfield, VA.

Freeman, R.A. 1973. Recovery of rainbow trout from aluminum poisoning. Trans. Am. Fish. Soc. 102:152-154.

Freeman, R.A. and W.H. Everhart. 1971. Toxicity of aluminum hydroxide complexes in neutral and basic media to rainbow trout. Trans. Am. Fish. Soc. 100:644-658.

Gibbons, M.V., F.D. Woodwick, W.H. Funk and H.L. Gibbons. 1984. Effects of multiphase restoration, particularly aluminum sulfate application, on the zooplankton community of a eutrophic lake in eastern Washington. J. Freshwater Ecol. 2:393-404.

Gunn, J.M. and W. Keller. 1984. Spawning site water chemistry and lake trout (Salvelinus namaycush) sac fry survival during spring snow melt. Can. J. Fish. Aquat. Sci. 41:319-329.

Gunn, J.M. and D.L.G. Noakes. 1986. Avoidance of low pH and elevated Al concentrations by brook charr (Salvelinus fontinalis) alevins in laboratory tests. Water Air Soil Pollut. 30:497-503.

Guthrie, R.K., F.L. Singleton and D.S. Cherry. 1977. Aquatic bacterial populations and heavy metals - II. Influence of chemical content of aquatic environments on bacterial uptake of chemical elements. Water Res. 11:643-646.

Hall, L.W., Jr., A.E. Pinkney, L.O. Horseman and S.E. Finger. 1985. Mortality of striped bass larvae in relation to contaminants and water quality in a Chesapeake Bay tributary. Trans. Am. Fish. Soc. 114:861-868.

Hamilton-Taylor, J., M. Willis and C.S. Reynolds. 1984. Depositional fluxes of metals and phytoplankton in Windermere as measured by sediment traps. Limnol. Oceanogr. 29:695-710.

Havas, M. 1985. Aluminum bioaccumulation and toxicity to *Daphnia magna* in soft water at low pH. Can. J. Fish. Aquat. Sci. 42:1741-1748.

Havas, M. and T.C. Hutchinson. 1982. Aquatic invertebrates from the Smoking Hills, N.W.T.: Effect of pH and metals on mortality. Can. J. Fish. Aquat. Sci. 39:890-903.

Havas, M. and T.C. Hutchinson. 1983. Effect of low pH on the chemical composition of aquatic invertebrates from tundra ponds at the Smoking Hills, N.W.T., Canada. Can. J. Zool. 61:241-249.

Havas, M. and G.E. Likens. 1985a. Changes in ^{22}Na influx and outflux in *Daphnia magna* (Straus) as a function of elevated Al concentrations in soft water at low pH. Proc. Natl. Acad. Sci. U. S. A. 82:7345-7349.

Havas, M. and G.E. Likens. 1985b. Toxicity of aluminum and hydrogen ions to *Daphnia catawba*, *Holopedium gibberum*, *Chaoborus punctipennis*, and *Chironomus anthrocinus* from Mirror Lake, New Hampshire. Can. J. Zool. 63:1114-1119.

Helliwell, S., G.E. Batley, T.M. Florence and B.G. Lumsden. 1983. Speciation and toxicity of aluminium in a model fresh water. Environ. Technol. Lett. 4:141-144.

Hem, J.D. 1968a. Aluminum species in water. In: Trace inorganics in water. Baker, R.A. (Ed.). Advances in Chemistry Series 73. American Chemical Society, Washington, DC. pp. 98-114.

Hem, J.D. 1968b. Graphical methods for studies of aqueous aluminum hydroxide, fluoride, and sulfate complexes. Water Supply Paper 1827-B. U.S. Geological Survey, U.S. Government Printing Office, Washington, DC.

Hem, J.D. and C.E. Roberson. 1967. Form and stability of aluminum hydroxide complexes in dilute solution. Water Supply Paper 1827-A. U.S. Geological Survey. U.S. Government Printing Office, Washington, DC.

Holtze, K.E. 1983. Effects of pH and ionic strength on aluminum toxicity to early developmental stages of rainbow trout (Salmo gairdneri Richardson). Ontario Ministry of the Environment, Rexdale, Ontario, Canada.

Howells, G.D., D.J.A. Brown and K. Sadler. 1983. Effects of acidity, calcium, and aluminium on fish survival and productivity - a review. J. Sci. Food Agric. 34:559-570.

Hsu, P.H. 1968. Interaction between aluminum and phosphate in aqueous solution. In: Trace inorganics in water. Baker, R.A. (Ed.). Advances in Chemistry Series 73. American Chemical Society, Washington, DC. pp. 115-127.

Hunn, J.B., L. Cleveland and E.E. Little. 1987. Influence of pH and aluminum on developing brook trout in a low calcium water. Environ. Pollut. 43:63-73.

Hunter, J.B., S.L. Ross and J. Tannahill. 1980. Aluminum pollution and fish toxicity. J. Water Pollut. Control Fed. 79:413-420.

Jay, F.B. and R.J. Muncy. 1979. Toxicity to channel catfish of wastewater from an Iowa coal beneficiation plant. Iowa State J. Res. 54:45-50.

Jones, J.R.E. 1939. The relation between the electrolytic solution pressures of the metals and their toxicity to the stickleback (Gasterosteus aculeatus L.). J. Exp. Biol. 16:425-437.

Jones, J.R.E. 1940. A further study of the relation between toxicity and solution pressure, with Polvcelis nigra as test animal. J. Exp. Biol. 17:408-415.

Kaiser, K.L.E. 1980. Correlation and prediction of metal toxicity to aquatic biota. Can. J. Fish. Aquat. Sci. 37:211-218.

Kimball, G. Manuscript. The effects of lesser known metals and one organic to fathead minnows (Pimephales promelas) and Daphnia magna. University of Minnesota, St. Paul, MN.

Knapp, S.M. and R.A. Soltero. 1983. Trout-zooplankton relationships in Medical Lake, WA following restoration by aluminum sulfate treatment. J. Freshwater Ecol. 2:1-12.

Lamb, D.S. and G.C. Bailey. 1981. Acute and chronic effects of alum to midge larva (Diptera: Chironomidae). Bull. Environ. Contam. Toxicol. 27:59-67.

Malley, D.F. and P.S.S. Chang. 1985. Effects of aluminum and acid on calcium uptake by the crayfish Orconectes virilis. Arch. Environ. Contam. Toxicol. 14:739-747.

Markarian, R.K., M.C. Matthews and L.T. Connor. 1980. Toxicity of nickel, copper, zinc and aluminum mixtures to the white sucker (Catostomus commersoni). Bull. Environ. Contam. Toxicol. 25:790-796.

Marquis, J.K. 1982. Aluminum neurotoxicity: An experimental perspective. Bull. Environ. Contam. Toxicol. 29:43-49.

Matheson, J.C., III. 1975. Availability of aluminum phosphate complexes to a green alga in various culture media. PB-268510. National Technical Information Service, Springfield, VA.

McCauley, D.J., L.T. Brooke, D.J. Call and C.A. Lindberg. 1986. Acute and chronic toxicity of aluminum to Ceriodaphnia dubia at various pH's. University of Wisconsin-Superior, Superior, WI.

McGarry, M.G. 1970. Algal flocculation with aluminum sulfate and polyelectrolytes. J. Water Pollut. Control. Fed. 42:R191-R201.

McKee, J.E. and H.W. Wolf. 1963. Water quality criteria. 2nd ed. State Water Quality Control Board, Sacramento, CA. pp. 129-132.

Minzoni, F. 1984. Effects of aluminium on different forms of phosphorus and freshwater plankton. Environ. Technol. Lett. 5:425-432.

Muramoto, S. 1981. Influence of complexans (NTA, EDTA) on the toxicity of aluminum chloride and sulfate to fish at high concentrations. Bull. Environ. Contam. Toxicol. 27:221-225.

Nalewajko, C. and B. Paul. 1985. Effects of manipulations of aluminum concentrations and pH on phosphate uptake and photosynthesis of planktonic communities in two Precambrian Shield lakes. Can. J. Fish. Aquat. Sci. 42:1946-1953.

Neville, C.M. 1985. Physiological response of juvenile rainbow trout, Salmo gairdneri, to acid and aluminum - prediction of field responses from laboratory data. Can. J. Fish. Aquat. Sci. 42:2004-2019.

Odonnell, A.R., G. Mance and R. Norton. 1984. A review of the toxicity of aluminium in fresh water. Technical Report TR 197. Water Research Centre Environment, Marlow, Bucks, England.

Ogilvie, D.M. and D.M. Stechey. 1983. Effects of aluminum on respiratory responses and spontaneous activity of rainbow trout, Salmo gairdneri. Environ. Toxicol. Chem. 2:43-48.

Olson, D.L. and G.M. Christensen. 1980. Effects of water pollutants and other chemicals on fish acetylcholinesterase (in vitro). Environ. Res. 21:327-335.

Orr, P.L., R.W. Bradley, J.B. Sprague and N.J. Hutchinson. 1986. Acclimation-induced change in toxicity of aluminum to rainbow trout (Salmo gairdneri). Can. J. Fish. Aquat. Sci. 43:243-246.

Peterson, S.A., W.D. Sanville, F.S. Stay and C.F. Powers. 1974. Nutrient inactivation as a lake restoration procedure. Laboratory investigations. EPA-660/3-74-032. National Technical Information Service, Springfield, VA.

Phillips, G.R. and R.C. Russo. 1978. Metal bioaccumulation in fishes and aquatic invertebrates: A literature review. EPA-600/3-78-103. National Technical Information Service, Springfield, VA.

Rao, V.N.R. and S.K. Subramanian. 1982. Metal toxicity tests on growth of some diatoms. Acta Bot. Indica 10:274-281.

Roberson, C.E. and J.D. Hem. 1969. Solubility of aluminum in the presence of hydroxide, fluoride, and sulfate. Water Supply Paper 1827-C. U.S. Geological Survey. U.S. Government Printing Office, Washington, DC.

Ruthven, J.A. and J. Cairns, Jr. 1973. Response of fresh-water protozoan artificial communities to metals. J. Protozool. 20:127-135.

Sanborn, N.H. 1945. The lethal effect of certain chemicals on fresh water fish. Canner, pp. 13-15.

Schindler, D.W. and M.A. Turner. 1982. Biological, chemical and physical responses of lakes to experimental acidification. Water Air Soil Pollut. 18:259-271.

Schofield, C.L. and J.R. Trojnar. 1980. Aluminum toxicity to brook trout (<u>Salvelinus fontinalis</u>) in acidified waters. Environ. Sci. Res. 17:341-366.

Seip, H.M., L. Muller and A. Naas. 1984. Aluminium speciation: Comparison of two spectrophotometric analytical methods and observed concentrations in some acidic aquatic systems in southern Norway. Water Air Soil Pollut. 23:81-95.

Smith, L.L., Jr., D.M. Oseid, G.L. Kimball and S.M. El-Kandelgy. 1976. Toxicity of hydrogen sulfide to various life history stages of bluegill Lepomis macrochirus). Trans. Am. Fish. Soc. 105:442-449.

Smith, R.W. and J.D. Hem. 1972. Chemistry of aluminum in natural water: Effect of aging on aluminum hydroxide complexes in dilute aqueous solutions. Water Supply Paper 1827-D. U.S. Geological Survey, U.S. Government Printing Office, Washington, DC.

Snodgrass, W.J., M.M. Clark and C.R. O'Melia. 1984. Particle formation and growth in dilute aluminum(III) solutions. Water Res. 18:479-488.

Sonnichsen, T. 1978. Toxicity of a phosphate-reducing agent (aluminium sulfate) on the zooplankton in the lake Lyngby So. Int. Ver. Theor. Angew. Limnol. Verh. 20:709-713.

Stanley, R.A. 1974. Toxicity of heavy metals and salts to Eurasian watermilfoil (Myriophyllum spicatum L.). Arch. Environ. Contam. Toxicol. 2:331-341.

Staurnes, M., T. Sigholt and O.B. Reite. 1984. Reduced carbonic anhydrase and Na-K-ATPase activity in gills of salmonids exposed to aluminium-containing acid water. Experientia 40:226-227.

Stearns, F.M., R.A. DeMaio and H.J. Eichel. 1978. Occurrence of cyanide-resistant respiration and of increased concentrations of cytochromes in Tetrahymena cells grown with various metals. Fed. Proc. 37:1516.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. National Technical Information Service, Springfield, VA.

Stumm, W. and J.J. Morgan. 1981. Aquatic chemistry. Wiley, New York, NY. pp. 176-177.

Tease, B. and R.A. Coler. 1984. The effect of mineral acids and aluminum from coal leachate on substrate periphyton composition and productivity. J. Freshwater Ecol. 2:459-467.

Thomas, A. 1915. Effects of certain metallic salts upon fishes. Trans. Am. Fish. Soc. 44:120-124.

Thompson, S.E., C.A. Burton, D.J. Quinn and Y.C. Ng. 1972. Concentration factors of chemical elements in edible aquatic organisms. UCRL-50564. Rev. 1. National Technical Information Service, Springfield, VA.

Unz, R.F. and J.A. Davis. 1975. Microbiology of combined chemical-biological treatment. J. Water Pollut. Control Fed. 47:185-194.

U.S. EPA. 1976. Quality criteria for water. PB-263943 or EPA-440/9-76-023. National Technical Information Service, Springfield, VA.

U.S. EPA. 1980. Water quality criteria documents. Federal Regist. 45:79318-79379. November 28.

U.S. EPA. 1983a. Methods for chemical analysis of water and wastes. EPA-600/4-79-020 (Revised March 1983). National Technical Information Service, Springfield, VA.

U.S. EPA. 1983b. Water quality standards regulation. Federal Regist. 48:51400-51413. November 8.

U.S. EPA. 1983c. Water quality standards handbook. Office of Water Regulations and Standards, Washington, DC.

U.S. EPA. 1985a. Appendix B - Response to public comments on "Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses." Federal Regist. 50:30793-30796. July 29.

U.S. EPA. 1985b. Water quality criteria. Federal Regist. 50:30784-30792. July 29.

U.S. EPA. 1985c. Technical support document for water quality-based toxics control. EPA-440/4-85-032 or PB86-150067. National Technical Information Service, Springfield, VA.

U.S. EPA. 1986. Chapter 1 - Stream design flow for steady-state modeling. In: Book VI - Design conditions. In: Technical guidance manual for performing waste load allocation. Office of Water, Washington, DC. August.

U.S. EPA. 1987. Permit writer's guide to water quality-based permitting for toxic pollutants. EPA-440/4-87-005. Office of Water, Washington, DC.

van Coillie, R. and A. Rousseau. 1974. Mineral composition of the scales of Catostomus commersoni from two different waters: Studies using electron microprobe analysis. J. Fish. Res. Board Can. 31:63-66.

van Dam, H., G. Suurmond and C.J.F. ter Braak. 1981. Impact of acidification on diatoms and chemistry of Dutch moorland pools. Hydrobiologia 83:425-459.

Wallen, I.E., W.C. Greer and R. Lasater. 1957. Toxicity to Gambusia affinis of certain pure chemicals in turbid waters. Sewage Ind. Wastes 29:695-711.

Witters, H., J.H.D. Vangenechten, S. Van Puymbroeck and O.L.J. Vanderborght. 1984. Interference of aluminum and pH on the Na-influx in an aquatic insect Corixa punctata (Illig.). Bull. Environ. Contam. Toxicol. 32:575-579.

Wooldridge, C.R. and D.P. Wooldridge. 1969. Internal damage in an aquatic beetle exposed to sublethal concentrations of inorganic ions. Ann. Entomol. Soc. Am. 62:921-922.

Wren, C.D., H.R. MacCrimmon and B.R. Loescher. 1983. Examination of bioaccumulation and biomagnification of metals in a Precambrian Shield lake. Water Air Soil Pollut. 19:277-291.

Zarini, S., D. Annoni and O. Ravera. 1983. Effects produced by aluminium in freshwater communities studied by "enclosure" method. Environ. Technol. Lett. 4:247-256.

[~~(6)~~](7) **Limited Aquatic Life:** [~~Criteria shall be developed on a segment specific basis.~~] The acute aquatic life criteria of Subsections I and J of this section [~~shall~~] apply to this subcategory. Chronic aquatic life criteria do not apply unless adopted on a segment-specific basis. Human health-organism only criteria apply only for persistent pollutants unless adopted on a segment-specific basis.

500. The Commission adopts the Department's proposals to delete the first sentence because the criteria specified in the rest of the paragraph are protective of the use, and adopting segment-specific criteria is an option when appropriate; and to add the last sentence for consistency with section 11.G regarding the applicability of human health-organism only criteria.

501. The Commission does not adopt Amigos Bravos' proposal to delete the limited aquatic life use because the criteria protect aquatic species that take advantage of habitats, such as ephemeral waters, that do not support fish populations. The use is assigned on a site-specific basis when a UAA demonstrates the attainment of higher uses is not feasible, and the applicable criteria are modified as appropriate for a particular water. This process safeguards against the inappropriate application of the use, and is neither confusing nor inappropriate, particularly since EPA has confirmed its consistency with the CWA. In this respect, contrary to Amigos Bravos' claims, the use fully addresses EPA's concerns. EPA approved both the use definition and criteria in section 900.H(7), provided a UAA is conducted to demonstrate that the use is appropriate for a particular water.

502. AB has provided no technical testimony supporting its concern that "the limited aquatic life use could be abused to lower water quality standards." The limited aquatic life designated use is appropriate for certain environmental conditions in New Mexico.

20.6.4.900

I. Hardness-dependent acute and chronic aquatic life criteria for metals are calculated using the following equations. The criteria are expressed as a function of dissolved hardness (as mg $CaCO_3$/L). With the exception of aluminum, the equations are valid only for dissolved hardness concentrations of 0-400 mg/L. For dissolved hardness concentrations above 400 mg/L, the criteria for 400 mg/L apply. For aluminum the equations are valid only for dissolved hardness concentrations of 0-220 mg/L. For dissolved hardness concentrations above 220 mg/L, the aluminum criteria for 220 mg/L apply.

(1) **Acute aquatic life criteria for metals.** The equation to calculate acute criteria in µg/L is $\exp(m_A[\ln(\text{hardness})] + b_A)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department. The equation parameters are as follows:

Metal	m_A	b_A	**Conversion factor (CF)**
Aluminum (Al)	1.3695	1.8308	
Cadmium (Cd)	0.8968	-3.5699	1.136672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	3.7256	0.316
Copper (Cu)	0.9422	-1.700	0.960
Lead (Pb)	1.273	-1.460	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	6.4676	
Nickel (Ni)	0.8460	2.255	0.998
Silver (Ag)	1.72	-6.59	0.85
Zinc (Zn)	0.9094	0.9095	0.978

(2) **Chronic aquatic life criteria for metals.** The equation to calculate chronic criteria in µg/L is $\exp(m_C[\ln(\text{hardness})] + b_C)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department. The equation parameters are as follows:

Metal	m_C	b_C	**Conversion factor (CF)**
Aluminum (Al)	1.3695	0.9161	
Cadmium (Cd)	0.7647	-4.2180	1.101672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	0.6848	0.860
Copper (Cu)	0.8545	-1.702	0.960
Lead (Pb)	1.273	-4.705	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	5.8743	
Nickel (Ni)	0.8460	0.0584	0.997
Zinc (Zn)	0.9094	0.6235	0.986

(3) Selected values of calculated acute and chronic criteria (µg/L).

Hardness as CaCO, dissolved (mg/L)	_	Al	Cd	Cr III	Cu	Pb	Mn	Ni	Ag	Zn
25	Acute	512	0.51	180	4	14	1,881	140	0.3	45
	Chronic	205	0.17	24	3	1	1,040	16	_	34
30	Acute	658	0.59	210	4	17	1,999	170	0.4	54
	Chronic	263	0.19	28	3	1	1,105	19	_	41
40	Acute	975	0.76	270	6	24	2,200	220	0.7	70
	Chronic	391	0.23	35	4	1	1,216	24	_	53
50	Acute	1,324	0.91	320	7	30	2,370	260	1.0	85
	Chronic	530	0.28	42	5	1	1,309	29	_	65
60	Acute	1,699	1.07	370	8	37	2,519	300	1.3	101
	Chronic	681	0.31	49	6	1	1,391	34	_	76
70	Acute	2,099	1.22	430	10	44	2,651	350	1.7	116
	Chronic	841	0.35	55	7	2	1,465	38	_	88
80	Acute	2,520	1.37	470	11	51	2,772	390	2.2	131
	Chronic	1,010	0.39	62	7	2	1,531	43	_	99
90	Acute	2,961	1.51	520	12	58	2,883	430	2.7	145
	Chronic	1,186	0.42	68	8	2	1,593	48	_	110
100	Acute	3,421	1.65	570	13	65	2,986	470	3.2	160
	Chronic	1,370	0.45	74	9	3	1,650	52	_	121

Hardness as CaCO$_3$ dissolved (mg/L)	-	Al	Cd	Cr III	Cu	Pb	Mn	Ni	Ag	Zn
200	Acute	8,838	2.98	1,010	26	140	3,761	840	11	301
	Chronic	3,541	0.75	130	16	5	2,078	90	-	228
220	Acute	10,071								
	Chronic	4,035								
300	Acute	10,071	4.21	1,400	38	210	4,305	1190	21	435
	Chronic	4,035	1.00	180	23	8	2,379	130	-	329
400 and above	Acute	10,071	5.38	1,770	50	280	4,738	1510	35	564
	Chronic	4,035	1.22	230	29	11	2,618	170	-	428

503. The Commission adopts the Department's proposal to reformat the criteria for ease of use.

504. The Commission adopts the Department's proposal to change the introductory paragraph to clarify that these criteria are hardness-dependent, must be expressed by an equation and cannot simply be listed in the table in subsection J.

505. The Commission adopts the Department's proposal to add a sentence clarifying that the criteria are a function of dissolved hardness because dissolved calcium and magnesium compete for sites on fish gills that might otherwise be occupied by metals, thereby reducing the toxicity of the metals. Therefore, the hardness value to be used in the equations should represent the dissolved fraction.

506. The Commission adopts the Department's proposal to move the applicable range of hardness from section 12.H to this location because the hardness range is an integral part of the criteria statement.

507. The Commission adopts the Department's proposal to delete the phrase "and those criteria listed in Subsection J for aquatic life shall apply to the subcategories of aquatic life identified in this section" because the phrase is incomplete (ammonia criteria in subsections K and L also apply to some

subcategories) and misplaced (subsection H indicates which aquatic life criteria apply to the aquatic life subcategories).

508. The Commission adopts the Department's proposal to add paragraphs (1) and (2) because they express the criteria equations in the more readable form used in EPA's National Recommended Water Quality Criteria.

509. The Commission adopts the Department's proposal to clarify that the chromium equations apply to the trivalent ion (chromium III) because it is consistent with EPA's recommended criteria.

510. The Commission adopts the Department's proposal to include a table showing selected calculated criteria values at a range of hardnesses to respond to complaints that criteria expressed as equations are difficult for the public to compare to water quality data.

511. The Commission adopts the proposal by Chevron Mining and Los Alamos National Laboratory/Department of Energy (CMI and LANS/DOE) to replace the current acute and chronic aquatic life criteria for aluminum in section 900.J with hardness-based criteria and to show total aluminum in this subsection to reflect findings of new toxicological studies.

512. The current New Mexico surface water quality standards for aluminum are based on the current standards document and the 1988 national aluminum toxicity databases, which do not reflect current scientific understanding of aluminum toxicity to aquatic life. CMI and LANS/DOE's proposal is based on an evaluation of the EPA recalculation procedure for Arid West effluent-dependent waters conducted by CMI's consultants as part of the Arid West Water Quality Research Project.

513. The incorporation of the new toxicity studies adds more than three dozen new data points and substantially increases the statistical confidence in the criteria.

514. The original proposal was refined to implement aluminum criteria on the basis of "total recoverable aluminum." Newer studies show that aluminum toxicity to aquatic organisms potentially can be caused not only by dissolved aluminum, but can also be caused by insoluble amorphous hydroxides suspended in the water column. This particle can cause suffocation in aquatic organisms. Because the Commission's existing aquatic life criteria consider only dissolved aluminum, the standards need to be modified to also allow for assessment of aluminum hydroxides.

515. The total form is recommended by EPA. Most of the data is derived from studies on the total form. It is recognized that field samples of the total form may capture aluminum in nontoxic materials, such as clays and sands.

516. The criteria are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department because some native sands, silts and clays contain forms of aluminum that are not toxic to aquatic organisms, and can be removed from the sample. The filter pore-size would be selected to allow the potentially toxic aluminum hydroxide particles to pass through the filter and be measured during sample analysis, but would exclude the non-toxic solid phases.

517. The newer scientific literature demonstrates that hardness has a significant influence on aluminum toxicity and, hence, should be incorporated into regulatory criteria. The aluminum criteria should be revised to reflect this hardness dependency using an equation rather than a single numeric value, as is done with the criteria for several other metals.

518. The same hardness relationship for the acute and chronic criteria is proposed for aluminum; EPA allows the acute hardness relationship to be applied to the chronic equation in the absence of better data.

519. The Commission adopts the proposed hardness range because using zero is consistent with the approach used for other hardness-dependent metals, and

capping the range at 220 is consistent with the highest hardness concentration used in toxicity tests. The new equations apply at hardness concentrations from 0 to 220 mg/L, and the criteria values for a hardness of 220 ug/L applies at higher hardness concentrations. The criteria values for a hardness of 25 ug/L apply at hardnesses less than 25 mg/L because no compelling basis exists for limiting the application of the proposed criteria to hardness of 25 mg/L and above, and because the criteria were based in part on toxicity studies conducted in waters softer than 25 mg/L.

520. The Commission adopts CMI and LANS/DOE's proposal to update the hardness-based acute and chronic aquatic life criteria for dissolved cadmium based on EPA's criteria derivation and recalculation procedures.

521. The current acute and chronic standards for dissolved cadmium in New Mexico are based on EPA's 2001 criteria update. The proposed changes are based on a more recent review technical review and update of the 2001 revised cadmium standards that resulted in new cadmium acute and chronic equations adopted by the State of Colorado in 2005 and approved by EPA.

522. The proposed change follows EPA's guidance for developing numeric criteria for the protection of aquatic life (USEPA, 1985). Updating the criteria as proposed retains the level of protection intended by EPA guidance for deriving numeric criteria for aquatic life designated uses.

523. The Commission adopts CMI and LANS/DOE's proposal to update the hardness-based acute and chronic aquatic life criteria for dissolved zinc based on EPA's criteria derivation and recalculation procedures.

524. The acute and chronic standards for zinc are based on EPA's 1996 criteria update. The proposed changes for zinc equations are based on a more recent review of the updated zinc standards adopted by the State of Colorado, a subsequent review of the EPA recalculation procedure, additional literature searches in 2008 as part of a site-specific zinc standards evaluation for Colorado streams, and additional data from

recently available studies conducted by the International Lead-Zinc Research Organization (ILZRO).

525. The proposed change follows EPA's guidance for developing numeric criteria for the protection of aquatic life (USEPA, 1985). Updating the criteria as proposed retains the level of protection intended by EPA guidance for deriving numeric criteria for aquatic life designated uses.

526. The Commission adopts CMI's proposal to add acute and chronic criteria for dissolved manganese because the criteria rely on updated scientific information and are consistent with EPA's 1985 Guidelines.

527. Neither EPA nor New Mexico currently has manganese ambient water quality standards for the protection of aquatic life. Manganese can be a metal of concern in the west, where manganese deposits are present in the Rocky Mountain and Great Basin Regions. Additional sources of manganese come from iron manufacture industry, volcanic activity, and use of fertilizers. These sources, combined with the natural deposits, can contribute to elevated concentrations of manganese in watersheds with no apparent adverse effect on aquatic biota.

528. The proposed criteria follow the manganese criteria adopted in Colorado, which were developed based on available literature and toxicity testing conducted jointly by industry and the Colorado Division of Wildlife. These hardness-based equations were developed based on the EPA standards derivation procedure, were adopted by the Colorado Water Quality Control Commission in 2000, and have been approved by EPA for use in Colorado.

J. Use-Specific Numeric criteria.

(1) Notes applicable to the Table of Numeric Criteria in paragraph (2):

(a) Where the letter "a" is indicated in a cell, the criterion is hardness-based and can be referenced in Subsection I of 20.6.4.900 NMAC.

(b) Where the letter "b" is indicated in a cell, the criterion can be referenced in Subsection C of 20.6.4.900 NMAC.

(c) Criteria are in µg/L unless otherwise indicated.

(d) Abbreviations are as follows: CAS – Chemical Abstracts Service (see definition for "CAS Number" in 20.6.4.7 NMAC); DWS – domestic water supply; Irr – irrigation; LW – livestock watering; WH – wildlife habitat; HH-OO – human health-organism only; C – cancer-causing; P – persistent.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1445 ROSS AVENUE, SUITE 1200
DALLAS, TX 75202-2733

JUN 1 8 2012

James Hogan, Acting Chief
Surface Water Quality Bureau
New Mexico Environment Department
Harold Runnels Building (N2050)
P.O. Box 5469
Santa Fe, NM 87502-5469

Dear Mr. Hogan:

I am writing in reference to the Environmental Protection Agency's (EPA or the Agency) April 30, 2012 action on amendments to the ***Standards for Interstate and Intrastate Surface Waters*** **20.6.4. NMAC**. In that action, EPA approved the remaining new/revised amendments with the exception of aluminum criteria under specific conditions.

In that action, EPA approved the application of the hardness-dependent equation for aluminum to those waters of the State at a pH of 6.5 to 9.0 because it will yield criteria that are protective of applicable uses in waters within that pH range. However, EPA disapproved the application of this equation in waters where the pH is below 6.5 as it may not be protective of applicable uses below that pH range. In that action, we stated that consistent with EPA's regulations, the previously approved 304(a) criteria for aluminum are thus the applicable water quality standards for purposes of the CWA in waters where the pH is at or below 6.5. We also stated that in such cases, as the permitting authority in New Mexico, EPA will apply the previously approved 87 μg/L chronic criterion, but inadvertently referred to the total recoverable form of aluminum - the previously approved criterion is the dissolved fraction. As a result, we are amending our action to clarify that as the permitting authority, EPA will apply the previously approved 87 ug/L dissolved aluminum criterion in those waters where the pH is below 6.5 as described in the enclosed amended Record of Decision (ROD) addendum. This correction does not affect other new/revised standards approved in our previous action.

I appreciate the State's cooperative efforts in resolving this issue. If you need additional detail concerning this letter or the enclosed amended addendum to our original ROD, please call me at (214) 665-3187, or have your staff contact Russell Nelson at (214) 665-6646.

Sincerely,

William K. Honker, P.E.
Acting Director
Water Quality Protection Division

for

Enclosure

cc: Wally Murphy
Field Supervisor
Ecological Services Office
USFWS
2105 Osuna Road NE
Albuquerque, NM 87113-1001

Lynn Wellman
Regional Water Quality Coordinator
USFWS
Box 1306
Albuquerque, NM 87103

RECORD OF DECISION ADDENDUM

New Mexico's Standards For
Interstate and Intrastate Surface Waters
20.6.4 NMAC

The purpose of this addendum is to explain the Environmental Protection Agency (EPA's or the Agency's) decision on those provisions of New Mexico's ***Standards for Interstate and Intrastate Surface Waters*** **20.6.4. NMAC** that EPA did not act on as part of its previous April 12, 2011 decision. EPA's decisions are based on a detailed review of supporting documentation for these provisions, discussions and correspondence with the State.

20.6.4.10 D. Site-specific Criteria

Federal regulations allow States the flexibility to modify EPA's 304(a) criteria to reflect site-specific conditions. Given this premise, EPA initially approved the majority of section **20.6.4.10(D) Site-specific Criteria** and took no action on subsection **20.6.4.10 (D)(1)(e)** because of specific concerns with that subsection of the provision. After additional analysis, EPA determined that section **20.6.4.10(D)** represents implementation procedures and does not constitute water quality standards that require the EPA's review or action under Section 303(c) of the Clean Water Act (CWA). Since the provisions in this section are not water quality standards, EPA has determined that it has no obligation to act on these provisions and as a result, rescinds that prior action. Section **20.6.4.10(D)** remains in effect for purposes of State law and may be used for the development of site-specific criteria; however, it is not a water quality standard that is effective for CWA purposes.

Although EPA is not approving the procedures in section **20.6.4.10 (D)** as water quality standards, we retain authority to act on site-specific criteria developed using these procedures. Given this authority, it is important that the State understand our concerns with subsection **20.6.4.10 (D)(1)(e)**. In a plain reading of this subsection, it is unclear what the reference to "...other factors or combinations of factors that...may warrant modifications of default criteria" means or how it will be applied or implemented. In an effort to determine the meaning and intent, EPA referred to the hearing record, the Commission's Statement of Reasons and the Hearing Officers Report. All referenced assurances from the New Mexico Environment Department (NMED) to 3rd-party petitioners that the Commission would consider "net ecological benefit" in establishing site-specific criteria. Given this, EPA believes it is important to reiterate the position outlined in comments provided to NMED that were included as Exhibit_89 in the State's hearing record and subsequent submission. As explained in those comments, the "net ecological benefit" concept is not supportable from an ecological perspective and is not consistent with federal regulations. As such, EPA is unlikely to approve site-specific criteria based on a net ecological benefit concept.

taken in the development of these recalculated criteria and conducted a detailed review to determine the appropriateness of applying these criteria statewide.

Based on our detailed review and correspondence with the State, EPA noted concerns with the selective exclusion and inclusion of specific studies that were used in the recalculation, including the use of non-native species. EPA learned that the recalculated criteria were derived by GEI as if they were an update to the national criteria. Although GEI generally followed methods outlined in EPA's criteria derivation and recalculation procedures (Stephan et al. 1985, USEPA 1994), since these updates are submitted by the State, EPA views them as State, not national criteria. As such, EPA recommends the use of indigenous species in the development of criteria intended to apply statewide.

Given that the implementation of metals criteria is complex due to the site-specific nature of their toxicity, the detailed review was also intended to determine if it would be appropriate to apply these recalculated values statewide. The studies GEI utilized were carried out over a pH range of 6.5 to 9.0. EPA previously established this pH range as an optimal in ambient freshwater (USEPA 1976), it is not reflective of the pH range that will be seen in all waters in New Mexico. Although GEI recognized the inverse toxicity and hardness relationship (within the pH range of 6.5 to 9.0) in the development of the acute equation, it does not appear that the significant effects that site-specific factors such as pH have on metals and particularly on aluminum toxicity were fully considered in applying these equations as statewide criteria. The pH significantly influences speciation and/or complexation of aluminum at low pH and should have been considered carefully in determining if these recalculated values would be appropriate when adopting these values as statewide criteria.

Given the significant variability in both pH and hardness in waters in New Mexico, EPA does not believe that these hardness-based equations are appropriate as a basis for statewide criteria and may not be protective of beneficial uses in all waters of the State. EPA has determined that the hardness-based equations would be protective for waters within the pH range of 6.5 to 9.0, particularly at low hardness levels, but would not be protective for waters below that pH range. Therefore, EPA is approving the hardness-based equation for aluminum for only those waters of the State where pH is equal to or greater than 6.5, but is disapproving these equations in waters where the pH is less than 6.5. To resolve this disapproval, EPA recommends that the State adopt a footnote for these equations specifying the following:

> "Where pH is equal to or greater than 6.5 in the receiving water after mixing, the chronic hardness-dependent equation will apply. Where pH is 6.5 or less in the receiving water after mixing, either the 87 µg/l chronic total recoverable aluminum criterion or the criterion resulting from the chronic hardness-dependent equation will apply, whichever is more stringent."

In the interim, for waters of the State where pH is 6.5 or less, in the receiving water after mixing, EPA will apply the 304(a) recommended 87 µg/L chronic dissolved aluminum criterion.

Literature Cited

GEI Consultants, Inc. Ambient Water Quality Standards for Aluminum – Review and Update, July 2009.

GEI Consultants, Inc. Ambient Water Quality Standards for Cadmium – Review and Update, August 2009.

GEI Consultants, Inc. Ambient Water Quality Standards for Zinc – Review and Update, August 2009.

State of New Mexico, Quality Control Commission – Statewide Water Quality Management Plan and Continuing Planning Process (2011).

State of New Mexico, Water Quality Control Commission - Transcript of Proceedings. WQCC-08-13(R) Volume 1 (2009).

State of New Mexico, Water Quality Control Commission - Hearing Officer's Report. WQCC-08-13, (2010).

State of New Mexico, Water Quality Control Commission - Order and Statement of Reasons for Amendment of Standards. WQCC-08-13 (2010).

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman, and W.A. Brungs. 1985. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses. PB-85-227049. U.S. Environmental Protection Agency, Office of Research and Development, Duluth, Minnesota.

U.S. Environmental Protection Agency (USEPA). 1994. *EPA Interim Guidance on Determination and Use of Water-Effect Ratios for Metals*. EPA-823-B-94-001. Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). Quality Criteria for Water, PB-263 943. Red Book (1976)

U.S. Environmental Protection Agency (USEPA). 1988. Ambient Water Quality Criteria for Aluminum - 1988. EPA 440/5-86-008. Office of Water, Washington, DC.

U.S. Environmental Protection Agency (USEPA). 2001. 2001 Update of Ambient Water Quality Criteria for Cadmium. EPA-822-R-01-001. Office of Water, Washington, DC.

AMENDED

TECHNICAL SUPPORT DOCUMENT

EPA Action on the New Mexico Water Quality Standards for Interstate and Intrastate Surface Waters
20.6.4 NMAC

2013 Triennial Revisions

U.S. EPA REGION 6
WATER QUALITY PROTECTION DIVISION
August 11, 2017

Commission modified this provision to reflect the use of updated methods for monitoring, assessment and reporting.

In future amendments, EPA recommends that the SWQB propose updating its terminology to reflect that used in EPA guidance, i.e., statistical threshold value and geometric mean.

20.6.4.900 H. NMAC.

H. Aquatic Life:

(3) **Marginal Coldwater:** Dissolved oxygen [~~6~~] 6.0 mg/L or more, 6T3 temperature 25°C (77°F), maximum temperature 29°C (84°F) and pH within the range from 6.6 to 9.0. Where a single segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature and no 6T3 temperature applies.

(4) **Coolwater:** Dissolved oxygen 5.0 mg/L or more, maximum temperature 29°C (84°F) and pH within the range of 6.6 to 9.0.

(5) **Warmwater:** Dissolved oxygen [~~5~~] 5.0 mg/L or more, maximum temperature 32.2°C (90°F) and pH within the range of 6.6 to 9.0. Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

(6) **Marginal Warmwater:** Dissolved oxygen [~~5~~] 5.0 mg/L or more, pH within the range of 6.6 to 9.0 and maximum temperature 32.2°C (90°F). Where a segment-specific temperature criterion is indicated in 20.6.4.101-899 NMAC, it is the maximum temperature.

EPA Discussion:

Dissolved oxygen criteria have been revised in subparagraphs (3), (5) and (6) of 20.6.4.900 H. NMAC to show decimal places consistent with dissolved oxygen criteria for the other aquatic life designated uses. These are nonsubstantive modifications.

20.6.4.900 I.

I. Hardness-dependent acute and chronic aquatic life criteria for metals are calculated using the following equations. The criteria are expressed as a function of dissolved hardness (as mg $CaCO_3$/L). With the exception of aluminum, the equations are valid only for dissolved hardness concentrations of 0-400 mg/L. For dissolved hardness concentrations above 400 mg/L, the criteria for 400 mg/L apply. For aluminum the equations are valid only for dissolved hardness concentrations of 0-220 mg/L. For dissolved hardness concentrations above 220 mg/L, the aluminum criteria for 220 mg/L apply.

(1) **Acute aquatic life criteria for metals.** The equation to calculate acute criteria in µg/L is $\exp(m_A[\ln(\text{hardness})] + b_A)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department. The EPA has disapproved the hardness-based equation for total recoverable aluminum in waters where the pH is less than 6.5 in the receiving stream for federal purposes of the Clean Water Act. The equation parameters are as follows:

---

membrane-Thermotolerant *Escherichia coli* Agar (modified mTEC). U.S. Environmental Protection Agency, Office of Water, Washington D.C. EPA–821–R–02–023.

Metal	m_A	b_A	Conversion factor (CF)
Aluminum (Al)	1.3695	1.8308	
Cadmium (Cd)	0.8968	-3.5699	1.136672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	3.7256	0.316
Copper (Cu)	0.9422	-1.700	0.960
Lead (Pb)	1.273	-1.460	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	6.4676	
Nickel (Ni)	0.8460	2.255	0.998
Silver (Ag)	1.72	-6.59	0.85
Zinc (Zn)	0.9094	0.9095	0.978

(2) Chronic aquatic life criteria for metals. The equation to calculate chronic criteria in µg/L is $\exp(m_C[\ln(\text{hardness})] + b_C)(CF)$. Except for aluminum, the criteria are based on analysis of dissolved metal. For aluminum, the criteria are based on analysis of total recoverable aluminum in a sample that is filtered to minimize mineral phases as specified by the department. The EPA has disapproved the hardness-based equation for total recoverable aluminum in waters where the pH is less than 6.5 in the receiving stream for federal purposes of the Clean Water Act. The equation parameters are as follows:

Metal	[~~m_A~~] m_C	[~~b_A~~] b_C	Conversion factor (CF)
Aluminum (Al)	1.3695	0.9161	
Cadmium (Cd)	0.7647	-4.2180	1.101672-[(ln hardness)(0.041838)]
Chromium (Cr) III	0.8190	0.6848	0.860
Copper (Cu)	0.8545	-1.702	0.960
Lead (Pb)	1.273	-4.705	1.46203-[(ln hardness)(0.145712)]
Manganese (Mn)	0.3331	5.8743	
Nickel (Ni)	0.8460	0.0584	0.997
Zinc (Zn)	0.9094	0.6235	0.986

EPA Discussion:

In today's action, EPA is reaffirming its June 8, 2017 action approving the new narratives in Subsections 20.6.4.900 I. (1) and (2) NMAC. Following subsequent discussions with NMED related to this actions, EPA agrees that some clarification is needed to describe what criteria apply to differing classes of waters as a result of EPA's initial 2012 and 2017 actions.

In its April 30, 2012 action, EPA approved the hardness-based equations for aluminum for only those waters of the State within a pH range of 6.5 to 9.0, but disapproved these equations in waters where the pH is less than 6.5. The EPA stated that it will apply the 304(a) recommended 87 µg/L chronic *total recoverable* aluminum criterion in the receiving water after mixing where pH is 6.5 or less. In its subsequent June 30, 2012 amended action, EPA clarified that it would apply New Mexico's previously approved 87 µg/L chronic *dissolved* aluminum criterion to such waters.

The EPA did not approve the removal of the existing 750 ug/L acute and 87 ug/L chronic aluminum criteria from Subsection 20.6.4.900. J. (2) NMAC in its April 30th or subsequent June 8, 2012 actions. EPA stated in its April 30, 2012 letter that "*Consistent with EPA's regulations, the previously approved 304(a) criteria for aluminum are thus the applicable water quality standards for purposes of the CWA in waters where the pH is at or below 6.5.*" As noted in the 2012 disapproval, as the permitting authority, EPA intended to apply the 87 µg/L chronic dissolved aluminum criterion in waters of the State where pH is 6.5 or less to ensure protection of those aquatic/aquatic dependent species that tolerate low pH levels. However, in our 2012 action EPA did not consider that Subsection 20.6.4.900 H. (7) NMAC which prohibits the application of chronic aquatic life criteria to waters with the limited aquatic life use unless adopted on a segment-specific basis, such as Sulphur Creek. Although no chronic criteria for toxics apply to waters designated as limited aquatic life use unless adopted on a segment-specific basis as described above, given that the existing 750 ug/L acute and 87 ug/L chronic aluminum criteria remain effective for CWA purposes, the 750 ug/L acute aluminum criterion is still effective for CWA purposes in New Mexico waters, including limited aquatic life use waters.

It should be noted that EPA has recently announced the release of its draft updated aquatic life criteria for aluminum in freshwater and a corresponding public comment period. EPA is updating the aluminum criteria to better reflect the latest science. Studies have shown that three water chemistry parameters; pH, dissolved organic carbon, and hardness, can affect the toxicity of aluminum by impacting aquatic species' overall exposure to aluminum. Unlike the fixed values recommended by EPA in the 1988 document, the draft updated criteria take these three important parameters into account and provide users the flexibility to develop site-specific criteria based on a site's water chemistry. To support the development of site-specific criteria, EPA is providing lookup tables as well as an Aluminum Criteria Calculator. EPA recommends that New Mexico track that effort, and consider whether any updates to the state's aluminum criteria are warranted as a result.

20.6.4.900 I. (3) NMAC

(3) Selected values of calculated acute and chronic criteria (µg/L).

Hardness as [~~CaCO~~] $CaCO_3$, dissolved (mg/L)		Al	Cd	Cr III	Cu	Pb	Mn	Ni	Ag	Zn
25	Acute	512	0.51	180	4	14	1,881	140	0.3	45
	Chronic	205	0.17	24	3	1	1,040	16		34
30	Acute	658	0.59	210	4	17	1,999	170	0.4	54
	Chronic	263	0.19	28	3	1	1,105	19		41
40	Acute	975	0.76	270	6	24	2,200	220	0.7	70
	Chronic	391	0.23	35	4	1	1,216	24		53
50	Acute	1,324	0.91	320	7	30	2,370	260	1.0	85
	Chronic	530	0.28	42	5	1	1,309	29		65
60	Acute	1,699	1.07	370	8	37	2,519	300	1.3	101
	Chronic	681	0.31	49	6	1	1,391	34		76
70	Acute	2,099	1.22	430	10	44	2,651	350	1.7	116
	Chronic	841	0.35	55	7	2	1,465	38		88
80	Acute	2,520	1.37	470	11	51	2,772	390	2.2	131
	Chronic	1,010	0.39	62	7	2	1,531	43		99

United States
Environmental Protection
Agency

Office of Water
4304T

EPA-820-R-16-002
March 2016

AQUATIC LIFE

AMBIENT WATER QUALITY CRITERIA

CADMIUM - 2016

NMED Exhibit 70

EPA 820-R-16-002

AQUATIC LIFE

AMBIENT WATER QUALITY CRITERIA

CADMIUM

(CAS # 7440-43-9)

2016

March 2016

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Health and Ecological Criteria Division
Washington, D.C.

NOTICES

This document provides information to states and tribes authorized to establish water quality standards under the Clean Water Act (CWA), to protect aquatic life from toxic effects of cadmium. Under the CWA, states and tribes are to establish water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from these criteria when appropriate. While this document contains EPA's scientific recommendations regarding ambient concentrations of cadmium that protect aquatic life, it does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. EPA may change this document in the future. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document can be downloaded from: http://www.epa.gov/waterscience/criteria/aqlife.html Notices.

FOREWORD

Section 304(a) (l) of the Clean Water Act, 33 U.S.C. § 1314(a)(1), directs the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is EPA's new recommended ambient water quality criteria (AWQC) for the protection of aquatic life based upon consideration of available information relating to effects of cadmium on aquatic organisms, and consideration of independent external peer review and EPA workgroup comments.

The term "water quality criteria" is used in two sections of the Clean Water Act: section 304(a)(l) and section 303(c)(2). The term has different meanings in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological and human health effects. The criteria presented in this document are such a scientific assessment of ecological effects. In section 303(c), the term water quality criteria refers to criteria adopted by a state as part of their legally-binding water quality standards. Criteria in water quality standards establish the maximum acceptable pollutant concentrations in ambient waters protective of the state's designated uses. States may adopt water quality criteria in their water quality standards that have the same numerical values as EPA's recommended section 304(a)(1) criteria. However, states may decide to adopt water quality criteria different from EPA's section 304 recommendations to reflect local environmental conditions and human exposure patterns. Alternatively, states may use different data and assumptions than EPA in deriving numeric criteria that are scientifically defensible and protective of designated uses. It is not until their adoption as part of state water quality standards and approved by EPA (or in limited instances promulgated by EPA) under section 303(c) that criteria become applicable water quality standards for Clean Water Act purposes. Information to assist the states and Indian tribes in modifying the recommended criteria presented in this document is contained in the Water Quality Standards Handbook (U.S. EPA 2014). This handbook and additional information on the development of water quality standards and other water-related programs of this agency have been developed by the Office of Water.

This document does not establish or affect legal rights or obligations. It does not establish a binding norm and cannot be finally determinative of the issues addressed. Agency decisions in any particular situation will be made by applying the Clean Water Act and EPA regulations on the basis of specific facts presented and scientific information then available.

Elizabeth Southerland
Director
Office of Science and Technology

AUTHORS / REVIEWERS / ACKNOWLEDGEMENTS

Technical Analysis Leads
Michael Elias, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division, Washington, DC
elias.mike@epa.gov

Susan Laessig, Office of Pollution Prevention and Toxics, Risk Assessment Division, Washington, DC

Joseph Beaman, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division, Washington, DC

Reviewers (2015-2016)
Elizabeth Behl and Kathryn Gallagher, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division, Washington, DC

EPA Peer Reviewers (2015)
Cindy Roberts, U.S. EPA, Office of Research and Development, Office of Science Policy, Washington, DC

Russ Hockett, U.S. EPA, Office of Research and Development, Mid-Continent Ecology Division, Duluth, MN

Jim Lazorchak, U.S. EPA, Office of Research and Development, National Exposure Research Laboratory, Cincinnati, OH

Susan Laessig, U.S. EPA, Office of Pollution Prevention and Toxics, Risk Assessment Division, Washington, DC

Glynis Hill, U.S. EPA, Office of Policy, Office of Regulatory Policy and Management, Washington, DC

Jeff Gallagher, U.S. EPA, Office of Chemical Safety and Pollution Prevention, Office of Pollution Prevention and Toxics, Washington, DC

Joe Beaman and Wade Lehmann, U.S. EPA, Office of Water, Health and Ecological Criteria Division, Washington, DC

Lars Wilcut and Erica Fleisig, U.S. EPA, Office of Water, Office of Science and Technology, Washington, DC

Amelia Letnes, U.S. EPA, Office of Water, Office of Wastewater Management, Washington, DC

Ruth Chemerys and Rosaura Conde, U.S. EPA, Office of Water, Office of Wetlands, Oceans, and Watersheds, Washington, DC

Cheryl Atkinson, Frank Borsuk, and Kuo-Liang Lai, U.S. EPA Region 3, Philadelphia, PA

Amy Bergdale, U.S. EPA Region 3, Wheeling, WV

Joel Hansel and Katherine Snyder, U.S. EPA Region 4, Atlanta, GA

Candice Bauer and Kay Edly, U.S. EPA Region 5, Chicago, IL

Lareina Guenzel, U.S. EPA Region 8, Denver, CO

Janet Hashimoto and Terrence Fleming, U.S. EPA Region 9, San Francisco, CA

Lisa Macchio, Kathleen Collins, John Palmer, and Burt Shephard, U.S. EPA Region 10, Seattle, WA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS

ACR	Acute-to-Chronic Ratio
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation Factor
CCC	Criterion Continuous Concentration
CF	Conversion Factor
CMC	Criterion Maximum Concentration
CV	Chronic Value (expressed in this document as an EC_{20} or MATC)
CWA	Clean Water Act
EC_x	Effect Concentration at X Percent Effect Level
ELS	Early Life Stage
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FACR	Final Acute-to-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
GMAV	Genus Mean Acute Value
GMCV	Genus Mean Chronic Value
LC_x	Lethal Concentration at X Percent Survival Level
LOEC	Lowest Observed Effect Concentration
MATC	Maximum Acceptable Toxicant Concentration (expressed mathematically as the geometric mean of the NOEC and LOEC)
MDR	Minimum Data Requirements
NOEC	No Observed Effect Concentration
NPDES	National Pollutant Discharge Elimination System
SD	Sensitivity Distribution
SMACR	Species Mean Acute-to-Chronic Ratio
SMAV	Species Mean Acute Value
SMCV	Species Mean Chronic Value
TMDL	Total Maximum Daily Load
TRAP	EPA's Statistical Program: Toxicity Relationship Analysis Program (Version 1.21)
WQBELS	Water Quality-based Effluent Limitations
WQC	Water Quality Criteria
WQS	Water Quality Standards

EXECUTIVE SUMMARY

EPA has updated the Agency's recommended cadmium aquatic life ambient water quality criteria in accord with provisions of §304(a) of the Clean Water Act to periodically revise Ambient Water Quality Criteria (AWQC) in order to reflect the latest scientific knowledge. EPA originally developed recommended 304(a) water quality criteria for cadmium in 1980 (EPA 440/5-80-025, U.S. EPA 1980), and subsequently updated in 1985 (EPA 440/5-84-032, U.S. EPA 1985c), 1995 (EPA-820-B-96-001, U.S. EPA 1996a) and 2001 (EPA-822-R-01-001, U.S. EPA 2001). EPA has updated cadmium aquatic life criteria in this revision consistent with methods described in U.S. EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (1985 Guidelines) (Stephan et al. 1985).

EPA based these revisions in this update on data that have become available since 2001. Literature searches of laboratory aquatic toxicity tests with cadmium published prior to 2016 identified over 100 new studies containing acute and chronic toxicity data that are acceptable for deriving the updated cadmium criteria. EPA also updated the relationship of cadmium toxicity to total hardness with the newly acquired data (see **Table 6** and **Table 8**). The 2016 update incorporates data for 75 new species and 49 new genera. The dataset used to develop the updated criteria is composed of 75 freshwater genera for acute toxicity (compared to 55 genera in the 2001 criteria), 20 freshwater genera for chronic toxicity (compared to 16 genera in the 2001 criteria), and 79 estuarine/marine genera for acute toxicity (compared to 54 genera in the 2001 criteria). No new chronic toxicity data were available for estuarine/marine genera.

Studies evaluating the freshwater acute toxicity of cadmium are available for nine Federally-listed species (hereafter referred to as Listed Species). Eight of these species are fish and one is a freshwater mussel. The most sensitive Listed species are in the family Salmonidae, as represented by the genera *Oncorhynchus* (*O. kisutch, O. mykiss* and *O. tshawytscha*) and *Salvelinus* (*S. confluentus*). Acute toxicity data are also available for the Listed freshwater mussel Neosho mucket (*Lampsilis rafinesqueana*). Studies evaluating the freshwater chronic toxicity of cadmium are available for four Federally-listed species, three of which are also represented by the genus *Oncorhynchus* (*O. kisutch, O. mykiss* and *O. tshawytscha*) and one by the genus *Salmo* (*S. salar*). Acute estuarine/marine toxicity data are available for the Listed

Oncorhynchus kisutch. There are no acceptable chronic toxicity data for estuarine/marine Listed species. Summaries provided in the document describe the best available data for Listed species that have been tested for sensitivity to cadmium; these data demonstrate that the 2016 cadmium criteria update is protective of these tested species.

Sufficient toxicity data were available to fulfill requirements of calculating acute and chronic freshwater and acute estuarine/marine criteria using a species sensitivity distribution, as described in the 1985 Guidelines. Data were not sufficient to calculate the chronic estuarine/marine criterion, and Acute-Chronic Ratios (ACRs) were therefore used to derive this criterion. The Final Acute-Chronic Ratio (FACR) for this update was derived from seven genera ACRs (two freshwater invertebrate genera, four freshwater fish genera, and one acutely sensitive saltwater mysid genus). The freshwater ACR values used represent a range of species acute sensitivities, from very sensitive to moderately sensitive, and have taxonomically-related marine species. This differs from the 2001 update, where only two saltwater ACRs were available and used to calculate the saltwater FACR; however these two species are now re-classified as a single genus, *Americamysis*.

EPA updated the acute and chronic hardness slopes with data for several new species. The updated acute cadmium hardness slope incorporates data for 13 species (eight species used in the 2001 criteria and five new species) (see **Table 6**). The updated chronic slope incorporates data for four species (two species used in the 2001 criteria and two new species) (see **Table 8**). The new chronic slope uses EC_{20} estimates for three of the four species, instead of only Maximum Acceptable Toxicant Concentrations (MATCs) used for the 2001 chronic slope (MATCs were used only for *Daphnia magna* in the 2016 slope to retain the invertebrate species).

The 2016 freshwater and estuarine/marine acute criteria, known as the Criterion Maximum Concentrations (CMCs) and the chronic criteria, known as the Criterion Continuous Concentrations (CCCs) values for cadmium are summarized and compared to corresponding 2001 criteria values in **Table 1**. The available freshwater toxicity data for cadmium, evaluated using procedures described in the 1985 Guidelines, indicate that freshwater aquatic life should be protected if the 1-hour average CMC does not exceed:

$$\text{CMC } (\mu\text{g/L, dissolved conc.}) = e^{(0.9789 \text{ x } \ln(\text{hardness}) - 3.866)} \text{ x CF} \qquad \text{(Eq. 1)}$$

Where CF (conversion factor from total to dissolved) = 1.136672 - [(ln hardness) x (0.041838)]; and the four-day average CCC does not exceed:

$$\text{CCC } (\mu g/L\text{, dissolved conc.}) = e^{(0.7977 \times \ln(\text{hardness}) - 3.909)} \times \text{CF} \qquad \text{(Eq. 2)}$$

Where CF (conversion factor from total to dissolved) = 1.101672 - [(ln hardness) x (0.041838)]. These values are recommended not to be exceeded more than once every three years on average.

The 2016 freshwater acute criterion (CMC) is 1.8 µg/L dissolved cadmium based on a hardness of 100 mg/L as $CaCO_3$. EPA derived the CMC to be protective of the commercially and recreationally important rainbow trout (*Oncorhynchus mykiss*), consistent with procedures described in the 1985 Guidelines, and is also protective of all salmonid species for which toxicity data are available. This value is lower than the 2001 CMC of 2.0 µg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_3$. For the 2016 acute criteria, EPA has changed the duration to 1-hour from the 24 hours EPA applied in the 2001 final cadmium criteria document. EPA made this change to the 2016 criteria to reflect the acute criteria duration recommended in the 1985 Guidelines (see **Section 5.1.4**). The 2016 freshwater chronic CCC is 0.72 µg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_{3,}$ and is an increase (i.e., less stringent) from the 2001 criteria of 0.25 µg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_3$. This increase is primarily due to use of EC_{20}s over MATCs, new data for existing species and the inclusion of a new sensitive genus (*Cottus*), which now represents the third most sensitive genus.

The 2016 estuarine/marine acute CMC of 33 µg/L dissolved cadmium is more stringent than the 2001 recommended criterion of 40 µg/L, which is primarily due to the addition of three new sensitive genera, consisting of a mysid (*Neomysis*), a copepod (*Tigriopus*), and a jellyfish (*Aurelia*). The estuarine/marine chronic CCC based on the use of an acute-to-chronic ratio (ACR) is now 7.9 µg/L dissolved cadmium compared to the 2001 CCC of 8.8 µg/L. The estuarine/marine chronic criteria is lower than the 2001 value based primarily on the lowering of the acute value in conjunction with use of an ACR to derive the chronic value. Available data suggest the acute toxicity of cadmium may be influenced by salinity, with a trend of decreasing sensitivity to cadmium with increasing salinity. However, this trend could not be definitively characterized and a mathematical relationship could not be described to define the dependency (see **Section 5.4.1**), thus salinity was not included in the estuarine/marine criteria derivation.

Table 1. Summary of 2001 and 2016 Aquatic Life AWQC Recommendations for Dissolved Cadmium.

	2016 AWQC Update[a]		2001 AWQC[a]	
	Acute (1-hour, dissolved Cd)[d]	**Chronic (4-day, dissolved Cd)**	**Acute (1-day, dissolved Cd)**	**Chronic (4-day, dissolved Cd)**
Freshwater (Total Hardness = 100 mg/L as $CaCO_3$)[b]	1.8 µg/L[c]	0.72 µg/L	2.0 µg/L[c]	0.25 µg/L
Estuarine/marine	33 µg/L	7.9 µg/L	40 µg/L	8.8 µg/L

[a] Values are recommended not to be exceeded more than once every three years on average.

[b] Freshwater acute and chronic criteria are hardness-dependent and were normalized to a hardness of 100 mg/L as $CaCO_3$ to allow the presentation of representative criteria values.

[c] Lowered to protect the commercially and recreationally important species (rainbow trout), as per the 1985 Guidelines, Stephan et al. (1985).

[d] The duration of the 2016 acute criteria was changed to 1-hour to reflect the 1985 Guidelines-based recommended acute duration.

1 INTRODUCTION AND BACKGROUND

National Recommended Ambient Water Quality Criteria (AWQC) are established by the United States Environmental Protection Agency (EPA) under the Clean Water Act (CWA). Section 304(a)(1) aquatic life criteria serve as recommendations to states and tribes by defining ambient water concentrations that will protect against unacceptable adverse ecological effects to aquatic life resulting from exposure to pollutants found in water. Aquatic life criteria address the CWA goals of providing for the protection and propagation of fish and shellfish. Once EPA publishes final section 304(a) recommended water quality criteria, states and authorized tribes may adopt these criteria into their water quality standards to protect designated uses of water bodies. States and authorized tribes may also modify these criteria to reflect site-specific conditions or use other scientifically-defensible methods to develop criteria before adopting these into standards. After adoption, states are to submit new and revised water quality standards (WQS) to EPA for review and approval or disapproval. When approved by EPA, the state's WQS become applicable WQS for CWA purposes. Such purposes include identification of impaired waters and establishment of TMDLs under CWA section 303(d) and derivation of water quality-based effluent limitations in permits issued under the CWA section 402 National Pollutant Discharge Elimination System (NPDES) permit program.

As required by the CWA, EPA periodically reviews and revises section 304(a) AWQC to ensure they are consistent with the latest scientific information. This 2016 peer-reviewed and finalized update supersedes the AWQC for cadmium that EPA last updated in 2001 (EPA-822-R-01-001, U.S. EPA 2001). EPA updated the cadmium water quality criteria provided in this document in accordance with methods outlined in the Agency's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (referred to as the 1985 Guidelines) (Stephan et al. 1985). This document describes scientifically defensible water quality criteria values for cadmium pursuant to CWA section 304(a), derived utilizing best available data in a manner consistent with the 1985 Guidelines and reflecting best professional scientific judgments of toxicological effects.

1.1 History of the EPA Cadmium AWQC for Aquatic Life

EPA first published AWQC for cadmium in 1980 (EPA 440/5-80-025), and updated the criteria in 1985 (EPA 440/5-84-032), 1995 (EPA-820-B-96-001) and again in 2001 (EPA-822-R-

01-001[1]). Each update supersedes the previous EPA aquatic life water quality criteria and uses the most recent data to estimate maximum and continuous concentrations of cadmium that would protect most aquatic organism populations from unacceptable short- or long-term effects.

The 1980 acute and chronic freshwater and saltwater criteria were expressed as total recoverable cadmium. The acute and chronic freshwater criteria were adjusted for ambient water hardness since the presence of calcium and other ions in freshwater are known to reduce the toxicity of cadmium. An acute saltwater criterion was calculated and the effects of temperature and salinity were considered, but no clear relationship to toxicity could be established with the available data, thus the acute saltwater criteria was not adjusted for temperature or salinity. Because of a limited dataset at the time, a chronic saltwater criterion was not developed. Data for aquatic plants indicated that a reduction in growth occurred at concentrations above the lowest effect concentrations for fish and invertebrates, so aquatic life criteria were not developed for plants.

The 1985 criteria update was developed using the measurement of acid-soluble cadmium instead of total recoverable cadmium, based on the conservatism of using total recoverable cadmium in situations where it is occluded in minerals, clays, and sand, or strongly sorbed to particulate matter. While the 1985 criteria provided extensive scientific and practical rationale for using acid-soluble cadmium measurements, no standard analytical method was available. In the absence of an EPA-approved method for the measurement of acid-soluble cadmium, total recoverable cadmium was considered the preferred concentration measure.

Acute toxicity values for 44 freshwater genera (52 species) were used for the 1985 criteria update to develop a Final Acute Value (FAV), which was lowered further to protect the commercially important rainbow trout, the most sensitive species. The acute freshwater criterion was set at 3.589 µg/L at a hardness of 50 mg/L as $CaCO_3$, not to be exceeded over a 1-hour average more than once every 3 years, on average. Acute toxicity values were available at that time for 35 estuarine/marine species (33 genera)(**Table 2**) and the most sensitive genera was *Mysidopsis*. Acute toxicity was generally found to increase with decreasing salinity, while the effect of temperature on acute toxicity appeared to occur on a species-specific basis. However,

---

[1] http://www.epa.gov/nscep/

correction factors were not developed for either due to limitations in supporting data. The estuarine/marine FAV was 85.09 µg/L, not to be exceeded over a 1-hour average more than once every 3 years, on average.

Chronic freshwater toxicity values used to derive the 1985 criteria were available for 16 species (13 genera). The Final Chronic Value (FCV) was calculated in the same manner as the FAV because the acute-to-chronic ratios, which were available for eight species, varied widely. The resulting freshwater FCV was 0.6582 µg/L at a hardness of 50 mg/L as $CaCO_3$, not to be exceeded over a 4-day average more than once every 3 years, on average. The mean acute-to-chronic ratio for two saltwater species was used to calculate an estuarine/marine FCV of 9.345 µg/L, not to be exceeded over a 4-day average more than once every 3 years, on average.

The 1995 criteria revision (U.S. EPA 1996a) updated freshwater criteria based on the incorporation of new acute and chronic data and the re-evaluation of existing data. Several Species Mean Acute Values (SMAVs) were changed based on a preference for flow-through tests and measured test concentrations. Data from tests conducted with uncharacterized river water were removed from the acceptable acute dataset. The resulting acute dataset consisted of 43 Genus Mean Acute Values (GMAVs). The FAV was 4.134 µg/L total recoverable cadmium, normalized to a hardness of 50 mg/L. The FAV was not lowered to protect a commercially or recreationally important species. Genus Mean Chronic Values (GMCVs) were changed based on the availability of additional test data, the removal of two test values conducted in river water, and the removal of a test value where cadmium concentrations were not measured. The resulting chronic dataset consisted of 12 GMCVs. The FCV was calculated using an "N" of 43, which was the number of GMAVs, rather than 12, the number of GMCVs. The FCV was 1.429 µg/L total recoverable cadmium, normalized to a hardness of 50 mg/L.

The 2001 criteria update was based on dissolved cadmium (passing through a 0.45 µm filter) to more accurately account for bioavailability and reflect the latest EPA policy for metals risk assessment (U.S. EPA 1993b). Freshwater SMAVs for cadmium were available for 65 species in 55 genera (24 fish, 39 invertebrates, 1 frog, and 1 salamander) (**Table 2**). The most sensitive vertebrate species was brown trout (*Salmo trutta*). The most sensitive invertebrate species was *Daphnia magna*, which was approximately nine times less sensitive than brown trout. Freshwater criteria were corrected for hardness based on separate acute and chronic cadmium toxicity versus hardness slopes that were generated using acute data for 12 species and chronic data for three species. Conversion factors were applied to convert total recoverable to dissolved cadmium concentrations.

Acceptable freshwater chronic test data were available for 14 fish species and 7 invertebrate species (**Table 2**), with the amphipod *Hyalella azteca* identified as the most sensitive species in the 2001 criteria. Acute-to-chronic ratios were calculated for 6 species. The 2001 estuarine/marine acute criterion was based on SMAVs for 61 species in 54 genera (50 invertebrates and 11 fish species) (**Table 2**), with mysids and striped bass identified as the most sensitive species. Chronic saltwater tests were available for two mysid species, from which acute-to-chronic ratios were calculated.

Bioconcentration factors (BCFs) reported in the 2001 criteria document for freshwater species ranged from 7 to 6,910 for invertebrates and from 3 to 2,213 for fishes. BCFs for saltwater invertebrates ranged from 5 to 3,160. Toxicity values for freshwater and saltwater aquatic plants were reviewed and acute values were found to be in the same range as toxicity values for fish and invertebrates, while chronic values were found to be considerably higher.

The resulting 2001 freshwater acute criterion (or CMC) was 2.0 µg/L dissolved cadmium and the resulting freshwater chronic criterion (or CCC) was 0.25 µg/L dissolved cadmium, when normalized to a total hardness of 100 mg/L as $CaCO_3$. The 2001 saltwater CMC was 40 µg/L dissolved cadmium, while the 2001 saltwater CCC was 8.8 µg/L.

Table 2. Number of Aquatic Species Included in Cadmium AWQC.

	Freshwater Acute	Freshwater Chronic	Estuarine/Marine Acute	Estuarine/Marine Chronic
1980	29	13	31	1
1985	52	16	35	2
1995	NA[a]	NA	NA	NA
2001	65	21	61	2
2016	101	27	94	2

[a] NA = Not Available

For the 2016 update, EPA conducted a literature search and review of acute and chronic toxicity data that have become available since the 2001 update. This update incorporates additional toxicity data for the development of both freshwater and estuarine/marine acute and chronic criteria and new toxicity data related to water hardness, which remains the primary quantitative correlation used to modify metal toxicity estimates in fresh water (U.S. EPA 1996a). EPA also re-evaluated studies with *Hyalella azteca* and freshwater mussel glochidia (a larval stage of unionid mussels), both of which were used in the development of the 2001 criteria. EPA re-evaluated studies with *H. azteca* because recent research has shown that the outcome of toxicity tests with *H. azteca* can be impacted by culture and test conditions (e.g., chloride concentration, food quantity and composition) and that tests using standard recommended test methods may not be acceptable. All *Hyalella* studies were therefore re-evaluated for acceptability with newly developed guidelines (**Appendix K**). The acceptable duration of tests using glochidia was also reconsidered. Glochidia are a larval stage of unionid freshwater mussels that occur in the water column and remain viable for only a limited period of time prior to attaching to a host fish. The duration of an acceptable toxicity test was adjusted to 24 hours to account for potential adverse effects to glochidia during this larval stage, as recent information indicates that glochidia can be the most sensitive life stage for some chemicals and plays an important role in the viability of unionid mussel populations.

2 PROBLEM FORMULATION

Problem formulation provides a strategic framework to develop water quality criteria by providing an overview of a chemical's sources and occurrence, fate and transport in the environment, and toxicological characteristics and factors affecting toxicity. A problem formulation uses this information to develop a conceptual model and identify the most relevant chemical properties and endpoints for evaluation. The structure of the problem formulation developed for cadmium is consistent with U.S. EPA's Guidelines for Ecological Risk Assessment (U.S. EPA 1998).

2.1 Overview of Cadmium Sources and Occurrence

Cadmium is a relatively rare, naturally occurring metal found in mineral deposits and distributed widely at low concentrations in the environment. Cadmium is a minor metallic element that was first discovered in Germany in 1817 as a by-product of the zinc refining process (International Cadmium Association 2013). The primary current industrial uses of cadmium are for manufacturing batteries, pigments, plastic stabilizers, metal coatings, alloys and electronics (Fulkerson and Goeller 1973; Hutton 1983; Pickering and Gast 1972; Wilson 1988). Nickel-cadmium (NiCd) batteries account for the majority (over 80%) of global cadmium consumption, followed by its use in pigments, coatings and plating, stabilizers for plastics, nonferrous alloys and other specialized uses (e.g., photovoltaic devices) (USGS 2013). Of particular note is the recent use of cadmium (as cadmium selenide or cadmium sulfide) in the manufacture of nanoparticles (also referred to as quantum dots) used as a semiconductor in photovoltaic devices (e.g., solar cells and emitters for color displays). The ecological and toxicological effects of these emerging materials to aquatic organisms are largely unknown at this time, and therefore represent a new source of cadmium to the environment (Tang 2013). Demand for cadmium has increased based on its use in NiCd batteries, while more traditional uses of cadmium in coatings, pigments and stabilizers have been declining due to environmental and health concerns (USGS 2013). Cadmium is also present as an impurity in zinc, lead and copper ore mine wastes, fossil fuels, iron and steel, cement, and fertilizers (Cook and Morrow 1995; International Cadmium Association 2013), and is present as a natural or introduced constituent in inorganic phosphate fertilizers (MNDH 2014).

In 2012, approximately 70 percent of the world's new cadmium supply was produced in Asia, with China, the Republic of Korea and Japan representing the leading producers (USGS 2013). Cadmium is no longer actively mined in the U.S. or Canada (USGS 2013), but it is produced domestically as a by-product of the extraction, smelting and refining of zinc, copper and lead ores. A leading source of cadmium (23% of the global supply) is from the recovery of spent NiCd batteries and other cadmium-bearing scrap materials (International Cadmium Association 2013; USGS 2013). In 2010, an estimated 637 metric tons of refined cadmium was produced domestically from recovered materials (USGS 2013). The amount of cadmium contained in products imported to the U.S. in 2007 was estimated to be about 1,900 metric tons (USGS 2007).

Cadmium concentrations in natural sources vary with geographic location and type of deposit. Concentrations of cadmium in mineral deposits, such as mineral sulfides, typically range from 0.1 to 0.2 mg/kg, with an average concentration of 0.18 mg/kg (Babich and Stotzky 1978; EC 2001; Nriagu 1980). As a phosphate rock impurity, cadmium can vary in concentration from as low as 0.1 mg/kg in Tennessee ores to as high as 980 mg/kg in western ores (U.S. EPA 1993a). In the U.S., cadmium concentrations in coal range from 5.47 mg/kg in the Interior Province, to 2.89 mg/kg in the Illinois Basin, 0.28 mg/kg in Alaska, and 0.13 mg/kg in the Appalachian region. This range in cadmium concentration depends on the type of coal, with bituminous coal having the highest average concentration (0.91 mg/kg) and anthracite coal having the lowest average concentration (0.22 mg/kg).

Cadmium enters the environment as a result of both natural processes (weathering and erosion of rock and soils, natural combustion from volcanoes and forest fires) and anthropogenic sources (mining, agriculture, urban activities, and waste streams from industrial processes, manufacturing, coal ash ponds/pits, fossil fuel combustion, incineration and municipal effluent) (Hem 1992; Hutton 1983; Morrow 2001; Pickering and Gast 1972; Shevchenko et al. 2003; U.S. EPA 2016; WHO 2010). Anthropogenic sources account for more than 90 percent of the total cadmium present in surface water, with atmospheric particulate deposition from fossil fuel combustion (including coal) contributing approximately 40 percent of the total cadmium present in surface water (Wood et al. 2012). The agricultural application of phosphate fertilizer releases 33 to 56 percent of total anthropogenic cadmium to the environment (Pan et al. 2010; Panagapko

2007). Waste from cement manufacturing and metallurgic smelting and refining operations account for the other major sources (Pan et al. 2010; Wood et al. 2012).

In the U.S., industrial and manufacturing facilities and mining operations report the volume of cadmium and other toxic substances released to the environment via the U.S. EPA Toxics Release Inventory (TRI). Data from the TRI indicate the average yearly release of cadmium and cadmium compounds to the environment from all industries (between 2002 and 2012) ranged from approximately 2.6 million pounds in 2009 to 10 million pounds in 2012. In coastal zones, continental riverine runoff represents a major secondary source of cadmium to estuaries and adjoining coastal waters (Cullen and Maldonado 2013), and elevated cadmium concentrations are often detected in runoff from urban and industrial areas, which increases the loading of cadmium to nearby waterways and sediments (Gobel et al. 2007).

Cadmium concentrations in unpolluted freshwaters are typically very low and frequently below analytical detection limits (Mebane 2006). In natural waters, cadmium co-occurs with zinc at a dissolved Cd/Zn ratio of approximately 0.3 percent (Wanty et al. 2009). Dissolved cadmium concentrations in unpolluted waters of the U.S. have been estimated to range from 0.002 to 0.08 µg/L (Stephan et al. 1994). Surface water monitoring of the Great Lakes between 2003 and 2006 indicated cadmium concentrations ranging from <0.001 µg/L (below detection limit) to 0.015 µg/L in Lake Huron, 0.098 µg/L in Lake Erie, 0.028 µg/L in Lake Ontario, 0.015 µg/L in Lake Superior and 0.005 µg/L in Lake Michigan (Lochner and Water Quality Monitoring and Surveillance 2008; Rossmann and Barres 1992). Cadmium concentrations in the world’s oceans are estimated to range from <0.005 to 0.110 µg/L, with higher concentrations reported near some coastal areas (Cook and Morrow 1995; Elinder 1985; Jensen and Bro-Rasmussen 1992; OECD 1994; Pan et al. 2010; WHO 1992). Cadmium concentrations in surface waters of impacted environments are frequently 2-3 µg/L or greater (Abbasi and Soni 1986; Allen 1994; Annune et al. 1994; Flick et al. 1971; Friberg et al. 1971; Henriksen and Wright 1978; Nilsson 1970; Spry and Wiener 1991).

2.2 Environmental Fate and Transport of Cadmium in the Aquatic Environment

Cadmium has two oxidation states. The metallic state (Cd^0) is insoluble and rarely present in water, while several salts of the divalent state (e.g., $CdCl_2$ and $CdSO_4$) freely dissolve in water (Merck 1989). Divalent cadmium is the predominant form in most well oxygenated freshwaters that are low in organic carbon. The physical and chemical properties of cadmium are summarized in **Table 3**.

Table 3. Physical and Chemical Properties of Cadmium.

CAS Registry Number	7440-43-9
Atomic weight	112.40 g/mol
Physical form	Soft, white solid
Density	8.64 g/cm^3 (@ room temperature)
Melting point[a]	321ºC
Boiling point[a]	765ºC
Vapor pressure[b]	1 torr at 394ºC
Water solubility (g/L)[a]	
Cadmium	Insoluble
Cadmium carbonate ($CdCO_3$)	Insoluble
Cadmium chloride ($CdCl_2$)	1400 @ 20ºC
Cadmium hydroxide ($Cd(OH)_2$)	0.0026 @ 26ºC
Cadmium nitrate ($Cd(NO_3)_2$)	Soluble
Cadmium sulfate ($CdSO_4$)	755 @ 0ºC

[a] Reference: Merck 1989.
[b] Reference: ATSDR 2012.

Upon entering the freshwater or estuarine/marine aquatic environment, cadmium becomes strongly adsorbed to clays, muds, humic and organic materials and some hydrous oxides (Watson 1973). This complexation tends to remove cadmium from the water column by precipitation (Lawrence et al. 1996), where it may not be bioavailable except to benthic feeders and bottom dwellers (Callahan et al. 1979; Kramer et al. 1997). It is estimated that up to 93 percent of cadmium entering surface waters will react with constituents in the water column and will be removed to sediments (Lawrence et al. 1996), and the formation of these complexes is considered to be the most important factor in determining the fate and transport of cadmium in the aquatic environment.

Once in sediments, cadmium can be re-suspended in particulate form or can return to the water column in dissolved form following hydrolysis or via upwelling in coastal zones (Bewers et al. 1987; U.S. EPA 1979). The solubility of cadmium compounds in water depends both on the specific cadmium compound (**Table 3**) and on abiotic conditions, such as pH, alkalinity, hardness and organic matter. Sorption processes, for example, become increasingly important with increasing pH.

2.3 Mode of Action and Toxicity

Cadmium is a non-essential metal (NRC 2005) with no biological function in aquatic animals (Eisler 1985; Lee et al. 1995; McGeer et al. 2012; Price and Morel 1990; Shanker 2008). In one study comparing the acute toxicity of all 63 atomically stable heavy metals in the periodic table, cadmium was found to be the most acutely toxic metal to the amphipod, *Hyalella azteca*, based on the results of seven-day acute aquatic toxicity tests (Borgmann et al. 2005). In addition to acute toxicity, cadmium is a known teratogen and carcinogen, is a probable mutagen and is known to induce a variety of other short- and long-term adverse physiological effects in fish and wildlife at both the cellular and whole-animal level (ATSDR 2012; Eisler 1985; Okocha and Adedeji 2011). Chronic exposure leads to adverse effects on growth, reproduction, immune and endocrine systems, development, and behavior in aquatic organisms (McGeer et al. 2012). Other toxic effects include histopathologies of the gill, liver and kidney in fish, renal tubular damage, alterations of free radical production and the antioxidant defense system, immunosuppression, and structural effects on invertebrate gills (Giari et al. 2007; Jarup et al. 1998; McGeer et al. 2011; Okocha and Adedeji 2011; Shanker 2008).

Toxic effects are thought to result from the free ionic form of cadmium (Goyer et al. 1989), which causes acute and chronic toxicity in aquatic organisms primarily by disrupting calcium homeostasis and causing oxidative damage. In freshwater fish, cadmium competes with calcium at high affinity binding sites in the gill membrane and blocks the uptake of calcium from water by interfering with ion uptake in specialized calcium channels that are located in the mitochondria-rich chloride cells (Carroll et al. 1979; Evans 1987; McGeer et al. 2012; Morel and Hering 1993; Pagenkopf 1983; Tan and Wang 2009). The combined effect of competition for the binding sites and blockage of calcium uptake on the gill membrane results in acute hypocalcaemia in freshwater fish, which is characterized by cadmium accumulation in tissues as well as decreased calcium concentrations in plasma (McGeer et al. 2011; Roch and Maly 1979; Wood et al. 1997). This mechanism is also thought to be the target of cadmium toxicity in marine fish (McGeer et al. 2012; Schlenk and Benson 2005), although cadmium is generally considered to be less toxic in sea water than in fresh water. The lesser sensitivity of marine fish and aquatic organisms in general may be both a function of physiology and environmental condition. Rocha et al. (2015) observed an increase in catalase activity (oxidative stress) in the marine mussel, *Mytilus galloprovincialis*, suggesting a possible mode of action for this taxon. Mebane et al. (2006), for example, suggests the energy demands for fish to maintain homeostasis in the lower ionic composition freshwater environment may make fish more sensitive to metals, such as cadmium, which inhibit ion regulation. Higher levels of calcium and chloride in seawater are also believed to compete to a greater degree with cadmium, potentially making it less bioavailable to aquatic life (Engel and Flower 1979). However, application of the calcium competition for apical entry and the subsequent osmoregulatory disturbance toxicity mechanism for insects has been questioned by Poteat and Buchwalter (2013). Their research (Poteat et al. 2012, 2013) has demonstrated the lack of interaction between calcium and cadmium at the apical surface of aquatic insects in dissolved exposures. Cadmium exposure is also associated with the disruption of sodium balance and accompanying Na^+/K^+-ATPase activity (Atli and Canli 2007). Once inside the cell, cadmium can disrupt enzymatic function (Okocha and Adedeji 2011), by either directly affecting Ca-ATPase activity or inhibiting antioxidant processes. Cadmium also inhibits enzymes such as catalase, glutathione reductase, and superoxide dismutase and reducing agents such as GSH, ascorbate, b-carotene and a-tocopherol, all of which can lead to the generation of excess reactive oxygen species and reduced ATP production (McGeer et al. 2012).

Cadmium can bioaccumulate in aquatic organisms, with total uptake depending on the environmental cadmium concentration, exposure route and the duration of exposure (Annabi et al. 2013; Francis et al. 2004; McGeer et al. 2000; Roméo et al. 1999). Cadmium concentrations typically build up in tissues at the site of exposure, such as the gill surface and gut tract wall (Chevreuil et al. 1995). Cadmium is then transferred via circulation to nearly all other tissues and organs, with the liver and kidney (in addition to the gill or gut) typically accumulating high concentrations relative to muscle tissues (Annabi et al. 2013; McGeer et al. 2012). Although cadmium bioaccumulates in some aquatic species, there does not appear to be a consistent relationship between body burden and toxicological effect. In a detailed review of this relationship, Mebane (2006) concluded that for both aquatic invertebrates and fish, tissue concentrations associated with adverse effects regularly overlap with tissue concentrations where no adverse effects were observed. This inconsistent relationship between whole body tissue concentration and effect may be related to specific organs and/or tissues within which the accumulation is occurring and which would not be accurately quantified by whole body tissue residue analysis, and/or to the metabolic bioavailability of cadmium in tissues. Detoxification

NMED Exhibit 70

mechanisms in aquatic organisms, including the formation and activation of antioxidants, metallothionein, glutathione, and heat shock proteins (McGeer et al. 2011), effectively sequester the metal in a detoxified form, thereby allowing the organism to accumulate elevated levels of cadmium before displaying a toxic response. While the amount of detoxified metal that an aquatic organism can accumulate is theoretically unlimited, an organism will only experience toxic effects once the concentration of metabolically available metal is exceeded (Mebane 2006; Rainbow 2002). Under natural conditions, most accumulated cadmium in tissues is expected to exist in the detoxified state, which may explain the poor relationship between toxic effect and whole body tissue residue concentrations of trace metals reported by Rainbow (2002) for aquatic invertebrates and fish. Mebane (2006) concluded that, although there were not adequate data to establish acceptable tissue effect concentrations for aquatic life, cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at calculated chronic criterion concentrations. The evaluation of direct exposure effects to organisms via water is therefore considered more applicable to the development of criteria for aquatic life.

Mammals and avian wildlife could be exposed to cadmium while foraging in aquatic habitats or via the ingestion of prey that have bioaccumulated cadmium from the aquatic environment. Although few adverse effects to mammals and avian wildlife have been demonstrated from the presence of cadmium in the aquatic environment, a number of laboratory-based investigations have demonstrated a range of sublethal and lethal toxic effects, the majority of which are associated with chronic exposure (Burger 2007; Cooke and Johnson 1996; Eisler 1985; Furness 1996; Henson and Chedrese 2004). However, the biological integrity of aquatic systems is considered to be at greater risk from cadmium than terrestrial systems based on the greater sensitivity of aquatic organisms relative to birds and mammals (Burger 2007; Wren et al. 1995). Freshwater biota are the most sensitive to cadmium, marine organisms are generally considered to be more resistant than freshwater organisms, while mammals and birds are considered to be comparatively resistant to cadmium (Burger 2007; Eisler 1985). Based on this trend, criteria that are protective of aquatic life are also considered to be protective of mammalian and avian wildlife (including aquatic-dependent wildlife) and are accordingly the focus of this evaluation.

2.3.1 Water quality parameters affecting cadmium toxicity

Water quality parameters such as hardness, pH, salinity, alkalinity, some metals, and organic carbon can alter the toxicity of metals to aquatic organisms. When adequate data are available, water quality criteria can be adjusted to quantify how these environmental factors affect the toxicity of a chemical. Water hardness, which is the amount of minerals (primarily calcium and to a lesser extent magnesium) dissolved in surface water, is one important water quality parameter influencing the toxicity of cadmium.

The acute toxicity of cadmium has been shown to decrease with increasing water hardness in most tested freshwater animals (Sprague 1985). Available data for 14 genera (representing six of the eight required Minimum Data Requirements (MDR) families) listed in **Appendix A** indicate that cadmium is more acutely toxic in soft than in hard water. Acute tests conducted with *Daphnia magna* at three different water hardness levels, for example, demonstrate that daphnids are at least five times more sensitive to cadmium in soft water than in hard water (Chapman et al. 1980). Similarly, the acute toxicity of cadmium to *D. magna* was reduced (48-hr LC_{50} increased from 7.5 to 24.8 μg/L) as the calcium concentration was increased from 0.46 to 192 mg/L (Tan and Wang 2011). The ability of calcium to reduce the toxicity of cadmium was also observed in water with *D. pulex* (Clifford and McGeer 2010), rainbow trout (*Oncorhynchus mykiss*) (Niyogi et al. 2008) and brook trout (*Salvelinus fontinalis*) (Carroll et al. 1979).

In addition to hardness, other water quality characteristics have been shown to influence the toxicity of cadmium to aquatic species. Increased levels of dissolved organic carbon, for example, have been shown to reduce the toxicity of cadmium to daphnids by reducing the bioavailability of cadmium through complexation (Clifford and McGeer 2010; Giesy et al. 1977; Niyogi et al. 2008). Conversely, other water chemistry variables, including magnesium, pH and alkalinity have been shown to have little or no effect on cadmium toxicity (Clifford and McGeer 2010; Niyogi et al. 2008). The relationship between salinity and temperature and cadmium effects could not be quantitatively established. These analyses are described in detail in **Section 5.4.1**.

Development of an initial (phase I) biotic ligand model (BLM – formerly the “gill model”) was attempted for cadmium to better account for the bioavailability of this metal to aquatic life. The cadmium BLM is based on a conceptual model similar to the gill site model

NMED Exhibit 70

proposed by Pagenkopf (1983), but it is recognized that the gill itself may be a general surrogate for the actual site of toxic action. For cadmium, it is thought that more highly specific enzymatic binding sites affecting the activity of Ca^{2+}-ATPase may be the actual site of toxic action (Fu et al. 1989; Hogstrand and Wood 1996). Based on the preliminary findings in 2003 during the Phase I development of a cadmium BLM (HydroQual 2003), a significant pH effect was also observed when pH was decreased from 7.0 to 4.7 for steelhead trout, *Oncorhynchus mykiss*. In the BLM framework, this was explained as a competitive interaction between H^+ and Cd^{2+} at the biotic ligand, rather than a change in cadmium speciation. Preliminary results for the cadmium BLM for more complex interactions indicate the effect levels should generally increase with increasing DOC, pH and hardness (both as calcium and magnesium) (U.S. EPA 2004). Further development of the BLM for cadmium may help to better quantify the bioavailable fraction of this chemical. However, because hardness is a surrogate for other ions affecting cadmium toxicity, and based on available data, EPA believes that a cadmium BLM model is not necessary for the current criteria update.

2.4 Conceptual Model

A conceptual model characterizes relationships between human activities, stressors, and ecological effects on the assessment endpoints identified for evaluation (U.S. EPA 1998). The conceptual model links exposure characteristics with the ecological endpoints important for the development of management goals. Under the CWA, these management goals are established by states and tribes as designated uses of waters of the United States (for example, the protection of aquatic life). In deriving aquatic life criteria, EPA is developing acceptable thresholds for pollutants that, if not exceeded, are expected to be protective of aquatic life. A state and/or tribe may implement these criteria by adopting them into their respective water quality standards.

The conceptual model depicted in **Figure 1** provides a broad overview of how aquatic organisms could be exposed to cadmium. As depicted in **Figure 1** and discussed in **Section 2.1**, cadmium enters the environment from both natural and anthropogenic sources. Natural sources of cadmium, which largely result from the weathering and erosion of rock and soils, represent a relatively minor source to the environment compared to anthropogenic sources. Although there are multiple anthropogenic sources (see **Section 2.1**), emissions of cadmium to the atmosphere (e.g., combustion, smelting/refining, and manufacturing) and contributions from leaching/runoff (via the application of phosphate fertilizers) represent the major cadmium inputs (40 and up to 56 percent, respectively) to surface water (Pan et al. 2010).

Up to 93 percent of cadmium entering surface water will react with organic and inorganic constituents in the water column, including particulate matter, iron oxides, and clay materials, and will be removed to sediments (Lawrence et al. 1996). Sediments are therefore a reservoir for cadmium in the aquatic environment and can become a source of exposure for benthic and water column dwelling aquatic life and higher trophic level species. **Figure 1** depicts exposure pathways for the biological receptors of concern (e.g., aquatic animals) and the potential attribute changes (i.e., effects such as reduced survival, growth and reproduction) in those receptors from cadmium exposure. Although the multiple potential exposure pathways depicted in **Figure 1** are likely to be complete, the development of the water quality criteria for cadmium focuses on evaluating the direct exposure of aquatic life to cadmium in surface water because this potential exposure pathway, and the potential for adverse effects on survival, growth, and reproduction from direct aqueous exposure, is considered to represent the greatest potential risk to most aquatic species, and is consistent with the approach established in the 1985 Guidelines. Nevertheless, consideration of the fate and transport mechanisms, exposure pathways, and receptors depicted in **Figure 1** may be helpful for states and tribes as they adopt criteria into standards and evaluate potential exposure pathways affecting designated uses.

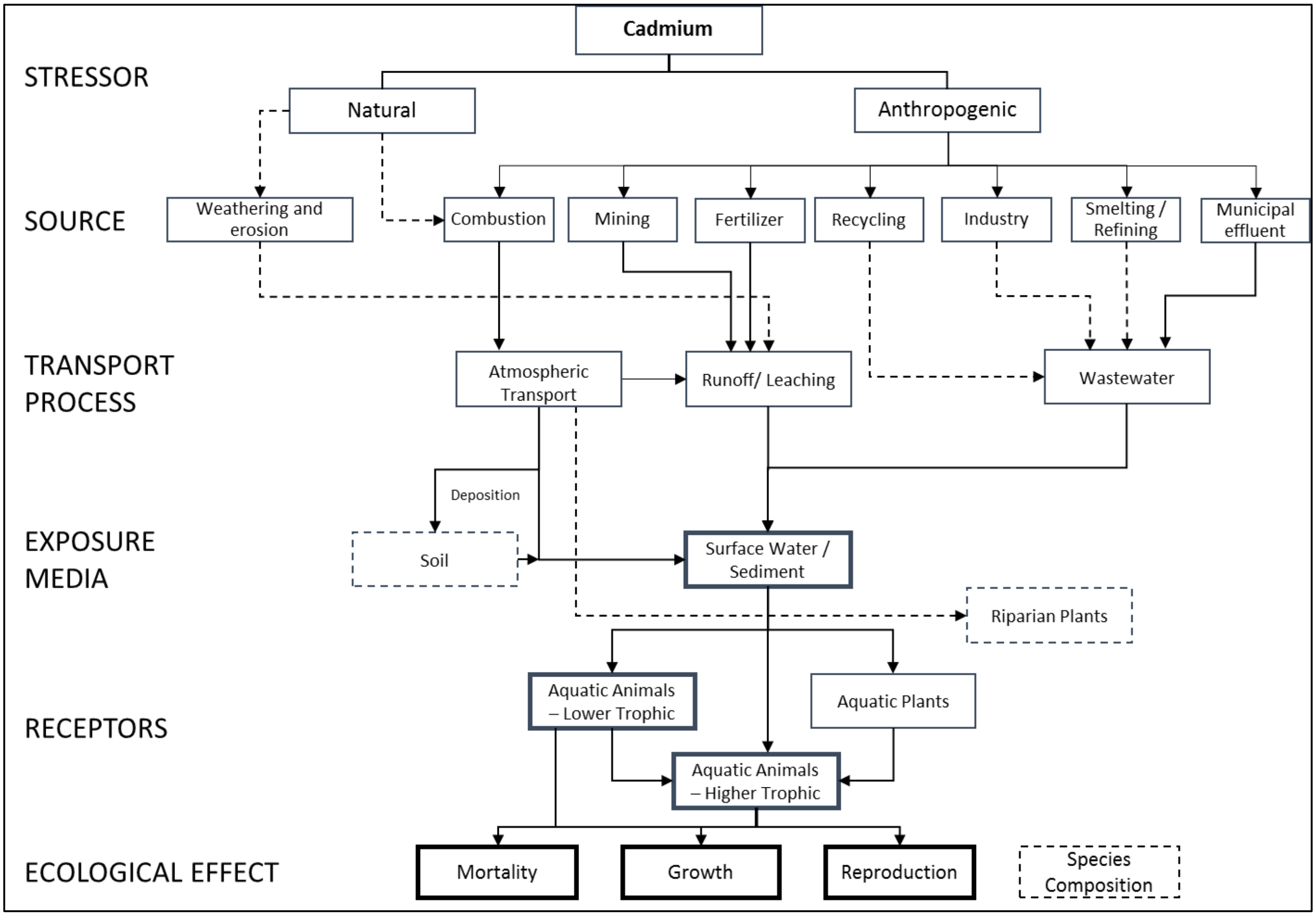


Figure 1. Conceptual Model Depicting the Major Sources, Transport and Exposure Media and Ecological Effects of Cadmium in the Environment.
(Note: Solid line indicates potentially important pathway/media/receptor; dashed line indicates secondary pathway/media/receptor).

2.5 Assessment Endpoints

Assessment endpoints are defined as the explicit expressions of the environmental values to be protected and are comprised of both the ecological entity (e.g., a species, community, or other entity) and the attributes or characteristics of the entity to be protected (U.S. EPA 1998). Assessment endpoints may be identified at any level of organization (e.g., individual, population, community). In context of the CWA, aquatic life criteria for toxic substances are typically determined based on the results of toxicity tests with aquatic organisms, for which adverse effects on growth, reproduction, or survival are measured. This information is aggregated into a species sensitivity analysis that characterizes an impact to the aquatic community. Criteria are designed to be protective of the vast majority of aquatic animal species in an aquatic community (i.e., approximately the 95th percentile of tested aquatic animals representing the aquatic community). Assessment endpoints consistent with the criteria developed in this document are summarized in **Table 4**.

The concept of using laboratory toxicity tests to protect North American bodies of water and resident aquatic species and their uses is based on the theory that effects occurring to a species in appropriate laboratory tests will generally occur to the same species in comparable field situations. Since aquatic ecosystems are complex and diversified, the 1985 Guidelines require acceptable data be available for at least eight genera with a specified taxonomic diversity (the standard eight-family minimum data requirement, or MDR). The intent of the eight-family MDR is to serve as a typical surrogate sample community representative of the larger and generally much more diverse natural aquatic community, not necessarily the most sensitive species in a given environment. For many aquatic life criteria, enough data are available to describe a species sensitivity distribution to represent the distribution of sensitivities in natural ecosystems. In addition, since aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places are not deemed necessary (the intent is to protect 95 percent of a group of diverse taxa, and any commercially and recreationally important species). Thus, if properly derived and used, the combination of a freshwater or estuarine/marine acute CMC and chronic CCC should provide an appropriate degree of protection of aquatic organisms and their uses from acute and chronic toxicity to animals, toxicity to plants, and bioaccumulation by aquatic organisms (Stephan et al. 1985).

2.6 Measurement Endpoints

Assessment endpoints require one or more measures of ecological effect, which are termed “measurement endpoints”. Measurement endpoints are the measures of ecological effect used to characterize or quantify changes in the attributes of an assessment endpoint or changes in a surrogate entity or attribute, in this case a response to chemical exposure. Toxicity data are used as measures of direct and indirect effects on representative biological receptors. The selected measures of effect for the development of aquatic life criteria encompass changes in the growth, reproduction, and survival of aquatic organisms.

The toxicity data used for the development of aquatic life criteria depend on the availability of applicable toxicity test outcomes, the acceptability of test methodologies, and an in-depth evaluation of the acceptability of each specific test, as performed by EPA. Measurement endpoints for the development of aquatic life criteria are derived using acute and chronic toxicity studies for representative test species, which are then quantitatively and qualitatively analyzed, as described in the Analysis Plan below. Measurement endpoints considered for each assessment endpoint in this criteria document are summarized in **Table 4**. The following sections discuss toxicity data requirements for the fulfillment of these measurement endpoints.

Overview of Toxicity Data Requirements

EPA has specific data requirements to assess the potential effects of a stressor on an aquatic ecosystem and develop 304(a) aquatic life criteria under the CWA. Acute toxicity test data (short term effects on survival) for species from a minimum of eight diverse taxonomic groups are required for the development of acute criteria to ensure the protection of various components of an aquatic ecosystem.

- Acute freshwater criteria require data from the following taxonomic groups:
  - the family Salmonidae in the class Osteichthyes
  - a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish)
  - a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian)
  - a planktonic crustacean (e.g., cladoceran, copepod)
  - a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish)
  - an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge)
  - a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca)
  - a family in any order of insect or any phylum not already represented
- Acute estuarine/marine criteria require data from the following taxonomic groups:
  - two families in the phylum Chordata
  - a family in a phylum other than Arthropoda or Chordata
  - a family from either Mysidae or Penaeidae
  - three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)
  - any other family

Chronic toxicity test data (longer-term effects on survival, growth, or reproduction) are generally required for a minimum of three taxa, with at least one chronic test being from an acutely-sensitive species. Acute-chronic ratios (ACRs) can be calculated with data for species of aquatic animals from at least three different families if the following data requirements are met:

- at least one is a fish
- at least one is an invertebrate
- at least one is an acutely sensitive freshwater species, for freshwater chronic criterion (the other two may be saltwater species)
- at least one is an acutely sensitive saltwater species for estuarine/marine chronic criterion (the other two may be freshwater species)

Because acceptable chronic values for all eight MDRs were available for cadmium in fresh water, the chronic criterion was derived following the same genus level sensitivity distribution (SD) approach used to calculate the acute criterion (see the 1985 Guidelines for additional detail). The chronic estuarine/marine criterion for cadmium was derived using the ACR approach.

The 1985 Guidelines also require at least one acceptable test with a freshwater alga or vascular plant. If plants are among the aquatic organisms most sensitive to the chemical, results of a plant in another phylum should also be available. Data on toxicity to aquatic plants are examined to determine whether plants are likely to be unacceptably affected by concentrations below those expected to cause unacceptable effects on aquatic animals. However, as discussed in **Section 2.7**, the relative sensitivity of fresh and estuarine/marine algae and plants to cadmium (**Appendix E** and **Appendix F**) is less than vertebrates and invertebrates, so plant criteria are not developed.

Measures of Effect

Measure of cadmium exposure concentration

Consistent with previous AWQC documents for cadmium, only effects data from tests that used the following cadmium salts (either anhydrous or hydrated) were used for development of the AWQC:

- cadmium chloride ($CdCl_2$) (CAS # 10108-64-2)
- cadmium nitrate ($Cd(NO_3)_2$) (CAS # 10325-94-7)
- cadmium sulfate ($CdSO_4$) (CAS # 10124-36-4)

Measured concentrations of cadmium can be expressed as either total recoverable cadmium, acid-soluble cadmium, or total dissolved cadmium (using a conversion factor) based on the different forms of cadmium present in the aquatic environment. Previous aquatic life criteria for cadmium were expressed either in terms of total recoverable cadmium (U.S. EPA 1980; 1983a) or as acid-soluble cadmium (U.S. EPA 1985c). Since 1993, EPA has recommended using dissolved metal concentrations (defined as the metal in solution that passes through a 0.45-µm membrane filter) for developing criteria, based on the greater bioavailability of dissolved metals in surface water. Cadmium criteria are accordingly expressed as dissolved metal concentrations consistent with current recommendations (Prothro 1993; U.S. EPA 1993b, 1994a), which typically involves converting measured total recoverable cadmium concentrations to estimated dissolved cadmium concentrations using a conversion factor. It should be noted, however, the majority of cadmium present in natural surface water is in the dissolved form and differences between the 0.45-µm filtered (dissolved) and unfiltered (total) concentrations in surface water samples are usually small, with dissolved concentrations typically averaging 90 to 95 percent of the concentration present in an unfiltered sample (Clark 2002; Mebane 2006; Stephan 1995). These averages are generally consistent with the dissolved fraction present in unfiltered concentrations of 94 percent for fresh water (at a total hardness of 100 mg/L as $CaCO_3$) and 99 percent for marine environments that are used for the updated criteria, respectively.

The acute freshwater conversion factors were determined empirically whereby total and dissolved cadmium concentrations were measured during actual 48- and 96-hour *Daphnia magna* and fathead minnow fed and unfed static toxicity tests conducted at different total hardness levels (Stephan 1995; University of Wisconsin – Superior 1995). Either cadmium chloride or cadmium sulfate were spiked in Lake Superior water and measured at test initiation and completion. The time weighted averages obtained for percent dissolved cadmium for each simulation were used to determine the freshwater acute conversion factors of 0.973 at 50 mg/L, 0.944 at 100 mg/L and 0.915 at 200 mg/L total hardness (see **Appendix Table A-3**). Freshwater chronic conversion factors obtained from the same acute tests and extrapolation procedures were 0.938, 0.909 and 0.880 at 50, 100 and 200 mg/L total hardness (see **Appendix Table C-3**), respectively. The lower chronic conversion factors are due to the longer time weighted average period employed relative to the acute factors. The acute saltwater conversion factor of 0.99 determined by Lussier et al. (1999) was based on an *Americamysis bahia* 96-hr flow-through exposure and mean weighted total and dissolved cadmium concentrations. Narragansett Bay seawater was spiked with cadmium chloride and exposure concentrations were measured at 1- and 96 hours after test initiation.

All concentrations for toxicity tests are expressed as total cadmium in this document, not as the form of the chemical tested. In the aquatic environment, cadmium is measured as total recoverable metal or free divalent metal.

Acute measures of effect

The acute measures of effect on aquatic organisms are the LC_{50}, EC_{50}, and IC_{50}. LC stands for "Lethal Concentration" and an LC_{50} is the concentration of a chemical that is estimated to kill 50 percent of the test organisms. EC stands for "Effect Concentration" and the EC_{50} is the concentration of a chemical that is estimated to produce a specific effect in 50 percent of the test organisms. IC stands for "Inhibitory Concentration" and the IC_{50} is the concentration of a chemical that is estimated to inhibit some biological process (e.g., growth) in 50 percent of the test organisms. Data that were determined to have acceptable quality and to be useable in the derivation of water quality criteria as described in EPA's 1985 Guidelines for the derivation of a freshwater and estuarine/marine criteria are presented in **Appendix A** and **Appendix B**, respectively.

Acute toxicity data on freshwater mussel glochidia life stage

Glochidia are an early parasitic life stage of unionid freshwater mussels, which are free living in the water column prior to finding an appropriate fish host. Based on their unique life history compared to most aquatic life, glochidia toxicity tests were carefully examined to determine if they provided ecologically relevant toxicological information for the derivation of aquatic life criteria. Glochidia may be present in the water column for a period of time ranging from seconds to days, depending on the species, and they have potential to be exposed to contaminants in surface water during that time. EPA determined it was important to consider the potential for adverse effects to glochidia in the development of water quality criteria for cadmium because adverse effects on this sensitive early life stage could have implications on the viability of unionid mussel populations. The potential for adverse effects to glochidia was also considered in the development of ammonia criteria (U.S. EPA 2013).

In order for the toxicity test results with glochidia to be ecologically relevant, the duration of the acute toxicity test must be comparable to the duration of the free-living stage of glochidia prior to attaching to a host. Research conducted by Fritts et al. (2014) supports the recommendation of a maximum test duration of 24 hours for glochidia, corresponding with the ecologically relevant period of host infectivity of this parasitic life stage. Survival of glochidia at the end of 24 hours should be at least 90% in the laboratory control and if the viability is less than 90% at 24 hours in the control, then the next longest duration less than 24 hours that had at least 90% survival in the control is considered acceptable for use. These requirements for the acceptance of glochidia tests were put forward in the 2013 ammonia criteria document and were peer reviewed at that time (U.S. EPA 2013). Acceptable cadmium glochidia data were available only for the fatmucket (*Lampsilis siliquoidea*), but this life stage was less sensitive than the juvenile life stage and therefore glochidia results were not used to calculate the SMAV for this species.

Chronic measures of effect

The endpoint for chronic exposure is the EC_{20}, which represents a 20 percent effect/inhibition concentration. This is in contrast to a concentration that causes a low level of reduction in response, such as an EC_5 or EC_{10}, which is rarely statistically significantly different from the control treatment. EPA selected an EC_{20} to estimate a low level of effect that would be statistically different from control effects, but not severe enough to cause chronic effects at the population level (see U.S. EPA 1999c). Reported NOECs (No Observed Effect Concentrations) and LOECs (Lowest Observed Effect Concentrations) were only used for the derivation of chronic criterion when an EC_{20} could not be calculated for the genus. A NOEC is the highest test concentration at which none of the observed effects are statistically different from the control. A LOEC is the lowest test concentration at which the observed effects are statistically different from the control. When LOECs and NOECs are used, a Maximum Acceptable Toxicant Concentration (MATC) is calculated, which is the geometric mean of the NOEC and LOEC.

Regression analysis was used to characterize a concentration-effect relationship and to estimate concentrations at which chronic effects are expected to occur. For the calculation of chronic criterion, point estimates were selected for use as the measure of effect in favor of

NMED Exhibit 70

MATCs, as MATCs are highly dependent on the concentrations tested. Point estimates also provide additional information that is difficult to determine with an MATC, such as a measure of effect level across a range of tested concentrations. Chronic toxicity data that met the test acceptability and quality assurance/control criteria in EPA's 1985 Guidelines for the derivation of freshwater and estuarine/marine criteria are presented in **Appendix C** and **Appendix D**, respectively.

Table 4. Summary of Assessment Endpoints and Measures of Effect Used in Criteria Derivation.

Assessment Endpoints for the Aquatic Community	Measures of Effect
Survival, growth, biomass, and reproduction of fish and invertebrates (freshwater and estuarine/marine)	Acute: LC_{50}, EC_{50} Chronic: EC_{20}, MATC (only used when an EC_{20} could not be calculated for the genus)
Maintenance and growth of aquatic plants from standing crop or biomass (freshwater and estuarine/marine)	LOEC, EC_{20}, EC_{50}, IC_{50}, reduced growth rate, cell viability, calculated MATC

MATC = Maximum acceptable toxicant concentration (geometric mean of NOEC and LOEC)
NOEC = No observed effect concentration
LOEC = Lowest observed effect concentration
LC_{50} = Lethal concentration to 50% of the test population
EC_{50}/EC_{20} = Effect concentration to 50%/20% of the test population
IC_{50} = Concentration of cadmium at which some effect is inhibited 50% compared to control organism

Use of data from chronic tests with *Hyalella azteca*

The use of *H. azteca* data for criteria derivation has created an uncertainty due to issues with culture and testing conditions. Laboratory evidence indicates that sufficient levels of bromide and chloride are required for maintaining healthy *H. azteca* cultures, which are important to accurately characterizing the toxicity of pollutants to *H. azteca* (U.S. EPA 2009a). In response to this concern, each *H. azteca* acute and chronic toxicity test was evaluated with the acceptability criteria recommended by U.S. EPA (2012) (**Appendix K**). These criteria address the minimum levels of bromide and chloride in dilution water, along with other factors such as the use of a substrate and minimum survival of control to characterize test acceptability.

2.7 Analysis Plan

During CWA §304(a) criteria development, EPA reviews and considers all relevant toxicity test data. Information available for all relevant species and genera are reviewed to identify: 1) data from acceptable tests that meet data quality standards; and 2) whether the acceptable data meet the minimum data requirements (MDRs) as outlined in EPA's 1985 Guidelines (Stephan et al. 1985; U.S. EPA 1986a). The taxa represented by the different MDR groups represent taxa with different ecological, trophic, taxonomic and functional characteristics in aquatic ecosystems, and are intended to be a representative subset of the diversity within a typical aquatic community.

For this cadmium criteria update, the MDRs described in **Section 2.6** are met, and criteria values are developed for acute and chronic freshwater and acute and chronic estuarine/marine species. **Table 5** provides a summary of the Phyla, Families, Genera and Species for which toxicity data are available and that were used to fulfill the MDRs for calculation of acute and chronic criteria for both freshwater and estuarine/marine organisms. A relatively large number of tests from acceptable studies of aquatic algae and vascular plants are also available for possible derivation of a Final Plant Value. However, the relative sensitivity of fresh and estuarine/marine algae and plants to cadmium (**Appendix E** and **Appendix F**) is less than aquatic vertebrates and invertebrates so plant criteria are not developed.

Table 5. Summary Table of Acceptable Toxicity Data Used to Meet the Minimum Data Requirements in the "1985 Guidelines" and Count of Phyla, Families, Genera and Species.

Family Minimum Data Requirement (Freshwater)	Acute (Phylum / Family / Genus)	Chronic (Phylum / Family / Genus)
Family Salmonidae in the class Osteichthyes	Chordata / Salmonidae / Oncorhynchus	Chordata / Salmonidae / Oncorhynchus
Second family in the class Osteichthyes	Chordata / Catostomidae / Catostomus	Chordata / Catostomidae / Catostomus
Third family in the phylum Chordata	Chordata / Ambystomatidae / Ambystoma	Chordata / Cyprinodontidae / Jordanella
Planktonic Crustacean	Arthropoda / Daphniidae / Daphnia	Arthropoda / Daphniidae / Daphnia
Benthic Crustacean	Arthropoda / Cambaridae / Orconectes	Arthropoda / Hyalellidae / Hyalella
Insect	Arthropoda / Baetidae / Baetis	Arthropoda / Chironomidae / Chironomus
Family in a phylum other than Arthropoda or Chordata	Mollusca / Unionidae / Lampsilis	Mollusca / Unionidae / Lampsilis
Family in any order of insect or any phylum not already represented	Annelida / Tubificidae / Tubifex	Annelida / Lumbriculidae / Lumbriculus
Family Minimum Data Requirement (Estuarine/Marine)	**Acute (Phylum / Family / Genus)**	**Chronic (Phylum / Family / Genus)**
Family in the phylum Chordata	Chordata / Fundulidae / Fundulus	-
Family in the phylum Chordata	Chordata / Salmonidae / Oncorhynchus	-
Either the Mysidae or Penaeidae family	Arthopoda / Mysidae / Americamysis	Arthopoda / Mysidae / Americamysis
Family in a phylum other than Arthropoda or Chordata	Mollusca / Mytilidae / Mytilus	-
Family in a phylum other than Chordata	Echinodermata / Strongylocentrotidae / Strongylocentrotus	-
Family in a phylum other than Chordata	Echinodermata / Asteriidae / Asterias	-
Family in a phylum other than Chordata	Annelida / Capitellidae / Capitella	-
Any other family	Mollusca / Pectinidae / Argopecten	-

Dash (-) indicates requirement not met (*i.e.*, no acceptable data).

	Freshwater Acute			Freshwater Chronic			Estuarine/Marine Acute			Estuarine/Marine Chronic		
Phylum	**Families**	**GMAVs**	**SMAVs**	**Families**	**GMCVs**	**SMCVs**	**Families**	**GMAVs**	**SMAVs**	**Families**	**GMCVs**	**SMCVs**
Annelida	4	11	12	2	2	2	6	10	10	-	-	-
Arthropoda	18	22	32	3	4	6	30	37	44	1	1	2
Bryozoa	3	3	3	-	-	-	-	-	-	-	-	-
Chordata	15	27	35	8	11	16	14	14	16	-	-	-
Cnidaria	1	1	4	-	-	-	2	2	2	-	-	-
Echinodermata	-	-	-	-	-	-	3	3	4	-	-	-
Mollusca	4	9	13	3	3	3	9	12	17	-	-	-
Nematoda	-	-	-	-	-	-	1	1	1	-	-	-
Platyhelminthes	2	2	2	-	-	-	-	-	-	-	-	-
Total	**47**	**75**	**101**	**16**	**20**	**27**	**66**	**79**	**94**	**1**	**1**	**2**

2.7.1 Hardness adjustment

The hardness adjustment is used as a surrogate for this criteria revision to estimate the effect of all ions on the toxicity of cadmium. EPA's 1985 Guidelines state that when sufficient data are available to demonstrate that toxicity is related to a water quality characteristic, the relationship should be taken into account using an analysis of covariance (Stephan et al. 1985). As noted in the 1985 Guidelines, the relationship between hardness and the toxicity of metals in freshwater is best described by a log-log relationship. The ratio of calcium and magnesium ions influence the toxicity of cadmium and the subsequent cadmium toxicity-hardness relationship, especially since cadmium is known to behave like a calcium analog (Playle et al. 1993a). An analysis of covariance was conducted to examine the relationship between hardness and cadmium toxicity to freshwater aquatic animals. The analysis of covariance was performed separately for acute and chronic toxicity, using the R statistical program (Dixon and Brown 1979; Neter and Wasserman 1974; R Core Team 2015).

Before conducting the analysis of covariance, currently available toxicity data with available hardness values were evaluated for each species to determine if they were useful for characterizing the relationship between hardness and cadmium toxicity in freshwater. The 1985 Guidelines do not provide explicit rules regarding whether data for a particular species are useful, but they do emphasize the importance of having a range of tested hardness values for a particular species. Since the publication of the 1985 Guidelines, EPA has determined that in order to meet the precondition for inclusion in the covariance model for determining the hardness relationship, a species should have definitive toxicity values available over a range of hardness levels, such that the highest hardness is at least three times the lowest, and at least 100 mg/L higher than the lowest (U.S. EPA 2001). As such, EPA evaluated the cadmium studies per the 1985 Guidelines conditions prior to inclusion in the covariance model and excluded studies from the analysis where only a single acute toxicity value was available, or where multiple tests were conducted at the same hardness. Examples of excluded tests include those that were conducted to evaluate the effects of cadmium to a non-hardness parameter, such as Na or K (e.g., Clifford 2009). In cases where the hardness-toxicity relationship for a particular species is highly divergent between studies, then data from these studies were only used when they were specifically designed to investigate the effects of hardness, and when both the toxicity and hardness values provided were definitive (not greater than or less than values). For example, the hardness-toxicity relationship for the fathead minnow is highly divergent from one life stage to another. Adult fathead minnow responses are highly correlated, while fry responses are not, so only tests conducted with adults were used (U.S. EPA 2001).

As noted above, this 2016 cadmium update evaluated definitive toxicity values available over a specified range of hardness levels to develop the acute and chronic hardness-toxicity relationships. This procedure was very similar to that used for the 2001 update and the 2015 draft cadmium criteria, except that only studies where the concentrations of cadmium was measured were used, multiple tests conducted at the same hardness level were excluded, and data from the same study were favored over highly divergent data from multiple studies for a particular species. In addition, EC_{20} and MATC values are used in the chronic slope for this effort, whereas the 2001 update used only MATCs. The data used to calculate the acute and chronic hardness-toxicity relationships are identified in **Appendix Table A-2** and **Appendix Table C-2**, respectively.

An analysis of covariance, to evaluate the relationship between natural log transformed hardness and natural log transformed cadmium toxicity to the tested species, is the first step following data selection. If the analysis of covariance model term describing the similarity of hardness slopes among individual species is not statistically significant at an alpha of 0.05 ($P>0.05$), then a model with a single hardness slope is statistically equivalent to a model with separate hardness slopes for each species, and a pooled slope can be calculated. The pooled hardness slope is then calculated using linear regression, and is considered the best estimate for characterizing the relationship between toxicity and hardness for all test species. The results of the acute and chronic hardness correction procedures are described in **Section 3.1.1** and **Section 3.1.2**, respectively, and individual species slopes are provided in **Table 6** and **Table 8**.

2.7.2 Acute criterion

Acute criteria are derived from the sensitivity distribution (SD) of genus mean acute values (GMAVs), calculated from species mean acute values (SMAVs) for available and acceptable data. SMAVs are calculated using the geometric mean for all acceptable toxicity tests for a given species (e.g., all tests for *Daphnia magna*). If only one test is available, the SMAV is that test value by default. As stated in the 1985 Guidelines, flow-through measured test data are normally given preference over other test exposure types (i.e., renewal, static, unmeasured) for a species, when available. When relationships are apparent between life-stage and sensitivity, only values for the most sensitive life-stage are considered.

GMAVs are calculated using the geometric means of all calculated SMAVs within a given genus (e.g., all SMAVs for genus *Daphnia* – including *Daphnia pulex, Daphnia magna*). If only one SMAV is available for a genus, then the GMAV is represented by that value. GMAVs derived for each of the genera are then rank-ordered by sensitivity, from most (Rank 1) to least sensitive (Rank *N*).

Acute freshwater and estuarine/marine criteria are based on the Final Acute Value (FAV). The FAV is determined by first ordering the GMAVs by rank from most to least sensitive for regression analysis. The regression analysis is typically driven by the four most sensitive genera in the sensitivity distribution, based on the need to interpolate or extrapolate (as appropriate) to the 5th percentile of the distribution represented by the tested genera. Use of a sensitivity distribution where the criteria values are based on the four most sensitive taxa in a triangular distribution represents a censored statistical approach that improves estimation of the lower tail when the shape of the whole distribution is uncertain, while accounting for the total number of genera within the whole distribution. Since there were more than 59 GMAVs in both the freshwater and estuarine/marine cadmium acute datasets, the four GMAVs closest to the 5th percentile of the distribution were used to calculate the FAV, consistent with procedures described in the 1985 Guidelines. The acute criterion, defined as the Criterion Maximum Concentration (CMC), is then calculated by dividing the FAV by two, which is intended to provide an acute criterion protective of nearly all individuals in the distribution (Stephan et al. 1985); the FAV/2 approach was developed to estimate minimal effect levels, those which approximate control mortality limits, and is based on the analysis of 219 acute toxicity tests for a range of chemicals, as described in the *Federal Register* on May 18, 1978 (43 FR 21506-18).

2.7.3 Chronic criterion

A chronic criterion is typically determined by one of two methods. If MDRs are met with acceptable chronic test data available for all eight families, then the chronic criteria can be derived using the same method as for the acute criteria, employing chronic values (e.g., EC_{20}) estimated from acceptable toxicity tests. While this is the case for the freshwater cadmium chronic dataset, acceptable chronic data are not available for all eight families for estuarine/

marine species. For the estuarine/marine chronic dataset, the chronic criterion was therefore derived by determining an appropriate Final Acute-Chronic Ratio (FACR).

The procedure used to calculate an FACR involves dividing an acute toxicity test value by a "paired" chronic test value. Tests for a chemical are considered paired when they are conducted by the same laboratory, with the same test organism and with the same dilution water (see Stephan et al. 1985). If there is a clear trend, the FACR may be the geometric mean of the available ACRs, or an individual ACR (or combination thereof), based on the most sensitive taxa. The Final Chronic Value (FCV) for estuarine/marine aquatic animals was obtained by dividing the FAV by the FACR, consistent with procedures described in Section IV.A of Stephan et al. (1985).

Available chronic toxicity data for freshwater and estuarine/marine plants were reviewed to determine whether plants are more sensitive to cadmium than freshwater and estuarine/marine animals (see **Appendix A**, **Appendix B**, **Appendix E** and **Appendix F**). Plants were found to be less sensitive, and in most cases, at least an order of magnitude less sensitive to cadmium than other aquatic species. It was therefore not necessary to develop chronic criteria based on plant toxicity values in this update.

3 EFFECTS ANALYSES FOR AQUATIC ORGANISMS

The data used to update the acute and chronic criteria for cadmium were collected via literature searches of EPA's ECOTOX database, as described in the ECOTOX User Guide Version 4.0 (see: http://cfpub.epa.gov/ecotox/blackbox/help/userhelp4.pdf). ECOTOX is an extensive database of selected toxicity data for aquatic life, terrestrial plants, and wildlife created and maintained by the U.S. EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory's Mid-Continent Ecology Division (U.S. EPA 2007a). The search of cadmium and cadmium compounds for this update includes data entered in ECOTOX through December 2015.

Newly acquired data were evaluated for acceptability based on data quality guidelines given in the1985 Guidelines (Stephan et al. 1985). Selected data included in the 2001 cadmium criteria were re-evaluated for various reasons (e.g., divergent values for a species, hardness normalization derivation, etc.), as part of the 2016 update, as needed. All acute and chronic toxicity data (see **Appendices A-I**) determined to be applicable and reliable were used to recalculate the CMC and the CCC, consistent with the 1985 Guidelines and as described in the following sections.

3.1 Freshwater Toxicity to Aquatic Animals

3.1.1 Acute toxicity

Acceptable data on the acute effects of cadmium in freshwater are available for a total of 101 species representing 75 genera (**Appendix Table A-1**), the diversity of which satisfy the eight taxonomic MDRs specified in the 1985 Guidelines. Ranked GMAVs for cadmium in freshwater based on acute toxicity are identified in **Table 7** and plotted in **Figure 3**. The following sections detail the derivation of these GMAV summaries.

Hardness correction

The hardness adjustment is used as a surrogate to estimate the effect of primarily calcium on the toxicity of cadmium. Data to be used for the calculation of the hardness correction were selected according to procedures described in **Section 2.7.1**. An analysis of covariance was then performed using a subset of the data from **Appendix A** (each study used in the acute hardness slope is compiled in **Appendix Table A-2**) for the 13 species for which the appropriate data were available, as shown in **Table 6**. These included eight species used in the determination of the acute toxicity hardness slope in the 2001 criteria document (U.S. EPA 2001) and five new species. For all 13 species, the highest hardness was at least three times the lowest, and the highest hardness was at least 100 mg/L greater than the lowest (**Appendix Table A-1**). One major difference between this 2016 update and previous cadmium criteria documents, including the 2015 draft criteria, is that only measured studies were evaluated for use in the acute toxicity hardness slope. In addition, for *Hydra circumcincta, Daphnia pulex, Chironomus riparius*, and *Danio rerio*, only studies for which multiple tests were conducted across a hardness gradient were used. Consistent with data quality criteria used for development of the 2001 AWQC for cadmium and as discussed in **Section 2.7.1**, the dataset used for *Pimephales promelas* consisted of only tests conducted with adults. For *Daphnia magna,* the relationship between acute toxicity and hardness had a very shallow slope and a large confidence interval (and large standard error), indicating a poor correlation. This outcome was based on the poor correlation between hardness and acute toxicity for *D. magna* across the various studies. Accordingly, only the five *D. magna* tests from Chapman et al. (1980) were used since the author specifically evaluated the effects of hardness on the less than 24-hr old neonates. Finally, several data sources were eliminated from further evaluation. Data from six tests by Davies et al. (1993) were excluded because hardness was manipulated with magnesium instead of calcium; data from two tests by Davies and Brinkman (1994b) were excluded based on the use of atypical control water; data from three tests by Niyogi et al. (2008) were excluded because water quality parameters in addition to hardness were manipulated; data from Niyogi et al. (2004b) were excluded because they were identified as possible outliers; and data from studies by Hollis et al. (1999, 2000a) were excluded because fish may have been fed.

Based on the final dataset used to calculate the acute hardness slope and consistent with the 1985 Guidelines, an analysis of covariance was performed to determine if a single pooled species slope would be acceptable. The P-value of the model term describing the relationship between hardness and species was 0.42, indicating that the individual species hardness slopes are not significantly different from one another, and that a single pooled slope could be calculated.

The pooled slope for the log-log relationship between hardness and acute toxicity was 0.9789. A list of the species and accompanying slopes used to estimate the final acute hardness slope is provided in **Table 6** and graphically illustrated in **Figure 2**.

Table 6. Pooled and Individual Species Slopes Calculated for the Cadmium Acute Toxicity vs. Hardness Relationship.

Species	n	Slope	R^2 Value	95% Confidence Interval	df
***Hydra circumcincta*[a]**	3	0.5363*	1.000	0.4706 – 0.6020	1
Limnodrilius hoffmeisteri	2	0.7888	---	---	0
Villosa vibex	2	0.9286	---	---	0
Daphnia magna[b]	5	1.182*	0.915	0.5194-1.845	3
Daphnia pulex[c]	7	0.9307*	0.867	0.5113-1.350	5
***Chironomus riparius*[d]**	2	0.4571	---	---	0
***Oncorhynchus mykiss*[e]**	28	0.9475*	0.681	0.6862-1.209	26
Salmo trutta	6	1.256*	0.900	0.6762-1.837	4
Carassius auratus[f]	2	1.588	---	---	0
***Danio rerio*[g]**	2	0.9270	---	---	0
Pimephales promelas	13	1.814*	0.475	0.5494-3.078	11
Lepomis cyanellus	2	0.4220	---	---	0
Lepomis macrochirus	6	0.8548*	0.955	0.5975-1.112	4
Final Pooled Model	80	0.9789*#	0.971	0.7907-1.167	66

Species highlighted in bold are new for the 2016 updated hardness slope.

* Slope is significantly different than 0 ($p<0.05$)

Individual species slopes not significantly different ($p=0.42$)

a – 3 tests from Clifford (2009) at different hardness levels where hardness was manipulated as Ca.

b – Following the procedure described in the 2001 AWQC document, used 5 tests from Chapman et al. (Manuscript) performed at different hardness levels.

c – 7 tests from Clifford (2009); Clifford and McGeer (2010) at different hardness levels where hardness was manipulated as Ca.

d – 2 tests from Gillis and Wood (2008) at different hardness levels.

e – Excluded 6 tests from Davies et al. (1993) where hardness manipulated as Mg; excluded 2 tests from Davies and Brinkman (1994b) because of atypical control water; excluded 3 tests from Niyogi et al. (2008) that manipulated water quality parameters in addition to hardness; excluded possible outliers (Niyogi et al. 2004b); excluded studies where the fish were possibly fed (Hollis et al. 1999, 2000a).

f – 2 tests from McCarty et al. (1978) at different hardness levels.

g – 2 tests from Alsop and Wood (2011) at different hardness levels.

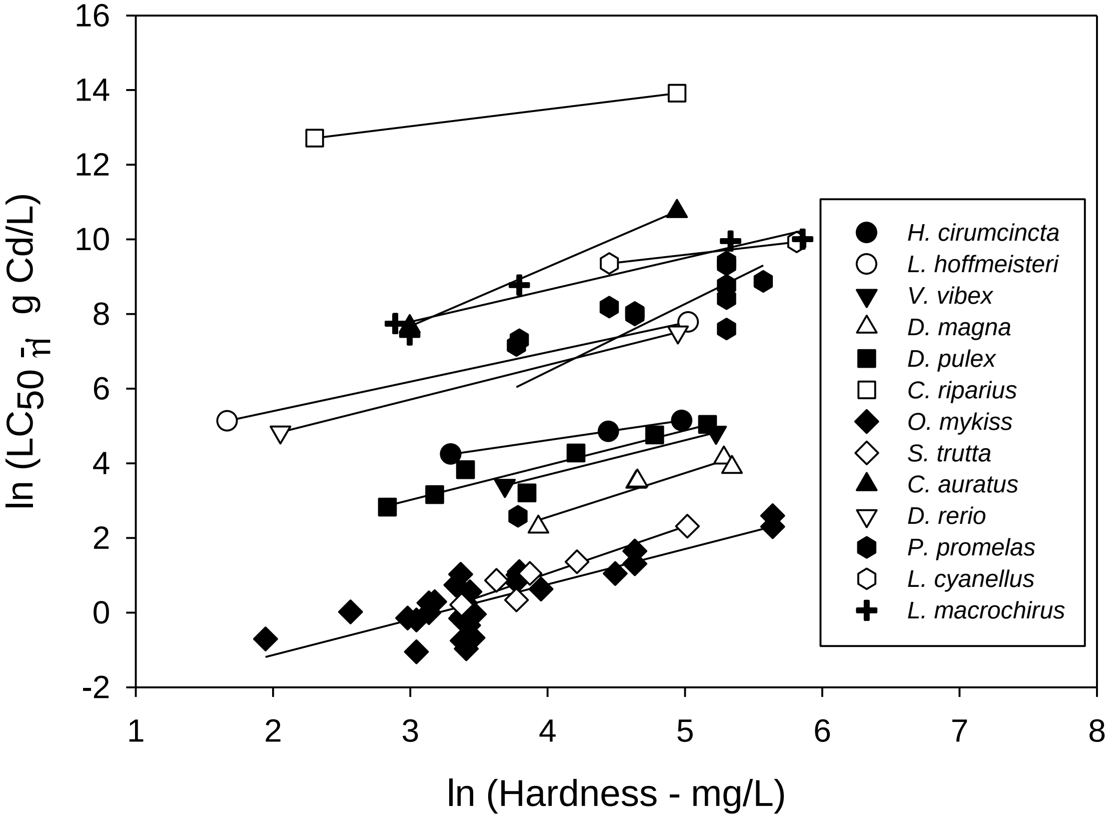


Figure 2. Species Acute Hardness Slopes.
Natural log transformed hardness and acute toxicity concentrations for each species used to calculate the pooled acute hardness correction slope. Results of individual regression lines are shown in **Table 6.**

Summaries of studies used in acute criterion determination

The 2016 update includes acute toxicity data for 66 invertebrate species, 33 fish species, one salamander species, and one frog species, for a total of 101 species grouped into 75 genera. Of the 75 Genus Mean Acute Values (GMAV) in the updated dataset, 38 genera have new data (**Table 7** and **Appendix A**). The most sensitive genus is the fish *Salvelinus* with a GMAV of 4.190 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate genus is represented by the amphipod *Hyalella azteca*, with the seventh most sensitive normalized GMAV of 23.00 µg/L. As noted in **Table 7**, if the SMAVs for a genus differ by greater than a factor of 10, then the most sensitive SMAV(s) is used in the GMAV calculation. This difference was primarily due to the sensitivity between the life stage tested for each species and was applied to the GMAV calculation for *Salvelinus*, *Ptychocheilus*, *Physa* and *Orconectes*. This approach ensures that the most sensitive effect level is used for each genus.

The pooled slope of 0.9789 was used to normalize the freshwater acute values in **Appendix A** to a hardness = 100 mg/L $CaCO_3$, except where it was not possible because no hardness value was reported or a value could not be estimated. SMAVs were calculated as geometric means of the normalized acute values. Only the underlined EC_{50}/LC_{50} values shown in **Appendix A** were used to calculate the SMAVs for each species.

The SMAVs for freshwater invertebrates ranged from 23.00 µg/L total cadmium for the amphipod, *H. azteca*, to >152,301 µg/L total cadmium for the midge, *Chironomus riparius*. Of the fish species tested, the rainbow trout, *Oncorhynchus mykiss*, had the lowest SMAV of 3.727 µg/L total cadmium, and the tilapia, *Oreochromis niloticus*, had the highest SMAV of 66,720 µg/L total cadmium. As indicated by the data, both invertebrate and fish species display a wide range of sensitivities to cadmium.

Fish species represent the six most acutely sensitive genera to cadmium (**Table 7**), and salmonids (*Salmo*, *Salvelinus*, *Oncorhynchus* and *Prosopium*) represent four of the six most sensitive fish genera. The most sensitive genus, *Salvelinus*, a vertebrate genus, is over 11,700 times more sensitive than the most resistant, *Chironomus*, an invertebrate genus.

The second through fifth most sensitive genera (out of a total of 75) were used in the computation of the Final Acute Value (FAV). As stated above, whenever there are 59 or more GMAVs in the acute criteria dataset, the FAV is calculated using the four GMAVs closest to the 5th percentile of the distribution. The distribution of ranked freshwater GMAVs for cadmium is depicted in **Figure 3** and is expressed as normalized total cadmium (see **Section 4.3.1**).

The four taxa and hardness-normalized associated endpoint (GMAV) used in calculating the acute criterion (sensitivity rank 2-5) are ranked below from most to least sensitive:

2. *Cottus* (GMAV=4.411 µg/L total Cd)
3. *Salmo trutta*, Brown trout (GMAV=5.642 µg/L total Cd)
4. *Morone saxatilis*, Striped bass (GMAV=5.931 µg/L total Cd)
5. *Oncorhynchus* (GMAV=6.141 µg/L total Cd)

The most sensitive genus, *Salvelinus* (GMAV of 4.190 µg/L total cadmium), represented by brook trout data, is not included in the criteria numeric calculation because its rank falls below the 5th percentile in the distribution of 75 genera included in the dataset (see **Section 2.7.2**). Because there is a greater than 10-fold difference in SMAVs for the genus, consistent with the 1985 Guidelines, only the most sensitive SMAV is used in the calculation. Therefore, only bull trout, and not brook trout, was used to determine GMAV for *Salvelinus*. The calculated FAV for *Salvelinus* is 5.733 µg/L total cadmium. However, despite the *Salvelinus* genus ranking as the most sensitive taxa for the freshwater acute data, its GMAV is greater than the commercially and recreationally important rainbow trout (*Oncorhyncus mykiss*) SMAV (**Table 7**). The rainbow trout SMAV is also lower than the calculated FAV, and the SMAVs for cutthroat trout, brown trout, bull trout, and shorthead and mottled sculpin. Thus, as recommended by the 1985 Guidelines, the freshwater FAV for total cadmium is being lowered to protect the commercially and recreationally important rainbow trout, resulting in an FAV of 3.727 µg/L at a hardness of 100 mg/L. Because rainbow trout was the most sensitive salmonid species tested (and lowest SMAV in the acute dataset), this lowered value is also expected to be protective of all the salmonid species for which toxicity data are available, and other sensitive fish species as well. Summaries are provided below for the individual species or genera (in cases where more than one species is included in the calculation of the GMAV) used to calculate the freshwater FAV. All values are provided in terms of total cadmium.

Cottus

Two species of sculpin, *Cottus bairdii* and *Cottus confusus*, are used to derive the normalized GMAV of 4.411 µg Cd/L, the second most sensitive genus in the acute dataset, and the lowest of the four GMAVs used to calculate the FAV (**Table 7**). Besser et al. (2006, 2007) and Brinkman and Vieira (2007) exposed fry of *C. bairdii* to flow-through measured conditions to yield normalized 96-hr LC_{50}s ranging from 2.817 to >65.08 µg/L, with the SMAV of 4.418 µg/L cadmium. The *C. confusus* normalized SMAV of 4.404 µg/L cadmium is based on the static-renewal measured test result reported by Mebane et al. (2012).

Salmo trutta

The hardness-normalized SMAV/GMAV of 5.642 µg/L total cadmium for the brown trout is based on the geometric mean of five 96-hr LC_{50}s as reported by Davies and Brinkman (1994c), Brinkman and Hansen (2004a, 2007) and Stubblefield (1990). All tests were flow-through measured exposures and used either the fingerling or fry life stage (see **Appendix Table A-1**). The GMAV for the brown trout is the third lowest in the acute dataset.

Morone saxatilis

Two acceptable acute values from one study (Palawski et al. 1985) were used to calculate the hardness-normalized SMAV/GMAV for the striped bass, *Morone saxatilis*. The 63-day old fish were exposed in static, unmeasured chambers at two different test hardness levels (40 and 285 mg/L as $CaCO_3$). The GMAV for the species is 5.931 µg/L total cadmium and is the fourth lowest in the acute dataset.

Oncorhynchus

The hardness-normalized GMAV of 6.141 µg/L total cadmium for the genus *Oncorhynchus* is the fifth lowest in the acute dataset, and is calculated from SMAVs of four different species (cutthroat trout, *Oncorhynchus clarkii;* coho salmon, *O. kisutch*; rainbow trout, *O mykiss*; Chinook salmon, *O. tshawytscha*). *Oncorhynchus* is one of the most widely tested genera in the freshwater acute dataset. All but the cutthroat trout are Listed species. Hardness-normalized SMAVs range from 3.727 to 11.88 µg/L total cadmium (**Table 7**) and are composed of anywhere from one (*O. kisutch*) to 30 (*O. mykiss*) acute values (**Appendix Table A-1**). As noted above, despite *Oncorhynchus* ranking as the fifth most sensitive genus to acute cadmium exposure, the SMAV for the commercially and recreationally important rainbow trout species (3.727 µg/L at a hardness of 100 mg/L) is the basis for the acute criteria FAV, as recommended by the 1985 Guidelines. Rainbow trout was the most sensitive species tested, thus the use of the rainbow trout SMAV as the basis for the acute criteria is expected to be protective of all salmonid species and all other sensitive species for which toxicity data are available.

As noted in the 1985 Guidelines, acute values that appear to be questionable in comparison with other acute data for the same species and for other species in the same genus probably should not be used in the calculation of a SMAV. Consistent with the 1985 Guidelines, several values were identified as outliers and removed from the *Oncorhynchus mykiss* dataset. Values from Hollis (1999, 2000a) (normalized LC_{50} of 15.82 and 10.00 µg/L, respectively) and Niyogi (2004) (normalized LC_{50} of 15.89 µg/L) were not used in the SMAV calculation for rainbow trout because cadmium nitrate salts were used, and for salmonids, tests with cadmium nitrate averaged three to four times higher than tests with chloride or sulfate, the dominant forms of cadmium in surface water. Acute values for Davies (1993) with high test water hardness (>400 mg/L) were also removed from the SMAV calculation because magnesium alone was used to adjust the test hardness which is not reflective of conditions in most water bodies where calcium is the dominant mineral influencing water hardness (i.e., the acute values were lower than expected). Values for insensitive life stages were also not used for chinook salmon and rainbow trout SMAV calculations because data were available that demonstrated clear life stage sensitivity differences. For chinook salmon, insensitive parr and smolt normalized LC_{50} values of 14.75 µg/L and >12.22 µg/L, respectively, were not used in the SMAV calculation, while the normalized LC_{50} values for juveniles (5.477 µg/L) and swim-up fry (7.586 µg/L) were retained from the Chapman study (1978). Similarly from Chapman (1978), insensitive smolt and alevin rainbow trout normalized LC_{50} values of >12.22 µg/L and >113.8 µg/L, respectively, were not used, while the normalized LC_{50} values for swim-up fry (5.479 µg/L) and parr (4.214 µg/L) were retained for calculation of the SMAV (**Appendix Table A-1**).

Table 7. Ranked Freshwater GMAVs.

(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$ and expressed as total cadmium).
(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
75	**49,052**	Midge, *Chironomus plumosus*	**15,798**
-	-	Midge, *Chironomus riparius*	**>152,301**
74	**30,781**	Common carp, *Cyprinus carpio*	**30,781**
73	**26,837**	Nile tilapia, *Oreochromis niloticus*	**66,720**
-	-	Mozambique tilapia, *Oreochromis mossambica*	**10,795**
72	**26,607**	Planarian, *Dendrocoelum lacteum*	**26,607**
71	**22,138**	Mayfly, *Rhithrogena hageni*	**22,138**
70	**>20,132**	Little green stonefly, *Sweltsa sp.*	**>20,132**
69	12,100	Mosquitofish, *Gambusia affinis*	12,100
68	**11,627**	Oligochaete, *Branchiura sowerbyi*	**11,627**

Rank[a]	**GMAV (µg/L total)**	**Species**	**SMAV (µg/L total)**
67	11,171	Oligochaete, *Rhyacodrilus montana*	11,171
66	11,045	Threespine stickleback, *Gasterosteus aculeatus*	11,045
65	9,917	Channel catfish, *Ictalurus punctatus*	9,917
64	9,752	Oligochaete, *Stylodrilus heringianus*	9,752
63	**7,798**	Mayfly, *Hexagenia rigida*	**7,798**
62	7,752	Green sunfish, *Lepomis cyanellus*	6,276
-	-	Bluegill, *Lepomis macrochirus*	9,574
61	7,716	Red shiner, *Cyprinella lutrensis*	7,716
60	7,037	Oligochaete, *Spirosperma ferox*	6,206
-	-	Oligochaete, *Spirosperma nikolskyi*	7,979
59	**6,808**	Yellow perch, *Perca flavescens*	**6,808**
58	6,738	Earthworm, *Varichaetadrilus pacificus*	6,738
57	5,947	White sucker, *Catostomus commersonii*	5,947
56	5,674	Oligochaete, *Quistadrilus multisetosus*	5,674
55	5,583	Flagfish, *Jordanella floridae*	5,583
54	4,929	Guppy, *Poecilia reticulata*	4,929
53	4,467	Mayfly, *Ephemerella subvaria*	4,467
52	**4,193**	Tubificid worm, *Tubifex tubifex*	**4,193**
51	3,350	Amphipod, *Crangonyx pseudogracilis*	3,350
50	**3,121**	Copepod, *Diaptomus forbesi*	**3,121**
49	**2,967**	Zebrafish, *Danio rerio*	**2,967**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
48	**2,231**	African clawed frog, *Xenopus laevis*	**2,231**
47	**1,983**	Crayfish, *Procambarus acutus*	**812.8**
-	-	Crayfish, *Procambarus alleni*	**6,592**
-	-	Red swamp crayfish, *Procambarus clarkii*	**1,455**
46	1,656	Goldfish, *Carassius auratus*	1,656
45	**>1,637**	Caddisfly, *Arctopsyche sp.*	**>1,637**
44	1,593	Oligochaete, *Limnodrilus hoffmeisteri*	1,593
43	**1,582**	Fathead minnow, *Pimephales promelas*	**1,582**
42	1,023	Northwestern salamander, *Ambystoma gracile*	1,023
41	983.8	Isopod, *Caecidotea bicrenata*	983.8
40	**>808.4**	Snail, *Gyraulus sp.*	**>808.4**
39	**651.3**	Lake whitefish, *Coregonus clupeaformis*	**651.3**
38	539.7	Bryozoa, *Plumatella emarginata*	539.7
37	501.7	Cladoceran, *Alona affinis*	501.7
36	453.0	Cyclopoid copepod, *Cyclops varicans*	453.0
35	**427.9**	Pond snail, *Lymnaea stagnalis*	**427.9**
34	**410.4**	Planarian, *Dugesia dorotocephala*	**410.4**
33	392.5	Leech, *Glossiphonia complanata*	392.5
32	**350.4**	Mayfly, *Baetis tricaudatus*	**350.4**
31	346.6	Bryozoa, *Pectinatella magnifica*	346.6
30	275.0	Worm, *Lumbriculus variegatus*	275.0

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
29	208.0	Snail, *Physa acuta*	**2,152**[b]
-	-	Pouch snail, *Physa gyrina*	208.0
28	204.1	Snail, *Aplexa hypnorum*	204.1
27	154.3	Amphipod, *Gammarus pseudolimnaeus*	154.3
26	**145.5**	Worm, *Nais elinguis*	**145.5**
25	**120.1**	Hydra, *Hydra circumcincta*	**184.8**
-	-	Hydra *Hydra oligactis*	**154.8**
-	-	Green hydra, *Hydra viridissima*	**38.85**
-	-	Hydra, *Hydra vulgaris*	**187.1**
24	**103.1**	Cladoceran, *Diaphanosoma brachyurum*	**103.1**
23	99.54	Isopod, *Lirceus alabamae*	99.54
22	**94.67**	Crayfish, *Orconectes immunis*	>22,579[b]
-	-	Crayfish, *Orconectes juvenilis*	**134.0**
-	-	Crayfish, *Orconectes placidus*	**66.89**
-	-	Crayfish, *Orconectes virilis*	22,800[b]
21	86.51	Cladoceran, *Moina macrocopa*	86.51
20	80.38	Bonytail, *Gila elegans (LS)*	80.38
19	76.02	Razorback sucker, *Xyrauchen texanus (LS)*	76.02
18	74.28	Bryozoa, *Lophopodella carteri*	74.28
17	**73.67**	Cladoceran, *Ceriodaphnia dubia*	**64.03**
-	-	Cladoceran, *Ceriodaphnia reticulata*	84.76

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
16	**71.76**	Mussel, *Utterbackia imbecillis*	**71.76**
15	70.76	Southern rainbow mussel, *Villosa vibex*	70.76
14	**68.51**	Mussel, *Lasmigona subviridis*	**68.51**
13	67.90	Mussel, *Actinonaias pectorosa*	67.90
12	**61.42**	Cladoceran, *Daphnia ambigua*	**24.81**
-	-	Cladoceran, *Daphnia magna*	**40.62**
-	-	Cladoceran, *Daphnia pulex*	**109.2**
-	-	Cladoceran, *Daphnia similis*	**129.3**
11	57.71	Cladoceran, *Simocephalus serrulatus*	57.71
10	**51.34**	Neosho mucket, *Lampsilis rafinesqueana (LS)*	**44.67**
-	-	Fatmucket, *Lampsilis siliquoidea*	**35.73**
-	-	Southern fatmucket, *Lampsilis straminea claibornensis*	93.17
-	-	Yellow sandshell, *Lampsilis teres*	46.71
9	**46.79**	Colorado pikeminnow, *Ptychocheilus lucius (LS)*	46.79
-	-	Northern pikeminnow, *Ptychocheilus oregonensis*	4,265[b]
8	**<33.78**	White sturgeon, *Acipenser transmontanus (LS)*	**<33.78**
7	**23.00**	Amphipod, *Hyalella azteca*	**23.00**
6	**>15.72**	Mountain whitefish, *Prosopium williamsoni*	**>15.72**
5	**6.141**	Cutthroat trout, *Oncorhynchus clarkii*	**5.401**
-	-	Coho salmon, *Oncorhynchus kisutch (LS)*	11.88
-	-	Rainbow trout, *Oncorhynchus mykiss (LS)*	**3.727**

Rank[a]	**GMAV (µg/L total)**	**Species**	**SMAV (µg/L total)**
-	-	Chinook salmon, *Oncorhynchus tshawytscha (LS)*	**5.949**
4	5.931	Striped bass, *Morone saxatilis*	5.931
3	**5.642**	Brown trout, *Salmo trutta*	**5.642**
2	**4.411**	Mottled sculpin, *Cottus bairdii*	**4.418**
-	**-**	Shorthead sculpin, *Cottus confusus*	**4.404**
1	**4.190**	Bull trout, *Salvelinus confluentus*	4.190
-	-	Brook trout, *Salvelinus fontinalis (LS)*	**3,055**[b]

[a] Ranked from least to most sensitive based on Genus Mean Acute Value.

[b] There is a 10-fold difference in SMAVs for the genus, only most sensitive SMAV is used in the calculation. Therefore, only bull trout, and not brook trout, was used to determine GMAV for *Salvelinus*.

[The following species were not included in the Ranked GMAV Table because hardness was not reported and therefore toxicity values could not be normalized to the standard total hardness of 100 mg/L as $CaCO_3$: Leech, *Nephelopsis obscura*; Crayfish, *Orconectes limosus*; Prawn, *Macrobrachium rosenbergii*; Mayfly, *Drunella grandis grandis*; Stonefly, *Pteronarcella badia*; Midge, *Culicoides furens*; Grass carp, *Ctenopharyngodon idellus*.]

LS = Federally-listed species

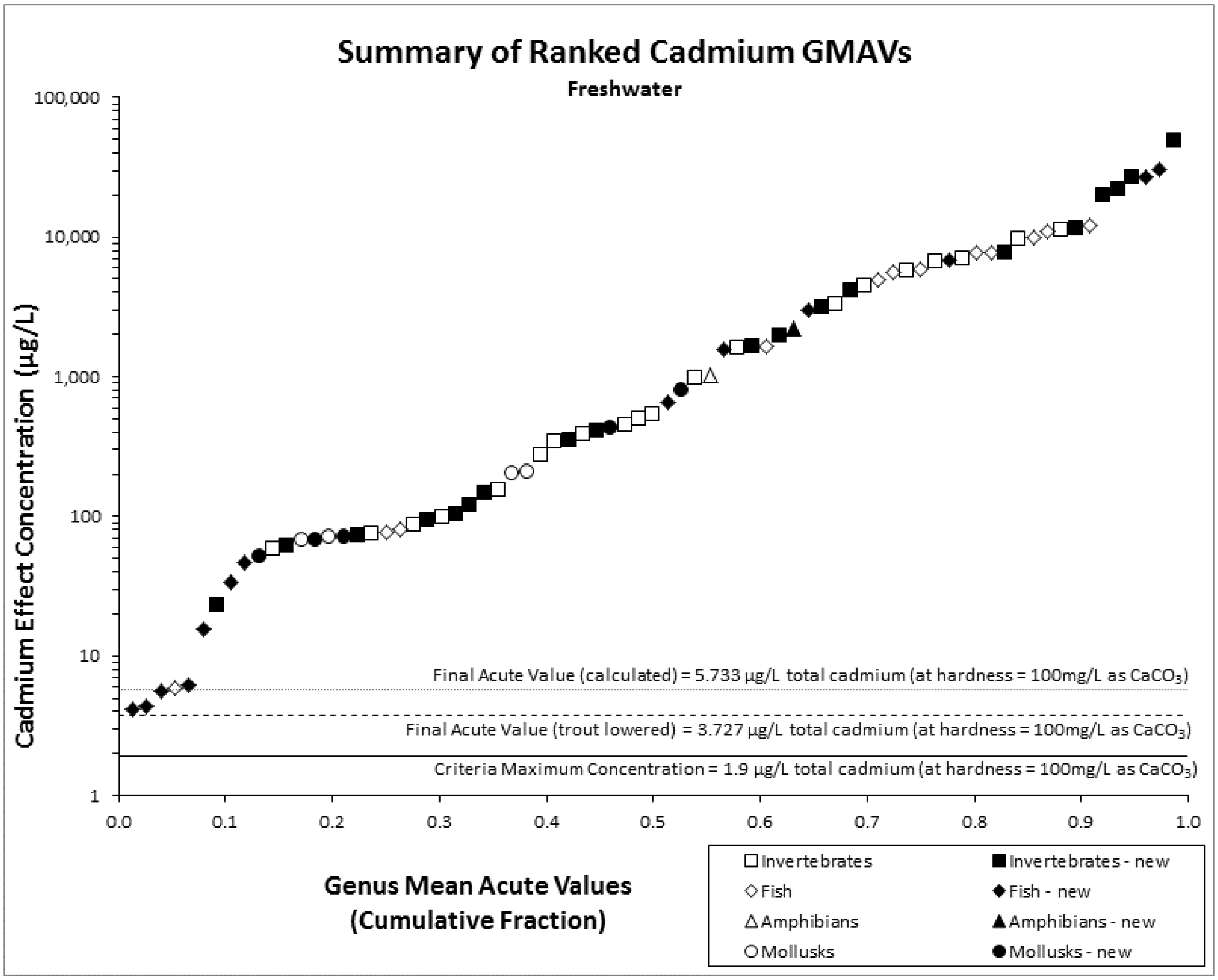


Figure 3. Ranked Freshwater Cadmium GMAVs.

3.1.2 Chronic toxicity

Acceptable data on the chronic effects of cadmium in freshwater are available for 27 species, grouped into 20 genera (**Appendix C**). As with the freshwater cadmium acute dataset, the diversity of species representing the chronic dataset satisfy the eight MDRs specified in the 1985 Guidelines, and regression analysis was therefore used to derive the new freshwater CCC. This is in contrast to the acute-chronic ratio methodology, which can be used when the MDRs are not met. Ranked GMCVs for cadmium in fresh water based on chronic toxicity are identified in **Table 9** and plotted in **Figure 5**. The following sections detail the derivation of these GMCV summaries.

Hardness correction

Following the procedures described in **Section 2.7.1**, an analysis of covariance was applied to the data in **Appendix C** (each study used in the chronic hardness slope derivation is compiled in **Appendix Table C-2**) to calculate the chronic hardness correction slope for four species (*Daphnia magna*, *Oncorhynchus mykiss*, *Salmo trutta* and *Salvelinus fontinalis*) (**Table 8**). Two of the four species (*O. mykiss* and *S. fontinalis*) were not included in the 2001 AWQC dataset. Although included in the 2001 revision, data for *P. promelas* were not used for the hardness correction slope in the 2016 update because no EC_{20} values and only MATCs were available for these tests. For *D. magna*, both EC_{20} values and MATCs were available, but the EC_{20} values from multiple studies were too divergent. Therefore, the same three MATC values from Chapman et al. (Manuscript) used in the 2001 revision were retained in the 2016 update so that an invertebrate species could be included in the calculation of the chronic cadmium toxicity-hardness slope. The acceptable data for rainbow trout were limited to data from Brown et al. (1994), Davies and Brinkman (1994b), Besser et al. (2007), and Mebane et al. (2008). Rainbow trout data from Davies et al. (1993) were not included, as differences in toxicity due to different levels of hardness were attributed entirely to magnesium amendments.

Using the final dataset to calculate the chronic cadmium toxicity-hardness slope, an analysis of covariance test was performed to determine whether a single pooled species slope was acceptable for use in the criteria derivation. The P-value of the resulting relationship between hardness and individual species slopes was 0.15, indicating that individual species hardness slopes were not significantly different from one another, and that a single pooled slope could be used. The pooled slope for the log-log relationship between hardness and chronic toxicity was 0.7977. A list of the species and accompanying slopes used to estimate the final chronic hardness slope is provided in **Table 8** and graphically illustrated in **Figure 4**.

Table 8. Pooled and Individual Species Slopes Calculated for the Cadmium Chronic Toxicity vs. Hardness Relationship.

Species	n	Slope	R^2 Value	95% Confidence Interval	df
Daphnia magna[a]	3	0.7712	0.962	-1.166-2.709	1
Oncorhynchus mykiss[b]	6	0.4602*	0.705	0.04712-0.8732	4
Salmo trutta	6	1.329*	0.765	0.3072-2.350	4
Salvelinus fontinalis	3	1.078	0.862	-4.406-6.563	1
Final Model	18	0.7977*#	0.841	0.4334-1.162	13

Species highlighted in bold are new relative to the 2001 AWQC hardness slope estimation.

* Slope is significantly different than 0 ($p<0.05$).

\# Individual species slopes not significantly different ($p=0.15$).

[a] Includes 3 MATCs from Chapman et al. (Manuscript).

[b] Includes one value from Brown et al. (1994), two values from Davies and Brinkman (1994b), one value from Besser et al. (2007) and two from Mebane et al. (2008). Excluded 3 values from Davies et al. (1993) because hardness was manipulated using magnesium.

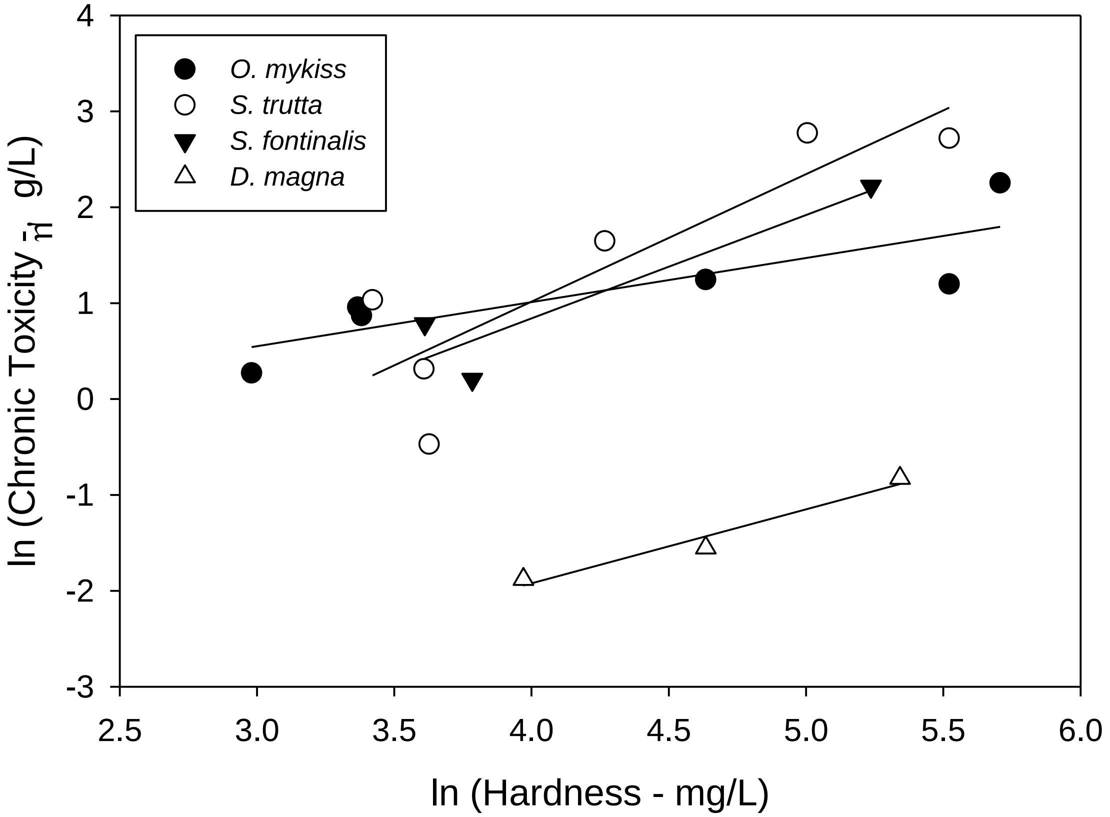


Figure 4. Species Chronic Hardness Slopes.
Natural log transformed hardness and chronic toxicity concentrations for each species used to calculate the pooled chronic hardness correction slope. Results of individual regression lines are shown in **Table 8**.

Summaries of studies used in chronic freshwater criterion determination

Of the 20 Genus Mean Chronic Values (GMCV) in the updated chronic criteria dataset, four of the genera included previously in the 2001 update have new data. A new species in the updated dataset, mottled sculpin (*C. bairdii*) now represents the most sensitive fish species and the third most sensitive genus in the distribution with a GMCV = 1.470 µg/L (total cadmium and normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate is the amphipod *Hyalella azteca* with a normalized GMCV = 0.7453 µg/L (based on the 42-day reproduction endpoint). There are sufficient data to fulfill the requirements to calculate a chronic freshwater criterion using the species sensitivity distribution (SD) method. Acceptable data on the chronic effects of cadmium on freshwater animals include 11 species of invertebrates and 16 species of fish grouped into 20 genera (**Table 9**). Six new species include the oligochaete (*Lumbriculus variegatus*), the fatmucket (*Lampsilis siliquoidea*), the snail (*Lymnaea stagnalis*), the Rio Grande cutthroat trout (*O. clarkii virginalis*), the mottled sculpin (*C. bairdii*) and the cladoceran (*Ceriodaphnia reticulata*). All of the toxicity values and SMCVs derived are tabulated and included in **Appendix C**. The first through fourth most sensitive genera (out of a total of 20) were used in the computation of the Final Chronic Value (FCV) and are ranked below from most to least sensitive:

1. *Hyalella azteca,* Amphipod (GMCV=0.7453 µg/L total Cd)
2. *Ceriodaphnia*, Cladoceran (GMCV=1.293 µg/L total Cd)
3. *Cottus bairdii,* Mottled sculpin (GMCV=1.470 µg/L total Cd)
4. *Chironomus dilutus*, Midge (GMCV=2.000 µg/L total Cd)

The resulting calculated FCV is 0.7945 µg/L total cadmium. Summaries are provided below for the individual species or genera (in cases where more than one species is included in the calculation of the GMCV) used to calculate the freshwater FCV. All values are provided in terms of total cadmium.

Hyalella azteca

One full-life cycle study satisfied the acceptability criteria for *H. azteca* (Ingersoll and Kemble 2001) based on recently recommended culture and control conditions, which were also used in the 2013 ammonia criteria (see **Appendix K**). *H. azteca* were exposed under flow-through measured conditions (control, low, middle and high exposures) at a mean temperature of

23°C and a total hardness of 280 mg/L as $CaCO_3$. A 3-mm nylon mesh substrate was provided during the test. The seven- to eight-day old amphipods were exposed to water only mean total cadmium concentrations of 0.10 (control), 0.12, 0.32, 0.51, 1.9 and 3.2 µg/L for 42 days. The water used for this test (USGS Columbia Lab well water) is acceptable for *H. azteca* studies (around 25 mg Cl/L and 0.08 mg Br/L). For this study, both dry weight (measured by scale) and length data were taken as measures of growth, and there are differences in the growth inferred by these two measures. Through direct consultation with the study authors, it was determined that at the time this study was conducted length provided a more accurate and reliable measure of growth than the direct measure of weight. This was based largely on the small sizes of the organisms and limitations in the accuracy of the scales at the time the study was conducted. This same laboratory has developed a robust empirical relationship between amphipod length and weight, which has been used in multiple peer reviewed publications (Besser et al. 2013, 2015a,b; Ivey and Ingersoll 2016; Kemble et al. 2013). Applying this formula, the 28-d average control length of 4.37 mm represents an average dry weight of 0.434 mg and the 42-d average control length of 4.67 mm translates to an average dry weight of 0.524 mg. These weight values are above the minimum control performance values listed in **Appendix K** and in ASTM (2005). In addition, the average control reproduction (6.4 young/female) also met minimum performance values. Although the feeding rate used in this test was below that recommended for *H. azteca* exposures lasting longer than 10 days, the finding that control organisms met performance criteria applied in tests using a higher feeding rate supports retaining these data for use in deriving AWQC. The most sensitive endpoint from this test was reproduction; the reproduction EC_{20} for this test is 1.695 µg/L, or 0.7453 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_3$. *H. azteca* is now the most chronically sensitive genus in the dataset with a hardness-normalized SMCV/GMCV of 0.7453 µg/L (**Table 9**). This value is a revision to the 42-day MATC of 0.9844 µg/L that was previously used in the 2001 AWQC cadmium document (see **Section 5.2.1** for additional discussion on suitability of chronic *Hyalella* studies).

Ceriodaphnia dubia

An acceptable *C. dubia* seven-day static-renewal toxicity test was conducted by Jop et al. (1995) using reconstituted soft laboratory water. The <24-hr old neonates were exposed to 1, 5, 10, 19 and 41 µg/L measured cadmium concentrations in addition to a laboratory water control at 25°C. The NOEC and LOEC were 10 and 19 µg/L cadmium, respectively, with a resulting chronic value of 13.78 µg/L cadmium. An EC_{20} could not be calculated with the information provided for this test. Similarly, both Spehar and Fiandt (1986) and Brooks et al. (2004) lacked the details necessary to calculate EC_{20}s. MATCs for these tests were reported at 2.20 and 1.93 µg/L total cadmium, respectively. Chronic values for these three studies ranged from 1.264 to 49.75 µg/L total cadmium when normalized to a total hardness of 100 mg/L as $CaCO_3$.

Researchers at Southwest Texas State University (2000) also evaluated the chronic toxicity of cadmium to *C. dubia*. Five replicate tests were conducted using static-renewal exposures and laboratory reconstituted hard water at a hardness of 270 mg/L as dilution water for the five cadmium concentrations. For reproduction, NOECs ranged from 1.073 to 5.457 µg/L, LOECs from 2.391 to 9.934 µg/L, and the MATCs from 1.602 to 7.259 µg/L cadmium. Reproductive EC_{20}s for these tests were very similar to the MATCs, and ranged from 1.341 to 6.129 µg/L cadmium at 270 mg/L hardness, which is equivalent to 0.6071 to 2.775 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_3$. An EC_{20} could not be estimated for *C. reticulata* (**Table 9**), and data from this study were not used in the GMCV calculation. The resultant hardness-normalized SMCV and GMCV for this species is 1.293 µg/L, and is the second most sensitive genus in the chronic dataset.

Cottus bairdii

Besser et al. (2007) evaluated the chronic toxicity of cadmium to the mottled sculpin, (*Cottus bairdii*), via a 28-day flow-through measured concentration early life stage (ELS) test. Swim-up fry were exposed to five cadmium concentrations diluted with a well water/reverse osmosis treated water mixture (103 mg/L average total hardness). Survival, growth and biomass were evaluated at test termination. Survival was the most sensitive endpoint with a NOEC, LOEC and MATC of 1.4, 2.6 and 1.91 µg/L cadmium, respectively. The estimated hardness-normalized 28-day survival EC_{20} of 1.721 µg/L cadmium is very similar to the MATC at the test hardness of 103 mg/L. The authors also conducted a 21-day ELS test with the mottled sculpin using the same dilution water, and observed a more sensitive survival effect concentration of 0.8758 µg/L cadmium for the MATC, and an estimated EC_{20} of 1.285 µg/L cadmium. Both tests were used to calculate a SMCV/GMCV of 1.470 µg/L cadmium, and ranks *Cottus* as the third most chronically sensitive genus to cadmium.

Chironomus dilutus

Ingersoll and Kemble (2001) exposed the midge *Chironomus dilutus* to cadmium under the same conditions listed above for the amphipod *H. azteca*, except that a thin 5 mL layer of sand was provided as a substrate. The <24-hr old larvae were exposed to water-only mean measured total cadmium concentrations of 0.15 (control), 0.50, 1.5, 3.1, 5.8 and 16.4 µg/L cadmium for 60 days. The mean weight, biomass, percent emergence and percent hatch 20-day NOEC and LOEC values for all endpoints were 5.8 and 16.4 µg/L cadmium, respectively. The calculated EC_{20} based on percent hatch was 4.548 µg/L total cadmium or 2.000 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_3$, and is the fourth most sensitive genus to cadmium in the chronic dataset.

Table 9. Ranked Freshwater GMCVs.
(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$ and expressed as total cadmium).
(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMCV (µg/L total)	Species	SMCV (µg/L total)
20	>38.66	Blue tilapia, *Oreochromis aureus*	>38.66[c]
19	**36.70**	Oligochaete, *Aeolosoma headleyi*	**36.70**
18	16.43	Bluegill, *Lepomis macrochirus*	16.43
17	**15.16**	Oligochaete, *Lumbriculus variegatus*	**15.16**
16	14.22	Smallmouth bass, *Micropterus dolomieu*	14.22[c]
15	14.17	Northern pike, *Esox lucius*	14.17[c]
14	14.16	Fathead minnow, *Pimephales promelas*	14.16
13	13.66	White sucker, *Catostomus commersonii*	13.66[c]
12	**11.29**	Fatmucket, *Lampsilis siliquoidea*	**11.29**
11	**9.887**	Pond snail, *Lymnaea stagnalis*	**9.887**
10	8.723	Flagfish, *Jordanella floridae*	8.723

Rank[a]	GMCV (µg/L total)	Species	SMCV (µg/L total)
9	3.516	Snail, *Aplexa hypnorum*	3.516
8	**3.360**	Atlantic salmon, *Salmo salar (LS)*	2.389
-	-	Brown trout, *Salmo trutta*	**4.725**
7	**3.251**	Rio Grande cutthroat trout, *Oncorhynchus clarkii virginalis*	**3.543**
-	**-**	Coho salmon, *Oncorhynchus kisutch (LS)*	**NA[b]**
-	-	Rainbow trout, *Oncorhynchus mykiss (LS)*	**2.192**
-	-	Chinook salmon, *Oncorhynchus tshawytscha (LS)*	4.426
6	2.356	Brook trout, *Salvelinus fontinalis*	2.356
-	-	Lake trout, *Salvelinus namaycush*	**NA[b]**
5	**2.024**	Cladoceran, *Daphnia magna*	**0.9150**
-	-	Cladoceran, *Daphnia pulex*	**4.478**
4	2.000	Midge, *Chironomus dilutus*	2.000
3	**1.470**	Mottled sculpin, *Cottus bairdii*	**1.470**
2	**1.293**	Cladoceran, *Ceriodaphnia dubia*	**1.293**
-	-	Cladoceran, *Ceriodaphnia reticulata*	**NA[b]**
1	0.7453	Amphipod, *Hyalella azteca*	0.7453

[a] Ranked from most resistant to most sensitive based on Genus Mean Chronic Value.
[b] Not included in the GMCV calculation because normalized EC_{20} data are available for the genus.
[c] Calculated from the MATC and not EC_{20}, but retained to avoid losing a GMCV.
[The following species were not included in the Ranked GMCV table because hardness test conditions were not reported and therefore toxicity values could not be normalized to the standard hardness of 100 mg/L as $CaCO_3$: Mudsnail, *Potamopyrgus antipodarum*.]
LS = Federally-listed species

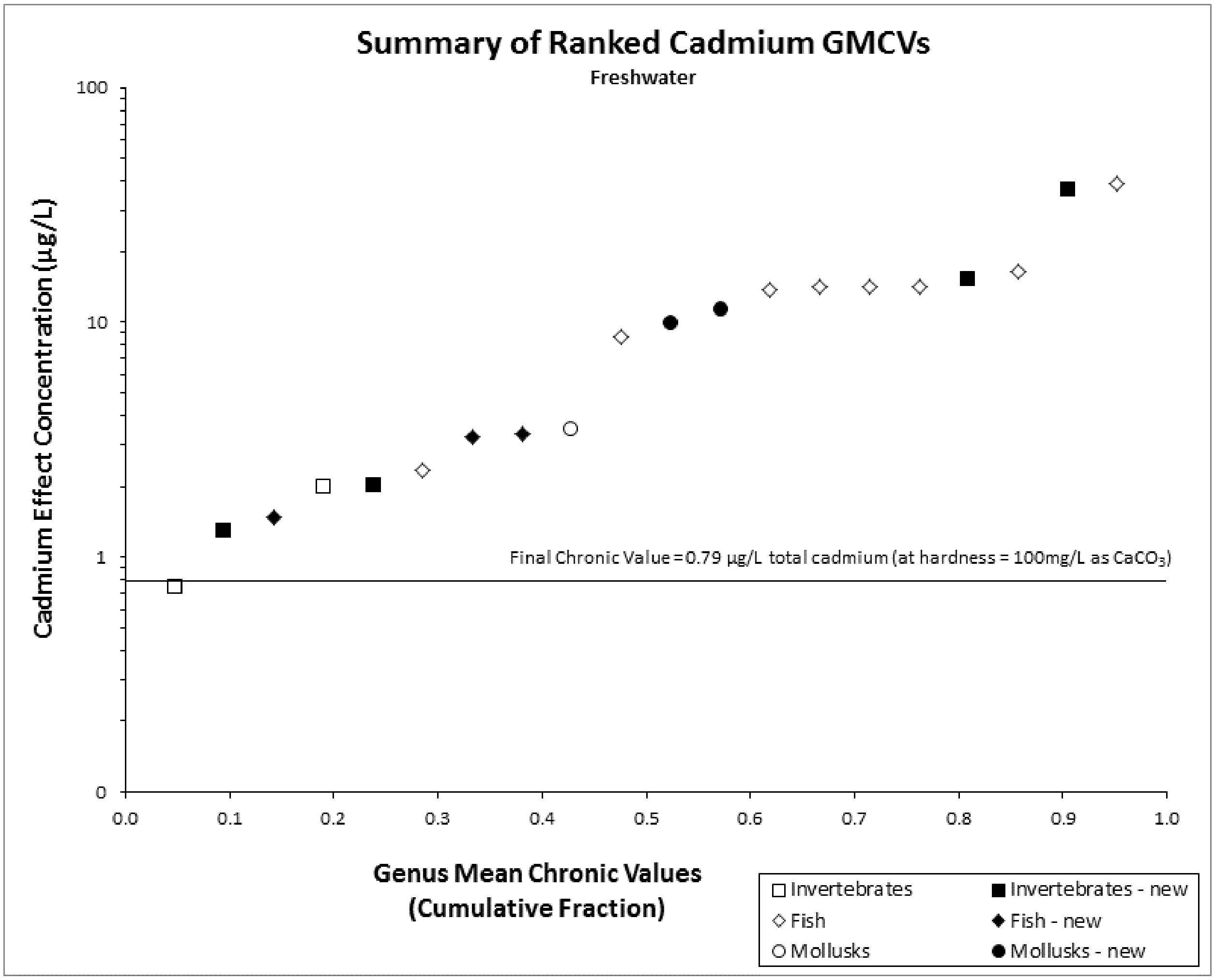


Figure 5. Ranked Freshwater Cadmium GMCVs.

3.2 Estuarine Toxicity to Aquatic Animals

3.2.1 Acute toxicity

Acceptable acute data for cadmium are available for 94 different estuarine/marine species representing 79 genera (**Table 10**). **Figure 6** plots the ranked GMAVs for cadmium in estuarine/marine environments based on acute toxicity. The following sections detail the derivation of these GMAV summaries.

Water quality parameters affecting toxicity

Estuarine/marine fish species are generally more resistant to cadmium than freshwater fish species with SMAVs ranging from 75.0 µg/L for the striped bass (at a salinity of 1 g/kg) to >80,000 µg/L for the Mozambique tilapia (**Appendix B**). There are several water quality parameters that appear to affect the toxicity of cadmium to estuarine/marine species. In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, for example, Voyer (1975) found that 96-hr LC_{50}s at a salinity of 32 g/kg were about one-half of 96-hr LC_{50}s at salinities of 10 and 20 g/kg. As discussed in **Section 5.4.1**, this increase in toxicity with increasing salinity is not consistent with other data reported in **Appendix B** and **Appendix I**, and a salinity correction factor could not be developed.

Limited investigations have been conducted to characterize the influence of temperature on cadmium toxicity. O'Hara (1973a) investigated the effect of water temperature and salinity on the toxicity of cadmium to the fiddler crab, *Uca pugilator*. LC_{50}s at 20°C were 32,300, 46,600 and 37,000 µg/L at salinities of 10, 20 and 30 g/kg, respectively. Increasing the water temperature from 20 to 30°C lowered the LC_{50} at all of the salinities tested. Toudal and Riisgard (1987) reported that increasing the water temperature from 13 to 21°C at a salinity of 20 g/kg also lowered the LC_{50} value of cadmium for the copepod, *Acartia tonsa*. Thus, increasing temperature levels generally resulted in the greater toxicity of cadmium to aquatic organisms, but sufficient data are not available to develop a quantitative relationship.

Summaries of studies used in acute estuarine/marine criterion determination

Suitable cadmium acute toxicity test results for estuarine/marine organisms are now available for 78 invertebrate species and 16 fish species, for a total of 94 species grouped into 79 genera (**Appendix B**). Forty of the 79 GMAVs in the updated dataset have new data. Three new invertebrate species, *Neomysis americana*, *Tigriopus brevicornis* and *Aurelia aurita* now represent the three most sensitive taxa in the distribution (GMAVs of 28.14, 29.14 and 61.75 µg/L, respectively). The most sensitive fish is the striped bass, *Morone saxatilis*, with a GMAV = 75.0 µg/L and ranked the 5th most sensitive species in the new dataset (**Table 10**).

Acute sensitivity ranges widely amongst the estuarine/marine genera for which acute values are available, with the most sensitive species approximately 6,000 times more sensitive than the most resistant species. The GMAVs for estuarine/marine invertebrate species range from 28.14 µg/L for the mysid, *Neomysis* to 169,787 µg/L for the horseshoe crab, *Limulus* (**Table 10**). The SMAVs for estuarine/marine polychaetes range from 200 µg/L for *Capitella capitata* to 12,052 µg/L for *Neanthes arenaceodentata*. Estuarine/marine molluscs have SMAVs that range from 60 µg/L for the horse clam (*Tresus capax*) to 23,200 µg/L for the dog whelk (*Nucella lapillus*). Acute values are available for more than one species in each of 15 genera, and the range of SMAVs within each genus is no more than a factor of 10 for 14 of the 15 genera. Oysters (*Crassostrea*) include SMAVs that differ by a factor of 21.9, which is possibly due to different exposure conditions between the tested species. As described for the freshwater data, only the most sensitive SMAV is used in calculating the GMAV for *Crassostrea*. Furthermore, to avoid using test results from studies in which the life stage tested is known to be less sensitive than other life stages (**Appendix B**), only the data from Reish et al. (1976) were used for *C. capitata*, and only data from Martin et al. (1981) and Nelson et al. (1988) were used for *M. edulis*. Similarly, only data from Sullivan et al. (1983) were used for *E. affinis*, while only data from Wright and Frain (1981) were used for *Marinogammarus obtusatus*. Finally, only data from Cripe (1994) were used for *F. duorarum*, only data from Park et al. (1994) were used for *Rivulus marmoratus* and only data from Hilmy et al. (1985) were used for *Mugil cephalus*. The distribution of ranked estuarine/marine GMAVs for cadmium is depicted in **Figure 6**.

There are sufficient data to fulfill the necessary requirements to calculate an acute criterion for cadmium in estuarine/marine water using the species sensitivity distribution (SD) method. The second through fifth most sensitive genus were used in the computation of the Final Acute Value (FAV) and are ranked below from most to least sensitive:

2. *Tigriopus brevicornis*, Copepod (GMAV=29.14 µg/L total Cd)
3. *Aurelia aurita*, Moon jellyfish (GMAV=61.75 µg/L total Cd)
4. *Americamysis* (GMAV=67.39 µg/L total Cd)
5. *Morone saxatilis*, Striped bass (GMAV=75.0 µg/L total Cd)

The most sensitive genus was represented by the species, *Neomysis americana* (GMAV=28.14 µg/L total cadmium), which is not included in the criteria numeric calculation because it is not within the four GMAVs closest to the 5th percentile of sensitivity in the distribution of 79 genera included in the dataset. In the 2015 draft criteria document, this genus was represented by the species *Neomysis integer*, which was the third most sensitive genus. *Neomysis integer* has been subsequently removed from the database since it does not occur in North America waters and data for the North American estuarine/marine species, *Neomysis americana*, has been obtained, thus making the use of a non-native species as a surrogate for this genus unnecessary. The resulting calculated FAV is 66.25 µg/L total cadmium. Summaries are provided below for the individual species or genera (in cases where more than one species is included in the calculation of the GMAV) used to calculate the estuarine/marine FAV. All values are provided in terms of total cadmium.

Tigriopus brevicornis

The GMAV/SMAV of 29.14 µg/L cadmium for the copepod, *Tigriopus brevicornis*, is based on the geometric mean of three 96-hr LC_{50}s from tests conducted with three different life stages and a salinity that ranged from 34.5 to 35 g/kg. (Forget et al. 1998). The copepods were exposed to unmeasured static cadmium chloride solutions and the resulting acute values were 17.4, 29.7 and 47.9 µg/L cadmium for the nauplius, copepodid and ovigerous female life stages, respectively (**Appendix B**).

Aurelia aurita

Free-swimming larvae (ephyra) of the moon jellyfish, *Aurelia aurita*, were exposed to cadmium nitrate in a static, unmeasured test for 48-hr (Faimali et al. 2013). The SMAV/GMAV of 61.75 µg/L cadmium is the fifth most sensitive species in the estuarine/marine acute dataset and the third most sensitive genus (**Table 10**).

Americamysis

The GMAV of 67.39 µg/L cadmium for *Americamysis* is the geometric mean of the SMAVs for the two mysid species *A. bahia* and *A. bigelowi* (formerly identified as *Mysidopsis bigelowi*). Acceptable acute values for *A. bahia* range from 11.1 to 110 µg/L total cadmium. While there are 14 acceptable acute values, the SMAV of 41.29 µg/L total cadmium is calculated from only the two flow-through measured exposures conducted at salinities of 10-17 g/kg (Nimmo et al. 1977a) and 30 g/kg (Gentile et al. 1982; Lussier et al. 1985).

Morone saxatilis

The striped bass has a GMAV/SMAV of 75.0 µg/L cadmium and is the most sensitive fish species and the fifth most sensitive genus in the estuarine/marine acute dataset (Palawski et al. 1985). This value is based on a test where 63-day old fish were exposed to static and unmeasured concentrations of cadmium chloride for 96-hr at a salinity of 1 g/kg.

Table 10. Ranked Estuarine/Marine GMAVs.
(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
79	**169,787**	Horseshoe crab, *Limulus polyphemus*	**169,787**
78	135,000	Oligochaete worm, *Monopylephorus cuticulatus*	135,000
77	**>80,000**	Mozambique tilapia, *Oreochromis mossambicus*	**>80,000**
76	**62,000**	Scorpionfish, *Scorpaena guttata*	**62,000**
75	**28,196**	Sheepshead minnow, *Cyprinodon variegatus*	**28,196**
74	**25,900**	Cunner, *Tautogolabrus adspersus*	**25,900**
73	24,000	Oligochaete worm, *Tubificoides gabriellae*	24,000
72	**23,200**	Dog whelk, *Nucella lapillus*	**23,200**
71	**22,887**	Amphipod, *Eohaustorius estuarius*	**22,887**
70	19,550	Mummichog, *Fundulus heteroclitus*	18,200
-	-	Striped killifish, *Fundulus majalis*	21,000
69	19,170	Eastern mud snail, *Nassarius obsoletus*	19,170
68	14,297	Winter flounder, *Pseudopleuronectes americanus*	14,297
67	**12,755**	Fiddler crab, *Uca pugilator*	21,238
-	-	Fiddler crab, *Uca triangularis*	**7,660**
66	**12,052**	Polychaete worm, *Neanthes arenaceodentata*	**12,052**
65	11,000	Shiner perch, *Cymatogaster aggregata*	11,000
64	>10,200	California market squid, *Loligo opalescens*	>10,200
63	10,114	Polychaete worm, *Alitta virens*	10,114
62	10,000	Oligochaete, *Tectidrilus verrucosus*	10,000

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
61	**9,217**	Striped mullet, *Mugil cephalus*	7,079
-	-	White mullet, *Mugil curema*	**12,000**
60	**9,100**	Nematode, *Rhabditis marina*	**9,100**
59	**>8,000**	Isopod, *Excirolana sp.*	**>8,000**
58	7,400	Sand dollar, *Dendraster excentricus*	7,400
57	7,120	Wood borer, *Limnoria tripunctata*	7,120
56	6,700	Amphipod, *Diporeia spp.*	6,700
55	6,600	Atlantic oyster drill, *Urosalpinx cinerea*	6,600
54	**4,900**	Mud crab, *Eurypanopeus depressus*	**4,900**
53	4,700	Polychaete, *Nereis grubei*	4,700
52	4,100	Green shore crab, *Carcinus maenas*	4,100
51	**4,058**	Blue crab, *Callinectes sapidus*	2,594
-	-	Lesser blue crab, *Callinectes similis*	**6,350**
50	**3,925**	Polychaete, *Ophryotrocha diadema*	**3,925**
49	3,500	Scud, *Marinogammarus obtusatus*	3,500
48	**3,142**	Polychaete worm, *Ctenodrilus serratus*	**3,142**
47	2,900	Amphipod, *Ampelisca abdita*	2,900
46	2,600	Cone worm, *Pectinaria californiensis*	2,600
45	2,413	Common starfish, *Asterias forbesi*	2,413
44	**2,110**	Pacific sand crab, *Emerita analoga*	**2,110**
43	**2,060**	Gastropod, *Tenguella granulata*	**2,060**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
42	**1,720**	Tiger shrimp, *Penaeus monodon*	**1,720**
41	1,708	Copepod, *Pseudodiaptomus coronatus*	1,708
40	1,672	Soft-shell clam, *Mya arenaria*	1,672
39	**1,510**	Amphipod, *Rhepoxynius abronius*	**1,510**
38	**1,506**	Brown mussel, *Perna perna*	**1,146**
-	-	Green mussel, *Perna viridis*	**1,981**
37	1,500	Coho salmon, *Oncorhynchus kisutch (LS)*	1,500
36	**1,271**	White shrimp, *Litopenaeus setiferus*	**990**
-	-	White shrimp, *Litopenaeus vannamei*	**1,632**
35	1,228	Daggerblade grass shrimp, *Palaemonetes pugio*	1,983
-	-	Grass shrimp, *Palaemonetes vulgaris*	760
34	**1,184**	Starlet sea anemone, *Nematostella vectensis*	**1,184**
33	**1,054**	Atlantic silverside, *Menidia menidia*	**1,054**
32	**1,041**	Amphipod, *Corophium insidiosum*	**1,041**
31	**1,000**	Pinfish, *Lagodon rhomboides*	**1,000**
30	**862.9**	Green sea urchin, *Strongylocentrotus droebachiensis*	1,800
-	-	Purple sea urchin, *Strongylocentrotus purpuratus*	**413.7**
29	800	Rivulus, *Rivulus marmoratus*	800
28	794.5	Harpacticoid copepod, *Nitokra spinipes*	794.5
27	**765.6**	Bay scallop, *Argopecten irradians*	1,480
-	-	Scallop, *Argopecten ventricosus*	**396**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
26	**739.2**	Amphipod, *Leptocheirus plumulosus*	**739.2**
25	**736.2**	Blue mussel, *Mytilus edulis*	1,073
-	-	Blue mussel, *Mytilus trossolus*	**505.0**
24	716.2	Amphipod, *Elasmopus bampo*	716.2
23	645.0	Longwrist hermit crab, *Pagurus longicarpus*	645.0
22	**630.7**	Amphipod, *Grandidierella japonica*	**630.7**
21	630	Amphipod, *Chelura terebrans*	630
20	**490**	Barnacle, *Amphibalanus amphitrite*	**490**
19	**422.6**	Mangrove oyster, *Isognomon californicum*	**422.6**
18	**410.3**	Mysid, *Praunus flexuosus*	**410.3**
17	410.0	Isopod, *Joeropsis sp.*	410.0
16	320	Sand shrimp, *Crangon septemspinosa*	320
15	310.5	Northern pink shrimp, *Farfantepenaeus duorarum*	310.5
14	235.7	Rock crab, *Cancer plebejus*	250
-	-	Dungeness crab, *Cancer magister*	222.3
13	224	Harpacticoid copepod, *Sarsamphiascus tenuiremis*	224
12	>200	Cabezon, *Scorpaenichthys marmoratus*	>200
11	200	Polychaete worm, *Capitella capitata*	200
10	**188.1**	Horse clam, *Tresus capax*	**60**
-	-	Horse clam, *Tresus nuttalli*	**590**
9	**173.2**	Pacific oyster, *Crassostrea gigas*	**173.2**

Rank[a]	**GMAV (µg/L total)**	**Species**	**SMAV (µg/L total)**
-	-	American oyster, *Crassostrea virginica*	**3,800**[b]
8	147.7	Calanoid copepod, *Eurytemora affinis*	147.7
7	130.7	Copepod, *Acartia clausi*	144
-	-	Calanoid copepod, *Acartia tonsa*	118.7
6	78	American lobster, *Homarus americanus*	78
5	75.0	Striped bass, *Morone saxatilis*	75.0
4	67.39	Mysid, *Americamysis bahia*	41.29
-	-	Mysid, *Americamysis bigelowi*	110
3	**61.75**	Moon jellyfish, *Aurelia aurita*	**61.75**
2	**29.14**	Harpacticoid copepod, *Tigriopus brevicornis*	**29.14**
1	**28.14**	Mysid, *Neomysis americana*	**28.14**

[a] Ranked from least to most sensitive based on Genus Mean Acute Value.

[b] There is a 10x difference in SMAVs for the genus, only most sensitive SMAV is used in the calculation.

LS = Federally-listed species

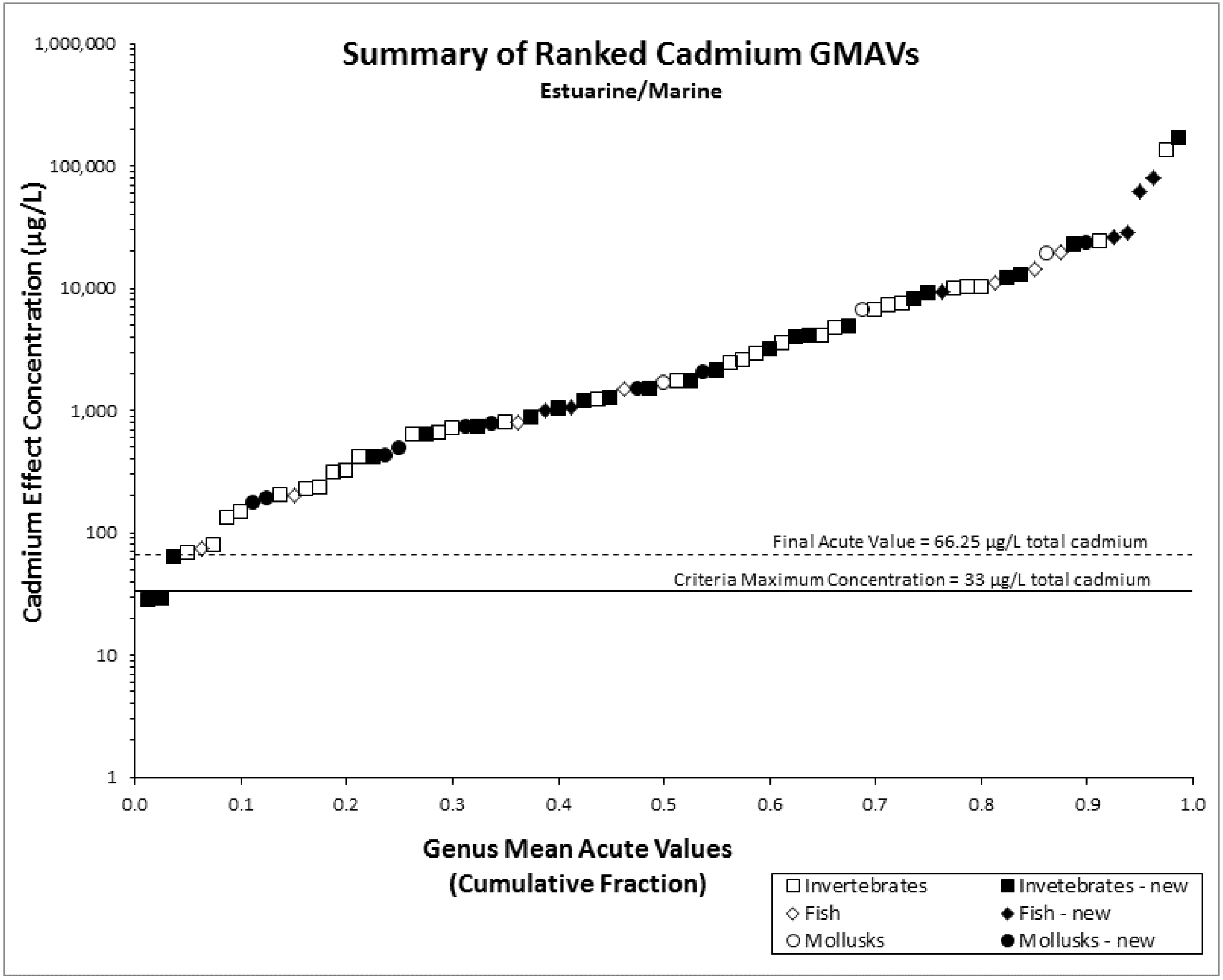


Figure 6. Ranked Estuarine/Marine Cadmium GMAVs.

3.2.2 Chronic toxicity

Chronic studies were available for only two species of mysids for consideration in deriving a chronic criterion for cadmium in estuarine/marine water. The taxonomic nomenclature of one of those species has recently changed so there is now only one genus represented by the two species (**Table 11**). Because the MDR is not met for derivation of the estuarine/marine FCV, the ACR approach was employed whereby the estuarine/marine FAV is divided by the FACR (see **Section 4.4.2**). Although three ACRs are typically required to calculate an FACR, only two ACRs for estuarine/marine species were used in 2001 to calculate the estuarine/marine FACR. Freshwater ACRs were not used in 2001 to support the derivation of the estuarine/marine FACR because the range of freshwater ACR values was considered too large for inclusion (see **Section 5.9.5**). With the availability of additional freshwater toxicity data, the updated estuarine/marine

FACR now incorporates six freshwater genus-level ACRs and one estuarine/marine genus-level ACR. EPA believes that inclusion of the freshwater species ACRs (that are acutely sensitive and have taxonomically-related marine species) with the estuarine/marine species ACRs is the most appropriate and representative method for deriving the FACR.

The GMCV for estuarine/marine species based on chronic cadmium toxicity in a saltwater medium is identified in **Table 11**. This GMCV is plotted in **Figure 7** in relation to the new FCV/CCC of 8.0 µg/L total cadmium. The following presents a discussion of estuarine/marine chronic data used in deriving the estuarine/marine chronic criterion for cadmium. The chronic values are based on estimated EC_{20} values for each of two species. The EC_{20} values and SMCVs derived are tabulated and included in **Appendix D**.

Americamysis

Three chronic toxicity tests have been conducted with the estuarine/marine invertebrate, *Americamysis bahia*, formerly classified as *Mysidopsis bahia*, and one acceptable study was conducted with *Americamysis bigelowi*, formerly classified as *Mysidopsis bigelowi*. Nimmo et al. (1977a) conducted a 23-day life-cycle test with *A. bahia* at a temperature ranging from 20 to 28°C and a salinity ranging from 15 to 23 g/kg. Survival was 10 percent at 10.6 µg/L cadmium, 84 percent at the next lower test concentration of 6.4 µg/L cadmium, and 95 percent in the controls. No unacceptable effects were observed at cadmium concentrations ≤ 6.4 µg/L. The chronic toxicity limits, therefore, are 6.4 and 10.6 µg/L cadmium, with a MATC chronic value of 8.237 µg/L cadmium. The accompanying reproductive EC_{20} estimate was 5.605 µg/L cadmium and the 96-hr LC_{50} was 15.5 µg/L cadmium, resulting in an acute-chronic ratio of 2.765.

Another life-cycle test was conducted with *A. bahia* at a constant temperature of 21°C and salinity of 30 g/kg (Gentile et al. 1982; Lussier et al. 1985). All organisms died in 28 days at 23 µg/L cadmium. At 10 µg/L cadmium, a series of morphological aberrations occurred at the onset of sexual maturity. External genitalia in males were aberrant, females failed to develop brood pouches, and both sexes developed a carapace malformation that prohibited molting after release of the initial brood. Although initial reproduction at this concentration was successful, successive broods could not be born because molting resulted in death. No reproductive effects on initial or successive broods were noted in the controls or at 5.1 µg/L cadmium. Thus, the chronic limits for this study are 5.1 and 10 µg/L cadmium, resulting in a MATC of 7.141 µg/L cadmium. The corresponding EC_{20} estimate for survival was 10.93 µg/L cadmium and the LC_{50}

at 21°C and salinity of 30 g/kg was 110 µg/L cadmium, which results in an ACR of 10.06 from this study (Gentile et al. 1982; Lussier et al. 1985).

These Nimmo et al. (1977a) and the Gentile et al. (1982) and Lussier et al. (1985) studies had excellent agreement between the chronic values, but considerable divergence between the acute values and acute-chronic ratios. As discussed in **Section 5.4.1**, several studies have demonstrated an increase in the acute toxicity of cadmium with decreasing salinity and increasing temperature (**Appendix B** and **Appendix I**), and the observed differences in acute toxicity to the mysids might be partially explained on this basis. Nimmo et al. (1977a) conducted their acute test at 20 to 28°C and salinity of 15 to 23 g/kg, whereas the test conducted by Gentile et al. (1982) and Lussier et al. (1985) was performed at 21°C and salinity of 30 g/kg.

A third *A. bahia* chronic study was conducted by Carr et al. (1985) at a salinity of 30 g/kg, but the temperature varied from 14 to 26°C over the 33 day study. At test termination, >50 percent of the organisms had died in cadmium exposures ≥8 µg/L. After 18 days of exposure, growth in 4 µg/L cadmium, the lowest concentration treatment group, was significantly reduced when compared to the controls. The resultant chronic limits based on growth are a NOEC <4 µg/L and a LOEC of 4 µg/L (LOEC) cadmium. The accompanying survival EC_{20} estimate was 5.833 µg/L cadmium. The SMCV for *A. bahia* is the geometric mean of the three EC_{20} values, or 6.149 µg/L. Acute data were not reported for this study.

Gentile et al. (1982) also conducted a life-cycle test with the mysid, *A. bigelowi*, and the results were very similar to those for *A. bahia*. The EC_{20} for this test was 11.61 µg/L cadmium and the ACR is 9.475 when paired with the acute LC_{50} for *A. bigelowi* of 110 µg/L cadmium. The resulting GMCV for *Americamysis* is 8.449 µg/L cadmium (**Table 11**) and is the only GMCV in the estuarine/marine chronic dataset.

Table 11. Ranked Estuarine/Marine GMCVs.
(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMCV (µg/L total)	Species	SMCV (µg/L total)
1	8.449	Mysid, *Americamysis bahia*	6.149
-	-	Mysid, *Americamysis bigelowi*	11.61

[a] Ranked from least to most sensitive based on Genus Mean Chronic Value.

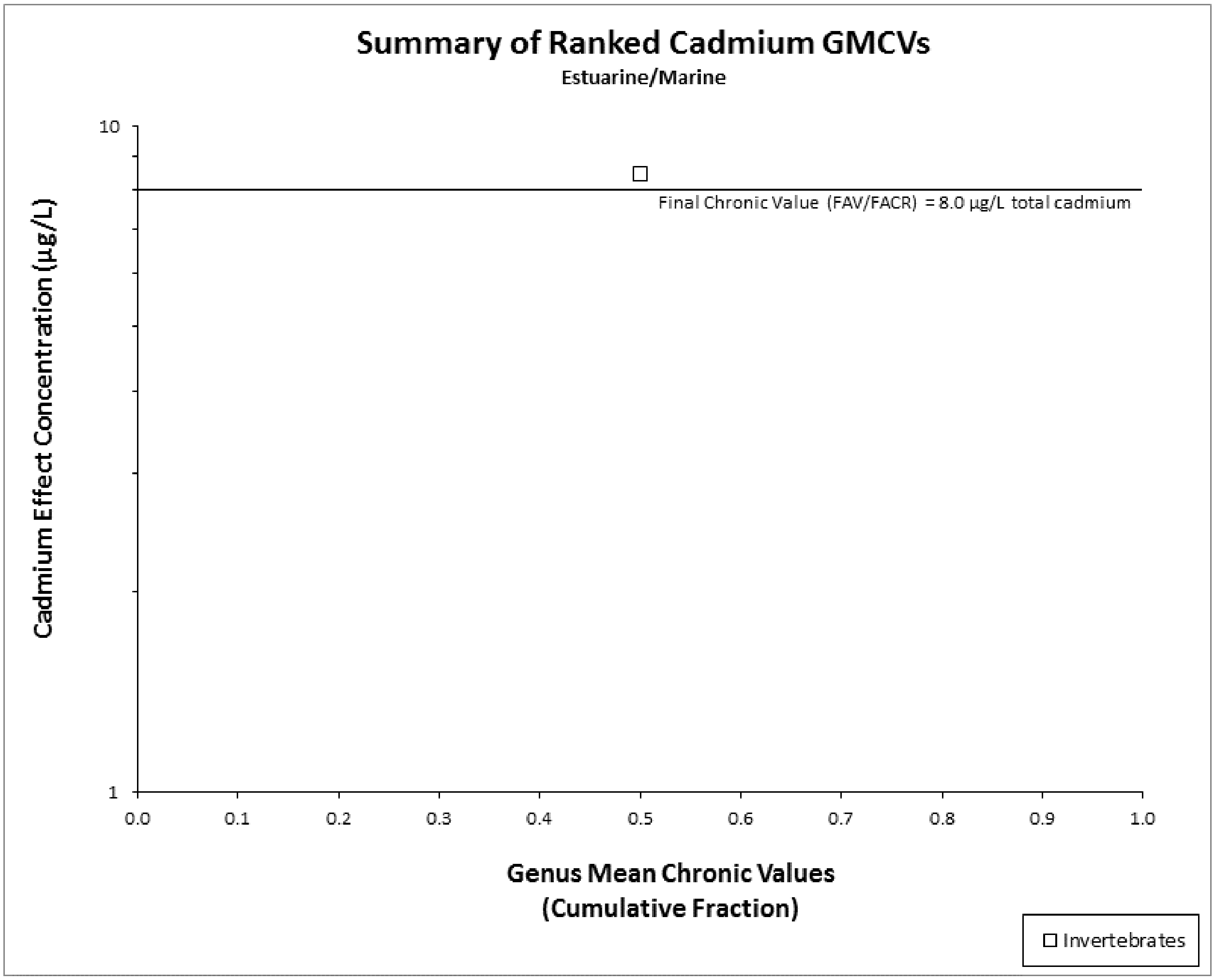


Figure 7. Ranked Estuarine/Marine Cadmium GMCVs.

3.3 Bioaccumulation

No U.S. Food and Drug Administration (FDA) action level or other maximum acceptable concentration in tissue, as defined in the 1985 Guidelines, is available for cadmium. Therefore, a Final Residue Value was not developed for fish tissue. However, as discussed in **Section 2.3**, although cadmium can bioaccumulate in the tissues of aquatic life, at criteria concentrations it is unlikely to accumulate to levels that would result in adverse effects to aquatic invertebrates, fish, or wildlife from the ingestion of aquatic life that have accumulated cadmium in their tissues. This conclusion is supported by the extensive amount of tissue residue-effects data in the literature, more than is available for any other chemical (Jarvinen and Ankley 1999, Bridges and Lutz 1999). Most aquatic organisms are considered to be more susceptible to cadmium from direct aqueous exposure than through bioaccumulation, and the development of criteria protective of direct exposure effects are considered more applicable to the development of criteria for aquatic life. Acceptable bioaccumulation data are provided in **Appendix G** and discussed in **Section 5.6**.

3.4 Toxicity to Aquatic Plants

Available data for aquatic plants and algae were reviewed to determine if they were more sensitive to cadmium than aquatic animals (see **Appendix A** and **Appendix E** for freshwater species; see **Appendix B** and **Appendix F** for estuarine/marine species). Effect concentrations for freshwater plants and algae were well above the freshwater criteria. With only a few exceptions, estuarine/marine plants were less sensitive than estuarine/marine animals, and it was therefore unnecessary to develop criteria based on the toxicity of cadmium to aquatic plants in this update. The only two exceptions were the green algae *Dunaliella viridis* and *Scenedesmus sp.*, each having a static-unmeasured 10-d MATC of 7.07 µg/L cadmium. As recommended in the 1985 Guidelines (Stephan et al. 1985), these unmeasured plant studies were not used for the derivation of a Final Plant Value.

4 THE NATIONAL CRITERIA FOR CADMIUM

4.1 The Freshwater Cadmium Criteria

Freshwater Acute Criterion, the Criterion Maximum Concentration (CMC)

$$\text{CMC}= e^{(0.9789 \times \ln(\text{hardness}) - 3.866)} \times \text{CF}$$

Where CF (conversion factor from total to dissolved) = 1.136672 - [(ln hardness) x (0.041838)]. The resultant **CMC of 1.8 µg/L** for dissolved cadmium at a hardness of 100 mg/L as $CaCO_3$. The CMC was derived to be protective of the commercially and recreationally important rainbow trout (*Oncorhynchus mykiss*), consistent with procedures described in the 1985 Guidelines, and is below all the SMAVs in **Table 7,** when the SMAVs are expressed on a dissolved basis. A comparison of the updated CMC to the 2001 CMC across various hardness levels is presented in **Table 12**.

Freshwater Chronic Criterion, the Continuous Concentration (CCC)

$$\text{CCC} = e^{(0.7977 \times \ln(\text{hardness}) - 3.909)} \times \text{CF}$$

Where CF (conversion factor from total to dissolved) = 1.101672 - [(ln hardness) x (0.041838)]. The resultant **CCC of 0.72 µg/L** for dissolved cadmium at a hardness of 100 mg/L is below all the SMCVs in **Table 9**. A comparison of the updated CCC to the 2001 CCC across various hardness levels is presented in **Table 12**.

Table 12. Freshwater CMC and CCC at Various Water Hardness.

Hardness (mg/L as $CaCO_3$)	CMC (µg/L Cd dissolved)		CCC (µg/L Cd dissolved)	
	2001 Criteria (superseded)	2016 Criteria	2001 Criteria (superseded)	2016 Criteria
25	0.52	0.49	0.09	0.25
50	1.0	0.94	0.15	0.43
75	1.5	1.4	0.20	0.58
100	2.0	**1.8**	0.25	**0.72**
150	3.0	2.6	0.33	1.0
200	3.9	3.4	0.40	1.2
250	4.9	4.2	0.46	1.4
300	5.9	5.0	0.53	1.6
350	6.8	5.8	0.59	1.8
400	7.7	6.5	0.64	2.0

4.2 The Estuarine/Marine Cadmium Criteria

Estuarine/Marine Criterion Maximum Concentration (CMC)

CMC:

Total Cadmium Final Acute Value = 66.25 µg/L

Total Cadmium Criterion Maximum Concentration = (66.25 µg/L)/2 = 33.13 µg/L

Dissolved Cadmium Criterion Maximum Concentration = 0.994 x (33.13 µg/L) = **33 µg/L**

Estuarine/Marine Criterion Continuous Concentration (CCC)

CCC:

Final Acute-Chronic Ratio = 8.291 (see **Section 4.4.2**)

Total Cadmium Final Chronic Value = (66.25 µg/L)/8.291 = 7.991 µg/L

Dissolved Cadmium Final Chronic Value = 0.994 x (7.991 µg/L) = **7.9 µg/L**

4.3 Freshwater Criteria Calculations

4.3.1 Acute

The freshwater Final Acute Value (FAV) for total cadmium at a total hardness of 100 mg/L as $CaCO_3$ was calculated to be 5.733 µg/L total cadmium (**Table 13**), based on the fGMAVs shown in **Table 7**. This value is below all other SMAVs listed in **Table 7** (see also **Figure 3**), with the exception of the SMAVs for rainbow trout, mottled sculpin, shorthead sculpin, bull trout, cutthroat trout and brown trout. However, since the SMAV for the commercially and recreationally important rainbow trout is below this value, the FAV was lowered to 3.727 µg/L total cadmium (at a hardness of 100 mg/L) to protect this species. This lowered value is also protective of all other species, including salmonids, for which toxicity data are available. The resulting freshwater Criterion Maximum Concentration (CMC) at a hardness of 100 mg/L as $CaCO_3$ for total cadmium is (in µg/L) = $e^{(0.9789[\ln(\text{hardness})]-3.866)}$, and is equal to 1.9 µg/L. When the CMC based on total cadmium concentration is converted to dissolved cadmium using the 0.944 conversion factor, which was determined at a hardness of 100 mg/L as $CaCO_3$ (Stephan 1995; Univ. of Wisconsin-Superior 1995), the freshwater CMC for dissolved cadmium (in µg/L) = 0.944 x [$e^{(0.9789[\ln(\text{hardness})]-3.866)}$]. The resultant 1.8 µg/L CMC for dissolved cadmium at a hardness of 100 mg/L is lower than all of the SMAVs/GMAVs presented in **Table 7**, as illustrated graphically in **Figure 3**.

Conversion factors

Although past water quality criteria for cadmium (and other metals) have been established based upon the loosely defined term of "acid soluble metals," EPA made the decision to allow the expression of metal criteria on the basis of dissolved metal concentration (U.S. EPA 1994), which is operationally defined as the portion of metal that passes through a 0.45 µm filter. Because most of the data in existing databases are from tests that provide only total cadmium concentrations, a procedure was required to convert total to dissolved concentrations. Conversion factors (CFs), corresponding to the percent of the total recoverable metal that are dissolved, were applied to total metal concentrations to estimate dissolved metal concentrations. The CFs for cadmium were derived using data from "simulation tests" that were conducted to test the relationship between total and dissolved cadmium concentrations at a range of different hardness values. The objective of the simulation tests was to estimate the cadmium concentrations that would have been detected if dissolved metal concentrations had been measured (Lussier et al. 1995; Stephan 1995; Univ. of Wisconsin-Superior 1995). Hardness was the focus of the simulation tests (and development of the CFs) because it was determined to be the most important variable affecting cadmium toxicity in freshwater.

The data presented in this document are in most cases provided as total cadmium. Only the final cadmium criteria values are converted from total to dissolved concentrations using the appropriate CFs, which are hardness-dependent in fresh water. Acute freshwater total cadmium concentrations were converted to dissolved concentrations using the factor of 0.973 at a total hardness of 50 mg/L as $CaCO_3$, 0.944 at a total hardness of 100 mg/L as $CaCO_3$, and 0.915 at a total hardness of 200 mg/L as $CaCO_3$. The equation for the acute freshwater conversion factor is CF = 1.136672 - [(ln hardness) x (0.041838)] where the (ln hardness) is the natural logarithm of the hardness (Stephan 1995; U.S. EPA 2009b).

Table 13. Freshwater FAV Calculation.

GMAV *N*	Rank	Genus	GMAV	ln(GMAV)	$\ln(\mathrm{GMAV})^2$	P=R/(N+1)	sqrt(P)
75	5	*Oncorhynchus*	6.141	1.82	3.29	0.066	0.256
	4	*Morone*	5.931	1.78	3.17	0.053	0.229
	3	*Salmo*	5.642	1.73	2.99	0.039	0.199
	2	*Cottus*	4.411	1.48	2.20	0.026	0.162
	Sum:			**6.81**	**11.66**	**0.184**	**0.847**

$S^2 =$ 13.60
L = 0.922
A = 1.746
FAV = 5.733
FAV (trout lowered) 3.727
CMC= **1.9**

Where, S=slope, L=intercept, A=ln(FAV); and FAV=final acute value (total cadmium).

4.3.2 Chronic

All chronic values, which were expressed as EC_{20}s whenever possible and MATCs when necessary, were adjusted to a total hardness of 100 mg/L as $CaCO_3$ using the pooled slope of 0.7977 (see **Section 3.1.2**). Normalized chronic values agreed well for most test organisms within a species and for most species within a genus. The exception was the three values for Atlantic salmon, which were very different. Twenty-seven SMCVs were calculated from the underlined values in **Appendix C**. From these 27 SMCVs, 20 GMCVs were calculated and ranked (**Table 9**). A freshwater Final Chronic Value was calculated from the 20 GMCVs using regression analysis (**Table 14**). The freshwater Final Chronic Value for total cadmium at a hardness of 100 mg/L as $CaCO_3$ is (in µg/L) = $e^{(0.7977[\ln(\mathrm{hardness})]-3.909)}$, and is equal to 0.79 µg/L. For dissolved cadmium, the Final Chronic value at a hardness of 100 mg/L as $CaCO_3$ is (in µg/L) = 0.909 x [$e^{(0.7977[\ln(\mathrm{hardness})]-3.909)}$], and is equal to 0.72 µg/L. The equation for the chronic freshwater conversion factor is CF = 1.101672 - [(ln hardness) x (0.041838)]. At a hardness of 100 mg/L as $CaCO_3$, all of the SMCVs and GMCVs are above the CCC (dissolved metal basis).

Table 14. Freshwater FCV Calculation.

FCV *N*	Rank	Genus	GMCV	ln(GMCV)	$\ln(\mathrm{GMCV})^2$	P=R/(N+1)	sqrt(P)
20	4	*Chironomus*	2.000	0.69	0.48	0.190	0.436
	3	*Cottus*	1.470	0.39	0.15	0.143	0.378
	2	*Ceriodaphnia*	1.293	0.26	0.07	0.095	0.309
	1	*Hyalella*	0.7453	-0.29	0.09	0.048	0.218
	Sum:			**1.04**	**0.78**	**0.476**	**1.34**

$S^2 =$ 19.27
L = -1.212
A = -0.230
FCV = 0.79 µg/L

Where, S=slope, L=intercept, A=ln(FCV); and FCV=final chronic value (total cadmium).

4.4 Estuarine/Marine Criteria Calculations

4.4.1 Acute

The estuarine/marine Final Acute Value for total cadmium calculated from the Genus Mean Acute Values shown in **Table 10** is 66.25 µg/L. This FAV is below the SMAV for striped bass (75.0 µg/L), but higher than the SMAVs for the mysid *N. americana* (28.14 µg/L), copepod *T. brevicornis* (29.14 µg/L), mysid *A. bahia* (41.29 µg/L), moon jellyfish *Aurelia aurita* (61.75 µg/L) and horse clam *Tresus capax* (60 µg/L). The resultant estuarine/marine Criterion Maximum Concentration (CMC) for total cadmium is 33 µg/L (FAV/2 or 66.25 µg/L/2). If the total cadmium CMC is converted to dissolved cadmium using the 0.994 factor determined experimentally by EPA according to the procedure described in **Section 4.3.1**, the estuarine/marine CMC for dissolved cadmium is 33 µg/L (**Table 15**). The resultant CMC of 33 µg/L based on dissolved cadmium is below all but two of the estuarine/marine SMAVs (the copepod, *Tigriopus brevicornis* and mysid, *Neomysis americana*) presented in **Table 10** (**Figure 6**).

Table 15. Estuarine/Marine FAV Calculation.

GMAV *N*	Rank	Genus	GMAV	ln(GMAV)	ln(GMAV)^2	P=R/(N+1)	sqrt(P)
79	5	*Morone*	75.0	4.32	18.64	0.063	0.250
	4	*Americamysis*	67.39	4.21	17.73	0.050	0.224
	3	*Aurelia*	61.75	4.12	17.00	0.038	0.194
	2	*Tigriopus*	29.14	3.37	11.37	0.025	0.158
	Sum:			**16.02**	**64.74**	**0.18**	**0.83**

S^2 = 118.2
L = 1.763
A = 4.193
FAV = 66.25
CMC = 33

Where, S=slope, L=intercept, A=ln(FAV); and FAV=final acute value.

4.4.2 Chronic

While there were sufficient data to calculate a freshwater chronic criterion using regression analysis, the estuarine/marine chronic database consists of data representing only one Genus/Family (**Appendix D**). Therefore, the alternative ACR approach was used for deriving an estuarine/marine chronic criterion. This AWQC document update for cadmium recommends the use of seven genus-level ACRs to calculate the FACR for estuarine/marine water (four freshwater fish genera represented by five species, two freshwater invertebrate genera represented by three species, and one acutely sensitive saltwater mysid genera represented by two species). Acceptable ACRs are available for six freshwater invertebrates, eight freshwater fish and two saltwater invertebrate species representing a diverse number of families (**Table 16**). Unfortunately, none of the four methods suggested in the 1985 Guidelines (Stephan et al. 1985) for calculating the FACR are appropriate for cadmium (e.g., the species mean ACR does not increase or decrease as the SMAV increases; the ACRs for a number of species are greater than a factor of ten). Thus, an alternate approach was used to determine the FACR.

The recommended FACR of 8.291 was obtained from the geometric mean of seven genus-level ACRs: one based on estuarine/marine mysids (7.070, which is the geometric mean of 5.275 for *Americamysis bahia* and 9.476 for *A. bigelowi*), two based on freshwater invertebrates (the cladocerans *Ceriodaphnia dubia* (19.84) and *Daphnia* (23.90, which is the geometric mean of 57.23 for *D. magna* and 9.977 for *D. pulex*), and four based on freshwater fish (the mottled sculpin, *Cottus bairdii* (11.22), the salmonids *Oncorhynchus* and *Salmo* (both raised to 2.0 since the ACRs for *O. mykiss*, *O. tshawytscha* and *S. trutta* were all below 2.0), and the fathead minnow, *Pimephales promelas* (17.90)). The fish *C. bairdii, S. trutta, Oncorhynchus* and *P. promelas* represent the second, third, fifth and forty-third most acutely sensitive freshwater genera, respectively, and the cladocerans *Daphnia* and *C. dubia* are the twelfth and seventeenth most acutely sensitive genera. The seven ACRs differ by a factor of 11.95, represent a diverse mix of species, and are protective of the marine environment. The ACRs for the other freshwater species were not used because they have no taxonomically-related marine species (e.g., pulmonate snails), and/or the ACRs appear to be outliers.

This approach was chosen because EPA believes that use of combined ACRs for a variety of freshwater and estuarine/marine species is the most appropriate and representative method for deriving the FACR. When the estuarine/marine Final Acute Value of 66.25 µg/L is divided by the FACR of 8.291, the resulting estuarine/marine FCV is 8.0 µg/L total cadmium. The dissolved cadmium FCV is computed by multiplying the total FCV by the conversion factor of 0.994, resulting in a concentration of 7.9 µg/L.

Table 16. Acute-to-Chronic Ratios.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Species ACR	Reference
FRESHWATER SPECIES					
Snail, *Aplexa hypnorum*	93	4.002	23.24	-	Holcombe et al. 1984; Phipps and Holcombe 1985
Snail, *Aplexa hypnorum*	93	0.8737	106.4	49.74	Holcombe et al. 1984; Phipps and Holcombe 1985
Pond snail, *Lymnaea stagnalis*	367.5	28.68	12.81	12.81	Pais 2012
Fatmucket, *Lampsilis siliquoidea*	16	5.868	2.727	2.727	Wang et al. 2010d
Cladoceran, *Ceriodaphnia dubia*	38.3	1.93	19.84	19.84	Brooks et al. 2004
Cladoceran, *Daphnia magna*	9.9	0.1523	65.00	-	Chapman et al. manuscript
Cladoceran, *Daphnia magna*	33	0.2118	155.8	-	Chapman et al. manuscript
Cladoceran, *Daphnia magna*	49	0.3545	138.2	-	Chapman et al. manuscript
Cladoceran, *Daphnia magna*	30	0.37	81.08	-	Canton and Slooff 1982
Cladoceran, *Daphnia magna*	12.66[a]	1.10	11.51	-	Baird et al. 1990; 1991

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Species ACR	Reference
Cladoceran, *Daphnia magna*	>6.85[e]	2.496	>2.745[b]	-	Chadwick Ecological Consultants 2003
Cladoceran, *Daphnia magna*	>3.43[e]	2.373	>1.446[b]	-	Chadwick Ecological Consultants 2003
Cladoceran, *Daphnia magna*	41.1	1.528	26.89	57.23	Jemec et al. 2007; 2008
Cladoceran, *Daphnia pulex*	62	6.214	9.977	-	Niederlehner 1984
Cladoceran, *Daphnia pulex*	>14.6[e]	3.051	>4.785[b]	9.977	Chadwick Environmental Consultants 2003
Rio Grande cutthroat trout, *Oncorhynchus clarkii virginalis*	2.467	1.871	1.319	1.319	Brinkman 2012
Rainbow trout, *Oncorhynchus mykiss*	2.834[f]	2.473	1.146	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	4.391[f]	4.762	0.922	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	6.564[f]	3.808	1.724	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	8.54	1.82	4.692	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	13.4	9.508	1.409	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	2.79	2.604	1.071	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	5.200	3.471	1.498	-	Besser et al. 2007
Rainbow trout, *Oncorhynchus mykiss*	>12	5.3	>2.264[b]	1.527	Wang et al. 2014a
Chinook salmon, *Oncorhynchus tshawytscha*	1.41	1.465	0.9626	0.9626	Chapman 1975, 1982
Brown trout, *Salmo trutta*	2.37	0.6240	3.798	-	Davies and Brinkman 1994c
Brown trout, *Salmo trutta*	10.1	13.56	0.7448	-	Brinkman and Hansen 2004a; 2007
Brown trout, *Salmo trutta*	3.9	6.36	0.6132	-	Brinkman and Hansen 2004a; 2007
Brown trout, *Salmo trutta*	1.23	2.807	0.4382	0.9337	Brinkman and Hansen 2004a; 2007
Fathead minnow, *Pimephales promelas*	5,995[c]	24.71	242.6	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	13.2	10.0	1.320	17.90	Spehar and Fiandt 1986
Flagfish, *Jordanella floridae*	2,500	5.018	498.2	498.2	Spehar 1976a;b

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Species ACR	Reference
Bluegill, *Lepomis macrochirus*	21,100	29.35	718.9	718.9	Eaton 1974, 1980
Mottled sculpin, *Cottus bairdii*	19.77[d]	1.76	11.22	11.22	Besser et al. 2007
ESTUARINE/MARINE SPECIES					
Mysid, *Americamysis bahia*	15.5	5.605	2.766	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	110	10.93	10.06	5.275	Gentile et al. 1982; Lussier et al. 1985
Mysid, (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	110	11.61	9.476	9.476	Gentile et al. 1982

[a] Geometric mean of 6 LC$_{50}$s from Baird et al. (1991).

[b] Not used to calculate the species ACR because it is an undefined value.

[c] Geometric mean of 5 LC$_{50}$s from Pickering and Gast (1972).

[d] Geometric mean of 2 LC$_{50}$s from Besser et al. (2007).

[e] Test species fed.

[f] Geometric mean of 2 LC$_{50}$s from Davies et al. 1993.

5 EFFECTS CHARACTERIZATION

The purpose of this section is to characterize the potential effects of cadmium on aquatic life based on available test data and to describe additional lines of evidence not used directly in the criteria calculations, but which support the 2016 criteria values. This section also provides a summary of the uncertainties and assumptions associated with the criteria derivation and explanations for decisions regarding data acceptability and usage in the effects assessment. Finally, this section describes substantive differences between the 2001 cadmium AWQC and the 2016 update resulting from incorporation of the latest scientific knowledge.

All acceptable acute and chronic values used to derive criteria are presented in **Appendix A** (Acceptable Freshwater Acute Toxicity Data), **Appendix B** (Acceptable Estuarine/Marine Acute Toxicity Data), **Appendix C** (Acceptable Freshwater Chronic Toxicity Data) and **Appendix D** (Acceptable Estuarine/Marine Chronic Toxicity Data). Acceptable aquatic plant toxicity data are presented in **Appendix E** (Acceptable Freshwater Plant Toxicity Data) and **Appendix F** (Acceptable Estuarine/Marine Plant Toxicity Data), though as discussed in **Section 3.4**, the vast majority of plants are less sensitive than other aquatic species and were not directly used for the derivation of criteria. Acceptable bioaccumulation data are presented in **Appendix G** (Acceptable Bioaccumulation Data), and since direct toxic effects occur more rapidly than bioaccumulation effects, direct effects were therefore the focus of the criteria development. Studies identified as scientifically sound, but that do not meet the screening guidelines for inclusion in criterion calculations (e.g., duration too long or short, too few exposure concentrations, unmeasured chronic test, atypical endpoint) are presented in **Appendix H** (Other Freshwater Toxicity Data) and **Appendix I** (Other Estuarine/Marine Toxicity Data). Where appropriate, these other data are often used qualitatively to support toxicity data compiled for existing species to derive the criteria. The toxicity values in **Appendix H** and **Appendix I** for *Hyalella azteca* and the glochidia and juvenile life stages of mussels represent studies that did not satisfy the recommended test procedures and/or latest science as described in **Sections 2.6**, **5.1.2** and **5.2.1** of this document.

5.1 Freshwater Acute Toxicity Data

Acceptable acute toxicity data supporting the development of acute criteria are available for 101 freshwater species grouped into 75 genera. In general, fish are more acutely sensitive to

NMED Exhibit 70

cadmium than are aquatic invertebrates. Fish comprise eight of the ten most sensitive genera to cadmium, with an amphipod (*H. azteca*) ranked eighth, and a mussel (*Lampsilis*) ranked tenth. The least sensitive genus is the midge *Chironomus.*

Several fish studies were identified as not meeting screening guidelines for inclusion in the criteria calculations (**Appendix H**), but showed similar ranges of response to the most sensitive fish species. Davies and Brinkman (1994a) reported a 96-hr LC_{50} of 1.87 µg/L cadmium for *S. trutta* (fed during the exposure), which is very similar to the unfed 96-hr LC_{50} of 2.37 µg/L determined by the same authors using the same dilution water. The data generated for rainbow trout and reported in Hansen et al. (2002b) showed similar sensitivities to other acceptable data for rainbow trout. Five-day LC_{50} values ranged from 1.108 to 2.729 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_3$. Buhl and Hamilton (1991) and Chapman and Stevens (1978) reported LC_{50}s for Coho salmon of 14.36 µg/L (96-hr) and 8.804 µg/L (217-hr), respectively, when normalized to a total hardness of 100 mg/L as $CaCO_3$. In unmeasured, flow-through cadmium exposures with sockeye salmon, Servizi and Martens (1978) reported unnormalized 7-day LC_{50} values ranging from 8 to 4,500 µg/L for fry and alevins, respectively. The range in sensitivity of the life stages tested by these authors is similar to other salmonid studies used quantitatively to derive the acute criterion (**Appendix A**).

Sublethal effects of cadmium to invertebrate and vertebrate species have been reported by a number of authors (**Appendix H**), many above the 2016 criteria levels. Bluegill sunfish (*Lepomis macrochirus*) cough rate increased when exposed to 50 µg/L cadmium for three days (Bishop and McIntosh 1981) and Low (2009) observed an increase in the auditory threshold for fathead minnows exposed to 2.1 µg/L cadmium for four days. Ivankovic et al. (2010) reported increased metallothionein levels in zebra mussels (*Dreissena polymorpha*) exposed to 10 µg/L cadmium for seven days, and after 10 days limb regeneration of the Northwestern salamander (*Ambystoma gracile*) was adversely affected at 44.6 µg/L cadmium (Nebeker et al. 1994). Shorter exposures using adult *Daphnia magna* (3-hr) and larval *Chironomus dilutes* (24-hr) resulted in a reduced phototactic index at 30 µg/L and increased HSP gene expression at 200 µg/L cadmium, respectively (Yuan et al. 2003; Lee et al. 2006b). In addition, rainbow trout exhibited significant avoidance to 52 µg/L cadmium after an 80 minute exposure (Black and Birge 1980).

5.1.1 Acute toxicity data for freshwater mussels

The only acceptable tests evaluating the acute toxicity of cadmium to glochidia were for the fatmucket, *Lampsilis siliquoidea*. However, the glochidia data were not used to derive the SMAV for this species because data for a more sensitive life stage were available (Wang et al. 2010d). For the fatmucket, *Lampsilis siliquoidea,* 5-day old juveniles (LC_{50} of 35.73 µg/L) were much more sensitive than glochidia (LC_{50} of >507.0 µg/L), and the data for the 5-day old juveniles were included in the acute toxicity dataset.

All other glochidia test results were considered unacceptable and were not included in the acute dataset (see Section 2.6). These included results from tests conducted by Black (2001), who exposed *Fusconia masoni* and *Utterbackia imbecillis* glochidia to cadmium for 24 hours but did not report the control mortality adequately for the data to be used quantitatively.

5.1.2 Suitability of acute *Hyalella azteca* data

Eleven studies investigated the acute toxicity of cadmium to the amphipod, *H. azteca*. Of those 11 studies, only one was considered acceptable for quantitative use, while the others were classified as supporting data and not used to derive the SMAV for this species (**Table 17**). Data from the ten studies were deemed unacceptable for the following reasons: test species were fed (Schubauer-Berigan et al. 1993; Collyard et al. 1994; Suedel et al. 1997); dilution water was not adequately characterized (Mackie 1989); the dilution water was river water and had high TOC (Spehar and Carlson 1984); or the test duration was too short (<96 hr) (McNulty et al. 1999; Gust 2006) or too long (Phipps et al. 1995; Borgmann et al. 2005).

Only results reported in Nebeker et al. (1986b) were considered acceptable and only the EC_{50} of 8 µg/L cadmium from Nebeker et al. (1986b) was used to derive the *H. azteca* SMAV, which is equivalent to 23.00 µg/L cadmium when normalized to a total hardness of 100 mg/L as $CaCO_3$. As demonstrated in **Table 7**, the amphipod *H. azteca* is the most acutely sensitive invertebrate species in the cadmium database.

Table 17. Acute Studies of Hyalella azteca Evaluated for Cadmium Freshwater Criterion.

Reference	Life stage	Hardness (mg/L as $CaCO_3$)	Concentration (µg/L)	Normalized Effect Concentration (µg/L)[a]	Result of Evaluation
Nebeker et al. 1986b	Large juvenile & young adult	34	8	23.00	Acceptable
Spehar and Carlson 1984a,b	-	55-79	285	421.7	High TOC; River dilution water not characterized
Mackie 1989	-	15.3 (pH=5.0)	12	75.37	Dilution water not adequately characterized (Cl- concentration unknown)
Mackie 1989	-	15.3 (pH=5.5)	16	100.5	Dilution water not adequately characterized (Cl- concentration unknown)
Mackie 1989	-	15.3 (pH=6.0)	33	207.3	Dilution water not adequately characterized (Cl- concentration unknown)
Schubauer-Berigan et al. 1993	-	280-300	230	81.10	Test species fed
Collyard et al. 1994	0-2 d	90	≈13	14.41	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	2-4 d	90	≈7.5	8.313	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	4-6 d	90	≈9.5	10.53	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	10-12 d	90	≈7	7.759	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	16-18 d	90	≈11.5	12.75	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	24-26 d	90	≈14	15.52	Test species fed; Data graphed, could only get approximate value
Phipps et al. 1995	-	44-47	2.8	6.051	Duration too long (10 d)
Suedel et al. 1997	14-21 d	17	2.8	15.86	Test species fed; Did not meet specific acceptability criteria for this species
McNulty et al. 1999	-	217-301 (starved for 48 hr before test)	99.34	39.13	Duration too short (24 hr)
McNulty et al. 1999	-	217-301 (starved for 72 hr before test)	82.17	32.36	Duration too short (24 hr)
McNulty et al. 1999	-	217-301 (starved for 96 hr before test)	65.00	25.60	Duration too short (24 hr)
McNulty et al. 1999	-	217-301	107.3	42.27	Duration too short (24 hr)
McNulty et al. 1999	-	217-301	75.42	29.71	Duration too short (24 hr)
McNulty et al. 1999	-	217-301	74.20	29.22	Duration too short (24 hr)
Jackson et al. 2000	7-10 d	48	3.8	7.794	Lack of control survival information; No bromide in dilution water
Jackson et al. 2000	7-10 d	118	12.1	10.29	Lack of control survival information; No bromide in dilution water

Reference	Life stage	Hardness (mg/L as $CaCO_3$)	Concentration (µg/L)	Normalized Effect Concentration (µg/L)[a]	Result of Evaluation
Borgmann et al. 2005	1-11 d	18	0.15	0.8036	Duration too long (7 d)
Borgmann et al. 2005	1-11 d	124	1.60	1.296	Duration too long (7 d)
Gust 2006	-	-	1.9	-	Duration too short (72 hr)

[a] Normalized to a hardness of 100 mg/L using the pooled acute slope of 0.9789.

5.1.3 Uncertainty in the freshwater FAV calculation

A number of uncertainties are associated with calculation of the freshwater FAV as recommended by the 1985 Guidelines (Stephan et al. 1985), and include use of limited data for a species or genus, acceptability of widely variable data for a genus, application of safety factors, and extrapolation of laboratory data to field situations. There are a number of cases in the acute database where only one acute test is used to determine the SMAV and subsequently the GMAV is based on the one acute test. In this situation there is a level of uncertainty associated with the GMAV based on the one test result since it does not incorporate the range of values that would be available if multiple studies were available. The GMAV is still valid, in spite of absence of these additional data.

The acute database also includes several genera where two or more widely different SMAVs (>10x factor) are available for estimating the GMAV. In this case the 1985 Guidelines recommend that some or all of the values probably should not be used in calculations. To resolve this, only the more sensitive SMAV (primarily due to a more sensitive life stage tested) was used to calculate the GMAV, thereby ensuring protection of the genus, as explained in **Section 3.1.1**.

The final step in the acute criteria derivation process is to divide the FAV by a safety factor of 2 to yield the CMC. The CMC is set equal to half of the FAV to represent a low level of effect for the fifth percentile genus, rather than a 50% effect. This adjustment factor was derived from an analysis of 219 acute toxicity tests with a variety of chemicals (see 43 FR 21506-21518 for a complete description) where mortality data were used to determine the highest tested concentration that did not cause mortality greater than that observed in the control (or between 0 and 10%). Application of this safety factor is justified in that the concentration represents minimal acute toxicity to the species.

Application of water-only laboratory toxicity tests to protect aquatic species is a basic premise of the 1985 Guidelines, supported by the requirements of a diverse assemblage of eight families and the protection of 95 percent of all species. Confirmation has been reported by a number of researchers, thereby indicating that on the whole, extrapolation of laboratory data does a reasonably good job of protecting natural aquatic communities. Certain exoskeleton bearing aquatic organisms (e.g., aquatic insects), however, may not be adequately protected due to their differential accumulation of aqueous vs. dietary cadmium (Poteat and Buchwalter 2014), and this therefore represents uncertainty in the derived CMC. As discussed in **Section 5.6.1**, selected insect species evaluated by different researchers exhibited cadmium dietary effect levels lower than aqueous exposed organisms. The most sensitive insect in the acute database based on water-only laboratory toxicity tests is the mayfly *Baetis*, ranked as the 32nd most sensitive genus.

5.1.4 Acute criteria duration

For the 2016 acute cadmium criteria, EPA has changed the duration to 1-hour from the 24 hours EPA applied in the 2001 final cadmium criteria document. EPA made this change to the 2016 criteria to reflect the acute criteria duration recommended in the 1985 Guidelines. The draft 2001 cadmium criteria document used a 1-hour duration, which EPA subsequently revised to 24 hours in the final criteria document. The final cadmium criteria document did not detail the rationale for this change, and EPA has further examined this issue as part of the 2016 criteria update.

The 24-hour duration used in the 2001 final cadmium criteria document was based on a limited number of fish toxicity studies that were conducted in the mid-1990s and which suggested that cadmium time-to-effect may be longer than reflected by the 1-hour averaging period. These studies were focused on fish and did not address trends in duration for other aquatic species, such as invertebrates. Because of the limited nature of these investigations and absence of additional supporting information, EPA decided to revise the acute duration in this document to be consistent with the more protective 1-hour duration, which is generally supported by and consistent with the 1985 Guidelines. Page 5 of the 1985 Guidelines, for example, states that "For the CMC the averaging period should again be substantially less than the lengths of the tests it is based on, i.e., substantially less than 48 to 96 hours. One hour is probably an appropriate averaging period because high concentrations of some materials can cause death in one to three hours. Even when organisms do not die within the first hour or so, it is not known how many might have died due to delayed effects of this short of an exposure. Thus it is not appropriate to allow concentrations above the CMC to exist for as long as one hour. The durations of the averaging periods in national criteria have been made short enough to restrict allowable fluctuations in the concentration of the pollutant in the receiving water and to restrict the length of time that the concentration in the receiving water can be continuously above a criterion concentration." Page 6 of the 1985 Guidelines further states that "the one-hour average should never exceed the CMC."

Additional information supporting the 1-hour averaging period is presented in page 35 of the *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA 1991) which states that "For acute criteria, EPA recommends an averaging period of 1-hour. That is, to protect against acute effects, the 1-hour average exposure should not exceed the CMC. The 1-hour acute averaging period was derived primarily from data on response time for toxicity to ammonia, a fast-acting toxicant. The l-hour averaging period is expected to be fully protective for the fastest-acting toxicants, and even more protective for slower-acting toxicants." The frequency of allowed exceedances is once in three years on average, as recommended in the Guidelines (Stephan et al. 1985). This is based on the ability of aquatic ecosystems to recover from the exceedences, which will depend in part on the magnitudes and durations of the exceedences. Frequency and duration will be further considered as part of the 1985 Guidelines update, but the duration for the 2016 cadmium acute criteria will be 1-hour.

5.2 Freshwater Chronic Toxicity Data

Acceptable chronic toxicity data are available for 27 freshwater species representing 20 different genera (**Appendix C**). In contrast to the acute toxicity test results, invertebrates were generally more sensitive to cadmium than fish based on chronic toxicity. The four most sensitive genera were the amphipod *Hyalella*, followed by the cladoceran *Ceriodaphnia*, the sculpin *Cottus*, and the midge *Chironomus*. For the acceptable chronic toxicity data, normalized chronic toxicity values ranged from 0.7453 to 36.70 µg/L for invertebrates, and from 1.470 to >38.66 µg/L for fish. The blue tilapia was the least sensitive organism to cadmium and had a normalized MATC of >38.66 µg/L.

Additional chronic toxicity data that were not used quantitatively to derive a criterion are available for cadmium (**Appendix H**). Suedel et al. (1997) conducted a *C. dubia* static, measured life-cycle assessment. The normalized NOEC of 4.110 µg/L and LOEC of 16.44 µg/L reported for this study are only slightly higher than chronic values that were used quantitatively to derive a criterion (**Appendix C**). The 17 to 21-day NOEC and LOEC values reported for *Daphnia magna* and *D. pulex* by Biesinger and Christensen (1972), Winner (1986), Winner and Whitford (1987), Enserink et al. (1993), and Knops et al. (2001) were similar to other acceptable chronic values reported in **Appendix C** for these species, as were values from long term studies with Atlantic salmon (Rombough and Garside 1982; Peterson et al. 1983) and brown trout (Davies and Brinkman 1994c; Brinkman and Hansen 2004a, 2007).

Other sublethal effects data also not used to derive criteria are provided in **Appendix H**, with many studies again reporting effect levels above the criteria. Asian clams (*Corbicula fluminea*) exhibited reduced phagocytosis activity when exposed to 3 µg/L cadmium for 30 days (Champeau et al. 2007), and goldfish (*Carassius auratus*) experienced reduced plasma sodium levels when exposed to 44.5 µg/L cadmium for 50 days (McCarty and Houston 1976). Scherer et al. (1997) evaluated lake trout (*Salvelinus namaycush*) for eight months and reported decreased thyroid follicle epithelial cell height at 5 µg/L cadmium. Delayed development and forelimb emergence was observed in African clawed frog (*Xenopus laevis*) embryos after a 47 day exposure to 855 µg/L cadmium (Sharma and Patino 2008).

An artificial stream channel employed by Riddel et al. (2005a) assessed the prey choice and capture efficiency of *Salvelinus fontinalis* exposed to two cadmium concentrations (0.5 and 5.0 µg/L) for 30 days using dechlorinated tap water at a total hardness of 156 mg/L (as $CaCO_3$). The juvenile brook trout preferred non-motile over motile prey, and prey capture efficiency decreased by 20-55% with increasing Cd concentration. Additional artificial stream channel studies by Riddel et al. (2005b) that employed the same two cadmium exposures and dilution water evaluated the foraging and predator avoidance behaviors of mayfly nymphs (*Baetis tricaudatus*), and predator-prey interactions of stonefly nymphs (*Kogotus nonus*) and the longnose dace (*Rhinichthys cataractae*). Altered mayfly and stonefly behaviors were observed at 5.0 µg/L, whereas the foraging behavior of the dance was unaffected by the highest cadmium exposure. Mebane et al. (2104) exposed larval insects for 32 days to four cadmium concentrations (0.018, 0.091, 0.35 and 1.02 µg/L) in experimental streams that circulated river water with a total hardness of 17 mg/L. Preliminary results indicate that reduced mayfly abundance EC_{20}s normalized to a total hardness of 100 mg/L ranged from 0.41 µg/L for *Ephemerella infrequens* to 3.29 µg/L for *Rhithrogena sp.*

For the 2016 chronic cadmium criteria, the duration is a four-day averaging period as recommended in the Guidelines (Stephan et al 1985). This averaging period is short enough to restrict allowable fluctuations in the concentration of the pollutant in the receiving water and to restrict the length of time that the concentration in the receiving water can be continuously above a criterion concentrations. In addition, the frequency of allowed exceedances is once in three years on average, same as for the acute criteria.

5.2.1 Suitability of chronic *Hyalella azteca* data

A total of eight *H. azteca* chronic studies were reviewed for acceptability as recommended in **Appendix K**. Only data from the Ingersoll and Kemble (2001) study using USGS Columbia, Missouri Lab well water as dilution water was considered acceptable for deriving a freshwater chronic criterion (**Appendix C**). Thus, the *H. azteca* normalized SMCV (and GMCV) of 0.7453 µg/L cadmium is based on only this study. Although the seven other studies were not used for deriving the updated cadmium freshwater chronic criterion, the effect levels observed for each study are provided below and demonstrate the similar sensitivity of the amphipod to cadmium, despite the issues which precluded their use in developing the SMCV and GMCV. The normalized effect concentrations for these seven studies ranged from 0.3749 to 4.907 µg/L cadmium, with the majority of values ranging from 0.4-2.0 µg/L (**Table 18**).

Table 18. Chronic Studies of Hyalella azteca Evaluated for Cadmium Freshwater Criterion.

Reference	Method[a]	Life stage	Exposure	Effect	EC_{20}/ MATC (TH=100) (µg/L)	Result of Evaluation
Ingersoll and Kemble (2001)	F, M	7-8 d old	42 days	Reproduction	0.7453	Acceptable
Borgmann et al. 1989b	R, M	<7-d old	42 days	Survival	0.6348	Not acceptable Only 64% control survival (need ≥80%)
Borgmann et al. 1991	R, M	<7-d old	42 days	Survival	0.4299 (EC_{50})	Not acceptable Low control weight of 0.34 mg dwt (need ≥ 0.50 mg dwt after 42 days of testing)

Reference	Method[a]	Life stage	Exposure	Effect	EC_{20}/ MATC (TH=100) (µg/L)	Result of Evaluation
Suedel et al. 1997	S, M	14-21 d old	14 days	Survival/ growth	0.6576	Not acceptable Test organisms underfed (control weights not reported). Low ionic composition of dilution water.
Chadwick Ecological Consultants 2003	F, M	7-8 d old	28 days (recon lab water)	Survival	0.3749	Not acceptable Low control weight of 0.25 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)
Chadwick Ecological Consultants 2003	F, M	7-8 d old	28 days (surface water)	Survival	0.4461	Not acceptable 0.2 µg Cd/L in dilution water
Stanley et al. 2005	R, M	7-14 d old	42 days	Survival	2.414	Not acceptable Only 45% control survival (need ≥80%)
Straus 2011	R, M	2-9 d old	21 days	Survival	4.907	Not acceptable Low control weight of 0.136 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)
Straus 2011	R, M	2-9 d old	28 days	Survival	2.277	Not acceptable Low control weight of 0.064 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)
Pais 2012	R, M	2-9 d old	28 days	Survival	0.5127	Not acceptable Low control weight of 0.135 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured; TH=total hardness

Borgmann et al. (1989b) Chronic Survival Study

This long-term (6 week) study investigated the effect of cadmium on *H. azteca* survival, growth and reproduction and was primarily a methods development effort. The static-renewal life cycle test was initiated with <7-day old organisms and was conducted at 25°C in dechlorinated Burlington City tap water with exposure concentrations of 0.28 (control), 0.57, 0.92, 1.49, 2.23, 3.42 and 6.28 µg/L cadmium. The water used for testing is acceptable, with a chloride concentration of approximately 26 mg/L and bromide concentration of around 0.047 mg/L. Other common ion (Na, K, Ca, Mg, SO4, and HCO_3) concentrations in this water are reasonable for testing with *H. azteca*. However, the food and feeding levels used in this test are questionable. The authors tested up to 20 organisms in each beaker and added 4 mg Tetramin flakes once per week to each test beaker, with additional feedings given up to two times each week on an as needed basis. It is not clear how they determined when more food was required.

Furthermore, the reported control survival was only 64 percent, while 80 percent is considered to be the minimum acceptable control survival for a 6-week test. The calculated EC_{20} for survival was 0.7827 µg/L, or 0.6348 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$.

Borgmann et al. (1991) Chronic Survival Study

An additional *H. azteca* 6-week chronic test was conducted by Borgmann using the same dechlorinated Burlington City tap water. As mentioned previously, this tap water is considered acceptable for *H. azteca* testing. However, it appears that organisms in this long-term test were also underfed (similar to other tests conducted by this group). The authors state that the animals were fed Tetramin at a rate of only 5 mg Tetramin/beaker/week, which equates to about 0.25 mg/organism/week. This feeding rate is much lower than currently recommended for chronic tests. Results of other chronic amphipod tests with diets limited to Tetramin had limited success, suggesting that amphipods require dietary supplements in addition to the Tetramin (e.g., YCT or diatoms) to achieve acceptable growth and reproduction (J.R. Hockett, personal communication). Based on the organism control weights obtained at the end of the test (0.34 mg estimated average dry weight), it appears amphipod growth was limited by the feeding rate and dietary composition. Acceptable average ending dry weights typically fall within the range of 0.7 to 1.0 mg/organism for a 42-d test. This poor growth and low feeding rate excluded the use of these data in calculating the SMCV for this species. The reported EC_{50} for survival in the study was 0.53 µg/L, or 0.4299 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$.

Suedel et al. (1997) Chronic Survival and Growth Study

This paper presents the results of several toxicity tests. Although limited information is provided, the tests appear to be static exposure without renewal. Five tests were conducted (48-hr, 96-hr, 7-day, 10-day, and 14-day exposures). Organisms were fed in each test by adding leached, ground maple leaves to the test chambers at the beginning of each exposure. Especially for the longer duration tests (10-day and 14-day), it does not appear the test organisms were fed sufficiently, although this remains unclear because body weight data were not reported. Little information is provided about the test/control water other than hardness (6 to 28 mg/L), alkalinity (8 to 18 mg/L) and conductivity (22 to 130 µS/cm), which indicates the dilution water was low in ion composition. The authors noted that water conditions represent the limits of environmental tolerance for the tested species. The chronic value of 0.16 µg/L (based on growth and survival), or 0.6576 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$, was not used quantitatively in this assessment.

Chadwick Ecological Consultant (2003) Chronic Survival Study

The chronic toxicity of cadmium to *H. azteca* was tested with 28-day flow-through measured test procedures using two different dilution waters (reconstituted laboratory water and natural surface water from Horsetooth Reservoir) with different hardness levels. Both dilution waters were augmented with bromide and chloride to achieve nominal concentrations of approximately 0.80 mg/L Br and 60 mg/L Cl^-, which are above the minimum recommended levels of 0.02 mg/L Br and 15 mg/L Cl. The 28-day control survival was ≥90 percent for each test, which exceeds the 80 percent minimum requirement. The test organisms were fed 1.0 ml YCT daily and the authors reported mean control dry weights at day 28 of 0.25 mg for the reconstituted water test and 0.43 mg for the natural surface water test. The recommended mean control dry weight at day 28 is ≥0.35 mg and only the natural surface water test met the feeding/average control dry weight requirement. Even though the control dry weight of the natural surface water test met the recommended 0.35 mg average, there is an elevated level of cadmium in the Horsetooth Reservoir water (about 0.2 µg/L cadmium). In addition, the cadmium concentration measured at day 28 in the lowest nominal exposure concentration (0.6 µg/L) was very similar to the next higher concentration, which raises questions about whether organism response in the lowest concentration was exaggerated by an excursion in cadmium concentration, or if the measured concentration was an analytical anomaly. The 28-day MATC for the surface water test was 1.02 µg/L cadmium, which was slightly higher than the estimated 28-day survival EC_{20} of 0.6264 µg/L, or 0.4461 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$. The MATC for the reconstituted water was 0.74 µg/L, which was also higher than the normalized calculated EC_{20} of 0.3749 µg/L cadmium.

Stanley et al. (2005) Chronic Survival Study

Stanley et al. (2005) conducted one *H. azteca* 42-day chronic test in laboratory reconstituted water (ASTM hard water) and at a feeding rate of 1 ml YCT/test chamber/day. The lack of sufficient chloride and bromide ions in the dilution water and sub-optimal diet would not support the health of *H. azteca*, especially after 10 days of testing (**Appendix K**). Additionally, the control survival in this test was poor (45%). The results of this test were accordingly not used to develop AWQC. The non-normalized chronic limits based on survival are 2.49 and 5.09 µg/L with a MATC of 2.414 µg cadmium/L when normalized to a hardness of 100 mg/L as $CaCO_3$.

Straus (2011) Chronic Survival Studies

H. azteca neonates (2-9 days old) were exposed to cadmium for 21 days in artificial Lake Ontario reconstituted laboratory water (total hardness of 120-140 mg/L as $CaCO_3$) and for 28 days in a mixture of reverse osmosis and dechlorinated City of Waterloo tap water (blended to a total hardness of 22 mg/L as $CaCO_3$). Water in both tests was renewed every 48 hours and cotton gauze was used as a substrate. Although the test organisms were cultured in artificial media containing bromide, it is not clear if the artificial Lake Ontario water or the reverse osmosis/tap water mix contained bromide. The chloride concentrations also were not reported for either dilution water, although the nominal chloride concentration of the artificial Lake Ontario water is estimated to be approximately 28 mg/L. Test recommendations in **Appendix K** note that natural waters with a hardness of <80 mg/L as $CaCO_3$ typically have <10 mg Cl^-/L. Control organism survival was 93 percent in the 21-day test and 81.8 percent in the 28-day test. Control organism mean dry weight averaged 0.136 for the 21-day test and 0.064 mg for the 28-day test. When all factors are considered, these two studies do not meet the test acceptability requirements outlined in **Appendix K**. The EC_{20}s calculated for these two tests based on survival are 6.42 µg/L for the 21-day test and 0.68 µg/L for the 28-day test, or 4.907 for the 21-day test and 2.277 µg/L for the 28-day test when normalized to a hardness of 100 mg/L as $CaCO_3$.

Pais (2012) Chronic Survival Study

H. azteca neonates (2-9 days old) were exposed to cadmium for 28 days in laboratory water that was renewed every 48 hours. The dilution water was a mix of reverse osmosis and dechlorinated City of Waterloo tap water blended to a total hardness of 90 mg/L as $CaCO_3$. A cotton gauze substrate was used during the test. The bromide and chloride levels were not reported by the author, but since the total hardness of the reverse osmosis/tap water blend was 90 mg/L as $CaCO_3$, the dilution water may have contained an acceptable amount of chloride. U.S. EPA (2012) notes that natural waters with a hardness of <80 mg/L as $CaCO_3$ typically have chloride concentrations of <10 mg/L. The bromide level was not reported, but the tap water may have supplied the minimum bromide level (0.02 mg Br/L) recommended in **Appendix K**. The 28-day control survival was 100 percent, which exceeds the 80 percent minimum requirement.

However, the authors reported a mean control organism weight of 0.135 mg, which is much less than the recommended ≥0.35 mg dwt at day 28. Accordingly, this study does not meet the test acceptability requirements and the normalized 28-day survival EC_{20} of 0.5127 µg/L was not used for criteria derivation.

5.2.2 Uncertainty in the freshwater FCV calculation

In addition to the uncertainties described above for the freshwater acute criteria derivation (**Section 5.1.3**), the freshwater FCV calculation is also influenced by the availability of limited data, estimation of chronic values with either EC_{20} or MATC methods, selection of either life cycle or early life-stage test results for a species, and the use of the most representative test duration for the *C. bairdii* ELS test.

The freshwater chronic database is comprised of 27 species and 20 genera that satisfy the eight-family MDR as recommended in the 1985 Guidelines (Stephan 1985). There are several factors that contribute some uncertainty to the freshwater FCV (e.g., use of EC_{20}s over MATCs, the limited data used to develop the hardness relationship, limited data for *H. azteca*, selection of most appropriate exposure scenarios, and other data that is only used qualitatively). In this update EC_{20}s were selected as the most appropriate effect level, but not all studies reported EC_{20}s or did not provide the raw data in the paper so EC_{20}s could be calculated (Note: for all studies where raw data necessary to calculate EC_{20}s were not provided, authors were contacted to request the raw data, if available. Some requests are still outstanding). While EC_{20}s are the preferred effect level, so that chronic toxicity can be compared equally, this preference limits the amount of data that are used quantitatively in SMCV and GMCV calculations (**Table 9** and **Appendix C**). This was the case for several species (*C. dubia*, *C. reticulata*, *D. magna*, *O. kisutch*, *O. mykiss*, *S. trutta*, *S. fontinalis*, *S. namaycush*, and *P. promelas*). Conversely, only MATCs were available for several genera, and therefore the effect levels associated with those MATC concentrations are unknown (*Oreochromis*, *Micropterus*, *Esox*, and *Catostomus*). These values were retained in the ranked table to avoid losing the genus.

The use of EC_{20}s also limited the amount of data that were used to develop the chronic hardness relationship. Currently there are only enough EC_{20} data to explore this relationship for three fish species. This preference for EC_{20}s precluded the inclusion of data for *P. promelas*, but MATC data from a single study for *D. magna* (Chapman et al. Manuscript) were used so that an invertebrate could be included in the analysis. The rationale for the exclusion of *P. promelas* is that the effect of hardness would be better evaluated without the confounding factor of the level of effect being unknown (see **Section 2.6, Chronic measures of effect**).

The 1985 Guidelines recommend the use of full life-cycle (LC) tests over early life-cycle tests (ELS), with the rationale that LC tests will be more sensitive. However, this relationship was not always apparent. Normalized EC_{20}s of LC tests were more sensitive (lower effect concentrations) for *S. fontinalis* and *O. mykiss*, but ELS tests were more sensitive for *S. trutta*. To be conservative, the ELS tests were used to derive the SMAV for *S. trutta*.

As discussed above there is only one acceptable study using the new test requirements for *H. azteca*. While the other unacceptable data were not used quantitatively it appears that effect concentrations were similar, however the SMAV/GMAV for the most sensitive species in the freshwater chronic database is based on the results from one study (Ingersoll and Kemble 2001).

5.3 Additional Aquatic Life Water Quality Assessments for Cadmium

Mebane (2006) recently derived freshwater ambient water quality criteria for cadmium and included data from studies that focused on species and surface water conditions in Idaho. Acute and chronic toxicity were calculated from available effects data and normalized for hardness based on hardness-toxicity regression analyses. The four most sensitive genera to acute exposures were the fish *Oncorhynchus* (Northwest trout and Pacific salmon), *Salvelinus* (“char” trout), *Salmo* (other trout and Atlantic salmon), and *Cottus* (sculpin). The four most sensitive genera to chronic exposures were the aquatic invertebrates *Hyalella* and *Gammarus* and the fish *Cottus* and *Salvelinus*. Mebane (2006) reported a CMC of 0.75 µg/L total cadmium and a CCC of 0.37 µg/L total cadmium, based on a hardness of 50 mg/L as $CaCO_3$. Mebane (2006) reported cadmium in total (unfiltered) instead of dissolved (0.45-µm filtered) concentrations, but indicated that because cadmium is highly soluble in water, the difference between total and dissolved concentrations would be small, with dissolved cadmium concentrations expected to average about 90 to 95 percent of total concentrations (Stephan 1995; Clark 2002; Mebane 2006). When adjusted to a total hardness of 100 mg/L as $CaCO_3$, the CMC and CCC calculated using equations reported by Mebane (2006) are 1.35 and 0.55 µg/L, respectively. These values are lower than the 2016 updated EPA CMC of 1.9 µg/L and CCC of 0.79 µg/L, based on total cadmium and a hardness of 100 mg/L as $CaCO_3$. The differences in the criteria derived by

Mebane (2006) and this 2016 update are primarily due the addition of new data since 2006, the subsequent estimation of different updated acute and chronic hardness-toxicity slopes, and exclusion of specific test results based on EPA data acceptability criteria.

The British Columbia Ministry of Environment (BC-MOE) recently released a draft assessment of ambient water quality criteria for cadmium in freshwater to protect species resident to British Columbia, Canada (BC-MOE 2014). The proposed acute and chronic criteria are based on dissolved cadmium concentrations in freshwater. The criteria were adjusted for hardness using established methods to derive an equation from the results of multiple published studies (Mebane 2006; Stephan et al. 1985; U.S. EPA 2001). The BC-MOE used the lowest value from a primary study and applied a factor of 3.5 to account for uncertainty and protect the survival of the most sensitive species (<10% mortality) at all life stages. The resulting draft CMC of 0.339 µg/L total cadmium at a water hardness of 100 mg/L $CaCO_3$ was based on effects on rainbow trout fry growth after a 5-d exposure, as reported in Hansen et al. (2002b). The resulting draft CCC (30 days) of 0.0772 µg/L at a water hardness of 100 mg/L $CaCO_3$ was based on effects on *Hyalella azteca* survival, as reported in Ingersoll and Kemble (2001). The short-term hardness slope factor was 1.04 and the long-term hardness slope factor was 0.762; compared to the 2016 hardness slope factors of 0.9789 and 0.7977, respectively. The BC-MOE (2014) cadmium water quality guideline for long term exposure in marine environments is 0.12 µg/L. This is in contrast to the higher EPA 2016 estuarine/marine chronic CCC of 7.9 µg/L dissolved cadmium. No short term exposure guideline has been developed by BC-MOE for the marine environment. The BC-MOE proposed cadmium criteria are all lower than the EPA 2016 criteria, primarily due to differences in the methodology employed (use of lowest value), larger safety factors applied and hardness slope factor differences.

5.4 Estuarine/Marine Acute Toxicity Data

Acute toxicity data are available for 94 estuarine/marine species representing 79 genera. These data are adequate to support the development of an estuarine/marine acute criterion. SMAVs for cadmium range from 28.14 to 169,787 µg/L. The four most sensitive genera were invertebrates with GMAVs ranging from 28.14 to 67.39 µg/L (**Appendix B**).

Additional toxicity data on the effect of cadmium on estuarine/marine species were available, but did not meet standards of acceptability and were not used quantitatively in development of the criteria (**Appendix I**). However, the acute and chronic toxicity values for these tests are similar to those of the accepted studies, providing additional supporting evidence about the toxicity of cadmium to estuarine/marine aquatic life. These include data from Roast et al. (2001b), who reported a 6-day LC_{50} for *P. flexuosus* of 83.11 µg/L, which represents a similar outcome to those provided in **Appendix B**. Nimmo et al. (1977a) and Gentile et al. (1982) reported similar outcomes for *A. bahia* with 8 to 17-day EC_{50} values ranging from 11.3 to 60 µg/L.

Other non-traditional endpoints for marine/estuarine organisms exposed to cadmium for shorter time periods are presented in **Appendix I**. Daggerblade grass shrimp (*Palaemonetes pugio*) had increased LPO and ubiquitin levels when exposed for eight hours to 112.4 µg/L cadmium (Downs et al. 2001a). Reduction in swimming speed and reduced serum osmolality were observed for nauplii of the calanoid copepod *Eurytemora affinis* and the mysid *Americamysis bahia* subjected for 24 hours to 130 and 3.62 µg/L cadmium, respectively (Sullivan et al. 1983; De Lisle and Roberts 1994). Bellas et al. (2004) determined a 70-hr larval attachment EC_{50} of 752 µg/L for the sea squirt *Ciona intestinalis*, and the mud snail *Nassarius obsoletus* had increased oxygen consumption when exposed to 500 µg/L cadmium for 72 hours (MacInnes and Thurberg 1973). Osmotic pressure of the shore crab *Carcinus maenas* was affected at 34 µg/L cadmium after 10 days, but not at 3.4 µg/L (Burke et al. 2003). Choi et al. (2008) found that Pacific oysters (*Crassostrea gigas*) exposed to 10 µg/L cadmium for 11 days had an increased expression of MT mRNA in digestive gland and gills. Coho salmon (*Oncorhynchus kisutch*) exposed to 3.7 µg/L cadmium over 48 hours exhibited histological injury to the olfactory epithelium, and a significant loss of olfaction at concentrations greater than 347 µg/L, with the adverse effects of each still evident after a 16-day depuration in clean water (Williams and Gallagher 2013). The persistent nature of these effects could adversely alter the return rates of anadromous salmon species as noted by Baldwin et al. (2009).

5.4.1 Uncertainty in estuarine/marine FAV calculation

The influence of salinity on the acute toxicity of cadmium was investigated with 10 different genera of estuarine/marine animals. A general trend of decreasing toxicity with increasing salinity was observed for the majority of genera (**Appendix B**). Frank and Robertson (1979) reported that the acute toxicity of cadmium to juvenile blue crabs was reduced by increasing salinity levels, with 96-hr LC_{50}s of 320, 4,700 and 11,600 µg/L at salinities of 1, 15 and 35 g/kg, respectively (**Appendix B**). The same trend was observed by Bengtsson and Bergstrom (1987) for the harpacticoid copepod, *Nitocra spinipes*, Ringwood (1990) for the mangrove oyster, *Isognomon californicum*, Wu and Chen (2004) and Frias-Espericueta et al. (2001) for the white shrimp, *Litopenaeus vannamei*, and De Lisle and Roberts (1988) for the mysid, *Americamysis bahia*, amongst other species.

In contrast to the results presented above, several authors reported possible relationships with salinity that seem contradictory, some of which may have been influenced by other test variables. In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, *Fundulus heteroclitus*, Voyer (1975) found that 96-hr LC_{50}s at a salinity of 32 g/kg were about half of what they were at lower salinities of 10 and 20 g/kg. When tested at approximately 20°C, the 96-hr LC_{50}s were 73,000, 78,000 and 30,000 µg/L at salinities of 10, 20 and 32 g/kg, respectively (all exposures had sufficient dissolved oxygen levels throughout the test). The fiddler crab, *Uca pugilator*, showed a similar trend in that the crab was more sensitive to cadmium at the highest salinity tested (30 g/kg) as compared to the mid-level salinity (20 g/kg) test, and about the same sensitivity as the lowest salinity (10 g/kg) (O'Hara 1973a). Cadmium also appears to be more toxic to purple sea urchin embryos (*Strongylocentrotus purpuratus*) at a higher salinity, although salinity levels differed by only 4 mg/kg and test temperatures were higher in the higher salinity exposure, which may have confounded potential conclusions (Dinnel et al. 1989; Phillips et al. 2003). The potential relationship between salinity and cadmium saltwater acute toxicity was investigated using an analysis of covariance (Dixon and Brown 1979; Neter and Wasserman 1974) as noted in the 1985 Guidelines (Stephan et al. 1985). Despite the general relationship of decreasing toxicity with increasing salinity, a pooled species slope could not be calculated.

As noted in the 1985 Guidelines, a final acute equation should be derived based on a water quality parameter if acute toxicity is shown to be related to that parameter (Stephan et al. 1985). In order to derive a final acute equation from a water quality parameter, however, sufficient data are required to show that the factor similarly affects the results of tests with a variety of species (U.S. EPA 2001). Because a general trend was observed between increasing salinity and decreasing acute toxicity for the majority of genera, an analysis of covariance (Dixon and Brown 1979; Neter and Wasserman 1974) as noted in the 1985 Guidelines (Stephan et al. 1985) using the “R” statistical program, version 3.2.2 (R Core Team 2015), was performed to examine whether a salinity correction equation could be calculated.

Data for the ten species comprising ten genera were included in the analysis of covariance. These species had definitive acute values (less than or greater than values were not used) over a salinity range of at least 7 g/kg. For any given species, data were limited to studies conducted at representative and similar temperatures and dissolved oxygen concentrations. When test data for multiple life stages were available, data for the most sensitive life stage was used.

In the analysis of covariance model equation, the natural logarithm of the acute value is the dependent variable, species is the grouping variable, and the natural logarithm of salinity is the covariate or independent variable. A species-salinity interaction variable is included to assess the similarity of slopes among species. An F-test is then used to test whether a model with separate slopes for each species gives a statistically significantly better fit to the data than a model with a single pooled slope. If the P-value of the species-salinity interaction term is statistically significant (defined as a P-value of less than 0.05), then the model with separate species slopes provides the better fit to the data, and a single pooled slope cannot be calculated.

When data for all nine species were fit to the analysis of covariance model, the species-salinity interaction term used to test for equality of slopes produced a P=0.008, meaning that the model with separate species slopes provides the better fit to the data, and a single pooled slope could not be calculated. Individual species slopes were variable, ranging from -0.6998 for the mummichog *F. heteroclitus* to 5.538 for the amphipod *G. japonica* (**Table 19**). Individual species slopes were also plotted in **Figure 8**. As can be seen in **Figure 8,** eight of the nine species experience a decrease in acute cadmium toxicity with increasing salinity (i.e., a positive slope).

Table 19. Individual Species Slopes and Selected Regression Statistics for the Equation ln(LC$_{50}$Cd) = ln(Salinity).

A pooled species slope could not be calculated from these data.

Species name			**95% CI**				
Scientific	**Common**	**Slope**	**LCL**	**UCL**	**r^2**	**p**	**n**
M. edulis	Blue mussel	0.7399	na	na	na	na	2
I. californicum	Mangrove oyster	1.467	na	na	na	na	2
N. spinipes	Harpacticoid copepod	0.3725	-0.6744	1.419	0.95	0.14	3
A. bahia	Mysid	1.010	0.7158	1.305	0.98	<0.01	5
G. japonica	Amphipod	5.538	na	na	na	na	2
L. vannamei	Whiteleg shrimp	1.032	na	na	na	na	2
C. sapidus	Blue crab	1.006	0.8249	1.186	1.00	<0.01	3
U. pugilator	Fiddler crab	0.1673	-3.499	3.834	0.25	0.67	3
F. heteroclitus	Mummichog	-0.6998	-8.129	6.729	0.59	0.44	3

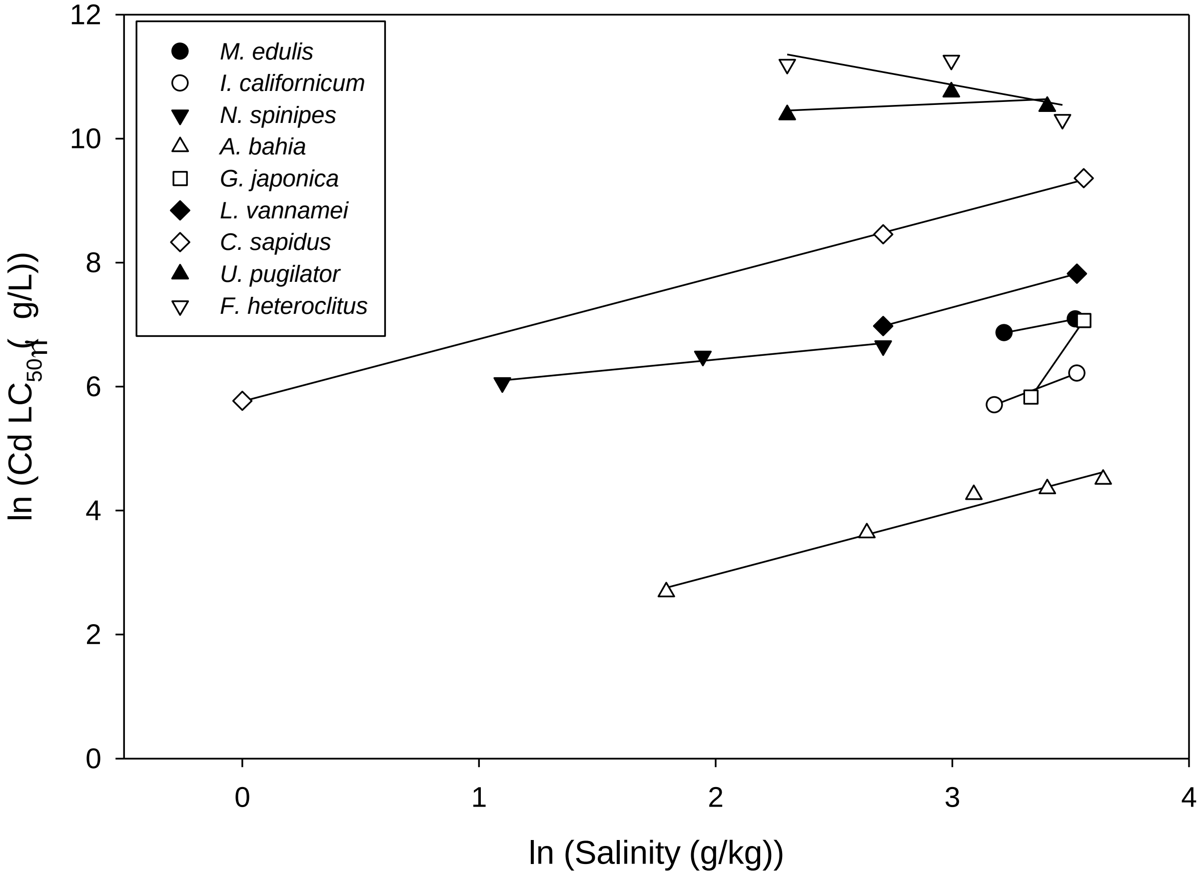


Figure 8. Individual Species Slopes Showing the Relationship between Natural Log Transformed Salinity and Natural Log Transformed Acute Cadmium Toxicity.

Data used to generate species slopes in **Table 19** have already accounted for the most sensitive life stage for a particular species. In addition to that consideration, following the recommendations of the EPA Guidelines (Stephan et al. 1985), individual species slopes were examined and a subsequent analysis of covariance model was used to test whether a pooled species slope could be calculated using only those species with slopes determined to cover a relatively broad range of the relevant water quality parameter, defined here as at least 50% of the range of reported salinities. Five species: *A. bahia*, *C. sapidus*, *F. heteroclitus*, *L. vannamei* and *U. pugilator*, had test data across a salinity range greater than 50% of the salinity range for all species. When data for these five species were fit to the analysis of covariance model, the species-salinity interaction term used to test for equality of slopes produced a P=0.009. As before, the model with separate species slopes provides the better fit to the data, and a single pooled slope could not be calculated. Despite the positive relationship between acute toxicity and salinity observed for eight of the nine species with available data, the species slopes are sufficiently variable that no pooled slope can be calculated. Thus, the estuarine/marine acute data are not normalized for salinity.

In addition to the uncertainties described above for the freshwater acute criteria derivation (**Section 5.1.3**), the lack of a statistically defensible salinity-toxicity relationship to normalize the acute data adds additional uncertainty to the estuarine/marine FAV. Despite the positive relationship between acute toxicity and salinity observed for eight of the nine species included in the analysis of covariance, a pooled slope could not be calculated, precluding salinity normalization of the data. As such, the data are used at the tested salinity level, which may or may not be the most sensitive for the species. Not all studies, however, reported a salinity level which would potentially exclude them from the FAV calculation if the data were salinity normalized.

5.5 Estuarine/Marine Chronic Toxicity Data

Data for only two estuarine/marine mysid species (*Americamysis bahia*, SMCV = 6.149 µg/L and *Americamysis bigelowi*, SMCV = 11.61 µg/L) are suitable for the derivation of a chronic criterion, and limited toxicity data are available for qualitative consideration in this document (see **Appendix I**). A 21-day survival chronic value of 111.8 µg/L was determined for the starlet sea anemone *Nematostella vectensis* (Harter and Matthews 2005), and 28-day LC_{50}s for the polychaete worms *Capitella capitata* and *Neanthes arenaceodentata* ranged from 630 to 3,000 µg/L (Reish et al. 1976). White shrimp (*Litopenaeus vannamei*), pink shrimp (*Farfantepenaeus duorarum*), daggerblade grass shrimp (*Palaemonetes pugio*), rock crab (*Cancer irroratus*) and blue crab (*Callinectes sapidus*) 21 to 30-day effect levels (LC_{50}s and LOECs) ranged from 19 to 720 µg/L (Nimmo et al. 1977b; Vernberg et al. 1977; Johns and Miller 1982; Guerin and Stickle 1995; Wu and Chen 2005a). Scallops were more sensitive to cadmium, with *Argopecten irradians* and *A. ventricosus* 42-day EC_{50} and 30-day LOEC growth effect levels at 10 and 78 µg/L, respectively (Pesch and Stewart 1980; Sobrino-Figueroa et al. 2007). Similarly, Atlantic silverside (*Menidia menidia*), cunner (*Tautogolabrus adspersus*) and winter flounder (*Pseodopleuronectes americanus*) 17 to 60-day survival effects ranged from 100 to >970 µg/L (MacInnes et al. 1977; Voyer et al. 1979). All of these effect levels are above those reported for the two mysid species that were used quantitatively for derivation of the chronic criterion.

Additional studies have reported the chronic sublethal effects of cadmium on estuarine/marine species (**Appendix I**). Delayed development and reduced food consumption were observed for rock crab larvae (*Cancer irroratus*) and white shrimp (*Litopenaeus vannamei*) exposed for 28 days to 50 and 200 µg/L cadmium, respectively (Johns and Miller 1982; Wu and Chen 2005a). Increased ATPase activity was exhibited by the American lobster (*Homarus americanus*) exposed to 6 µg/L cadmium for 30 days (Tucker 1979), and mud crab larvae (*Eurypanopeus depressus*) experienced a delay in metamorphosis when exposed to 10 µg/L cadmium for 44 days (Mirkes et al. 1978). When evaluating fish, significant reduction in gill tissue respiratory rate was reported for the cunner after a 30-day exposure to 50 µg/L (MacInnes et al. 1977). Dawson et al. (1977) also reported a significant decrease in gill-tissue respiration of striped bass at 5 µg/L after a 30-day exposure, as did Calabrese et al. (1975) after a 60-day exposure to 5 µg/L.

5.5.1 Final Acute-to-Chronic Ratio

The limited amount of acceptable estuarine/marine chronic toxicity data precluded the use of regression analysis to calculate the estuarine/marine CCC (as was done with the freshwater CCC). As stipulated in the 1985 Guidelines, the CCC was calculated as the FAV divided by the FACR. As previously mentioned, a minimum of three ACRs (a fish species and an invertebrate species, with one being acutely sensitive in saltwater) are typically used to estimate the FACR. This update has ACRs available for six freshwater invertebrates, eight freshwater fish and two saltwater invertebrate species representing a diverse number of families (**Table 16**). The 1985 Guidelines outline four primary ways to combine ACRs to calculate an appropriate FACR.

- If the species mean acute-chronic ratios seems to increase or decrease as the SMAV increases, the Final Acute-Chronic Ratio should be calculated as the geometric mean of the acute-chronic ratios for species whose SMAVs are close to the Final Acute Value.
- If no major trend is apparent and the acute-chronic ratios for a number of species are within a factor of ten, the Final Acute-Chronic Ratio should be calculated as the geometric mean of all the species mean acute-chronic ratios available for both freshwater and saltwater species.
- For acute tests conducted on metals and possibly other substances with embryos and larvae of barnacles, bivalve molluscs, sea urchins, lobsters, crabs, shrimp, and abalones, it is probably appropriate to assume that the acute-chronic ratio is 2. Thus, if the lowest available SMAVs were determined with embryos and larvae of such species, the Final Acute-Chronic Ratio should probably be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration.
- If the most appropriate species mean acute-chronic ratios are less than 2.0, and especially if they are less than 1.0, acclimation has probably occurred during the chronic test. Because continuous exposure and acclimation cannot be assured to provide adequate protection in field situations, the Final Acute-Chronic Ratio should be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration.

None of the four methods listed above could be used to calculate the FACR for cadmium. Therefore another approach was chosen to incorporate ACRs of sensitive species from both freshwater and estuarine/ marine environments to calculate an appropriate FACR. There were several possible methods to compile these values. One option would have been to use the ACRs available for the two *Americamysis* species (5.275 for *A. bahia* and 9.476 for *A. bigelowi*), the chinook salmon, *Oncorhynchus tshawytscha* (0.9626), and the fatmucket, *Lampsilis siliquoidea* (2.727). All are acutely sensitive, and the geometric mean of these four values yields an FACR of 3.385. If the freshwater fish is replaced by the rainbow trout, *Oncorhynchus mykiss* (ACR=1.527), the resulting FACR is 3.798. Alternatively, using the acutely sensitive mottled sculpin (*Cottus bairdii*) ACR of 11.22 instead of the ACR for the Chinook salmon results in an FACR of 6.254.

A final option would be to use ACRs from a diverse mix of freshwater and estuarine/marine species representing both invertebrates and fish, with the freshwater species having taxonomically-related marine species. Using this approach, seven genus-level ACRs were used to calculate the FACR for estuarine/marine water (representing five freshwater fish species, three freshwater invertebrate species, and the two acutely sensitive estuarine/marine mysids). An FACR of 8.291 was obtained from the geometric mean of seven genus-level ACRs: *Americamysis* (7.070), *Ceriodaphnia* (19.84), *Daphnia* (23.90), *Cottus* (11.22), *Oncorhynchus* (2.0), *Salmo* (2.0) and *Pimephales* (17.90). The fish *C. bairdii, S. trutta, Oncorhynchus and P. promelas* represent the second, fourth, fifth and forty-fourth most sensitive freshwater genera, respectively, and the cladocerans *Daphnia* and *C. dubia* are the eleventh and eighteenth most sensitive genera. This approach was chosen because EPA believes that use of combined ACRs for a variety of freshwater and estuarine/marine species is the most appropriate and representative method for deriving the FACR.

5.5.2 Uncertainty in the estuarine/marine FCV calculation

The primary source of uncertainty with the derivation of the estuarine/marine FCV is the lack of available data. There have been no new acceptable estuarine/marine chronic data generated since the 2001 AWQC was published. The only data available are for one genus of mysid, *Americamysis*, which is the fourth most sensitive acute genus. The chronic criterion is therefore based on the use of a FACR. The FACR assumes that the relationship between acute and chronic toxicity for each species is constant. Acceptable ACRs are averaged across taxa to calculate the final overall relationship between the acute and chronic toxicity values. Since freshwater ACRs are used to bolster the calculation of the FACR, due to only one estuarine/marine genus-level ACR being available, this creates an additional uncertainty in the estuarine/marine FCV.

The estuarine/marine FAV is also hampered by the lack of a statistically defensible salinity-toxicity relationship to normalize the acute data. Since the FAV is divided by the FACR to calculate the FCV, the FAV may not be representative of the true toxicity of cadmium across various salinity gradients (i.e., may be under protective in low salinity waters).

5.6 Bioaccumulation

Test level bioconcentration factors (BCFs) for cadmium in freshwater (**Appendix G**) range from 3 for brook trout muscle (Benoit et al. 1976) to 65,600 for the amphipod, *H. azteca* (Straus 2011). Fish typically accumulate only small amounts of cadmium in muscle as compared to most other tissues and organs (Benoit et al. 1976; Sangalang and Freeman 1979; Jarvinen and Ankley 1999). However, studies summarized by Jarvinen and Ankley (1999) showed that the skin, spleen, gill, fin, otolith and bone also have low bioconcentration factors. Sangalang and Freeman (1979) found that cadmium residues in fish reach steady-state only after exposure periods greatly exceed 28 days. *D. magna*, and presumably other invertebrates with about the same body size, were found to reach steady-state within a few days (Poldoski 1979).

Cadmium accumulated by fish from water is eliminated slowly (Benoit et al. 1976; Kumada et al. 1980), but Kumada et al. (1980) found that cadmium accumulated from food is eliminated much more rapidly. When all variables, except temperature, are kept the same, Tessier et al. (1994a) found that increased exposure temperature generally increased the rate of soft tissue bioconcentration for the snail, *Viviparus georgianus*, but not for the mussel, *Elliptio complanata*. Poldoski (1979) reported that humic acid decreased the uptake of cadmium by *D. magna*, but Winner (1984) did not find any effect. Ramamoorthy and Blumhagen (1984) reported that fulvic and humic acids increased the uptake of cadmium by rainbow trout.

The only BCF reported for an estuarine/marine fish is a value of 48 from a 21-day exposure of mummichog (Eisler et al. 1972) (**Appendix I**). However, among nine species of invertebrates for which values were available, the BCFs range from 22 to 3,160 for whole body and from 5 to 2,040 for muscle (**Appendix G**). The highest BCF (3,160) was reported for the polychaete, *Ophryotrocha diadema* (Klockner 1979). This BCF was reached after sixty-four days exposure using the renewal technique; however, tissue residues had not reached steady-state at the end of the exposure period.

BCFs for four species of estuarine/marine bivalve molluscs range widely, from 113 for the blue mussel (George and Coombs 1977) to 2,150 for the eastern oyster (Zaroogian and Cheer 1976). The range of reported BCFs is also large for some individual species. For example, two studies with the bay scallop resulted in BCFs of 168 (Eisler et al. 1972) and 2,040 (Pesch and Stewart 1980) and three studies with the blue mussel reported BCFs of 113, 306, and 710

(**Appendix G** and **Appendix I**). George and Coombs (1977) studied the importance of metal speciation on cadmium accumulation in the soft tissues of *Mytilus edulis*. Cadmium complexed as Cd-EDTA, Cd-alginate, Cd-humate, and Cd-pectate (**Appendix I**) was bioconcentrated (directly taken up from water) at twice the rate of inorganic cadmium (**Appendix G**). Because bivalve molluscs usually do not reach steady-state, comparisons between species may be difficult, and the length of exposure may be the major determinant of the BCF.

BCFs for five species of estuarine/marine crustaceans range from 22 to 307 for whole body and from 5 to 25 for muscle (**Appendix G** and **Appendix I**). Nimmo et al. (1977b) reported whole-body BCFs of 203 and 307 for two species of grass shrimp, *Palaemonetes pugio* and *P. vulgaris*. Vernberg et al. (1977) reported a BCF of 140 for *P. pugio* at 25°C (**Appendix I**), and Pesch and Stewart (1980) reported a BCF of 22 for the same species exposed at 10°C, indicating that temperature might be an important variable determining the rate of bioaccumulation. The commercially important crustaceans, the pink shrimp and lobster, were not effective bioaccumulators of cadmium with factors of 57 for whole body and 25 for muscle, respectively (**Appendix G** and **Appendix I**). It should be noted that the inverse relation relationship between BCF and exposure concentration explains much of the variation in the observed BCFs (McGeer et al. 2003; DeForest et al. 2007).

5.6.1 Uncertainty with cadmium exposure routes

As reported in the literature, aquatic organisms can accumulate cadmium from both aqueous and dietary exposure routes. The relative importance of each, however, is dependent upon the species. The filter feeding cladoceran *Ceriodaphnia dubia* was found to accumulate more cadmium from water than diet, and at a more rapid rate (Sofyan et al. 2007a). Barata et al. (2002d) observed during a 24-hour laboratory water exposure experiment that *Daphnia magna* juveniles accumulated approximately twice as much cadmium from laboratory water exposure than from an algal food diet. Water exposure accounted for over 50 percent of the cadmium body burden in the isopod *Asellus aquaticus* (van Hattum et al. 1998). Fisher et al. (2000) found that in *Acartia tonsa* approximately 60 percent of the cadmium was assimilated from water and 40 percent from food. The same trend of accumulating over 50 percent of cadmium from water was observed for the clam *Macoma balthica* (Harvey and Luoma 1985b) and the blue mussel *Mytilus edulis* (Borchardt 1983). In contrast, diet, rather than water, accounted for more than 50 percent of cadmium accumulated in the predatory insects *Chaoborus punctipennis* (Munger and Hare 1997), *Cryptochironomus sp*. and *Sialis velata* (Roy and Hare 1999), the water mite *Limnesia maculate*, the caddisfly *Mystacicks spp*. (Timmermans et al. 1992), and in five of the seven stonefly species evaluated by Martin et al. (2007). Diet also accounted for most (>95%) of the observed cadmium tissue burden of mayflies in the field (Cain et al. 2011). This field observation is consistent with the observations of Xie et al. (2010), who noted that periphyton is often a sink for cadmium in aquatic environments. In a natural lake experiment, Stephenson and Turner (1993) found that the grazing amphipod, *Hyalella azteca* derived more than half (58%) of accumulated cadmium from periphyton, when compared to the aqueous exposure route. In a different lake experiment, rainbow trout and lake whitefish (*Coregonus clupeaformis*) accumulated approximately five times as much cadmium from the food only exposure relative to the water only dose (Harrison and Klaverkamp 1989). Mebane (2006) summarized the contribution of aqueous versus dietary cadmium exposure to the bioaccumulation observed in various aquatic organisms and found the same species specific differences. In summary, the primary route of cadmium accumulation varies among species, with no discernable pattern.

The specific tissues/organs affected in an aquatic organism are also dependent on the exposure route. Wang and Fisher (1996) noted that bivalve molluscs primarily accumulate dissolved cadmium across the gills, and particulate forms via the gut, suggesting that cadmium speciation influences exposure route and the subsequent tissues and organs affected. In crustaceans, aqueous cadmium can be adsorbed to the body surface or taken up internally by ingestion, passive diffusion, or facilitated transport (Wang and Fisher 1998). For example, dissolved cadmium adsorbs onto the chitosan exoskeleton of pelagic and benthic crustaceans (Hook and Fisher 2001; Mohlenberg and Jensen 1980), or inert chitin surfaces of insects (Hare 1992), where it is rendered unavailable to interfere with internal metabolic processes. In contrast, ingested cadmium can accumulate into internal tissues potentially interfering with a variety of metabolic and reproductive processes, such as egg production in copepods (Hook and Fisher 2001). Cadmium assimilated from food is stored in the soft tissue of the oyster *Crassostrea gigas* (Nassiri et al. 1997). Norway lobsters (*Neohrops norvegica*) accumulated aqueous cadmium primarily in their gills and digestive gland, with most of the dietary cadmium deposited in the digestive gland (Canli and Furness 1995). The freshwater crayfish *Astacus leptodactylus* exposed to cadmium in water accumulated the greatest amount of cadmium in the hepatopancreas, with lesser amount in the gills, exoskeleton and abdominal muscles (Guner 2010).

In fish, uptake of dissolved cadmium is mainly across the gills, the primary site of toxic action, followed by transport to different organs (Wang and Fisher 1996; Wood et al. 2012). Accumulation of dissolved cadmium by the gills can be by either passive (diffusion) or active (pump) transport (Neff 2002). Fish exposed to cadmium in the presence of food initially absorb cadmium in the intestinal tract and to some degree the stomach, and subsequently transfer it to other tissues via the circulatory system (Wood et al. 2012). Water-borne cadmium primarily accumulated in the gills of rainbow trout and lake whitefish (Harrison and Klaverkamp 1989), the kidney of brook trout (Sangalang and Freeman 1979) and Nile tilapia *Oreochromis niloticus* (Cogun et al. 2003), and the liver of the perch *Perca fluviatilis* (Edgren and Notter 1980). In comparison, cadmium-spiked food accumulated mainly in muscle and the intestinal tract of rainbow trout (Kumada et al. 1980) and in the intestine, kidney and liver of the eel *Anguilla anguilla* (Haesloop and Schirmer 1985).

In an effort to determine the most toxic exposure route, a number of investigators have compared the adverse effects of cadmium to organisms exposed separately to both aqueous and dietary cadmium. Hook and Fisher (2001) reported that dietary exposure of marine copepods (*Acartia hudsonica and A. tonsa*) to cadmium was approximately 200 times more toxic than an aqueous exposure. Marine copepod reproduction significantly decreased at 0.5 µg/L dietary cadmium (algal food at 7.19 µg Cd/g dw), but it was not affected when the animals were exposed to dissolved cadmium at a similar concentration (reported aqueous LC_{50} of 112.4 µg/L). The hatching rate, ovarian development and egg protein content all decreased at the dietary effect level, suggesting that the process of yolk development (vitellogenesis) was affected. The more than two-fold difference (dietary LOEC of 0.5 µg/L vs. aqueous LOEC of >1.12 µg/L) in effect levels is likely due to the adsorption of aqueous cadmium to the exoskeleton where it is largely unavailable, whereas the food-borne cadmium accumulates in internal tissues and disrupts metabolic and reproductive processes.

Irving et al. (2003) exposed grazing mayfly nymphs (*Baetis tricaudatus*) to cadmium-contaminated diatom mats during a 13-day partial life-cycle experiment and observed significantly reduced grazing and growth at 10 µg/g cadmium (LOEC). The corresponding 96-hr LC_{50} determined for this was 1,611 µg/L. When evaluating the mayfly *Centroptilum triangulifer*, Xie and Buchwalter (2011) found that larvae exposed to dietary cadmium had significantly suppressed catalase and superoxide dismutase activities. Aqueous exposed larvae with similar cadmium tissue levels, however, had normal antioxidant enzyme activity. As shown by these studies, aqueous cadmium is adsorbed onto the chitin surface and potentially rendered unavailable to disrupt metabolic processes, whereas the food-borne cadmium accumulates in tissues and organs, and if not sequestered or detoxified, could interfere with a variety of metabolic and reproductive processes.

Female goldfish (*Carassius auratus*) were exposed to dietary cadmium for three years by Szczerbik et al. (2006) and the authors reported that the highest food dose of 10 mg/g (wet wt.) inhibited growth, disrupted behavior, prevented ovulation and decreased the gonado-somatic index. The lack of ovulation was due to disrupted oocyte development (most likely at the stages of vitellogenesis and oocyte maturation), thereby suggesting the site of toxic action. The only water exposure effects data available for this species were a 50-day reduced plasma sodium LOEC of 44.5 µg/L, a 7-day LC_{50} of 170 µg/L, and a SMAV (96-hr) of 1,656 µg/L.

Understanding the toxicological link between accumulated cadmium tissue levels and observation of adverse effects remains difficult to characterize, and therefore has received considerable interest in recent years (Adams et al. 2011; Mebane 2006; Wood et al 2012). The poorly understood link between cadmium tissue levels and corresponding adverse effects is in part due to the various mechanisms utilized by different species to detoxify and/or sequester cadmium, thereby rendering it biologically unavailable. A well-known and widespread cadmium detoxification mechanism is the production of metal binding proteins (e.g., metallothioneins) by a number of invertebrates and fish in response to a metal exposure. As pointed out by Mebane (2006), it is unclear if the cadmium accumulated in the kidneys of fish is bioavailable or sequestered. Therefore, the link between total cadmium tissue levels and adverse effects is difficult to quantify since the majority of accumulated cadmium may be in a detoxified form (Wood et al. 2012).

A summary of tissue residue levels for various aquatic organisms indicating the presence or absence of adverse cadmium effects is provided by Mebane (2006). He concluded that "the data reviewed on effects of cadmium tissue-residues in fish and invertebrates were insufficient to analyze quantitatively similarly to data on the effects of waterborne cadmium." For example, data compiled by Mebane (2006) for various studies indicate that different fish species can tolerate gill tissue residues ranging from 2 to 30 mg Cd/kg dw (Benoit et al 1976; Farag et al. 2003), whereas brook trout males died during spawning after exposure to 5.1 mg Cd/kg dw (Benoit et al. 1976). Likewise, kidney residue levels ranging from 10 to 94 mg Cd/kg dw produced no adverse effects, yet 50 mg Cd/kg dw also resulted in brook trout mortality during spawning (Benoit et al. 1976; McGeer et al. 2000). In addition, mayfly adverse effects were reported at whole body residues of 2 mg Cd/kg dw, while no effects were observed at 30 mg Cd/kg dw (Besser et al. 2001; Birge et al. 2000). Mebane (2006) also stated "the data reviewed on bioaccumulation and effects of dietary exposures to cadmium indicate that at chronic criterion concentrations, cadmium is unlikely to bioaccumulate to tissue residue levels expected to cause obvious adverse effects to aquatic invertebrates or fish." Adams et al. (2011) likewise noted that aquatic organisms contain a diverse array of homeostatic mechanisms that are both metal- and species-specific, and therefore the risk to the aquatic organism could not be determined by whole-body tissue residue levels for metals, further suggesting a tissue-based cadmium criteria may not accurately reflect ecotoxicological effects of cadmium under real-world exposure scenarios at the national-level.

5.7 Effects on Aquatic Plants

Ninety acceptable cadmium toxicity tests from 66 studies are available for a large number of freshwater algae and vascular plant species (**Appendix E**). These tests lasted anywhere from 4 to 32 days, and a reduction in growth was the most prominent toxic effect observed. Cadmium effect concentrations for most freshwater aquatic algae and plant species were well above 50 µg/L, and cadmium does not appear to be algicidal at a concentration less than 250,000 µg/L (**Appendix E**). However, several adverse effect concentrations are in the range known to cause chronic toxicity to aquatic life. For example, the growth rate of the diatom, *Asterionella formosa*, was reduced by an order of magnitude at 2 µg/L, while the growth EC_{50} for the green alga, *Chara vulgaris*, is 9.5 µg/L (**Appendix E**). Similarly, a significant reduction in the number of fronds of two aquatic vascular plant species, *Lemna valdiviana* and *Salvina natans*, occurred at 10 µg/L, and the MATC for growth of water lettuce, *Pistia stratiotes*, is 12.72 µg/L. A comparison of the freshwater plant and animal data presented in this document demonstrated that the lowest toxicity values for fish and aquatic invertebrate species are lower than the lowest toxicity values for plants. Thus, water quality criteria which protect freshwater animals should also protect freshwater plants and a final freshwater plant value was therefore not calculated.

Toxicity values are available for 10 species of estuarine/marine diatoms, five species of green microalgae, one dinoflagellate species, and eight species of macroalgae (**Appendix F**). Concentrations causing fifty percent reductions in the growth rates of diatoms range from 50 µg/L for *Chaetoceros calcitrans* and *Isochrysis galbana* to 7,560,000 µg/L for *Phaeodactylum tricornutum*. Green algae were the most sensitive species to cadmium, with reduced chlorophyll production observed for *Dunaliella viridis* and *Scenedesmus sp.* at 7.071 µg/L cadmium. The brown macroalga (kelp) exhibited mid-range sensitivity to cadmium, with an EC_{50}s that ranged from 355.5 to >1,124 µg/L. The most sensitive estuarine/marine macroalgae tested was the red alga, *Champia parvula*, with significant reductions in the growth of both the tetrasporophyte plant and female plant occurring at 22.8 µg/L. The estuarine/marine plant and animal data were also compared, and the most sensitive plant species (*C. parvula*) is more resistant than the most sensitive animal species in chronic tests. Therefore, water quality criteria for cadmium that protect estuarine/marine animals should also protect estuarine/marine plants and a final estuarine/marine plant value was therefore not calculated.

5.8 Protection of Listed Species

The dataset for cadmium is particularly extensive and includes data representing species that are Federally-listed as threatened or endangered by the U.S. Fish and Wildlife Service and/or NOAA National Marine Fisheries Service. Summaries provided here describing the best available data for the Federally-listed species that have been tested for sensitivity to cadmium demonstrate that the 2016 cadmium criteria update is protective of these tested species.

5.8.1 Acute toxicity data for listed species

There are nine Federally-listed freshwater species and one estuarine/marine species that have acceptable acute toxicity data. Eight of these species are fish and one is a freshwater mussel (**Table 20**). All of the freshwater data has been normalized to a hardness of 100 mg/L to facilitate comparison to the acute criteria value expressed at that hardness.

The least sensitive of the Listed freshwater species are bonytail chub, *Gila elegans,* and razorback sucker, *Xyrauchen texanus,* with normalized SMAVs of 80.38 and 76.02 µg/L total cadmium, respectively (**Appendix A**). Another Listed fish from the family Cyprinidae, Colorado pikeminnow (*Ptychocheilus lucius*), had a similar level of sensitivity with a normalized SMAV of 46.79 µg/L total cadmium. This species was much more sensitive to cadmium than the non-Listed northern pikeminnow, *Ptychocheilus oregonensis*, which is in the same genus and has a normalized SMAV of 4,265 µg/L total cadmium. All three endangered species were tested in the laboratory at the U.S. Geological Survey in Yankton, South Dakota, with laboratory test conditions designed to replicate conditions present in the Green River, Utah (Buhl 1997). One endangered freshwater mussel, Neosho mucket (*Lampsilis rafinesqueana*), has a normalized SMAV of 44.67 µg/L total cadmium, indicating a sensitivity that falls within the range of three other freshwater mussel species within the genus, with normalized SMAVs ranging from 93.17 (*Lampsilis straminea claibornensis*) to 35.73 (*Lampsilis siliquoidea*) µg/L total cadmium (**Appendix A**). All of these SMAVs are an order of magnitude higher than the freshwater acute cadmium criteria value.

The most sensitive Listed freshwater species with acceptable acute toxicity data are all from the family Salmonidae. Three species from the genus *Oncorhynchus* had normalized SMAVs that ranged from 3.727 to 11.88 µg/L total cadmium. The bull trout, *Salvelinus confluentus*, was almost as sensitive as the rainbow trout, *Oncorhynchus mykiss*, with a normalized SMAV of 4.190 µg/L total cadmium (*O. mykiss* SMAV of 3.727 µg/L total cadmium). As recommended by the 1985 Guidelines, the freshwater FAV for total cadmium at a hardness of 100 mg/L was lowered to 3.727 µg/L (3.518 µg/L dissolved cadmium) to protect the commercially and recreationally important rainbow trout, which also addresses the Listed steelhead trout. This lowered FAV, and resultant CMC of 1.8 µg/L dissolved cadmium yielded by the 1985 Guidelines procedure of dividing the LC_{50}-based FAV by a factor of 2, is also protective of the bonytail chub, razorback sucker, Colorado pikeminnow, and the freshwater mussel, Neosho mucket, which are less sensitive than all tested species with acceptable acute toxicity data from the family Salmonidae. The FAV/2 approach was developed to estimate minimal effect levels, with approximately equal control mortality limits, based on analysis of 219 acute toxicity tests on a range of chemicals, as described in the *Federal Register* on May 18, 1978 (43 FR 21506-18).

Several life stages of the white sturgeon, *Acipenser transmontanus*, were exposed in flow-through measured exposures by Calfee et al. (2014) and Wang et al. (2014a). The most sensitive life stage were the 61 day post hatch fish with a non-definitive normalized acute value of <33.78 µg/L total cadmium. However, all other test life stages were much less sensitive with normalized effect concentrations that ranged from >11.65 to >355.0 µg/L total cadmium (**Appendix A**).

While the 96-hr acute and 7-d chronic toxicity tests for the fountain darter, *Etheostoma fonticola*, conducted by Southwest Texas State University (2000) indicated this species was very sensitive, the study was determined to be unacceptable for inclusion in the core dataset because the test species was fed in the acute test and the duration was too short for the chronic test to be included (**Appendix H**). While this species is endemic to Texas and has a very limited distribution, the genus *Etheostoma* has several Listed species and widespread distribution across the United States. Despite these data being unacceptable for inclusion in the core criteria dataset, it is noteworthy that the 1.8 µg/L acute and 0.72 µg/L chronic dissolved cadmium criteria are protective of this species. (The reported LC_{50} was 9.62 µg/L dissolved cadmium for this test and found to be unacceptable for use in criteria derivation; the chronic values were in the 1.4 to 11.5 µg/L range).

The mottled sculpin (*Cottus bairdii*) represents the most sensitive of the acutely tested freshwater species with acceptable toxicity data. Similarly, shorthead sculpin (*C. confusus*) is also very sensitive. Although *C. bairdii* and *C. confusus* are not Listed freshwater species, the grotto sculpin (*Cottus specus*) is Listed as endangered and the pygmy sculpin (*Cottus paulus*) is Listed as threatened. Grotto sculpin are found in five cave systems and two surface streams in Perry County, Missouri, while pygmy sculpin is endemic to Alabama. Although no direct toxicity data are available for either of these sculpin species, *C. bairdii* and *C. confusus* had normalized SMAVs of 4.418 and 4.404 µg/L total cadmium, respectively. Dividing the GMAV for *Cottus* by two, which is consistent with the procedure used to derive the CMC from the FAV as indicated above, results in a concentration of 2.205 µg/L total cadmium (or 2.082 µg/L dissolved cadmium), which is a concentration that is expected to result in survival that is no different from the test controls. This normalized concentration is slightly higher than the 2016 freshwater CMC of 1.8 µg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_3$. The available data suggest the 2016 freshwater CMC would be protective of these Listed species.

Coho salmon (*Oncorhynchus kisutch*) smolts tested in natural filtered seawater with 28.83 g/kg salinity were relatively insensitive to cadmium, with an LC_{50} of 1,500 µg/L total cadmium (Dinnel et al. 1989). The estuarine/marine CMC of 33 µg/L total cadmium would be protective of this species.

Table 20. Acute Summary of Listed Species Tests.

Species	Number of normalized acute values	Range of normalized acute values (Hardness=100 mg/L)	SMAV (µg/L) (total cadmium)
Freshwater - Acute			
Neosho mucket, *Lampsilis rafinesqueana*	1*	44.67	44.67
Bonytail, *Gila elegans*	2	75.45 - 85.64	80.38
Razorback sucker, *Xyrauchen texanus*	2	70.86 - 81.56	76.02
Colorado pikeminnow, *Ptychocheilus lucius*	2	39.76 - 55.06	46.79
Coho salmon, *Oncorhynchus kisutch*	4	8.137 - 77.03	11.88
Rainbow trout, *Oncorhynchus mykiss*	56	1.227 - >113.8	3.727
Chinook salmon, *Oncorhynchus tshawytscha*	8	5.068 - >109.6	5.949
Bull trout, *Salvelinus confluentus*	6	2.891 - 9.390	4.190
White sturgeon, *Acipenser transmontanus*	7*	>11.65 - >355.0	<33.78
Estuarine/Marine – Acute			
Coho salmon, *Oncorhynchus kisutch*	1	1,500	1,500

* Indicates new species included since the 2001 cadmium document.

5.8.2 Chronic toxicity data for listed species

Four Listed freshwater fish in the family Salmonidae representing two genera (*Oncorhynchus* and *Salmo*) have acceptable chronic toxicity data for cadmium (**Table 21**). Of the 20 genera in the Ranked SMCV Table, these two genera are ranked seventh and eighth, respectively (**Table 9**). The Chinook salmon (*O. tshawytscha*) and rainbow trout (*O. mykiss*) have similar normalized SMCVs of 4.426 and 2.192 µg/L total cadmium, based on early life stage growth and survival, respectively. Insufficient detail was reported for Coho salmon (*O. kisutch*), the third Listed species in this genus, thus a normalized EC_{20} could not be calculated. A normalized SMCV based on the two MATCs reported for Coho salmon would be 7.467 µg/L total cadmium (**Appendix C**). The most sensitive endangered freshwater species, Atlantic salmon (*Salmo salar*), had a normalized SMCV of 2.389 µg/L total cadmium, which is somewhat more sensitive than brown trout (*Salmo trutta*), the other species in the genus. All of these freshwater fish species are expected to be adequately protected at the freshwater CCC of 0.80 µg/L total cadmium.

Mottled sculpin (*Cottus bairdii*) represent the third most sensitive of the chronically tested freshwater species with acceptable toxicity data. As discussed in the preceding section (**Section 5.8.1**), although *C. bairdii* is not a Listed species, grotto sculpin (*Cottus specus*) is Listed as endangered and pygmy sculpin (*Cottus paulus*) is Listed as threatened. *C. bairdii* had a normalized SMCV of 1.470 µg/L total cadmium. This normalized concentration is above the 2016 freshwater CCC of 0.72 µg/L dissolved cadmium based on a hardness of 100 mg/L as $CaCO_3$. The 2016 freshwater CCC is expected to be protective of these species. There are no acceptable chronic toxicity data for estuarine/marine Listed species.

Table 21. Chronic Summary of Listed Species Tests.

Species	Number of chronic values	Range of normalized chronic values
Freshwater - Chronic		
Coho salmon, *Oncorhynchus kisutch*	2	4.046 – 13.78 (MATCs)
Rainbow trout, *Oncorhynchus mykiss*	12	0.7962 – 6.989 (EC_{20}s and MATCs)
Chinook salmon, *Oncorhynchus tshawytscha*	1	4.426 (EC_{20})
Atlantic salmon, *Salmo salar*	3	2.389 – 392.5 (EC_{20}s)

5.9 Comparison of 2001 and 2016 Criteria Values

5.9.1 Comparison of acute freshwater criterion to 2001 document

The 2001 cadmium freshwater acute criterion was based on data from 39 species of invertebrates, 24 species of fish and 1 species each of salamander and frog for a total of 65 species grouped into 55 genera (**Table 22**). This 2016 update now includes 66 species of invertebrates, 33 species of fish, one salamander species, and one frog species for a total of 101 species grouped into 75 genera.

Of the 75 Genus Mean Acute Values (GMAV) in the updated dataset, 38 genera have new data for either species represented in the 2001 database or new species added to the GMAV calculation in this update (**Table 7**). A new genus in the updated dataset, sculpin (*Cottus*), also represents the second most sensitive genera in the distribution with a GMAV of 4.411 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate genus is represented by the amphipod *Hyalella azteca* with a normalized GMAV of 23.00 µg/L.

Table 22. Freshwater GMAVs Comparing Species Listed in the 2001 and 2016 Documents.
(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$).
(Values in bold new/revised data since the 2001 AWQC).

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
49,052	195,967	Midge, *Chironomus plumosus*	-	**15,798**	New species added to GMAV calculation
-	-	Midge, *Chironomus riparius*	195,967	**>152,301**	Revised the effect concentration from Williams et al. 1985
30,781	8,573	Common carp, *Cyprinus carpio*	8,573	**30,781**	New data for existing species
26,837	21,569	Nile tilapia, *Oreochromis niloticus*	-	**66,720**	New species added to GMAV calculation
-	-	Mozambique tilapia, *Oreochromis mossambica*	21,569	**10,795**	New data for existing species
26,607	28,454	Planarian, *Dendrocoelum lacteum*	28,454	**26,607**	Acute value edited from re-review of Ham et al. 1995
22,138	-	Mayfly, *Rhithrogena hageni*	-	**22,138**	New genus
>20,132	-	Little green stonefly, *Sweltsa sp.*	-	**>20,132**	New genus
12,100	13,146	Mosquitofish, *Gambusia affinis*	13,146	12,100	-
11,627	4,754	Oligochaete, *Branchiura sowerbyi*	4,754	**11,627**	New data for existing species
11,171	12,479	Oligochaete, *Rhyacodrilus montana*	12,479	11,171	-
11,045	11,002	Threespine stickleback, *Gasterosteus aculeatus*	11,002	11,045	-
9,917	10,225	Channel catfish, *Ictalurus punctatus*	10,225	9,917	-
9,752	10,894	Oligochaete, *Stylodrilus heringianus*	10,894	9,752	-
7,798	-	Mayfly, *Hexagenia rigida*	-	**7,798**	New genus
7,752	8,551	Green sunfish, *Lepomis cyanellus*	5,997	6,276	-
-	-	Bluegill, *Lepomis macrochirus*	12,194	9,574	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
7,716	7,762	Red shiner, *Cyprinella lutrensis*	7,762	7,716	-
7,037	7,861	Oligochaete, *Spirosperma ferox*	6,933	6,206	-
-	-	Oligochaete, *Spirosperma nikolskyi*	8,913	7,979	-
6,808	-	Yellow perch, *Perca flavescens*	-	**6,808**	New genus
6,738	7,527	Earthworm, *Varichaetadrilus pacificus*	7,527	6,738	(formerly, *Varichaeta pacifica*)
5,947	6,344	White sucker, *Catostomus commersonii*	6,344	5,947	-
5,674	6,338	Oligochaete, *Quistadrilus multisetosus*	6,338	5,674	-
5,583	5,759	Flagfish, *Jordanella floridae*	5,759	5,583	-
4,929	4,981	Guppy, *Poecilia reticulata*	4,981	4,929	-
4,467	4,607	Mayfly, *Empherella subvaria*	4,607	4,467	-
4,193	2,753	Tubificid worm, *Tubifex tubifex*	2,753	**4,193**	New data for existing species
3,350	3,439	Amphipod, *Crangonyx pseudogracilis*	3,439	3,350	-
3,121	-	Copepod, *Diaptomus forbesi*	-	**3,121**	New genus
2,967	-	Zebrafish, *Danio rerio*	-	**2,967**	New genus
2,231	3,093	African clawed frog, *Xenopus laevis*	3,093	**2,231**	New data for existing species
1,983	3,536	Crayfish, *Procambarus acutus*	-	**812.8**	New species added to GMAV calculation
-	-	Crayfish, *Procambarus alleni*	-	**6,592**	New species added to GMAV calculation
-	-	Red swamp crayfish, *Procambarus clarkii*	3,536	**1,455**	New data for existing species
1,656	1,707	Goldfish, *Carassius auratus*	1,707	1,656	-
>1,637	-	Caddisfly, *Arctopsyche sp.*	-	**>1,637**	New genus

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
1,593	1,568	Oligochaete, *Limnodrilus hoffmeisteri*	1,568	1,593	-
1,582	59.08	Fathead minnow, *Pimephales promelas*	59.08	**1,582**	Same studies but only used F,M tests to calculate GMAV
1,023	1,055	Northwestern salamander, *Ambystoma gracile*	1,055	1,023	-
983.8	955.0	Isopod, *Caecidotea bicrenata*	955.0	983.8	(formerly, *Asellus bicrenata*)
>808.4	-	Snail, *Gyraulus sp.*	-	**>808.4**	New genus
651.3	-	Lake whitefish, *Coregonus clupeaformis*	-	**651.3**	New genus
539.7	525.3	Bryozoa, *Plumatella emarginata*	525.3	539.7	-
501.7	500.1	Cladoceran, *Alona affinis*	500.1	501.7	-
453.0	451.6	Cyclopoid copepod, *Cyclops varicans*	451.6	453.0	-
427.9	-	Pond snail, *Lymnaea stagnalis*	-	**427.9**	New genus
410.4	-	Planarian, *Dugesia dorotocephala*	-	**410.4**	New genus
392.5	389.5	Leech, *Glossiphonia complanata*	389.5	392.5	-
350.4	-	Mayfly, *Baetis tricaudatus*	-	**350.4**	New genus
346.6	337.4	Bryozoa, *Pectinatella magnifica*	337.4	346.6	-
275.0	264.2	Worm, *Lumbriculus variegatus*	264.2	275.0	-
208.0	202.6	Snail, *Physa acuta*	-	**2,152[b]**	New species for existing genus, but ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-	-	Pouch snail, *Physa gyrina*	202.6	208.0	-
204.1	210.3	Snail, *Aplexa hypnorum*	210.3	204.1	-
154.3	159.2	Amphipod, *Gammarus pseudolimnaeus*	159.2	154.3	-
145.5	-	Worm, *Nais elinguis*	-	**145.5**	New genus

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
120.1	-	Hydra, *Hydra circumcincta*	-	**184.8**	New genus (formerly, *Hydra attenuata*)
-	-	Hydra *Hydra oligactis*	-	**154.8**	New genus
-	-	Green hydra, *Hydra viridissima*	-	**38.85**	New genus
-	-	Hydra, *Hydra vulgaris*	-	**187.1**	New genus
103.1	-	Cladoceran, *Diaphanosoma brachyurum*	-	**103.1**	New genus
99.54	97.98	Isopod, *Lirceus alabamae*	97.98	99.54	-
94.67	>23,632	Crayfish, *Orconectes immunis*	>23,281	>22,579[b]	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-	-	Crayfish, *Orconectes juvenilis*	-	**134.0**	New species added to GMAV calculation
-	-	Crayfish, *Orconectes placidus*	-	**66.89**	New species added to GMAV calculation
-	-	Crayfish, *Orconectes virilis*	23,988	22,800[b]	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
86.51	87.16	Cladoceran, *Moina macrocopa*	87.16	86.51	-
80.38	78.32	Bonytail, *Gila elegans*	78.32	80.38	-
76.02	74.08	Razorback sucker, *Xyrauchen texanus*	74.08	76.02	-
74.28	72.29	Bryozoa, *Lophopodella carteri*	72.29	74.28	-
73.67	72.61	Cladoceran, *Ceriodaphnia dubia*	63.46	**64.03**	New data for existing species
-	-	Cladoceran, *Ceriodaphnia reticulata*	83.08	84.76	-
71.76	86.82	Mussel, *Utterbackia imbecillis*	86.82	**71.76**	New data for existing species
70.76	71.16	Southern rainbow mussel, *Villosa vibex*	71.16	70.76	-
68.51	-	Mussel, *Lasmigona subviridis*	-	**68.51**	New genus
67.90	68.38	Mussel, *Actinonaias pectorosa*	68.38	67.90	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
61.42	50.44	Cladoceran, *Daphnia ambigua*	-	**24.81**	New species added to GMAV calculation
-	-	Cladoceran, *Daphnia magna*	27.14	**40.62**	New data for existing species and Attar and Maly (1982) was not used to calculate SMAV, see Unused data (Appendix J)
-	-	Cladoceran, *Daphnia pulex*	93.77	**109.2**	New data for existing species
-	-	Cladoceran, *Daphnia similis*	-	**129.3**	New species added to GMAV calculation
57.71	61.10	Cladoceran, *Simocephalus serrulatus*	61.10	57.71	-
51.34	68.29	Neosho mucket, *Lampsilis rafinesqueana*	-	**44.67**	New species added to GMAV calculation
-	-	Fatmucket, *Lampsilis siliquoidea*	-	**35.73**	New species added to GMAV calculation
-	-	Southern fatmucket, *Lampsilis straminea claibornensis*	96.44	93.17	-
-	-	Yellow sandshell, *Lampsilis teres*	48.35	46.71	-
46.79	452.6	Colorado pikeminnow, *Ptychocheilus lucius*	45.59	46.79	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-		Northern pike minnow, *Ptychocheilus oregonensis*	4,493	4,265[b]	-
<33.78	*Acipenser*	White sturgeon, *Acipenser transmontanus*	-	**<33.78**	New genus
23.00	-	Amphipod, *Hyalella azteca*	-	**23.00**	New genus
>15.72	-	Mountain whitefish, *Prosopium williamsoni*	-	**>15.72**	New genus
6.141	7.760	Cutthroat trout, *Oncorhynchus clarkii*	-	**5.401**	New species added to GMAV calculation
-	-	Coho salmon, *Oncorhynchus kisutch*	12.58	11.88	-
-	-	Rainbow trout, *Oncorhynchus mykiss*	4.265	**3.727**	New data for existing species
-	-	Chinook salmon, *Oncorhynchus tshawytscha*	8.708	**5.949**	No new data, but only the most sensitive life stage used for SMAV calculation
5.931	5.916	Striped bass, *Morone saxatilis*	5.916	5.931	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
5.642	3.263	Brown trout, *Salmo trutta*	3.263	**5.642**	New data for existing species
4.411	-	Mottled sculpin, *Cottus bairdii*	-	**4.418**	New genus
-	-	Shorthead sculpin, *Cottus confusus*	-	**4.404**	New genus
4.190	<3.971	Bull trout, *Salvelinus confluentus*	4.353	4.190	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-	-	Brook trout, *Salvelinus fontinalis*	<3.623	**3,055[b]**	Carroll et al. 1979 was not used to calculate SMAV, see Unused data (Appendix J)

[a] Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

[b] There is a 10x difference in SMAVs for the genus, only most sensitive SMAV is used in the GMAV calculation.

[The following species were not included in the Ranked GMAV Table because hardness test conditions were not reported and therefore toxicity values could not be normalized: Leech, *Nephelopsis obscura*; Crayfish, *Orconectes limosus*; Prawn, *Macrobrachium rosenbergii*; Mayfly, *Drunella grandis grandis*; Stonefly, *Pteronarcella badia*; Midge, *Culicoides furens*; Grass carp, *Ctenopharyngodon idellus*.]

Table 23 provides a comparison of the second to fifth most sensitive taxa (≥59 genera) used to calculate the freshwater CMC in this 2016 AWQC update document compared to the four most sensitive taxa used to calculate the CMC in the 2001 AWQC document. The 2016 CMC of 1.9 µg/L total cadmium is slightly lower than the 2.1 µg/L total cadmium CMC given in the 2001 document, both of which are normalized to a total hardness of 100 mg/L as $CaCO_3$ and lowered to protect a commercially and recreationally important salmonid species. Several genera (*Morone*, *Salmo*, *Salvelinus* and *Oncorhynchus*) are the most sensitive in both the 2001 and 2016 document, but the new genus, *Cottus*, is now one of the most sensitive in the current update.

One additional difference is that *Salvelinus*, previously the second most sensitive genus in the 2001 document, is now the most sensitive genus in the 2016 document. This is due to the reassessment and reclassification of the brook trout test by Carroll et al. (1979) as an unacceptable study because the measured concentration of cadmium in control water was greater than the LC_{50} value of 1.5 µg/L and the control had 100% survival. Elimination of this LC_{50} yields the normalized SMAV of 3,055 µg/L based on the studies by Drummond and Benoit (1976) and Holcombe et al. (1983). However, since there is greater than a 10-fold difference in the SMAVs for the genus only the SMAV for the more sensitive species, *S. confluentus*, was used in the GMAV calculation.

In addition, the number of GMAVs used to calculate the CMC increased from 55 in the 2001 criteria document to 75 in the current update based on the addition of the GMAVs for *Hydra*, worm *Nais*, planarian *Dugesia*, mussel *Lasmigona*, snails *Lymnaea* and *Gyraulus*, copepod *Diaptomus*, amphipod *Hyalella*, cladoceran *Diaphanosoma*, mayflies *Baetis*, *Hexagenia* and *Rhithrogena*, stonefly *Sweltsa*, caddisfly *Arctopsyche*, and fish *Acipenser*, *Coregonus*, *Cottus*, *Danio*, *Perca* and *Prosopium*.

Table 23. Comparison of the Four Taxa Used to Calculate the Freshwater FAV and CMC in the 2001 Cadmium Document and 2016 Update.

2001 Cadmium Freshwater FAV and CMC				**2016 Cadmium Update Freshwater FAV and CMC**		
Species	**SMAV[a] (µg/L)**	**SMAV[b] (µg/L)**	**GMAV[b] [Rank] (µg/L)**	**Species**	**SMAV[c] (µg/L)**	**GMAV[c] [Rank] (µg/L)**
				Cutthroat trout, *Oncorhynchus clarkii*	5.401	6.141 [5]
				Coho salmon, *Oncorhynchus kisutch*	11.88	
				Rainbow trout, *Oncorhynchus mykiss*	3.727	
Coho salmon, *Oncorhynchus kisutch*	6.221	12.58	7.760 [4]	Chinook salmon, *Oncorhynchus tshawytscha*	5.949	
Chinook salmon, *Oncorhynchus tshawytscha*	4.305	8.708		Striped bass, *Morone saxatilis*	5.931	5.931 [4]
Rainbow trout, *Oncorhynchus mykiss*	2.108	4.265		Brown trout, *Salmo trutta*	5.642	5.642 [3]
Striped bass, *Morone saxatilis*	2.925	5.916	5.916 [3]	Mottled sculpin, *Cottus bairdii*	4.418	4.411 [2]
Brook trout, *Salvelinus fontinalis*	<1.791	<3.623	<3.971 [2]	Shorthead sculpin, *Cottus confusus*	4.404	
Bull trout, *Salvelinus confluentus*	2.152	4.353		Bull trout, *Salvelinus confluentus*	4.190	4.190[e] [1]
Brown trout, *Salmo trutta*	1.613	3.263	3.263 [1]	Brook trout, *Salvelinus fontinalis*	3,055[d]	
Number of GMAVs	55			Number of GMAVs	75	
FAV (calculated)	2.764[a]	5.590[b]		FAV (calculated)	5.733[c]	
FAV (lowered to protect *O. mykiss*)	2.108[a]	4.265[b]		FAV (lowered to protect *O. mykiss*)	3.727	
CMC	1.054[a]	2.132[b]		CMC	1.9[c]	

[a] Normalized to total hardness of 50 mg/L as $CaCO_3$ (using pooled slope of 1.0166).

[b] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 1.0166).

[c] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 0.9789).

[d] There is a 10x difference in SMAVs for the genus, only most sensitive SMAV is used in the GMAV calculation.

[e] Not used in FAV calculation due to the number of genera (N≥59) (see text).

5.9.2 Comparison of chronic freshwater criterion to 2001 document

Of the 20 Genus Mean Chronic Values (GMCV) in the updated dataset, nine genera have new data for either species represented in the 2001 database or new species added to the GMCV calculation in this update (**Table 24**). A new species in the updated dataset, mottled sculpin (*C. bairdii*) represents the most sensitive fish species and the third most sensitive genus in the distribution with a GMCV of 1.470 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate is the amphipod, *Hyalella azteca,* with a normalized GMCV of 0.7453 µg/L. There are sufficient data to fulfill the requirements to calculate chronic criteria using species sensitivity distribution (SD) method.

Acceptable data on the chronic effects of cadmium on freshwater animals include 11 species of invertebrates and 16 species of fish grouped into 20 genera (**Table 9**). The previous updated criteria (2001) contained data from 7 species of invertebrates and 14 species of fish grouped into 16 genera. The update includes data for six new species added to the dataset, consisting of the oligochaete, *Lumbriculus variegatus*, fatmucket, *Lampsilis siliquoidea*, snail, *Lymnaea stagnalis*, Rio Grande cutthroat trout *Oncorhynchus clarkii virginalis*, mottled sculpin, *C. bairdii*, and cladoceran, *Ceriodaphnia reticulata*.

One additional difference between the 2001 document and this 2016 update is the estimation of EC_{20} values as the chronic endpoint for each acceptable toxicity test. EC_{20} values were used to estimate a low level of effect observed in chronic datasets that are available for cadmium (see **Section 2.6**, **Chronic measures of effect**).

Table 24. Freshwater GMCVs Comparing Species Listed in the 2001 and 2016 Documents.
(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$).
(Values in bold new/revised data since the 2001 AWQC).

2016 GMCV[a] (µg/L)	2001 GMCV (µg/L)	Species	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Comment
>38.66	>39.48	Blue tilapia, *Oreochromis aureus*	>39.48	>38.66[c]	(formerly, *Oreochromis aurea*)
36.70	34.66	Oligochaete, *Aeolosoma headleyi*	34.66	**36.70**	Different values used from Niederlehner et al. 1984 that was a more appropriate duration
16.43	29.05	Bluegill, Lepomis *macrochirus*	29.05	16.43	-
15.16	-	Oligochaete, *Lumbriculus variegatus*	-	**15.16**	New genus

2016 GMCV[a] (µg/L)	**2001 GMCV (µg/L)**	**Species**	**2001 SMCV (µg/L)**	**2016 SMCV (µg/L)**	**Comment**
14.22	13.58	Smallmouth bass, *Micropterus dolomieu*	13.58	14.22[c]	-
14.17	13.52	Northern pike, *Esox lucius*	13.52	14.17[c]	-
14.16	27.37	Fathead minnow, *Pimephales promelas*	27.37	14.16	-
13.66	13.04	White sucker, *Catostomus commersonii*	13.04	13.66[c]	-
11.29	-	Fatmucket, *Lampsilis siliquoidea*	-	**11.29**	New genus
9.887	-	Pond snail, *Lymnaea stagnalis*	-	**9.887**	New genus
8.723	8.886	Flagfish, *Jordanella floridae*	8.886	8.723	-
3.516	8.055	Snail, *Aplexa hypnorum*	8.055	3.516	-
3.360	10.52	Atlantic salmon, *Salmo salar*	13.24	2.389	-
-	-	Brown trout, *Salmo trutta*	8.360	**4.725**	New data for existing species, and more sensitive exposure scenario used
3.251	4.082	Rio Grande cutthroat trout, *Oncorhynchus clarkii virginalis*	-	**3.543**	New species added to GMCV calculation
-	-	Coho salmon, *Oncorhynchus kisutch*	7.127	**NA[b]**	See footnote
-	-	Rainbow trout, *Oncorhynchus mykiss*	2.186	**2.192**	New data for existing species
-	-	Chinook salmon, *Oncorhynchus tshawytscha*	4.366	4.426	-
2.356	7.726	Brook trout, *Salvelinus fontinalis*	4.416	2.356	-
-	-	Lake trout, *Salvelinus namaycush*	13.51	**NA[b]**	See footnote
2.024	<0.6340	Cladoceran, *Daphnia magna*	<0.6340	**0.9150**	New data for existing species
-	-	Cladoceran, *Daphnia pulex*	10.30[b]	**4.478**	New data for existing species
2.000	4.686	Midge, *Chironomus dilutus*	4.686	2.000	(formerly, *Chironomus tentans*)
1.470	-	Mottled sculpin, *Cottus bairdii*	-	**1.470**	New genus

2016 GMCV[a] (µg/L)	2001 GMCV (µg/L)	Species	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Comment
1.293	45.40	Cladoceran, *Ceriodaphnia dubia*	45.40	**1.293**	New data for existing species
-	-	Cladoceran, *Ceriodaphnia reticulata*	-	**NA[b]**	See footnote
0.7453	0.4590	Amphipod, *Hyalella azteca*	0.4590	0.7453	-

[a] Ranked from most resistant to most sensitive based on Genus Mean Chronic Value.
[b] Not included in the GMCV calculation because normalized EC_{20} data are available for the genus.
[c] Calculated from the MATC and not EC_{20} but retained to avoid losing a GMCV.
[d] Not used in GMCV calculation because species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.
[The following species were not included in the Ranked GMCV Table because hardness test conditions were not reported and therefore toxicity values could not be normalized: Mudsnail, *Potamopyrgus antipodarum*.]

Four new genera were added to the 2016 chronic freshwater database. The amphipod *Hyalella* is the most sensitive in both documents, but the cladoceran *Ceriodaphnia*, the mottled sculpin *Cottus* and the midge *Chironomus* are now the second, third and fourth most sensitive genera in the 2016 update (**Table 9**). The change in the four most sensitive genera presented in the 2016 update is partly due to the inclusion of the new sensitive genus *Cottus*, but also to the estimation of the chronic value by EC_{20} analysis and not the MATC (geometric mean of the NOEC and LOEC) as was done in the 2001 document.

As indicated in **Table 25**, the 2016 freshwater CCC is about 3 times the magnitude of the 2001 CCC (0.79 vs. 0.27 µg/L total cadmium) due to differences in the data used for the CCC derivations. As a result, the four lowest GMCVs in the 2016 CCC have a smaller range of variation in values (0.7453 to 2.000) when compared to the four lowest GMCVs in the 2001 CCC, which decreases the uncertainty of the 5th percentile GMCV estimation. In the 2001 CCC, there were also only 16 GMCVs in the dataset used to derive the CCC. In the 2016 CCC, there are 20 GMCVs used to derive the CCC, based on the addition of the GMCVs for the oligochaete, *Lumbriculus*, snail, *Lymnaea*, fatmucket, *Lampsilis* and the mottled sculpin, *Cottus*. The new GMCVs affect the chronic species sensitivity distribution. The cumulative probability (P) decreases as a function of the increased number of GMCVs and results in an increase in the FCV.

Table 25. Comparison of the Four Taxa Used to Calculate the Freshwater FCV and CCC in the 2001 Cadmium Document and 2016 Update.

2001 Cadmium Freshwater FCV and CCC				2016 Cadmium Update Freshwater FCV and CCC		
Species	**SMCV[a] (µg/L)**	**SMCV[b] (µg/L)**	**GMCV[b] [Rank] (µg/L)**	**Species**	**SMCV[c] (µg/L)**	**GMCV[c] [Rank] (µg/L)**
Midge, *Chironomus tentans*	2.804	4.686	4.686 [4]			
Coho salmon, *Oncorhynchus kisutch*	4.265	7.127	4.082 [3]			
Chinook salmon, *Oncorhynchus tshawytscha*	2.612	4.366		Midge, *Chironomus dilutus*	2.000	2.000 [4]
Rainbow trout, *Oncorhynchus mykiss*	1.308	2.186		Mottled sculpin, *Cottus bairdii*	**1.470**	1.470 [3]
Cladoceran, *Daphnia magna*	<0.3794	<0.6340	<0.6340 [2]	Cladoceran, *Ceriodaphnia dubia*	**1.293**	1.293 [2]
Cladoceran, *Daphnia pulex*	6.167	10.30[d]		Cladoceran, *Ceriodaphnia reticulata*	**NA[e]**	
Amphipod, *Hyalella azteca*	0.2747	0.4590	0.4590 [1]	Amphipod, *Hyalella azteca*	**0.7453**	0.7453 [1]
Number of GMCVs	16			Number of GMCVs	20	
FCV (calculated)	0.1618[a]	0.2703[b]		FCV (calculated)	0.79[c]	

[a] Normalized to total hardness of 50 mg/L as $CaCO_3$ (using pooled slope of 0.7490).

[b] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 0.7490).

[c] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 0.7977).

[d] Not used in GMCV calculation because species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

[e] Not included in the GMCV calculation because normalized EC_{20} data available for the genus.

5.9.3 Hardness correlation and equations for cadmium toxicity adjustment

Hardness is used as a surrogate for the ions that can affect the results of toxicity tests on cadmium. In spite of its limitations, hardness is currently the best surrogate available for metal toxicity adjustment. The hardness toxicity relationship applies the same methodology (covariance) as presented in the 2001 update. The hardness-toxicity relationship used to normalize the data for this revision is described above. A comparison of the data used in 2001 and this update is shown in **Table 26**.

Table 26. Hardness-Toxicity Relationship Data used in U.S. EPA (2001) Compared to this Update.

		Sample size	**Number of Vertebrates / Invertebrates Species**	**Hardness Range (mg $CaCO_3$/L)**
2001 AWQC	Acute	64	7 / 5	5.3 – 360
	Chronic	7	2 / 1	44 – 250
2016 Update	Acute	80	7 / 6	5.3 – 350
	Chronic	18	3 / 1	19.7 – 301

5.9.4 Comparison of acute estuarine/marine criterion to 2001 document

Of the 79 Genus Mean Acute Values (GMAV) in the updated dataset, 40 genera have new data for either species represented in the 2001 database or new species added to the GMAV calculation in this update (**Table 27**). Three new species in the updated dataset, the mysid, *Neomysis americana*, the copepod, *Tigriopus brevicornis,* and moon jellyfish, *Aurelia aurtia,* represent the three most sensitive species in the distribution with GMAVs of 28.14, 29.14 and 61.75 µg/L, respectively. The most sensitive fish species is the striped bass, *Morone saxatilis*, with a GMAV of 75.0 µg/L. There are sufficient data to fulfill the requirements to calculate acute criterion using the species sensitivity distribution (SD) method.

Suitable tests of the acute toxicity of cadmium to estuarine/marine organisms are now available for 78 species of invertebrates and 16 species of fish, or a total of 94 species grouped into 79 genera. The 2001 criteria were based on data from 50 species of invertebrates and 10 species of fish for a total of 60 species grouped into 54 genera (**Table 27**).

Table 27. Estuarine/Marine GMAVs Comparing Species Listed in the 2001 and 2016 Documents.

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
169,787	-	Horseshoe crab, *Limulus polyphemus*	-	**169,787**	New genus
135,000	135,000	Oligochaete worm, *Monopylephorus cuticulatus*	135,000	135,000	-
>80,000	-	Mozambique tilapia, *Oreochromis mossambicus*	-	**>80,000**	New genus
62,000	-	Scorpionfish, *Scorpaena guttata*	-	**62,000**	New genus
28,196	50,000	Sheepshead minnow, *Cyprinodon variegatus*	50,000	**28,196**	New data for existing species
25,900	-	Cunner, *Tautogolabrus adspersus*	-	**25,900**	New genus
24,000	24,000	Oligochaete worm, *Tubificoides gabriellae*	24,000	24,000	-
23,200	-	Dog whelk, *Nucella lapillus*	-	**23,200**	New genus
22,887	27,992	Amphipod, *Eohaustorius estuarius*	27,992	**22,887**	New data for existing species

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
19,550	19,550	Mummichog, *Fundulus heteroclitus*	18,200	18,200	-
-	-	Striped killifish, *Fundulus majalis*	21,000	21,000	-
19,170	19,170	Eastern mud snail, *Nassarius obsoletus*	19,170	19,170	-
14,297	14,297	Winter flounder, *Pseudopleuronectes americanus*	14,297	14,297	-
12,755	21,238	Fiddler crab, *Uca pugilator*	21,238	21,238	-
-	-	Fiddler crab, *Uca triangularis*	-	**7,660**	New species added to GMAV calculation
12,052	12,836	Polychaete worm, *Neanthes arenaceodentata*	12,836	**12,052**	New data for existing species
11,000	11,000	Shiner perch, *Cymatogaster aggregata*	11,000	11,000	-
>10,200	>10,200	California market squid, *Loligo opalescens*	>10,200	>10,200	-
10,114	6,895	Polychaete worm, *Alitta virens*	10,114	10,114	(formerly, *Nereis virens*)
10,000	10,000	Oligochaete, *Tectidrilus verrucosus*	10,000	10,000	(formerly, *Limnodriloides verrucosus*)
9,217	7,079	Striped mullet, *Mugil cephalus*	7,079	7,079	-
-	-	White mullet, *Mugil curema*	-	**12,000**	New species added to GMAV calculation
9,100	-	Nematode, *Rhabditis marina*	-	**9,100**	New genus (formerly, *Pellioditis marina*)
>8,000	-	Isopod, *Excirolana sp.*	-	**>8,000**	New genus
7,400	7,400	Sand dollar, *Dendraster excentricus*	7,400	7,400	-
7,120	7,120	Wood borer, *Limnoria tripunctata*	7,120	7,120	-
6,700	6,700	Amphipod, *Diporeia spp.*	6,700	6,700	-
6,600	6,600	Atlantic oyster drill, *Urosalpinx cinerea*	6,600	6,600	-
4,900	-	Mud crab, *Eurypanopeus depressus*	-	**4,900**	New genus

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
4,700	6,895	Polychaete, *Nereis grubei*	4,700	4,700	-
4,100	4,100	Green shore crab, *Carcinus maenas*	4,100	4,100	-
4,058	2,594	Blue crab, *Callinectes sapidus*	2,594	2,594	-
-	-	Lesser blue crab, *Callinectes similis*	-	**6,350**	New species added to GMAV calculation
3,925	-	Polychaete, *Ophryotrocha diadema*	-	**3,925**	New genus
3,500	3,500	Scud, *Marinogammarus obtusatus*	3,500	3,500	-
3,142	-	Polychaete worm, *Ctenodrilus serratus*	-	**3,142**	New genus
2,900	2,900	Amphipod, *Ampelisca abdita*	2,900	2,900	-
2,600	2,600	Cone worm, *Pectinaria californiensis*	2,600	2,600	-
2,413	2,413	Common starfish, *Asterias forbesi*	2,413	2,413	-
2,110	-	Pacific sand crab, *Emerita analoga*	-	**2,110**	New genus
2,060	-	Gastropod, *Tenguella granulata*	-	**2,060**	New genus (formerly, *Morula granulata*)
1,720	-	Tiger shrimp, *Penaeus monodon*	-	**1,720**	New genus
1,708	1,708	Copepod, *Pseudodiaptomus coronatus*	1,708	1,708	-
1,672	1,672	Soft-shell clam, *Mya arenaria*	1,672	1,672	-
1,510	-	Amphipod, *Rhepoxynius abronius*	-	**1,510**	New genus
1,506	-	Brown mussel, *Perna perna*	-	**1,146**	New genus (formerly, *Perna indica*)
-	-	Green mussel, *Perna viridis*	-	**1,981**	New genus
1,500	1,500	Coho salmon, *Oncorhynchus kisutch*	1,500	1,500	-
1,271	-	White shrimp, *Litopenaeus setiferus*	-	**990**	New genus (formerly, *Penaeus setiferus*)

2016 GMAV^{a} (µg/L)	**2001 GMAV (µg/L)**	**Species**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Comment**
-	-	White shrimp, *Litopenaeus vannamei*	-	**1,632**	New genus
1,228	1,228	Daggerblade grass shrimp, *Palaemonetes pugio*	1,983	1,983	-
-	-	Grass shrimp, *Palaemonetes vulgaris*	760	760	-
1,184	-	Starlet sea anemone, *Nematostella vectensis*	-	**1,184**	New genus
1,054	779.8	Atlantic silverside, *Menidia menidia*	779.8	**1,054**	Acute value removed after re-review of Cardin 1985
1,041	929.3	Amphipod, *Corophium insidiosum*	929.3	**1,041**	New data for existing species
1,000	-	Pinfish, *Lagodon rhomboides*	-	**1,000**	New genus
862.9	948.7	Green sea urchin, *Strongylocentrotus droebachiensis*	1,800	1,800	-
-	-	Purple sea urchin, *Strongylocentrotus purpuratus*	500	**413.7**	New data for existing species
800	800	Rivulus, *Rivulus marmoratus*	800	800	-
794.5	794.5	Harpacticoid copepod, *Nitokra spinipes*	794.5	794.5	(formerly, *Nitocra spinipes*)
765.6	1,480	Bay scallop, *Argopecten irradians*	1,480	1,480	-
-	-	Scallop, *Argopecten ventricosus*	-	**396**	New species added to GMAV calculation
739.2	590.5	Amphipod, *Leptocheirus plumulosus*	590.5	**739.2**	New data for existing species
736.2	1,073	Blue mussel, *Mytilus edulis*	1,073	1,073	-
-	-	Blue mussel, *Mytilus trossolus*	-	**505.0**	New species added to GMAV calculation
716.2	716.2	Amphipod, *Elasmopus bampo*	716.2	716.2	-
645.0	645.0	Longwrist hermit crab, *Pagurus longicarpus*	645.0	645.0	-
630.7	1,170	Amphipod, *Grandidierella japonica*	1,170	**630.7**	New data for existing species
630	630	Amphipod, *Chelura terebrans*	630	630	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
490	-	Barnacle, *Amphibalanus amphitrite*	-	**490**	New genus
422.6	-	Mangrove oyster, *Isognomon californicum*	-	**422.6**	New genus
410.3	-	Mysid, *Praunus flexuosus*	-	**410.3**	New genus
410.0	410.0	Isopod, *Joeropsis sp.*	410.0	410.0	(Formerly, *Jaeropsis sp.*)
320	320	Sand shrimp, *Crangon septemspinosa*	320	320	-
310.5	310.5	Northern pink shrimp, *Farfantepenaeus duorarum*	310.5	310.5	(formerly, *Penaeus duorarum*)
235.7	235.7	Rock crab, *Cancer plebejus*	250	250	(formerly, *Cancer irroratus*)
-	-	Dungeness crab, *Cancer magister*	222.3	222.3	-
224	224	Harpacticoid copepod, *Sarsamphiascus tenuiremis*	224	224	(formerly, *Amphiascus tenuiremis*)
>200	>200	Cabezon, *Scorpaenichthys marmoratus*	>200	>200	-
200	200	Polychaete worm, *Capitella capitata*	200	200	-
188.1	-	Horse clam, *Tresus capax*	-	**60**	New genus
-	-	Horse clam, *Tresus nuttalli*	-	**590**	New genus
173.2	930.6	Pacific oyster, *Crassostrea gigas*	227.9	**173.2**	U.S. EPA (2001) did not use the >100 values from Watling 1982 in the SMAV calculation
-	-	American oyster, *Crassostrea virginica*	3,800	3,800[b]	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
147.7	147.7	Calanoid copepod, *Eurytemora affinis*	147.7	147.7	-
130.7	130.7	Copepod, *Acartia clausi*	144	144	-
-	-	Calanoid copepod, *Acartia tonsa*	118.7	118.7	-
78	78	American lobster, *Homarus americanus*	78	78	-
75.0	75.0	Striped bass, *Morone saxatilis*	75.0	75.0	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
67.39	41.29	Mysid, *Americamysis bahia*	41.29	41.29	-
-	110	Mysid, *Americamysis bigelowi*	110	110	(formerly, *Mysidopsis bigelowi*)
61.75	-	Moon jellyfish, *Aurelia aurita*	-	**61.75**	New genus
29.14	-	Harpacticoid copepod, *Tigriopus brevicornis*	-	**29.14**	New genus
28.14	-	Mysid, *Neomysis americana*	-	**28.14**	New genus

[a] Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

[b] There is a 10x difference in SMAVs for the genus, only most sensitive SMAV is used in the GMAV calculation.

New acute data for estuarine/marine species have also been added to the 2016 document. A total of 79 genera are now used to derive the estuarine/marine CMC of 33 µg/L in the 2016 update in contrast to 54 genera and resultant CMC of 40.28 µg/L in the 2001 document (**Table 28**). The four most sensitive genera are once again used to calculate the CMC in the 2001 document (n<59), and the second to fifth most sensitive genera are used in the 2016 update (n≥59). The approximately 18 percent lower 2016 CMC is primarily due to the addition of three new sensitive genera, the mysid, *Neomysis*, the jellyfish, *Aurelia* and the copepod, *Tigriopus*. Both *A. bahia* (mysid) and the striped bass GMAVs are used to calculate the CMC in each document version. Additional genera included in the 2016 update include the polychaete worms, *Ctenodrilus* and *Ophryotrocha*, nematode, *Rhabditis,* mussel, *Perna*, clam, *Tresus,* whelk, *Nucella*, gastropod, *Tenguella,* barnacle, *Amphibalanus*, oyster, *Isognomon*, horseshoe crab, *Limulus*, isopod, *Excirolana*, copepod *Tigriopus*, amphipod, *Rhepoxynius*, mysids, *Neomysis* and *Praunus*, sea anemone *Nematostella*, shrimps, *Litopenaeus* and *Penaeus*, crabs, *Emerita* and *Eurypanopeus*, jellyfish *Aurelia,* and fish, *Lagodon*, *Oreochromis*, *Scorpaena* and *Tautogolabrus*.

Table 28. Comparison of the Four Taxa Used to Calculate the Estuarine/Marine FAV and CMC in the 2001 Cadmium Document and 2016 Update.

2001 Cadmium Estuarine/Marine FAV and CMC			2016 Cadmium Update Estuarine/Marine FAV and CMC		
Species	**SMAV (µg/L)**	**GMAV [Rank] (µg/L)**	**Species**	**SMAV (µg/L)**	**GMAV [Rank] (µg/L)**
			Striped bass, *Morone saxatilis*	75.0	75.0 [5]
			Mysid, *Americamysis bahia*	41.29	67.39 [4]
Mysid, *Mysidopsis bigelowi*	110	110 [4]	Mysid, (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	110	
American lobster, *Homarus americanus*	78	78 [3]	Moon jellyfish, *Aurelia aurita*	61.75	61.75 [3]
Striped bass, *Morone saxatilis*	75.0	75.0 [2]	Harpacticoid copepod, *Tigriopus brevicornis*	29.14	29.14 [2]
Mysid, *Americamysis bahia*	41.29	41.29 [1]	Mysid, *Neomysis americana*	28.14	28.14[a] [1]
Number of GMAVs	54		Number of GMAVs	79	
FAV (calculated)	80.55		FAV (calculated)	66.25	
CMC	40.28		CMC	33.13	

[a] Not used in FAV calculation due to the number of genera (N>59) (see text).

5.9.5 Comparison of chronic estuarine/marine criterion to 2001 document

No new data were identified on the chronic effects of cadmium to estuarine/marine species since the 2001 update (**Table 29** and **Table 30**). The same estuarine/marine chronic data presented in the 2001 cadmium document are also used in the 2016 document update (note that the mysid *Mysidopsis bigelowi* is now classified as *Americamysis bigelowi*). Due to the limited amount of estuarine/marine chronic data the CCC is derived by dividing the FAV by the FACR. In the 2001 document the FACR was determined based only on the two estuarine/marine ACRs. This is because the freshwater ACRs covered such a wide range, it was deemed inappropriate to use any of the available freshwater ACRs in the calculation of the saltwater FCV. Also the two estuarine/marine species for which acute-chronic ratios were available had SMAVs in the same range as the saltwater FAV, and it seemed reasonable to use the geometric mean of only those two ACRs. Given the addition of new sensitive estuarine/marine species to the acute criteria dataset, a new FACR was calculated using a combination of both freshwater and estuarine/marine ACRs (see **Section 5.5.1**). The 2016 estuarine/marine chronic CCC is 8.0 µg/L total cadmium (66.25 / 8.291) and the 2001 CCC is 8.9 µg/L total cadmium (80.55 / 9.106).

Table 29. Estuarine/Marine GMCVs Comparing Species Listed in the 2001 and 2016 Documents.

2016 GMCV (µg/L)[a]	2001 GMCV (µg/L)	Species	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Comment
8.449	6.173	Mysid, *Americamysis bahia*	6.173	6.149	-
-	7.141	Mysid, *Americamysis bigelowi*	7.141	11.61	(formerly, *Mysidopsis bigelowi*)

[a] Ranked from most resistant to most sensitive based on 2016 Genus Mean Chronic Value.

Table 30. Total Number of Toxicity Values for Species and Genera in 2001 AWQC and 2016 Update.

	2001 Criteria	2016 Update
Freshwater Acute Criterion		
Total # new acute toxicity values	-	53[a]
SMAV	65	101
GMAV	55	75
Freshwater Chronic Criterion		
Total # new chronic toxicity values	-	14[b]
SMCV	21	27
GMCV	16	20
Estuarine/Marine Acute Criterion		
Total # new acute toxicity values	-	43[c]
SMAV	61	94
GMAV	54	79
Estuarine/Marine Chronic Criterion		
Total # new chronic toxicity values	-	0[d]
SMCV	2	2
GMCV	2	1[e]

[a] See **Table 22**
[b] See **Table 24**
[c] See **Table 27**
[d] See **Table 29**
[e] Note: *Americamysis bigelowi* was formerly called *Mysidopsis bigelowi*.

6 UNUSED DATA

For this 2016 criteria update document, EPA considered and evaluated all available data that could possibly be used to derive the new acute and chronic criteria for cadmium in fresh and estuarine/marine waters. A substantial amount of those data were associated with studies that did not meet the basic QA/QC requirements described in the 1985 Guidelines (see Stephan et al. 1985). A list of all other studies considered but removed from consideration for use in deriving the criteria is provided in **Appendix J** with rationale indicating the reason(s) for exclusion. Note that unused studies from previous AWQC documents were not reevaluated.

7 REFERENCES

Abbasi, S.A. and R. Soni. 1986. An examination of environmentally safe levels of zinc (II), cadmium (II) and lead (II) with reference to impact on channelfish *Nuria denricus*. Environ. Pollut. (Series A) 40(1): 37-51.

Abbasi, S.A. and R. Soni. 1989. Relative toxicity of seven heavy metals with respect to impact towards larvae of amphibian *Rana tigrina*. Intern. J. Environ. Stud. 35: 121-122.

Abdallah, A.T. and M.A. Moustafa. 2002. Accumulation of lead and cadmium in the marine prosobranch *Nerita saxtilis*, chemical analysis, light and electron microscopy. Environ. Pollut. 116 (2): 185-191.

Abdallah, M.A.M. 2008. Trace element levels in some commercially valuable fish species from costal waters of Mediterranean Sea, Egypt. J. Mar. Syst. 73: 114-122.

Abdel-Baky, T.E., S.H. Hassan, A.E. Hagras and M.A. Zyadah. 1998. Seasonal variations of some heavy metals accumulated in the organs of *Clarias gariepinus* (Burchell, 1822) in Lake Manzala, Egypt. J. Environ. Sci. (Mansoura. Egypt) 15: 45-66.

Abel, P.D. and S.E. Papoutsoglou. 1986. Lethal toxicity of cadmium to *Cyprinus carpio* and *Tilapia aurea*. Bull. Environ. Contam. Toxicol. 37: 382-386.

Abel, P.D. and S.M. Garner. 1986. Comparisons of median survival times and median lethal exposure times for *Gammarus pulex* exposed to cadmium, permethrin and cyanide. Water Res. 20(5): 579-582.

Abel, T. and F. Barlocher. 1988. Uptake of cadmium by *Gammarus fossarum* (Amphipoda) from food and water. J. Appl. Ecol. 25: 223-231.

Abrahim, G.M S., R.J. Parker and S.L. Nichol. 2007. Distribution and assessment of sediment toxicity in Tamaki Estuary, Auckland, New Zealand. Environ. Geol. 52: 1315-1323.

Abtahi, B., M. Bahmani, E. Sharifpour, A. Esmaeili Sari, R. Kazemi and A. Hallajian. 2007. Study of histopathological effect of environmental factors of Caspian Sea on sturgeon fishes. Published by Iranian Fisheries Research Organization, Tehran, Iran.

Achiorno, C.L., C. De Villalobos and L. Ferrari. 2010. Validation test with embryonic and larval stages of *Chordodes Nobilii* (Gordiida, Nematomorpha): sensitivity to three reference toxicants. Chemosphere 81(2): 133-140.

Adam, C., B. Fraysse, J. Garnier-Laplace, J.P. Baudin and A. Boudou. 2002. Impact of cadmium and zinc prior exposure on ^{110m}silver, $^{58+60}$cobalt and ^{137}cesium uptake by two freshwater bivalves during a brief field experiment. Bull. Environ. Contam. Toxicol. 68(3): 428-435.

Adami, G., P. Barbieri, M. Fabiani, S. Piselli, S. Predonzani, S. and E. Reisenhofer. 2002. Levels of cadmium and zinc in hepatopancreas of reared *Mytilus galloprovincialis* from the Gulf of Trieste (Italy). Chemosphere. 48(7): 671-677.

Adams, M.S. and J.L. Stauber. 2004. Development of a whole-sediment toxicity test using a benthic marine microalga. Environ. Toxicol.Chem. 23(8): 1957-1968.

Adams, T.G., G.J. Atchison and R.J. Vetter. 1980. The impact of an industrially contaminated lake on heavy metal levels in its effluent stream. Hydrobiologia 69(1/2), 187-193.

Adams, W.J., R. Blust, U. Borgmann, K.V. Brix, D.K. DeForest, A.S. Green, J.S. Meyer, J.C McGeer, P.R Paquin, P.S. Rainbow and C.M. Wood. 2011. Utility of tissue residues for predicting effects of metals on aquatic organisms. Integr. Environ. Assess. Manage. 7(1): 75–98.

Adeyemi, J.A. and L.E. Deaton. 2012. The effect of cadmium exposure on digestive enzymes in the Eastern oyster *Crassostrea virginica*. J. Shell. Res. 31(3): 631-634.

Adham, K.G., S.S. Hamed, H.M. Ibrahim and R.A. Saleh. 2002. Impaired functions in Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1757), from polluted waters. Acta Hydrochimi.Hydrobiol. 29(5): 278-288.

Adhikari, S., L. Ghosh and S. Ayyappan. 2006. Combined effects of water pH and alkalinity on the accumulation of lead, cadmium and chromium to *Labeo rohita* (Hamilton). Int.J.Environ.Sci.Tech. 3(3): 289-296.

Adhikari, S., L. Ghosh and S. Ayyappan. 2007. Effect of calcium hardness on toxicity and accumulation of water-borne lead, cadmium and chromium to *Labeo rohita* (Hamilton). Asian J.Water Environ.Pollut. 4(2): 103-106.

Adiele, R.C. 2012. Involvement of mitochondria in cadmium toxicity in rainbow trout (*Oncorhynchus mykiss*). Ph.D. Thesis, University of Prince Edward Island (Canada), UMI# NR94087, 230 p.

Adiele, R.C., D. Stevens and C. Kamunde. 2010. Reciprocal enhancement of uptake and toxicity of cadmium and calcium in rainbow trout (*Oncorhynchus mykiss*) liver mitochondria. Aquat. Toxicol. 96(4): 319-327.

Adiele, R.C., D. Stevens and C. Kamunde. 2011. Cadmium- and calcium-mediated toxicity in rainbow trout (*Oncorhynchus mykiss*) *in vivo*: interactions on fitness and mitochondrial endpoints. Chemosphere 85(10): 1604-1613.

Adiele, R.C., D. Stevens and C. Kamunde. 2012a. Differential inhibition of electron transport chain enzyme complexes by cadmium and calcium in isolated rainbow trout (*Oncorhynchus mykiss*) hepatic mitochondria. Toxicol. Sci. 127(1): 110-9. 2012.

Adiele, R.C., D. Stevens and C. Kamunde. 2012b. Features of cadmium and calcium uptake and toxicity in rainbow trout (*Oncorhynchus mykiss*) mitochondria. Toxicol. In Vitro 26(1): 164-173.

Afonso, C., H.M. Lourenço, A. Dias, M.L. Nunes and M. Castro. 2007. Contaminant metals in black scabbard fish (*Aphanopus carbo*) caught off Madeira and the Azores. Food Chem. 101(1): 120-125.

Agency for Toxic Substances and Disease Registry (ATSDR). 2012. Toxicological profile for cadmium. U.S. Department of Health and Human Services, Public Health Service. Atlanta, GA.

Agnello, M., S. Filosto, R. Scudiero, A.M. Rinaldi and M.C. Roccheri. 2007. Cadmium induces an apoptotic response in sea urchin embryos. Cell Stress Chaperones. 12(1): 44-50.

Agrahari, S. and K. Gopal. 2007. Fate and toxicity of cadmium and lead accumulation in different tissues (gills, liver, kidney, brain) of a freshwater fish *Channa punctatus*. J. Ecophysiol. Occup. Health. 7(3/4): 151-155.

Aguilera, A. and R. Amils. 2005. Tolerance to cadmium in *Chlamydomonas sp.* (Chlorophyta) strains isolated from an extreme acidic environment, the Tinto River (SW, Spain). Aquat. Toxicol. 75(4): 316-329.

Ahmad, B., T.A. Qureshi, S. Manohar, P. Kaur and R. Khaliq. 2011. Effect of cadmium chloride on the histoarchitecture of liver and kidney of a freshwater catfish, *Clarias batrachus*. Int. J. Environ. Sci. Technol. (Tehran) 2(2): 531-536.

Ahmed, H. and D.P.Hader. 2010. Rapid ecotoxicological bioassay of nickel and cadmium using motility and photosynthetic parameters of *Euglena gracilis*. Environ. Exp.Bot. 69(1): 68-75.

Ahmed, M.K., E. Parvin, M. Arif, M.S. Akter, M.S. Khan, M. S. and M.M. Islam. 2010. Measurements of genotoxic potential of cadmium in different tissues of fresh water climbing perch *Anabas testudineus* (Bloch), using the comet assay. Environ. Toxicol. Pharmacol. 30(1): 80-84.

Ahn, I.Y., J. Kang and K.W. Kim. 2001. The effect of body size on metal accumulations in the bivalve *Laternula elliptica*. Antarct. Sci. 13(4): 355-362.

Ahn, I.Y., J.Y. Ji, H.J. Choi, S.H. Pyo, H. Park and J.W. Choi. 2006. Spatial variations of heavy metal accumulation in manila *Clam ruditapes* Philippinarum from some selected intertidal flats of Korea. Ocean Polar Res. 28(3): 215-224.

Ahsanullah, M. 1976. Acute toxicity of cadmium and zinc to seven invertebrate species from Western Port, Victoria. Aust. J. Mar. Freshwater Res. 27: 187.

Ahsanullah, M., and G. H. Arnott. 1978. Acute toxicity of copper, cadmium, and zinc to larvae of the crab Paragrapsusquadridentatus (H. Milne Edwards), and implications for water quality criteria. Aust. J. Mar. Freshwater Res. 29: 1-8.

Ahsanullah, M., D.S. Negilski and M.C. Mobley. 1981. Toxicity of zinc, cadmium, and copper to the shrimp *Callianassa australiensis*. I. Effects of individual metals. Mar. Biol. 64: 299-304.

Ahsanullah, M. and A.R. Williams. 1991. Sublethal effects and bioaccumulation of cadmium, chromium, copper and zinc in the marine amphipod *Allorchestes compressa*. Mar. Biol. 108: 59-65.

Ai, C.X., X.J. Wang, S.J. Li, G.Z. Wang and Q.W. Lin. 2008. Effects of heavy metal and pollutants on the non-special immunity of the shrimp and crab. Mar. Sci. Bull. 10(1): 54-63.

Airas, S., A. Duinker and K. Julshamn. 2004. Copper, zinc, arsenic, cadmium, mercury, and lead in blue mussels (*Mytilus edulis*) in the Bergen Harbor Area, Western Norway. Bull. Environ. Contam. Toxicol. 73(2): 276-284.

Akinola, M.O. and T.A. Ekiyoyo. 2006. Accumulation of lead, cadmium and chromium in some plants cultivated along the bank of River Ribila at Odo-Nla Area of Ikorodu, Lagos State, Nigeria. J. Environ. Biol. 27(3): 597-599.

Aktac, T., E. Bakar and U.Guener. 2010. The effects of short-term exposure to cadmium and copper on sialic acid in carp (*Cyprinus carpio*) tissues. Fresenius Environ. Bull. 19(3): 432-437.

Al-atia, G.R. 1978. The uptake and toxicity of cadmium in *Amoeba proteus*. J. Protozool. 25: 5B.

Al-atia, G.R. 1980. Toxicity of cadmium to *Amoeba proteus*: a biochemical approach. J. Protozool. 27: 128.

Albers, P.H. and M.B. Camardese. 1993a. Effects of acidification on metal accumulation by aquatic plants and invertebrates. 1. Constructed wetlands. Environ. Toxicol. Chem. 12: 959-967.

Albers, P.H. and M.B. Camardese. 1993b. Effects of acidification on metal accumulation by aquatic plants and invertebrates. 2. Wetlands, ponds and small lakes. Environ. Toxicol. Chem. 12: 969-976.

Albrecht, J., M. Abalos and T.M. Rice. 2007. Heavy metal levels in ribbon snakes (*Thamnophis sauritus*) and anuran larvae from the Mobile-Tensaw River Delta, Alabama, USA. Arch. Environ. Contam. Toxicol. 53(4): 647-654.

Albright, L.J., J.W. Wentworth and E.M. Wilson. 1972. Technique for measuring metallic salt effects upon the indigenous heterotrophic microflora of a natural water. Water Res. 6: 1589-1596.

Alderdice, D.F., H. Rosenthal and F.P.J. Velsen. 1979a. Influence of salinity and cadmium on the volume of Pacific herring eggs. Helgol. Wiss. Meeresunters. 32:163-178.

Alderdice, D.F., H. Rosenthal and F.P.J. Velsen. 1979b. Influence of salinity and cadmium on capsule strength in Pacific herring eggs. Helgol. Wiss. Meeresunters. 32: 149-162.

Alderdice, D.F., T.R. Rao and H. Rosenthal. 1979c. Osmotic responses of eggs and larvae of the Pacific herring to salinity and cadmium. Helgol. Wiss. Meeresunters. 32: 508-538.

Alhashemi, A.S., A.R. Karbassi, B.H. Kiabi, S.M. Monavari, S.M. Nabavi, and M.S. Sekhavatjou. 2011. Bioaccumulation of trace elements in trophic levels of wetland plants and waterfowl birds. Biol. Trace Elem. Res. 142(3): 500-516.

Al-Homaidan, A.A. 2007. Heavy metal concentrations in three species of green algae from the Saudi Coast of the Arabian Gulf. J. Food Agric. Environ. 5(3/4): 354-358.

Ali, I., P. Damdimopoulou, S.I. Makela, M. Berglund, U. Stenius, A. Adamsson, A. Akesson, H. Hakansson and K. Halldin. 2012. Endocrine modulatory effects of cadmium (CdCl2) *in vivo*. Toxicol. Letters 211, Suppl. (0): S38.

Allen, P. 1994. Accumulation profiles of lead and the influence of cadmium and mercury in *Oreochromis aureus* (Steindachner) during chronic exposure. Toxicol. Environ. Chem. 44: 101-112.

Allen, P. 1995a. Soft-tissue accumulation of lead in the blue tilapia, *Oreochromis aureus* (Steindachner), and the modifying effects of cadmium and mercury. Biol. Trace Element Research. 50: 193-208.

Allen, P. 1995b. Accumulation profiles of lead and cadmium in the edible tissues of *Oreochromis aureus* during acute exposure. J. Fish Biol. 47: 559-568.

Allen, Y., P. Calow and D.J. Baird. 1995. A mechanistic model of contaminant-induced feeding inhibition on *Daphnia magna*. Environ. Toxicol. Chem. 14(9): 1625-1630.

Allen, Y.T., J.E. Thain, S. Haworth and J. Barry. 2007. Development and application of long-term sublethal whole sediment tests with *Arenicola marina* and *Corophium volutator* using ivermectin as the test compound. Environ. Pollut. 146(1): 92-99.

Al-Madfa, H.A. 2002. Metals accumulation in the marine ecosystem around Qatar (Arabian Gulf). Fresenius Environ. Bull. 11(12A): 1042-1047.

Almaguer-Cantu, V., L.H. Morales-Ramos, I. Balderas-Renteria and V. Almaguer-Cantu. 2011. Biosorption of lead (II) and cadmium (II) using *Escherichia coli* genetically engineered with mice metallothionein I. Water Sci. Technol. 63(8): 1607-1613.

Almalki, S.G. and D. Richardson. 2010. Metallothionein content in the acanthocephalan *Leptorhynchoides thecatus* and tissues from largemouth bass (*Micropterus salmoides*) after cadmium exposure. M.S. Thesis, Quinnipiac University, Hamden, CT.

Almeida, E., R. Ueda and P.K. Chien. 1984. The effects of Cd++ on the glycine transport system in the intertidal gastropod *Tegula funebralis*: Kinetics and ultrastructures. Am. Zool. 24(3): 20A.

Almeida, J.A., E.L. Novelli, M. Dal pai Silva and R. Alves, Jr. 2001. Environmental cadmium exposure and metabolic responses of the Nile tilapia, *Oreochromis niloticus*. Environ. Pollut. 114(2): 169-175.

Almli, B., M. Mwase, T. Sivertsen, MM. Musonda and A. Flaoyen. 2005. Hepatic and renal concentrations of 10 trace elements in crocodiles (*Crocodylus niloticus*) in the Kafue and Luangwa rivers in Zambia. Sci. Total Environ. 337(1-3): 75-82.

Alonso, A., H.J. De Lange and E.T. Peeters. 2009. Development of a feeding behavioural bioassay using the freshwater amphipod *Gammarus pulex* and the multispecies freshwater biomonitor. Chemosphere. 75(3):341-6.

Alonso, A., H.J. De Lange and E.T.H.M. Peeters. 2010a. Contrasting sensitivities to toxicants of the freshwater amphipods *Gammarus pulex* and *G. Fossarum*. Ecotoxicol. 19(1): 133-140.

Alonso, A., V. Garcia-Johansson, H.J. De Lange and E.T.H.M. Peeters. 2010b. Effects of animal starvation on the sensitivity of the freshwater amphipod *Gammarus pulex* to cadmium. Chem. Ecol. 26(3): 233-242.

Alquezar, R., S.J. Markich and D.J. Booth. 2006a. Metal accumulation in the smooth toadfish, *Tetractenos glaber*, in estuaries around Sydney, Australia. Environ. Pollut. 142: 123-131.

Alquezar, R., S.J. Markich and D.J. Booth. 2006b. Effects of metals on condition and reproductive output of the smooth toadfish in Sydney estuaries, South-Eastern Australia. Environ. Pollut. 142: 116-122.

Alquezar, R., S.J. Markich and J.R. Twining. 2008. Comparative accumulation of super(109)Cd and super(75)Se from water and food by an estuarine fish (*Tetractenos glaber*). J. Environ. Radioact. 99(1): 167-180.

Al-Shami, S.A., C.S.M. Rawi, A.H. Ahmad and S.A.M. Nor. 2012. Genotoxicity of heavy metals to the larvae of *Chironomus kiiensis* Tokunaga after short-term exposure. Toxicol. Ind. Health 28(8): 734-739.

Al-Shwafi, N.A. and A.I. Rushdi. 2008. Heavy metal concentrations in marine green, brown, and red seaweeds from coastal waters of Yemen, the Gulf of Aden. Environ. Geol. 55(3): 653-660.

Alsop, D. and C.M. Wood. 2011. Metal uptake and acute toxicity in zebrafish: common mechanisms across multiple metals. Aquat. Toxicol. 105(3/4): 385-393.

Altindag, A. and S. Yigit. 2005. Assessment of heavy metal concentrations in the food web of lake Beysehir, Turkey. Chemosphere 60(4): 552-556.

Alvarado, N.E., A. Buxens, L.I. Mazon and M. Soto. 2005. Cellular biomarkers of exposure and biological effect in hepatocytes of turbot (*Scophthalmus maximus*) exposed to Cd, Cu and Zn and after depuration. Aquat. Toxicol. 74(2): 110-125.

Alvarado, N.E., I. Quesada, K. Hylland, I. Marigomez and M. Soto. 2006. Quantitative changes in metallothionein expression in target cell-types in the gills of turbot (*Scophthalmus maximus*) exposed to Cd, Cu, Zn and after a depuration treatment. Aquat. Toxicol. 77(1): 64-77.

Alvarez-Legorreta, T., D. Mendoza-Cozatl, R. Moreno-Sanchez and G. Gold-Boucho. 2008. Thiol peptides induction in the seagrass *Thalassia testudinum* (Banks Ex KÖNig) in response to cadmium exposure. Aquat. Toxicol. 86(1):12-19.

Alves de Oliveira, J.A., J. Cambraia, M.V. de Sousa and M.A. Oliva. 2009. Sulphate uptake and metabolism in water hyacinth and salvinia during cadmium stress. Aquat. Botany. 91(4): 257-261.

Amachree, D., A.J. Moody and R.D. Handy. 2013. Comparison of intermittent and continuous exposures to cadmium in the blue mussel, *Mytilus edulis*: Accumulation and sub-lethal physiological effects. Ecotoxicol. Environ. Saf. 95: 19-26.

Amado-Filho, G.M., L.T. Salgado, M.F. Rebelo, C.E. Rezende, C.S. Karez and W.C Pfeiffer. 2008. Heavy metals in benthic organisms from Todos Os Santos Bay, Brazil. Braz. J. Biol. 68(1): 95-100.

Amenu, G. 2011. A comparative study of water quality conditions between heavily urbanized and less urbanized watersheds of Los Angeles Basin. World Environmental and Water Resources Congress, pp. 680-690.

Amiard, J.C., C. Metayer, J.P. Baud and F. Ribeyre. 1994. Influence of some ecological and biological factors on metal bioaccumulation in young oysters (*Crassostrea gigas* Thunberg) during their spat rearing. Water Res. 28(1): 219-231.

Amiard, J.C., H. Perrein-Ettajani, A. Gerard, J.P. Baud and C. Amiard-Triquet. 2005. Influence of ploidy and metal-metal interactions on the accumulation of Ag,Cd, and Cu in Oysters *Crassostrea gigas* Thunberg. Arch. Environ. Contam. Toxicol. 48(1): 68-74.

Amiard, J.C., A. Geffard, C. Amiard-Triquet and C. Crouzet. 2007. Relationship between the lability of sediment-bound metals (Cd, Cu, Zn) and their bioaccumulation in benthic invertebrates. Estuar. Coast. Shelf Sci. 72(3): 511-521.

Amiard-Triquet, C., B. Berthet, C. Metayer and J.C. Amiard. 1986. Contribution to the ecotoxicological study of cadmium, copper and zinc in the mussel *Mytilus edulis*. Mar. Biol. 92: 7-13.

Amiard-Triquet, C, C. Metayer and J.C. Amiard. 1987. Etudes *in situ* et experimentales de leotoxicologie de quatre metaux (Cd, Pb, Cu, Zn) chez des algues et des mollusques gasteropodes brouteurs. Water, Air, Soil Pollut. 34: 11-30.

Amiard-Triquet, C., J.C. Amiard, B. Berthet and C. Metayer. 1988. Field and experimental study of the bioaccumulation of some trace metals in a coastal food chain: seston, oyster (*Crassostrea gigas*), drill (*Ocenebra erinacea*). Water Sci. Tech. 20(6/7): 13-21.

Amin, B., A. Ismail and C.K. Yap. 2008. Heavy metal concentrations in sediment and intertidal *Gastropod nerita* Lineata from two opposing sites in the Straits of Malacca. Wetland Sci. 6(3): 411-421.

Amin, O.A., L.I. Comoglio and E.M. Rodriguez. 2003. Toxicity of cadmium, lead, and zinc to larval stages of *Lithodes santolla* (Decapoda, Anomura). Bull. Environ. Contam. Toxicol. 71(3): 527-534.

Aminina, N.M. and T.V. Shaposhnikova. 2009. Brown algae metabolism under chronic toxic metal pollution. Phycologia. 48(4): Suppl.

Amutha, C. and P. Subramanian. 2013. Cadmium alters the reproductive endocrine disruption and enhancement of growth in the early and adult stages of *Oreochromis mossambicus*. Fish Physiol. Biochem. 39(2): 351-361.

Amweg, E.L. and D.P. Weston. 2007. Whole-sediment toxicity identification evaluation tools for *Pyrethroid insecticides*: I. piperonyl butoxide addition. Environ. Toxicol. Chem. 26(11): 2389-2396.

An, L., T. Cao and Y. Yu. 2006. Heavy Metals Contents in Haplocladium and Their Relationships With Shanghai City Environment. J. Appl. Ecol. 17(8):1490-1494.

Anadu, D.I. 1983. Fish acclimation and the development of tolerance to zinc as a modifying factor in toxicity. Ph.D.Thesis, Oregon State University, Corvallis, OR.

Anadu, D.I., G.A. Chapman, L.R. Curtis and R.A. Tubb. 1989. Effect of zinc exposure on subsequent acute tolerance to heavy metals in rainbow trout. Bull. Environ. Contam. Toxicol. 43: 329-336.

Anajjar, E.M., J.F. Chiffoleau, H. Bergayou, A. Moukrim, T. Burgeot and M. Cheggour. 2008. Monitoring of trace metal contamination in the Souss Estuary (South Morocco) using the clams *Cerastoderma edule* and *Scrobicularia plana*. Bull. Environ. Contam. Toxicol. 80: 283-288.

Anan, Y., T. Kunito, H. Sakai and S. Tanabe. 2002. Subcellular distribution of trace elements in the liver of sea turtles. Mar. Pollut. Bull. 45(1-12): 224-229.

Anderson, B.G. 1948. The apparent thresholds of toxicity to *Daphnia magna* for chlorides of various metals when added to Lake Erie water. Trans. Am. Fish. Soc. 78: 96.

Anderson, B.S., J.W. Hunt, B.M. Phillips, P.A. Nicely, R.S. Tjeerdema and M.A. Martin. 2004. Comparison of in situ and laboratory toxicity tests with the estuarine amphipod *Eohaustorius estuarius*. Arch. Environ. Contam. Toxicol. 46(1): 52-60.

Anderson, G.L., W.A. Boyd and P.L. Williams. 2001. Assessment of sublethal endpoints for toxicity testing with the nematode *Caenorhabditis elegans*. Environ. Toxicol. Chem. 20(4): 833-838.

Anderson, I.C., P.I. Parkin and C.D. Campbell. 2008. DNA- and RNA-derived assessments of fungal community composition in soil amended with sewage sludge rich in cadmium, copper and zinc. Soil Biol. Biochem. 40(9): 2358-2365.

Anderson, R.L., C.T. Walbridge and J.T. Fiandt. 1980. Survival and growth of *Tanytarsus dissimilis* (Chironomidae) exposed to copper, cadmium, zinc, and lead. Arch. Environ. Contam. Toxicol. 9(3): 329-335.

Anderson, R.V. 1977. Concentration of Cadmium, Copper, Lead, and Zinc in Thirty-Five Genera of Freshwater Macroinvertebrates From the Fox River, Illinois and Wisconsin. Bull. Environ. Contam. Toxicol. 18(3), 345-349.

Anderson, R.V., W.S. Vinikour and J.E. Brower. 1978. The distribution of Cd, Cu, Pb and Zn in the biota of two freshwater sites with different trace metal inputs. Holartic Ecol. 1(4): 377-384.

Andosch, A., M.J. Affenzeller, C. Lutz and U. Lutz-Meindl. 2012. A freshwater green alga under cadmium stress: ameliorating calcium effects on ultrastructure and photosynthesis in the unicellular model micrasterias. J. Plant Physiol. 169(15): 1489-1500.

Andreji, J., I. Stranai, M. Kacaniova, P. Massanyi and M. Valent. 2006a. Heavy metals content and microbiological quality of carp (*Cyprinus carpio*, L.) muscle from two southwestern slovak fish farms. J. Environ. Sci. Health 41A(6): 1071-1088.

Andreji, J., I. Stranai, P. Massanyi and M. Valent. 2006b. Accumulation of some metals in muscles of five fish species from Lower Nitra River. J. Environ. Sci. Health 41A: 2607-2622.

Andres, S., M. Baudrimont, Y. Lapaquellerie, F. Ribeyre, N. Maillet, C. Latouche and A. Boudou. 1999. Field transplantation of the freshwater bivalve *Corbicula fluminea* along a polymetallic contamination gradient (River Lot, France): I. Geochemical characteristics of sampling sites and cadmium and zinc bioaccumulation kinetics. Environ. Toxicol. Chem. 18(11): 2462-2471.

Andros, J.D. and R.R. Garton. 1980. Acute lethality of copper, cadmium, and zinc to northern squawfish. Trans. Am. Fish. Soc. 109: 235.

Angelo, R.T., M.S. Cringan and D.L. Chamberlain. 2007. Residual effects of lead and zinc mining on freshwater mussels in the Spring River Basin (Kansas, Missouri, and Oklahoma, USA). Sci.Total Environ. 384:467-496.

Ankley, G.T., R.A. Hoke, J.P. Giesy and P.V. Winger. 1989. Evaluation of the toxicity of marine sediments and dredge spoils with the microtox bioassay. Chemosphere 18(9/10): 2069-2075.

Annabi, A., I. Messaoudi, A. Kerkeni and K. Said. 2009. Comparative study of the sensitivity to cadmium of two populations of *Gambusia affinis* from two different sites. Environ. Monit. Assess. 155(1-4): 459-465.

Annabi, A., I. Messaoudi, A. Kerkeni and K. Said. 2011. Cadmium accumulation and histological lesion in mosquitofish (*Gambusia affinis*) tissues following acute and chronic exposure. Int. J. Environ. Res. 5(3): 745-756.

Annabi, A., K. Kessabi, A. Kerkeni, K. Said and I. Messaoudi. 2012. Influence of cadmium exposure on growth and fecundity of freshwater mosquitofish *Gambusia affinis*: in situ and in vivo studies. Biol. Trace Elem. Res. 148(3): 345-355.

Annabi, A., K. Said and I. Messaoudi. 2013. Cadmium: bioaccumulation, histopathology and detoxifying mechanisms in fish. Amer. J. Res. Comm. 1(4): 60-79.

Annune, P.A., S.O. Ebele and A.A. Oladimeji. 1994. Acute toxicity of cadmium to juveniles of *Clarias gariepinus* (Teugels) and *Oreochromis niloticus* (Trewavas). J. Environ. Sci. Health. A29(7): 1357-1365.

Anonymous. 1950. Ohio River Valley Water Sanitation Commission, Subcommittee on Toxicities, Metal Finishing Industries Action Committee Report No. 3.

Ansaldo, M., D.E. Nahabedian, C. Di Fonzo and E.A. Wider. 2009. Effect of cadmium, lead and arsenic on the oviposition, hatching and embryonic survival of *Biomphalaria glabrata*. Sci. Total Environ. 407: 1923-1928.

Anu, G., N.C. Kumar, K.V. Jayalakshmi and S.M. Nair. 2007. Monitoring of heavy metal partitioning in reef corals of Lakshadweep Archipelago, Indian Ocean. Environ. Monit. Assess. 128: 195-208.

Anushia, C., P.S. Kumar and P. Karthikeyan. 2012. Heavy metal induced enzyme response in *Tilapia mossambicus*. Int. J. Pharm. Res. Bio-Sci. 1(4): 371-385.

Apeti, D.A., G.G. Lauenstein and G.F. Riedel. 2009. Cadmium distribution in coastal sediments and mollusks of the U.S. Mar. Pollut. Bull. 58(7): 1016-1024.

Aramphongphan, A., S. Laovitthayanggoon and L. Himakoun. 2009. Snakehead-fish cell line, SSN-1 (*Ophicephalus striatus*) as a model for cadmium genotoxicity testing. Toxicol. In Vitro. 23(5): 963-968.

Aravind, P. and M.N.V. Prasad. 2003. Zinc alleviates cadmium-induced oxidative stress in *Ceratophyllum demersum* L.: a free floating freshwater macrophyte. Plant Physiol. Biochem. 41(4): 391-397.

Aravind, P. and M.N.V. Prasad. 2004. Zinc protects chloroplasts and associated photochemical functions in cadmium exposed *Ceratophyllum demersum* L., a freshwater macrophyte. Plant Sci. 166(5): 1321-1327.

Aravind, P. and M.N.V. Prasad. 2005. Zinc mediated protection to the conformation of carbonic anhydrase in cadmium exposed *Ceratophyllum demersum* L. Plant Sci. 169(1): 245-254. 2005.

Aravind, P., M.N.V. Prasad, P. Malec, A. Waloszek and K. Strzalka. 2009. Zinc protects *Ceratophyllum demersum* L. (free-floating hydrophyte) against reactive oxygen species induced by cadmium. J. Trace Elem. Med. Biol. 23(1): 50-60.

Arias-Almeida, J.C. and R. Rico-Martinez. 2011a. Inhibition of two enzyme systems in *Euchlanis dilatata* (Rotifera: Monogononta) as biomarker of effect of metals and pesticides. Biomarkers 16(1): 12-19.

Arias-Almeida, J.C. and R. Rico-Martinez. 2011b. Toxicity of cadmium, lead, mercury and methyl parathion on *Euchlanis dilatata* Ehrenberg 1832 (Rotifera: Monogononta). Bull. Environ. Contam. Toxicol. 87(2): 138-142.

Arikpo, G.E., M.E. Eja, L.O. Ogbonnaya and A.A. Opara. 2004. Cadmium uptake by the green alga *Chlorella emersonii*. Global J. Pure Appl. Sci. 10(2): 257-262.

Arillo, A., C. Margiocco, F. Melodia and P. Mensi. 1982. Biochemical effects of long-term exposure to Cr, Cd, Ni on rainbow trout (*Salmo gairdneri* Rich.): Influence of sex and season. Chemosphere 11(1): 47-57.

Arillo, A., D. Calamari, C. Margiocco, F. Melodia and P. Mensi. 1984. Biochemical effects of long-term exposure to cadmium and copper on rainbow trout (*Salmo gairdneri*): validation of water quality criteria. Ecotoxicol. Environ. Saf. 8(2): 106-117.

Arini, A., A.S. Feurtet-Mazel, R.G. Maury-Brachet, M. Coste and F.O. Delmas. 2012. Field translocation of diatom biofilms impacted by Cd and Zn to assess decontamination and community restructuring capacities. Ecol. Ind. 18(0): 520-531.

Arnac, M. and C. Lassus. 1985. Heavy metal accumulation (Cd, Cu, Pb and Zn) by smelt (*Osmerus mordax*) from the north shore of the St. Lawrence estuary. Water Res. 19(6): 725-734.

Arshaduddin, M., R. Yasmeen, M.M. Hussain and M.A. Khan. 1989. Effect of two heavy metals (lead and cadmium) on growth in the rotifer *Asplanchna intermedia*. Pollut. Res. 8(3): 129-128.

Arts, G.H.P., J.D.M. Belgers, C.H. Hoekzema and J.T.N.M. Thissen. 2008. Sensitivity of submersed freshwater macrophytes and endpoints in laboratory toxicity tests. Environ. Pollut. 153(1): 199-206.

Arulvasu, C., K. Padmini, P. Prabu, N. Thangaraju, D. Dinesh, S. Sellamuthu and C. Arulvasu. 2010. Evaluation of cadmium toxicity on the population growth of *Brachionus plicatilis* (O. F. Mueller). Ind. J. Sci.Technol. 3(1): 90-93.

Asagba, S.O., G.E. Eriyamremu and M.E. Igberaese. 2008. Bioaccumulation of cadmium and its biochemical effect on selected tissues of the catfish (*Clarias gariepinus*). Fish Physiol. Biochem. 34(1): 61-69.

Asagba, S.O., G.E. Eriyamremu, J. Emudainohwo and I. Okoro. 2010. Oxidative enzymes in tissues of the catfish (*Clarias gariepinus*) exposed to varying levels of cadmium. Environmentalist 30(3): 260-266.

Asato, S.L. and D.J. Reish. 1988. The effects of heavy metals on the survival and feeding of *Holmesimysis costata* (Crustacea: Mysidacea). *In*: Proc. 7th Int. Symp. on Mar. Biol., California State University, Long Beach, CA: 113-120.

Ashraf, P.M., B. Meenakumari and S.N. Thomas. 2007. Seasonal variation of metal concentration in barnacles (*Balanus spp.*) of Cochin Estuary, South West Coast of India. Fish. Technol. Soc. Fish. Technol.44(1): 73-84.

Ashraf, W. 2005. Accumulation of heavy metals in kidney and heart tissues of *Epinephelus microdon* fish from the Aarabian Gulf. Environ. Monit. Assess. 101(1-3): 311-316.

Askary S.A. and M. Beheshti. 2012. Cadmium, iron, lead and mercury bioaccumulation in Abu Mullet, *Liza abu*, different tissues from Karoun and Karkheh Rivers, Khozestan, Iran. Bull. Environ. Contam. Toxicol. 88(2): 158-161.

ASTM. 1998. Standard guide for conducting early life-stage toxicity tests with fishes. Method E1241-98. Pages 29 in Annual Book of ASTM Standards, volume 11.04. American Society for Testing and Materials, West Conshohocken, PA.

ASTM. 2005. Standard test method for measuring the toxicity of sediment-associated contaminants with freshwater invertebrates. Method E1706-05. American Society for Testing and Materials, West Conshohocken, PA.

Atici, T., H. Katircioglu and B. Akin. 2008. Sensitivity of freshwater microalgal strains (*Chlorella vulgaris* Beijerinck and *Scenedesmus obliquus* (Turpin) Ku(Dieresis)Tzing) to heavy metals. Fresenius Environ. Bull. 17(3): 268-274.

Atli, G. and M. Canli. 2007. Enzymatic responses to metal exposures in a freshwater fish *Oreochromis niloticus*. Comp. Biochem. Physiol. C Toxicol. Pharmacol. 145(2): 282-287.

Atli, G. and M. Canli. 2008. Responses of metallothionein and reduced glutathione in a freshwater fish *Oreochromis niloticus* following metal exposures. Environ. Toxicol. Pharmacol. 25(1): 33-38.

Attar, E.N. and E.J. Maly. 1982. Acute toxicity of cadmium, zinc, and cadmium-zinc mixtures to *Daphnia magna*. Arch. Environ. Contam. Toxicol. 11: 291.

Au, D.W.T., C.Y. Lee, K.L. Chan and R.S.S. Wu. 2001a. Reproductive impairment of sea urchins upon chronic exposure to cadmium. Part I: effects on gamete quality. Environ. Pollut. 111(1): 1-9.

Au, D.W.T., A.A. Reunov and R.S.S. Wu. 2001b. Reproductive impairment of sea urchin upon chronic exposure to cadmium. Part II: effects on sperm development. Environ. Pollut. 111(1): 11-20.

Audet, D. and P. Couture. 2003. Seasonal variations in tissue metabolic capacities of yellow perch (*Perca flavescens*) from clean and metal-contaminated environments. Can. J. Fish. Aquat. Sci. 60(3): 269-278.

Augier, H., J. D'Orso, I. Guillon-Cottard, N. Le Tallec and G. Ramonda. 1999. Variation of heavy metal contents of the green alga *Caulerpa taxifolia* (Vahl) C. Agardh in its area of expansion in the French Mediterranean Sea. Toxicol. Environ. Chem. 73(3-4): 207-219.

Auslander, M., Y. Yudkovski, V. Califa-Caspi, B. Herut, R. Ophir, R. Reinhardt, P.M. Neumann and M. Tom. 2008. Pollution-affected fish hepatic transcriptome and its expression patterns on exposure to cadmium. Mar. Biotechnol. 10(3): 250-261.

Austen, M.C. and A.J. McEvoy. 1997. The use of offshore meiobenthic communities in laboratory microcosm experiments: response to heavy metal contamination. J. Exp. Mar. Biol. Ecol. 211: 247-261.

Austin, A. and J. Deniseger. 1985. Periphyton community changes along a heavy metals gradient in a long narrow lake. Environ. Exp. Bot. 25(1): 41-52.

Avery, E.L., R.H. Dunstan and J.A. Nell. 1996. The detection of pollutant impact in marine environments: condition index, oxidative DNA damage, and their associations with metal bioaccumulation in the Sydney rock oyster *Saccostrea commercialis*. Arch. Environ. Contam. Toxicol. 31: 192-198.

Awasthi, M. and D.N. Das. 2005. Heavy metal stress on growth, photosynthesis and enzymatic activities of free and immobilized *Chlorella vulgaris*. Ann. Microbiol. 55(1): 1-7.

Awasthi, M. and L.C. Rai. 2005. Toxicity of nickel, zinc, and cadmium to nitrate uptake in free and immobilized cells of *Scenedesmus quadricauda*. Ecotoxicol. Environ. Saf. 61(2): 268-272.

Awasthi, M. and L.C. Rai. 2006. Interactions between zinc and cadmium uptake by free and immobilized cells of *Scenedesmus quadricauda* (Turp.) Breb. Acta Hydrochim.Hydrobiol. 34(1/2): 20-26.

Ayas, Z., G. Ekmekci, S.V. Yerli and M. Ozmen. 2007. Heavy metal accumulation in water, sediments and fishes of Nallihan Bird Paradise, Turkey. J. Environ. Biol. 28(3): 545-549.

Azeez, P.A. and D.K. Banerjee. 1987. Influence of light on chlorophyll, a content of blue-green algae treated with heavy metals. Bull. Environ. Contam. Toxicol. 38: 1062-1069.

Baas, J., B.P. Van Houte, C.A. Van Gestel and S.A. Kooijman. 2007. Modeling the effects of binary mixtures on survival in time. Environ. Toxicol. Chem. 26(6) 1320-1327.

Babich, H. and G. Stotzky. 1978. Effects of cadmium on the biota: Influence of environmental factors. Adv. Appl. Microbiol. 23: 55-117.

Babich, H. and G. Stotzky. 1982. Influence of chloride ions on the toxicity of cadmium to fungi. Zentbl. Bakteriol. Mikrobiol. Hyg. 1 Abt Orig. C 3(3): 421-426.

Babich, H., J.A. Puerner and E. Borenfreund. 1986. *In vitro* cytoxicity of metals to bluegill (Bf-2) cells. Arch. Environ. Contam. Toxicol. 15: 31-37.

Baby, K.V. and N.R. Menon. 1986. Oxygen uptake in the brown mussel, *Perna indica* (Kuriakose & Nair) under sublethal stress of Hg, Cd & Zn. Indian J. Mar. Sci. 15(2): 127-128.

Baby, K.V. and N.R. Menon. 1987. Salt forms of metals and their toxicity in the brown mussel *Perna indica* (Kuriakose and Nair). Indian J. Mar. Sci. 16(2): 107-109.

Backor, M., B. Pawlik-Skowronska, J. Budova and T. Skowronski. 2007. Response to copper and cadmium stress in wild-type and copper tolerant strains of the lichen alga *Trebouxia erici*: metal accumulation, toxicity and non-protein thiols. Plant Growth Regulat. 52 (1): 17-27.

Badr, N.B.E. and M. Fawzy. 2008. Bioaccumulation and biosorption of heavy metals and phosphorous by *Potamogeton pectinatus* L. And *Ceratophyllum demersum* L. in two Nile Delta lakes. Fresenius Environ. Bull. 17(3): 282.

Baer, K.N., D.G. Hutton, R.L. Boeri, T.J. Ward and R.G. Stahl, Jr. 1995. Toxicity evaluation of trap and skeet shooting targets to aquatic test species. Ecotoxicology 4(6): 385-392.

Baer, K.N., M.C. Ziegenfuss, S.D. Banks and Z. Ling. 1999. Suitability of high-hardness COMBO medium for ecotoxicity using algae, daphnids, and fish. Bull. Environ. Contam. Toxicol. 63(3): 289-296.

Bagwe, R. 2012. Effect of cadmium and seasonality on critical temperatures of aerobic metabolism in eastern oysters, *Crassostrea virginica* Gmelin 1791. Ph.D. Thesis, The University of North Carolina at Charlotte, Charlotte, NC.

Bagy, M.M.K., H.M.M. El-Sharouny, and A.A. El-Shanawany. 1991. Effect of pH and organic matter on the toxicity of heavy metals to growth of some fungi. Folia Microbiol. 36(4): 367-374.

Bah, A.M., H. Sun, F. Chen, J. Zhou, H. Dai, G. Zhang and F. Wu, F. 2010. Comparative proteomic analysis of *Typha angustifolia* leaf under chromium, cadmium and lead stress. J. Hazard. Mater. 184(1-3): 191-203.

Bai, X.J., L.J. Liu, C.H. Zhang, Y. Ge and W.D. Cheng. 2011. Effect of H_2O_2 pretreatment on Cd tolerance of different rice cultivars. Rice Science 18(1): 29-35.

Bailey, H.C., J.L. Miller, M.J. Miller and B.S. Dhaliwal. 1995. Application of toxicity identification procedures to the echinoderm fertilization assay to identify toxicity in a municipal effluent. Environ. Toxicol. Chem. 14(12): 2181-2186.

Baillieul, M. and R. Blust. 1999. Analysis of the swimming velocity of cadmium-stressed *Daphnia magna*. Aquat. Toxicol. 44: 245-254.

Baines, S.B. and N.S. Fisher. 2008. Modeling the effect of temperature on bioaccumulation of metals by a marine bioindicator organism, *Mytilus edulis*. Environ. Sci. Technol. 42(9): 3277-3282.

Baines, S.B., N.S. Fisher and E.L. Kinney. 2006. Effects of temperature on uptake of aqueous metals by blue mussels *Mytilus edulis* from arctic and temperate waters. Mar. Ecol. Prog. Ser. Vol. 308:117-128.

Baird, D.J. and P.J. Van den Brink. 2007. Using biological traits to predict species sensitivity to toxic substances. Ecotoxicol. Environ. Saf. 67: 296-301.

Baird, D.J., I. Barber and P. Calow. 1990. Clonal variation in general responses of *Daphnia magna* Straus to toxic stress. I. Chronic life-history effects. Funct. Ecol. 4(3): 399-407.

Baird, D.J., I. Barber, M. Bradley, A.M.V.M. Soares and P. Calow. 1991. A comparative study of genotype sensitivity to acute toxic stress using clones of *Daphnia magna* Straus. Ecotoxicol. Environ. Safety. 21: 257-265.

Bajguz, A. 2010. An enhancing effect of exogenous brassinolide on the growth and antioxidant activity in *Chlorella vulgaris* cultures under heavy metals stress. Environ. Exp. Bot. 68(2): 175-179.

Bajguz, A. 2011. Suppression of *Chlorella vulgaris* growth by cadmium, lead, and copper stress and its restoration by endogenous brassinolide. Arch. Environ. Contam. Toxicol. 60(3): 406-416.

Bakhmet, I.N., N.P. Kantserova, L.A. Lysenko and N.N. Nemova. 2012. Effect of copper and cadmium ions on heart function and calpain activity in blue mussel *Mytilus edulis*. J. Environ. Sci. Health 47A(11), 1528-1535.

Bako, S.P. and P. Daudu. 2007. Trace metal contents of the emergent macrophytes *Polygonum sp*. and *Ludwigia sp*. in relation to the sediments of two freshwater lake ecosystems in the Nigerian Savanna. J. Fish Aquat. Sci. 2(1): 63-70.

Baldisserotto, B., C. Kamunde, A. Matsuo and C.M. Wood. 2004a. Acute waterborne cadmium uptake in rainbow trout is reduced by dietary calcium carbonate. Comp. Biochem. Physiol. 137C(4): 363-372.

Baldisserotto, B., C. Kamunde, A. Matsuo and C.M. Wood. 2004b. A protective effect of dietary calcium against acute waterborne cadmium uptake in rainbow trout. Aquat. Toxicol. 67(1): 57-73.

Baldisserotto, B., M.J. Chowdhury and C.M. Wood. 2005. Effects of dietary calcium and cadmium on cadmium accumulation, calcium and cadmium uptake from the water, and their interactions in juvenile rainbow trout. Aquat.Toxicol. 72(1/2): 99-117.

Baldwin, D.H., J.A. Spromberg, T.K. Collier and N.L. Scholz. 2009. A fish of many scales: Extrapolating sublethal pesticide exposures to the productivity of wild salmon populations. Ecol. Appl. 19: 2004-2015.

Ball, A.L., U. Borgmann and D.G. Dixon. 2006. Toxicity of a cadmium-contaminated diet to *Hyalella azteca*. Environ.Toxicol. Chem. 25(9): 2526-2532. 2006.

Ball, I.R. 1967. The toxicity of cadmium to rainbow trout (*Salmo gairdnerii* Richardson). Water Res. 1: 805-806.

Balog, K. and Y. Shalanki. 1984. Crustacean zooplankton as indicators of Lake Balaton pollution with heavy metals. Aquat. Sci. Fish. Abstr. 14(11): 257.

Balogh, K.V. and J. Salanki. 1984. The dynamics of mercury and cadmium uptake into different organs of *Anodonta cygnea* L. Water Res. 18(11): 1381-1387.

Bambang, Y., G. Charmantier, P. Thuet and J.P. Trilles. 1994. Effect of cadmium on survival and osmoregulation of various developmental stages of the shrimp *Penaeus japonicus* (Crustacea: Decapoda). Mar. Biol. 123: 443-450.

Banerjee, S.K., S.G. Dastidar, P.K. Mukhopadhyay and P.V. Dehadrai. 1978. Toxicity of cadmium: a comparative study in the air-breathing fish, *Clarias batrachus* (Linn.) and in the non air-breathing one, *Tilapia mossumbica* (Peters). Indian J. Exp. Biol. 16: 1274-1277.

Banni, M., Z. Bouraoui, C. Clerandeau, J.F. Narbonne and H. Boussetta. 2009. Mixture toxicity assessment of cadmium and benzo[a]pyrene in the sea worm *Hediste diversicolor*. Chemosphere 77(7): 902-906.

Banni, M., L. Chouchene, K. Said, A. Kerkeni and I. Messaoudi. 2011. Mechanisms underlying the protective effect of zinc and selenium against cadmium-induced oxidative stress in zebrafish *Danio rerio*. BioMetals 24(6): 981-992.

Baraj, B., F. Niencheski, G. Fillmann and C.M.G. Martins. 2011. Assessing the effects of Cu, Cd, and exposure period on metallothionein production in gills of the brazilian brown mussel *Perna perna* by using factorial design. Environ. Monit. Assess. 179: 155-162.

Barata, C. and D.J. Baird. 2000. Determining the ecotoxicological mode of action of chemicals from measurements made on individuals: results from instar-based tests with *Daphnia magna* Straus. Aquat. Toxicol. 48: 195-209.

Barata, C., D.J. Baird and S.J. Markich. 1998. Influence of genetic and environmental factors on the tolerance of *Daphnia magna* Straus to essential and non-essential metals. Aquat. Toxicol. 42: 115-137.

Barata, C., D.J. Baird, A. Minarro and A.M.V.M. Soares. 2000. Do genotype responses always converge from lethal to nonlethal toxicant exposure levels? Hypothesis tested using clones of *Daphnia magna* Straus. Environ. Toxicol. Chem. 19(9): 2314-2322.

Barata, C., D.J. Baird, S.E. Mitchell and A.M.V.M. Soares. 2002a. Among- and within-population variability in tolerance to cadmium stress in natural populations of *Daphnia magna*: implications for ecological risk assessment. Environ. Toxicol. Chem. 21(5): 1058-1064.

Barata, C., S.J. Markich, D.J. Baird, G. Taylor and A.M.V.M. Soares. 2002b. Genetic variability in sublethal tolerance to mixtures of cadmium and zinc in clones of *Daphnia magna* Straus. Aquat. Toxicol. 60(1/2): 85-99.

Barata, C., D.J. Baird and A.M.V.M. Soares. 2002c. Demographic responses of a tropical cladoceran to cadmium: effects of Food Supply and Density. Ecol.Appl. 12(2): 552-564.

Barata, C., S.J. Markich, D.J. Baird, and A.M.V.M. Soares. 2002d. The relative importance of water and food as cadmium sources to *Daphnia magna* Straus. Aquat. Toxicol. 61: 143-154.

Barata, C., D.J. Baird, A.J.A. Nogueira, A.M.V.M. Soares and M.C. Riva. 2006. Toxicity of binary mixtures of metals and pyrethroid insecticides to *Daphnia magna* Straus. Implications for multi-substance risks assessment. Aquat. Toxicol. 78(1): 1-14.

Barata, C., D.J. Baird, A.J.A. Nogueira, A.R. Agra, and A.M.V.M. Soares. 2007. Life-history responses of *Daphnia magna* Straus to binary mixtures of toxic substances: pharmacological versus ecotoxicological modes of action. Aquat. Toxicol. 84(4): 439-449.

Barbieri, E. 2007. Use of oxygen consumption and ammonium excretion to evaluate the sublethal toxicity of cadmium and zinc on *Litopenaeus schmitti* (Burkenroad, 1936, Crustacea). Water Environ. Res. 79(6): 641-646.

Barbieri, E. 2009. Effects of zinc and cadmium on oxygen consumption and ammonium excretion in pink shrimp (*Farfantepenaeus paulensis*, Perez-Farfante, 1967, Crustacea). Ecotoxicol. 18(3): 312-318.

Barfield, M.L., J.L. Farris and M.C. Black. 2001. Biomarker and bioaccumulation responses of asian clams exposed to aqueous cadmium. J. Toxicol. Environ. Health Part A Curr. Issues 63(7): 495-510.

Bargagli, R., L. Nelli, S. Ancora and S. Focardi. 1996. Elevated cadmium accumulation in marine organisms from Terra Nova Bay (Antarctica). Polar Biol. (16)7: 513-520.

Barhoumi, S., I. Messaoudi, T., K. Said and A. Kerkeni. 2009. Cadmium bioaccumulation in three benthic fish species, *Salaria basilisca*, *Zosterisessor ophiocephalus* and *Solea vulgaris* collected from the Gulf of Gabes in Tunisia. J. Environ. Sci 21(7): 980-984.

Barjaktarovic, L. and L.I. Bendell-Young. 2001. Accumulation of 109Cd by second-generation chironominae propagated from wild populations sampled from low-, mid-, and high-saline environments. Arch. Environ. Contam. Toxicol. 40(3): 339-344.

Barjhoux, I., M. Baudrimont, B. Morin, L. Landi, P. Gonzalez and J. Cachot. 2012. Effects of copper and cadmium spiked-sediments on embryonic development of japanese medaka (*Oryzias latipes*). Ecotoxicol. Environ. Saf. 79: 272-282.

Barka, S. 2007. Insoluble detoxification of trace metals in a marine copepod *Tigriopus brevicornis* (Muller) exposed to copper, zinc, nickel, cadmium, silver and mercury. Ecotoxicology 16(7): 491-502.

Barka, S., J.F. Pavillon and C. Amiard-Triquet. 2010. Metal distributions in tigriopus brevicornis (Crustacea, Copepoda) exposed to copper, zinc, nickel, cadmium, silver, and mercury, and implication for subsequent transfer in the food web. Environ. Toxicol. 25(4): 350-360.

Barnthouse, L.W., G.W. Suter II, A.E. Rosen and J.J. Beauchamp. 1987. Estimating responses of fish populations to toxic contaminants. Environ. Toxicol. Chem. 6: 811-824.

Barque, J., A. Abahamid, Y. Bourezgui, H. Chacun and J. Bonaly. 1995. Growth responses of achlorophyllous *Euglena gracilis* to selected concentrations of cadmium and pentachlorophenol. Arch. Environ. Contam. Toxicol. 28: 8-12.

Barrento, S., A. Marques, B. Teixeira, M.L. Carvalho, P. Vaz-Pires and M.L. Nunes. 2009. Influence of season and sex on the contents of minerals and trace elements in brown crab (*Cancer pagurus*, Linnaeus, 1758). J. Agric. Food Chem. 57(8): 3253-3260.

Barrera-Escorcia, G. and C.I. Wong. 2010. Lipid peroxidation and metallothionein induction by chromium and cadmium in oyster *Crassostrea virginica* (Gmelin) from Mandinga Lagoon, Veracruz. Hidrobiologica 20(1): 31-40.

Barrera-Escorcia, G., I. Wong-Chang and G.Barrera-Escorcia. 2005. Mean lethal body concentration of cadmium in *Crassostrea virginica* from a Mexican Tropical Coastal Lagoon. Rev. Int. Contam. Ambient 21(2): 55-62.

Barrera-Escorcia, G., C. Vanegas-Perez and I. Wong-Chang. 2010. Filtration rate, assimilation and assimilation efficiency in *Crassostrea virginica* (Gmelin) fed with *Tetraselmis suecica* under cadmium exposure. J. Environ. Sci. Health. 45A(1): 14-22.

Bartlett, L., F.W. Rabe and W.H. Funk. 1974. Effects of copper, zinc and cadmium on *Selenastrum capricornutum*. Water Res. 8: 179-185.

Bartsch, M.R., W.G. Cope and R.G. Rada. 1999. Effects of cadmium-spiked sediment on cadmium accumulation and bioturbation by nymphs of the burrowing mayfly *Hexagenia bilineata*. Water Air Soil Pollut. 109: 277-292.

Barwick, M. and W. Maher. 2003. Biotransferance and biomagnification of selenium copper, cadmium, zinc, arsenic and lead in a temperate seagrass ecosystem from Lake Macquarie Estuary, NSW, Australia. Mar. Environ. Res. 56(4): 471-502.

Bascik-Remisiewicz, A. and Z. Tukaj. 2002. Toxicity of inorganic cadmium salts to the microalga *Scenedesmus armatus* (Chlorophyta) with respect to medium composition, pH and CO2 concentration. Acta Physiol. Plant. 24(1): 59-65.

Basha, P.S. and A.U. Rani. 2003. Cadmium-induced antioxidant defense mechanism in freshwater teleost *Oreochromis mossambicus* (Tilapia). Ecotoxicol. Environ. Saf. 56(2): 218-221.

Basic, N., N. Salamin, C. Keller, N. Galland and G. Besnard, G. 2006. Cadmium hyperaccumulation and genetic differentiation of *Thlaspi Caerulescens* poulations. Biochem. System. Ecol. 34 (9): 667-677.

Basile, A., S. Sorbo, B. Conte, R.C. Cobianchi, F. Trinchella, C. Capasso and V. Carginale. 2012. Toxicity, accumulation, and removal of heavy metals by three aquatic macrophytes. Int. J. Phytoremediat. 14(4): 374-387.

Batista, D., C. Pascoal and F. Cassio. 2012. Impacts of warming on aquatic decomposers along a gradient of cadmium stress. Environ. Pollut. 169(0): 35-41.

Battaglini, P., G. Andreozzi, R. Antonucci, N. Arcamone, P. De Giroloamo, L. Ferrara and G. Gargiulo. 1993. The effects of cadmium on the gills of the goldfish *Carassius auratus* L.: metal uptake and histochemical changes. Comp. Biochem. Physiol. 104C(2): 239-247.

Baudrimont, M., J. Metivaud, R. Maury-Brachet, F. Ribeyre and A. Boudou. 1997. Bioaccumulation and metallothionein response in the asiatic clam (*Corbicula fluminea*) after experimental exposure to cadmium and inorganic mercury. Environ. Toxicol. Chem. 16(10): 2096-2105.

Baudrimont, M., S. Andres, G. Durrieu and A. Boudou. 2003. The key role of metallothioneins in the bivalve *Corbicula fluminea* during the depuration phase, after in situ exposure to Cd and Zn. Aquat.Toxicol. 63(2): 89-102.

Baudrimont, M., J. Schafer, V. Marie, R. Maury-Brachet, C. Bossy, A. Boudou and G. Blanc. 2005. Geochemical survey and metal bioaccumulation of three bivalve species (*Crassostrea gigas*, *Cerastoderma edule* and *Ruditapes philippinarum*) in the Nord Medoc salt marshes (Gironde estuary, France). Sci. Total Environ. 337(1-3): 265-280.

Bauer, N.J., R.J. Seidler and M.D. Knittel. 1981. A simple, rapid bioassay for detecting effects of pollutants on bacteria. Bull. Environ. Contam. Toxicol. 27: 577-582.

Baumann, H.A., L. Morrison and D.B. Stengel. 2009. Metal accumulation and toxicity measured by PAM-chlorophyll fluorescence in seven species of marine macroalgae. Ecotoxicol. Environ. Saf. 72(4): 1063-1075.

Baumann, Z. and N.S. Fisher. 2011a. Relating the sediment phase speciation of arsenic, cadmium, and chromium with their bioavailability for the deposit-feeding polychaete *Nereis succinea*. Environ Toxicol Chem 30(3): 747-56.

Baumann, Z. and N.S. Fisher. 2011b. Modeling metal bioaccumulation in a deposit-feeding polychaete from labile sediment fractions and from pore water. Sci. Tot. Environ. 409(13): 2607-2615.

Baunemann, R. and W. Hofner. 1991. Influence of Cd, Cu, Ni and Zn on the synthesis of metalloproteins by *Scenedesmus subspicatus*. Z. Pflanzenernaehr. Bodenkd. 154(2): 81-85

Bay, S, R. Burgess and D. Nacci. 1993. Status and applications of echinoid (*Phylum echinodermata*) toxicity test methods. Environ. Toxicol. Risk. Assess., ASTM STP 1179, W.G. Landis, J.S. Hughes and M.A. Lewis (*Eds*.), American Society for Testing and Materials, Philadelphia. pp. 281-302.

Bazzaz, M.B. and Govindjee. 1974. Effects of cadmium nitrate on spectral characteristics and light reactions of chloroplasts. Environ. Lett. 6: 1-12.

Beattie, J.H. and D. Pascoe. 1978. Cadmium uptake by rainbow trout, *Salmo gairdneri* eggs and alevins. J. Fish Biol. 13: 631.

Beauvais, S.L., S.B. Jones, J.T. Parris, S.K. Brewer and E.E. Little. 2001. Cholinergic and behavioral neurotoxicity of carbaryl and cadmium to larval rainbow trout (*Oncorhynchus mykiss*). Ecotoxicol. Environ. Saf. 49(1): 84-90.

Bechard, K.M., P.L. Gillis and C.M. Wood. 2008. Acute toxicity of waterborne Cd, Cu, Pb, Ni, and Zn to first-instar *Chironomus riparius* larvae. Arch. Environ. Contam. Toxicol. 54(3): 454-459.

Bednarz, T. and H. Warkowska-Dratnal. 1983/1984. Toxicity of zinc, cadmium, lead, copper, and their mixture for *Chlorella pyrenoidosa* Chick. Acta Hydrobiol. 25/26(3/4): 389-400.

Beiras, R. and M. Albentosa. 2004. Inhibition of embryo development of the commercial bivalves *Ruditapes decussatus* and *Mytilus galloprovincialis* by trace metals; implications for the implementation of seawater quality criteria. Aquaculture. 230(1-4): 205-213

Beiras, R., E. His and M.N.L. Seaman. 1998. Effects of storage temperature and duration on toxicity of sediments assessed by *Crassostrea gigas* oyster embryo bioassay. Environ. Toxicol. Chem. 17(10): 2100-2105.

Bektas, S., O. Hisar, S.A. Hisar and T. Yanik. 2008. Inhibition effect of cadmium on carbonic anhydrase in rainbow trout (*Oncorhynchus mykiss*). Fresenius Environ. Bull. 17(7A): 793-796.

Belabed, W., N. Kestali, S. Semsari and A. Gaid. 1994. Toxicity study of some heavy metals with daphnia test. Tech. Sci. Methods. 6: 331-336.

Belanger, S.E. and D.S. Cherry. 1990. Interacting effects of pH acclimation, pH, and heavy metals on acute and chronic toxicity to *Ceriodaphnia dubia* (Cladocera). J. Crustacean Biol. 10(2): 225-235.

Bellas, J., E. Vazquez and R. Beiras. 2001. Toxicity of Hg, Cu, Cd, and Cr on early developmental stages of *Ciona intestinalis* (Chordata, Ascidiacea) with potential application in marine water quality assessment. Water Res. 35(12): 2905-2912.

Bellas, J., R. Beiras and E. Vazquez. 2004. Sublethal effects of trace metals (Cd,Cr,Cu,Hg) on embryogenesis and larval settlement of the ascidian *Ciona intestinalis*. Arch. Environ. Contam. Toxicol. 46(1): 61-66.

Bellavere, C. and J. Gorbi. 1981. A comparative analysis of acute toxicity of chromium, copper and cadmium to *Daphnia magna*, *Biomphalaria glabrata*, and *Brachydanio rerio*. Environ. Technol. Letters 2: 119.

Beltrame, M.O., S.G. De Marco and J.E. Marcovecchio. 2008. Cadmium and zinc in Mar Chiquita Coastal Lagoon (Argentina): salinity effects on lethal toxicity in juveniles of the burrowing crab *Chasmagnathus granulatus*. Arch. Environ. Contam. Toxicol. 55(1): 78-85.

Benaduce, A.P.S., D. Kochhann, E.M.M. Flores, V.L. Dressler and B. Baldisserotto. 2008. Toxicity of cadmium for silver catfish *Rhamdia quelen* (Heptapteridae) embryos and larvae at different alkalinities. Arch. Environ. Contam. Toxicol. 54(2): 274-282.

Bendell, L.I. 2010. Cadmium in shellfish: the British Columbia, Canada experience--a mini-review. Toxicol. Lett. 198(1): 7-12.

Bendell, L.I. and C. Feng. 2009. Spatial and temporal variations in cadmium concentrations and burdens in the pacific oyster (*Crassostrea gigas*) sampled from the Pacific North-West. Mar. Pollut. Bull. 58(8): 1137-1143.

Bendell-Young, L.I. 1994. Comparison of metal concentrations in the fore and hindguts of the crayfish *Cambarus bartoni* and *Orconectes virilis* and implications regarding metal absorption efficiencies. Bull. Environ. Contam. Toxicol. 53: 844-851.

Bendell-Young, L.I. 1999. Application of a kinetic model of bioaccumulation across a pH and salinity gradient for the prediction of cadmium uptake by the sediment dwelling chironomidae. Environ. Sci. Technol. 33: 1501-1508.

Bendell-Young, L.I., H.H. Harvey and J.F. Young. 1986. Accumulation of cadmium by white suckers (*Catostomus commersoni*) in relation to fish growth and lake acidification. Can. J. Fish. Aquat. Sci. 43: 806-811.

Bender, J.A. 1975. Trace metal levels in beach dipterans and amphipods. Bull. Environ. Contam. Toxicol. 14(2): 187-192.

Bengtsson, B. 1978. Use of harpacticoid copepod in toxicity tests. Mar. Pollut. Bull. 9: 238.

Bengtsson, B.E. and B. Bergstrom. 1987. A flow-through fecundity test with *Nitocra spinipes* (Harpacticoidea crustacea) for aquatic toxicity. Ecotoxicol. Environ. Safety. 14: 260-268.

Bennett, D.H., C.M. Falter and W.D. Sawle. 1996. Pilot sampling for heavy metals in fish flesh from Killarney Lake, Coeur D'Alene River System, Idaho. Govt. Reports Announcements & Index, Issue 03.

Benoit, D.A., E.N. Leonard, G.M. Christensen and J.T. Fiandt. 1976. Toxic effects of cadmium on three generations of brook trout (*Salvelinus fontinalis*). Trans. Am. Fish. Soc. 105(4): 550-560.

Benoot, D., L. Vergauwen, D. Knapen and R.A. Blust. 2009. A systems biology approach to the effects of cadmium exposure via water in zebrafish (*Danio rerio*). Comp. Biochem. Physiol. 154A (1, Suppl.1): S20.

Bentley, P.J. 1991. Accumulation of cadmium by channel catfish (*Ictalurus punctatus*): Influx from environmental solutions. Comp. Biochem. Physiol. 99C: 527-529.

Bere, T. and J.G. Tundisi. 2011. Toxicity and sorption kinetics of dissolved cadmium and chromium III on tropical freshwater phytoperiphyton in laboratory mesocosm experiments. Science of the Total Environment 409(22): 4772-4780.

Bere, T. and J.G. Tundisi. 2012a. Cadmium and lead toxicity on tropical freshwater periphyton communities under laboratory-based mesocosm experiments. Hydrobiologia 680(1): 187-197.

Bere, T. and J.G. Tundisi. 2012b. Effects of cadmium stress and sorption kinetics on tropical freshwater periphytic communities in indoor mesocosm experiments. Sci. Total Environ. 432: 103-112.

Berglind, R. 1985. The effects of cadmium on ala-d activity, growth and haemoglobin content in the water flea, *Daphnia magna*. Comp. Biochem. Physiol. 80C(2): 407-410.

Berglind, R. 1986. Combined and separate effects of cadmium, lead and zinc on ala-d activity, growth and hemoglobin content in *Daphnia magna*. Environ. Toxicol. Chem. 5: 989-995.

Bergquist, B.L. and E.C. Bovee. 1976. Cadmium: Quantitative methodology and study of its effect upon the locomotor rate of *Tetrahymena pyriformis*. Acta Protozool. 15(4): 471-483.

Bernds, D, D. Wubben and G.P. Zauke. 1998. Bioaccumulation of trace metals in polychaetes from the German Wadden Sea: evaluation and verification of toxicokinetic models. Chemosphere. 37(13): 2573-2587.

Berntssen, M.H.G. and A.K. Lundebye. 2001. Energetics in Atlantic salmon (*Salmo salar* L.) parr fed evelated dietary cadmium. Comp. Biochem. Physiol. 128C(3): 311-323.

Berntssen, M.H.G., O.O. Aspholm, K. Hylland, S.E. Wendelaar Bonga and A.K. Lundebye. 2001. Tissue metallothionein, apoptosis and cell proliferation responses in Atlantic salmon (*Salmo salar* L.) parr fed elevated dietary cadmium. Comp. Biochem. Physiol. 128C(3): 299-310.

Berntssen, M.H.G., R. Waagbo, H. Toften and A.K. Lundebye. 2003. Effects of dietary cadmium on calcium homeostasis, Ca mobilization and bone deformities in Atlantic salmon (*Salmo salar* L.) Parr. Aquac. Nutr. 9(3): 175-183.

Berquist, B.L. and E.C. Bovee. 1976. Cadmium: quantitative methodology and study of its effect upon the locomotor rate of *Tetrahymens pyriformis*. Acta Protozool. 15: 471-483.

Bertram, P.E. and B.A. Hart. 1979. Longevity and reproduction of *Daphnia pulex* (deGeer) exposed to cadmium-contaminated food or water. Environ. Pollut. 19: 295.

Bervoets, L., R. Blust and R. Verheyen. 1995. The uptake of cadmium by the midge larvae *Chironomus riparius* as a function of salinity. Aquat. Toxicol. 33: 227-243.

Bervoets, L., R. Blust and R. Verheyen. 1996. Effect of temperature on cadmium and zinc uptake by the midge larvae *Chironomus riparius*. Arch. Environ. Contam. Toxicol. 31: 502-511.

Bervoets, L., R. Blust and R. Verheyen. 2001. Accumulation of metals in the tissues of three spined stickelback (*Gasterosteus aculeatus*) from natural fresh waters. Ecotoxicol. Environ. Saf. 48(2): 117-127.

Bervoets, L., J. Voets, S. Chu, A. Covaci, P. Schepens and R. Blust, R. 2004. Comparison of accumulation of micropollutants between indigenous and transplanted zebra mussels (*Dreissena Polymorpha*). Environ. Toxicol. Chem. 23(8): 1973-1983.

Besser, J.M. and C.F. Rabeni. 1987. Bioavailability and toxicity of metals leached from lead-mine tailings to aquatic invertebrates. Environ. Toxicol. Chem. 6: 879-890.

Besser, J.M., W.G. Brumbaugh, T.W. May., S.E. Church and B.A. Kimball. 2001. Bioavailability of metals in stream food webs and hazards to brook trout (*Salvelinus fontinalis*) in the Upper Animas River Watershed, Colorado. Arch. Environ. Contam. Toxicol. 40(1): 48-59.

Besser, J.M., C.A. Mebane, C.D. Ivey, J.L. Kunz, I.E. Greer, T.W. May and C.G. Ingersoll. 2006. Relative sensitivity of mottled sculpins (*Cottus bairdi*) and rainbow trout (*Onchorhynchus mykiss*) to toxicity of metals associated with mining activities. Admin. Report (CERC-8355-FY04-20-06) to U.S. EPA , 38 p.

Besser, J.M., C.A. Mebane, D.R. Mount, C.D. Ivey, J.L. Kunz, I.E. Greer, T.W. May and C.G. Ingersoll. 2007. Sensitivity of mottled sculpins (*Cottus bairdi*) and rainbow trout (*Oncorhynchus mykiss*) to acute and chronic toxicity of cadmium, copper, and zinc. Environ. Toxicol. Chem. 26(8): 1657-1665.

Besser, J.M., W.G. Brumbaugh, A.L. Allert, B.C. Poulton, C.J. Schmitt and C.G. Ingersoll. 2009. Ecological impacts of lead mining on Ozark streams: toxicity of sediment and pore water. Ecotoxicol. Environ. Saf. 72(2): 516-526.

Besser JM, Brumbaugh WG, Ingersoll CG, Ivey CD, Kunz JL, Kemble NE, Schlekat CE, Garman ER. 2013. Chronic toxicity of nickel-spiked freshwater sediments: Variation in toxicity among eight invertebrate taxa and eight sediments. Environ. Toxicol. Chem. 32:2495-2506.

Besser JM, Ingersoll CG, Brumbaugh WG, Kemble NE, May TW, Wang N, MacDonald DD, Roberts AD. 2015. Toxicity of sediments from lead-zinc mining areas to juvenile freshwater mussels (*Lampsilis siliquoidea*), compared to standard test organisms. Environ. Toxicol. Chem. 34:626-639.

Besser JM, Ivey CD, Brumbaugh WG, Ingersoll CG. 2015. Effect of Diet Quality on Chronic Toxicity of Aqueous Lead to the Amphipod, *Hyalella azteca*. Environ. Toxicol. Chem. In press.Besson, A., A. Gravot, A. Pugin and D. Wendehenne. 2007. NO contributes to cadmium toxicity in *Arabidopsis thaliana*. Comp. Biochem. Physiol. 146A (4, Suppl. 1): S262-S263.

Besson-Bard, A. and D. Wendehenne. 2009. NO Contributes to cadmium toxicity in *Arabidopsis thaliana* by mediating an iron deprivation response. Plant Signaling and Behavior 4(3): 252-254.

Besson-Bard, A., A. Gravot, P. Richaud, P. Auroy, C. Duc, F. Gaymard, L. Taconnat, J.P. Renou, A. Pugin and D. Wendehenne. 2009. Nitric oxide contributes to cadmium toxicity in arabidopsis by promoting cadmium accumulation in roots and by up-regulating genes related to iron uptake. Plant Physiol. 149(3):1302-15.

Bewers, J. M., P.J. Barry and D.J. MacGregor. 1987. Distribution and cycling of cadmium in the environment. *In*: Cadmium in the aquatic environment, J.O. Nriagu and J.B. Sprague (*Eds.*) John Wiley and Sons, Toronto.

Beyrem, H., E. Mahmoudi, N. Essid, A. Hedfi, F. Boufahja. and P. Aissa. 2007. Individual and combined effects of cadmium and diesel on a nematode community in a laboratory microcosm experiment. Ecotoxicol. Environ. Saf. 68(3): 412-8.

Bhamre, P.R. and A.E. Desai. 2012. Impact of heavy metal compounds on oxygen consumption of freshwater mussel *Lamellidens consobrinus* (Lea). S. Asian J. Exp. Biol. 2(1): 1-4.

Bhamre, P.R., A.E. Desai and B.M. Deoray. 2010. Effects of cadmium intoxication on the gills of freshwater mussel *Parreysia favidens*. J. Exp. Zool. India 13(2): 409-411.

Bhattacharya, A.K., S.N. Mandal and S.K. Das. 2008. Heavy metals accumulation in water, sediment and tissues of different edible fishes in upper stretch of Gangetic West Bengal. Trends Appl. Sci. Res. 3(1): 61-68.

Bhilave, M.P., D.V. Muley and V.Y. Deshpande. 2008. Biochemical changes in the fish cirrhinus mrigala after acute and chronic exposure of heavy metals. Nat. Environ. Pollut. Technol. 7(1): 65-71.

Bicho, R.C., V.M. Mendonca, A.A. Al Kiyumi, S.M. Al Saady, A. Al Habsi, A. Al Kindi, I.Y. Mahmoud, H. Kalb, A.S. Rohde, K. Gayheart and K. Shanker. 2008. Accumulation in livers and excretion through eggs of heavy metals in a nesting population of green turtles, *Chelonia mydas*, in the Nw Indian Ocean. NOAA Tech. Mem. NMFS SEFSC. no. 582, p. 59.

Biddinger, G.R. and S.P. Gloss. 1984. The importance of trophic transfer in the bioaccumulation of chemical contaminants in aquatic ecosystems. Residue Rev. 91: 103-145.

Biesinger, K.E. and G.M. Christensen. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of *Daphnia magna*. J. Fish. Res. Board Can. 29: 1691.

Biesinger, K.E., G.M. Christensen and J.T. Fiandt. 1986. Effects of metal salt mixtures on *Daphnia magna* reproduction. Ecotoxicol. Environ. Safety. 11: 9-14.

Bigelow, L.K. and D.C. Lasenby. 1991. Particle size selection in cadmium uptake by the opossum shrimp, *Mysis relicta*. Bull. Environ. Contam. Toxicol. 47: 790-796.

Bigot, A., L. Minguez, L. Giamberini and F. Rodius. 2011. Early defense responses in the freshwater bivalve *Corbicula fluminea* exposed to copper and cadmium: transcriptional and histochemical studies. Environ. Toxicol. 26(6): 623-632.

Billoir, E., A.R.R. Pery and S. Charles. 2007. Integrating the lethal and sublethal effects of toxic compounds into the population dynamics of *Daphnia magna*: a combination of the debtox and matrix population models. Ecol. Model. 203(3-4): 204-214.

Billoir, E., H. Delhaye, B. Clement, M.L. Delignette-Muller, and C.S. Bayesian. 2011. Modelling of daphnid responses to time-varying cadmium exposure in laboratory aquatic microcosms. Ecotoxicol. Environ. Saf. 74(4): 693-702.

Billoir, E., H. Delhaye, C. Forfait, B. Clement, G. Triffault-Bouchet, S. Charles and M.L. Delignette-Muller. 2012. Comparison of bioassays with different exposure time patterns: the added value of dynamic modelling in predictive ecotoxicology. Ecotoxicol. Environ. Saf. 75(1): 80-86.

Birceanu, O. , M.J. Chowdhury, P.L. Gillis, J.C. McGeer, C.M. Wood and M.P. Wilkie. 2008. Modes of metal toxicity and impaired branchial ionoregulation in rainbow trout exposed to mixtures of Pb and Cd in soft water. Aquat. Toxicol. 89(4): 222-231.

Bird, D.J.,J.M. Rotchell, S.A. Hesp, L.C. Newton., N.G. Hall and I.C. Potter. 2008. To what extent are hepatic concentrations of heavy metals in *Anguilla anguilla* at a site in a contaminated estuary related to body size and age and reflected in the metallothionein concentrations? Environ. Pollut. 151(3): 641-651.

Birge, W.J. 1978. Aquatic toxicology of trace elements of coal and fly ash. *In:* J.H. Thorp and J.W. Gibbons (eds.), Energy and Environmental Stress in Aquatic Systems. CONF-771114. National Technical Information Service, Springfield, Virginia. p. 219.

Birge, W.J. and J.A. Black. 1981. *In Situ* acute/chronic toxicological monitoring of industrial effluents for the NPDES biomonitoring program using fish and amphibian embryo-larval stages as test organisms. Final Rep.WOEP-82-001, EPA Contract No.68-01-5052, Off. of Water Enforcement and Permits, U.S.EPA, Washington, DC, 121 p.

Birge, W.J., J.E. Hudson, J.A. Black and A.G. Westerman. 1978. Embryo-larval bioassay on inorganic coal elements and *in situ* biomonitoring of coal-waste effluents. *In:* D.E. Samuel, et al. (*Eds*.), Surface Mining and Fish/Wildlife Needs in the Eastern United States. PB 298353. National Technical Information Service, Springfield, Virginia. p. 97.

Birge, W.J., J.A. Black, A.G. Westerman and J.E. Hudson. 1979. The effects of mercury on reproduction of fish and amphibians. *In:* J.O. Nriagu (*Ed.*), The Biochemistry of Mercury in the Environment. Elsevier/North-Holland, New York. p. 629.

Birge, W.J., J.A. Black, A.G. Westerman and J.E. Hudson. 1980. Aquatic toxicity tests on inorganic elements occurring in oil shale. *In:* C. Gale (*Ed.*), Oil Shale Symposium: Sampling, Analysis and Quality Assurance. EPA-600/9-80-022. National Technical Information Service, Springfield, Virginia. p. 519.

Birge, W.J., J.A. Black and B.A. Ramey. 1981. The reproductive toxicology of aquatic contaminants. *In:* J. Saxena and F. Fisher (*Eds.*), Hazard Assessment of Chemicals: Current Developments. Vol. 1. Academic Press, New York. p. 59.

Birge, W.J., W.H. Benson and J.A. Black. 1983. Induction of tolerance to heavy metals in natural and laboratory populations of fish. PB84-111756. National Technical Information Service, Springfield, Virginia.

Birge, W.J., J.A. Black and A.G. Westerman. 1985. Short-term fish and amphibian embryo-larval tests for determining the effects of toxicant stress on early life stages and estimating chronic values for single compounds and complex effluents. Environ. Toxicol. Chem. 4: 807-821.

Birge, W.J., D.J. Price, J.R. Shaw, J.A. Spromberg, A.J. Wigginton and C. Hogstrand. 2000. Metal body burden and biological sensors as ecological indicators: Environ. Toxicol. Chem. 19(4): 1199–1212.

Birmelin, C., J. Cuzin-Roudy, M. Romeo, M. Gnassia-Barelli and S. Puiseux-Dao. 1995. The mysid *Siriella armata* as a test organisms in toxicology: effects of cadmium. Mar. Environ. Res. 39: 317- 320.

Bishop, W.E. and A.W. McIntosh. 1981. Acute lethality and effects of sublethal cadmium exposure on ventilation frequency and cough rate of bluegill *(Lepomis macrochirus*). Arch. Environ. Contam. Toxicol. 10: 519.

Bisova, K., J. Hendrychova, V. Cepak and V. Zachleder. 2003. Cell growth and division processes are differentially sensitive to cadmium in *Scenedesmus quadricauda*. Folia Microbiol. 48(6): 805-816.

Biswas, B. and A. Kaviraj. 2002. Size dependent tolerance of indian cat fish *Heteropneustes fossilis* (Bloch) to toxicity of cadmium and composted vegetation. Bull. Environ. Contam. Toxicol. 68(1): 37-42.

Bittner, M.A. 1994. The effect of dissolved natural organics on the chronic toxicity of cadmium to *Mysidopsis bahia molenock* (Crustacea: Mysidacea). George Mason University (USA), 209 pp.

Bitton, G., K. Jung and B. Koopman. 1994. Evaluation of a microplate assay specific for heavy metal toxicity. Arch. Environ. Contam. Toxicol. 27: 25-28.

Bitton, G., K. Rhodes, B. Koopman and M. Cornejo. 1995. Short-term toxicity assay based on daphnid feeding behavior. Water Environ. Res. 67(3): 290-293.

Bitton, G., K. Rhodes and B. Koopman. 1996. Ceriofast⌣: an acute toxicity test based on *Ceriodaphnia dubia* feeding behavior. Environ. Toxicol. Chem. 15(2): 123-125.

Bjerregaard, P. 1982. Accumulation of cadmium and selenium and their mutual interaction in the shore crab *Carcinus maenas*. Aquat. Toxicol. 2: 113.

Bjerregaard, P. 1985. Effect of selenium on cadmium uptake in the shore crab *Carcinus maenas* (L.). Aquat. Toxicol. 7: 177-189.

Bjerregaard, P. 1991. Relationship between physiological condition and cadmium accumulation in *Carcinus maenas* (L.). Comp. Biochem. Physiol. 99A(1/2): 75-83.

Bjerregaard, P. and M.H. Depledge. 1994. Cadmium accumulation in *Littorina littorea*, *Mytilus edulis* and *Carcinus maenas*: the influence of salinity and calcium ion concentrations. Mar. Biol. 119: 385-395.

Bjerregaard, P. and M.H. Depledge. 2002. Trace metal concentrations and contents in the tissues of the shore crab *Carcinus maenas*: effects of size and tissue hydration. Mar. Biol. 141(4): 741-752.

Bjerregaard, P., L. Bjorn, U. Norum and K.L. Pedersen. 2005. Cadmium in the shore crab *Carcinus maenas*: seasonal variation in cadmium content and uptake and elimination of cadmium after administration via food. Aquat.Toxicol. 72(1/2): 5-15.

Black, J.A. and W.J. Birge. 1980. An avoidance response bioassay for aquatic pollutants. PB80-180490. National Technical Information Service, Springfield, Virginia.

Black, M.C. 2001. Water quality standards for North Carolina's endangered mussels. Final Report, Dept. of Environ. Health Sci., Univ.of Georgia, Athens, GA, 34 p.

Black, M.C. 2003. Water quality standards for North Carolina's endangered mussels. Final Report (Revised), Dept. of Environ. Health Sci., Univ. of Georgia, Athens, GA, 26 p.

Blackmore, G. and W.X. Wang. 2002. Uptake and efflux of Cd and Zn by the green mussel *Perna viridis* after metal preexposure. Environ. Sci. Technol. 36(5): 989-995.

Blechinger, S. R., J.T. Warren, Jr., J.Y. Kuwada and P.H. Krone. 2002. Developmental toxicology of cadmium in living embryos of a stable transgenic zebrafish line. Environ. Health Perspect. 110(10): 1041-1046.

Blickens, E.A.M. 1978. Cadmium induced histopathological changes in the gills of the brown bullhead *Ictalurus nebulosus* (Lesueur). Ph.D. Thesis. New York University.

Blinova, I. 2004. Use of freshwater algae and duckweeds for phytotoxicity testing. Environ. Toxicol. 19: 425-428.

Block, M. and A.W. Glynn. 1992. Influence of xanthates on the uptake of ^{109}Cd by Eurasian dace (*Phoxinus phoxinus*) and rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 11: 873-879.

Block, M. and P. Part. 1992. Uptake of ^{109}Cd by cultured gill epithelial cells from rainbow trout (*Oncorhynchus mykiss*). Aquat. Toxicol. 23: 137-151.

Block, M, A.W. Glynn and P. Part. 1991. Xanthate effects on cadmium uptake and intracellular distribution in rainbow trout (*Oncorhynchus mykiss*) gills. Aquat. Toxicol. 20: 267-284.

Blondin, G.A., L.M. Knobeloch, H.W. Read and J.M. Harkin. 1989. An *in vitro* submitochondrial bioassay for predicting acute toxicity in fish. Aquat. Toxicol. Environ. Fate. ASTM STP 1007, G.W. Suter II and M.A. Lewis (*Eds.*), American Society for Testing and Materials, Philadelphia. 11: 551-563.

Blood, E.G., J.R. Reed and G.C. Grant. 1974. The influence of nitrilotriacetic acid on heavy metal ion uptake in bluegills, *Lepomis macrochirus* Rafinesque (Pisces). ASB Bull. 21(2): 40.

Bocchetti, R., D. Fattorini, M.C. Gambi and F. Regoli, F. 2004. Trace metal concentrations and susceptibility to oxidative stress in the polychaete *Sabella spallanzanii* (Gmelin) (Sabellidae): potential role of antioxidants in revealing stressful environmental conditions in the Mediterranean. Arch. Environ. Contam. Toxicol. 46(3): 353-361.

Bochenek, I., M. Protasowicki and E. Brucka-Jastrzebska. 2008. Concentrations of Cd, Pb, Zn, and Cu in roach, *Rutilus rutilis* (L.) from the lower reaches of the Oder River, and their correlation with concentrations of heavy metals in bottom sediments collected in the same area. Arch. Pol. Fish. 16(1): 21-36.

Bodar, C.W.M., I. Van der Sluis, P.A. Voogt and D.I. Zandee. 1988a. Effects of cadmium on consumption, assimilation and biochemical parameters of *Daphnia magna*: possible implications for reproduction. Comp. Biochem. Physiol. 90C(2): 341-346.

Bodar, C.W.M., C.J. Van Leeuwen, P.A. Voogt and D.I. Zandee. 1988b. Effect of cadmium on the reproduction strategy of *Daphnia magna*. Aquat. Toxicol. 12: 301-310.

Bodar, C.W.M., A.V.D. Zee, P.A. Voogt, H. Wynne and D.I. Zandee. 1989. Toxicity of heavy metals to early life stages of *Daphnia magna*. Ecotoxicol. Environ. Safety. 17: 333-338.

Bodar, C.W.M., P.A. Voogt and D.I. Zandee. 1990a. Ecdysteroids in *Daphnia magna*: their role in moulting and reproduction and their levels upon exposure to cadmium. Aquat. Toxicol. 17: 339-350.

Bodar, C.W.M., I. Van der Sluis, J.C.P., Van Montfort, P.A. Voogt and D.I. Zandee. 1990b. Cadmium resistance in *Daphnia magna*. Aquat. Toxicol. 16: 5633-40.

Boese, B.L., J.O. Lamberson, R.C. Swartz amd R.J. Ozretich. 1997. Photoinduced toxicity of fluoranthene to seven marine benthic crustaceans. Arch. Environ. Contam. Toxicol. 32(4): 389-393.

Boets, P., K. Lock, P.L.M. Goethals, C.R. Janssen and K.A.C.A. De Schamphelaere. 2012. Comparison of the short-term toxicity of cadmium to indigenous and alien gammarid species. Ecotoxicol. 21(4): 1135-1144.

Boga, A., S. Erdogan, and Y. Sertdemir. 2008. Effects of specific dosages of magnesium and zinc on the teratogenicity of cadmium, nickel, and cobalt in Xenopus embryos, as assessed by the fetax test. Dose Response. 6(1):16-29.

Bohn, A. and Mcelroy, R.O. 1976. Trace metals arsenic cadmium copper iron and zinc in arctic cod *Boreogadus saida* and selected zoo plankton from Strathcona Sound Northern Baffin Island. J Fish. Res. Board Can. 33(12): 2836-2840.

Boisson, F., F. Goudard, J.P. Durand, C. Barbot, J. Pier, J.C. Amiard and S.W. Fowler. 2003. Comparative radiotracer study of cadmium uptake, storage, detoxification and depuration in the oyster crassostrea gigas: potential adaptive mechanisms. Mar. Ecol. Prog. Ser. 254:177-186.

Bolanos, L., M. Garcia-Gonzalez, P. Mateo and I. Bonilla. 1992. Differential toxicological response to cadmium in *Anabaena* strain PCC 7119 grown with NO_3^- or NH_4^+ as nitrogen source. J. Plant Physiol. 140: 345-349.

Bonneris, E., O. Perceval, S. Masson, L. Hare and P.G.C. Campbell. 2005. Sub-cellular partitioning of Cd, Cu and Zn in tissues of indigenous unionid bivalves living along a metal exposure gradient and links to metal-induced effects. Environ.Pollut. 135(2): 195-208.

Boonyapookana, B., E.S. Upatham, M. Kruatrachue, P. Pokethitiyook and S. Singhakaew. 2002. Phytoaccumulation and phytotoxicity of cadmium and chromium in duckweed *Wolffia globosa*. Int. J. Phytoremed. 4(2): 87-100.

Borane, V.R., R.D. Patil and S.P. Zambare. 2008. Ascorbate effect on the cadmium induced alterations in the behavior of the fresh water fish *Channa orientalis* (Schneider). J. Aquat. Biol. 23(2): 155-158.

Borchardt, T. 1983. Influence of food quantity on the kinetics of cadmium uptake and loss via food and seawater in *Mytilus edulis*. Mar. Biol. 76: 67-76.

Borchardt, T. 1988. Biological monitoring in the central and southern north sea heavy metal contamination of mussels *Mytilus edulis* L.l. Z Angew. Zool. 75(1): 1988. 3-36.

Borcherding, J. and J. Wolf. 2001. The influence of suspended particles on the acute toxicity of 2-chloro-4-nitro-aniline, cadmium, and pentachlorophenol on the valve movement response of the zebra mussel (*Dreissena polymorpha*). Arch. Environ. Contam. Toxicol. 40(4): 497-504.

Bordajandi, L.R., G. Gomez, M.A. Fernandez, E. Abad, J. Rivera and M.J. Gonzalez. 2003. Study on PCBs, PCDD/Fs, organochlorine pesticides, heavy metals and arsenic content in freshwater fish species from the River Turia (Spain). Chemosphere 53(2): 163-171.

Borgmann, U. and K.M. Ralph. 1986. Effects of cadmium, 2,4-dichlorophenol, and pentachlorophenol on feeding, growth, and particle-size-conversion efficiency of white sucker larvae and young common shiners. Arch. Environ. Contam. Toxicol. 15: 473-480.

Borgmann, U., E.S. Millard and C.C. Charlton. 1989a. Effect of cadmium on a stable, large volume, laboratory ecosystem containing *Daphnia* and phytoplankton. Can. J. Fish. Aquat. Sci. 46: 399-405.

Borgmann, U., K.M. Ralph and W.P. Norwood. 1989b. Toxicity test procedures for *Hyalella azteca*, and chronic toxicity of cadmium and pentachlorophenol to *H. azteca*, *Gammarus fasciatus*, and *Daphnia magna*. Arch. Environ. Contam. Toxicol. 18: 756-764.

Borgmann, U., W.P. Norwood and I.M. Babirad. 1991. Relationship between chronic toxicity and bioaccumulation of cadmium in *Hyalella azteca*. Can. J. Fish. Aquat. Sci. 48: 1055-1060.

Borgmann, U., Y. Couillard, P. Doyle and D.G. Dixon. 2005. Toxicity of sixty-three metals and metalloids to *Hyalella azteca* at two levels of water hardness: Environ. Toxicol. Chem. 24(3): 641-652.

Borgmann, U., Y. Couillard and L.C. Grapentine. 2007. Relative contribution of food and water to 27 metals and metalloids accumulated by caged *Hyalella azteca* in two rivers affected by metal mining. Environ. Pollut. 145(3): 753-765.

Boscher, A., S. Gobert, C. Guignard, J. Ziebel, L. L'Hoste, A.C. Gutleb, H.M. Cauchie, L. Hoffmann and G. Schmidt. 2010. Chemical contaminants in fish species from rivers in the north of Luxembourg: potential impact on the Eurasian otter (*Lutra lutra*). Chemosphere 78(7): 785-92.

Bosnak, A.D. and E.L. Morgan. 1981. Acute toxicity of cadmium, zinc, and total residual chlorine to epigean and hypogean isopods (Asellidae). Natl. Speleolog. Soc. Bull. 43: 12.

Botton, M.L. 2000. Toxicity of cadmium and mercury to horseshoe crab (*Limulus polyphemus*) embryos and larvae. Bull. Environ. Contam. Toxicol. 64(1): 137-143.

Bouallam, S. and A. Nejmeddine. 2001. Effects of heavy metals - Cu, Hg, Cd - on three species of mosquitoes larvae (Diptera: Culicidae). Ann.Limnol. 37(1): 49-57.

Boughammoura, S., K. Kessabi, L. Chouchene and I. Messaoudi. 2013. Effects of cadmium and high temperature on some parameters of calcium metabolism in the killifish (*Aphanius fasciatus*). Biol. Trace Elem. Res. 154(1): 73-80.

Boullemant, A., S. Le Faucheur, C. Fortin and P.G. Campbell. 2011. Uptake of lipophilic cadmium complexes by three green algae: influence of humic acid and its pH dependence. J. Phycol. 47(4): 784-791.

Bouquegneau, J.M. and M. Martoja. 1982. La teneur en cuivre et son degre de complexation chez quatre gasteropodes marins. Donnees sur le cadmium et zinc. Oceanologica Acta 5: 219.

Bouraoui, Z., M. Banni, J. Ghedira, C. Clerandeau, H. Guerbej, J.F. Narbonne and H. Boussetta. 2008. Acute effects of cadmium on liver phase I and phase II enzymes and metallothionein accumulation on sea bream *Sparus aurata*. Fish Physiol. Biochem. 34(3): 201-207.

Bourgeault, A., C. Gourlay-France and M.H. Tusseau-Vuillemin. 2010. Modeling the effect of water chemistry on the bioaccumulation of waterborne cadmium in zebra mussels. Environ. Toxicol. Chem. 29(10): 2182-2189.

Bourret, V., P. Couture, P.G.C. Campbell and L. Bernatchez. 2008. Evolutionary ecotoxicology of wild yellow perch (*Perca flavescens*) populations chronically exposed to a polymetallic gradient. Aquat. Toxicol. 86(1): 76-90.

Boutet, C. and C. Chaisemartin. 1973. Specific toxic properties of metallic salts in *Austropotamobius pallipes pallipes* and *Orconectes limosus*. C.R. Soc. Biol. 167: 1933.

Bouzon, Z.L., E.C. Ferreira, R. dos Santos, F. Scherner, P.A. Horta, M. Maraschin and E.C. Schmidt. 2011. Influences of cadmium on fine structure and metabolism of *Hypnea musciformis* (Rhodophyta, Gigartinales) cultivated in vitro. Protoplasma. 249(3): 637-650.

Bovee, E.C. 1975. Effects of Certain Chemical Pollutants on Small Aquatic Animals. Res. Proj. Conducted by The Kansas Water Resour. Res. Inst., Univ.of Kansas, Lawrence, KS, 8 p.

Bowen, W.J. and D.W. Engel. 1996. Effects of protracted cadmium exposure on gametes of the purple sea urchin, *Arbacia punctulata*. Bull. Environ. Contam. Toxicol. 56: 493-499.

Bowmer, T., H.A. Jenner, E. Foekema and M. Van der Meer. 1994. The detection of chronic biological effects in the marine intertidal bivalve *Cerastoderma edule*, in model ecosystem studies with pulverised fuel ash: reproduction and histopathology. Environ. Pollut. 85(2): 191-204.

Boyd, W.A., S.J. McBride, J.R. Rice, D.W. Snyder and J.H. Freedman. 2010. A high-throughput method for assessing chemical toxicity using a *Caenorhabditis elegans* reproduction assay. Toxicol. Appl. Pharmacol. 245(2): 153-159.

Boyden, C.R. 1977. Effect of size upon metal content of shellfish. J. Mar. Biol. Assoc. U.K. 57: 675.

Boyer, H.A. 1984. Trace elements in the water, sediments, and fish of the Upper Mississippi River, Twin Cities metropolitan area. *In*: J.G. Wiener, R.V. Anderson and D.R. McConville (*Eds*.), Contaminants in the Upper Mississippi River: Boston, Butterworth Publishers, p. 195-230.

Boyle, D., K.V. Brix, H. Amlund, A.K. Lundebye, C. Hogstrand and N.R. Bury. 2008. Natural arsenic contaminated diets perturb reproduction in fish. Environ. Sci. Technol. 42(14): 5354-5360.

Bozcaarmutlu, A. and E. Arinc. 2007. Effect of mercury, cadmium, nickel, chromium and zinc on kinetic properties of NAPDH-Cytochrome P450 reductase purified from leaping mullet (*Liza saliens*). Toxicol. In Vitro 21(3) 408-416.

Bozeman, J., B. Koopman and G. Bitton. 1989. Toxicity testing using immobilized algae. Aquat. Toxicol. 14: 345-352.

Bradac, P., E. Navarro, N. Odzak, R. Behra and L. Sigg. 2009. Kinetics of cadmium accumulation in periphyton under freshwater conditions. Environ. Toxicol. Chem. 28(10): 2108-2116.

Bradac, P., B. Wagner, D. Kistler, J. Traber, R. Behra and L. Sigg. 2010. Cadmium speciation and accumulation in periphyton in a small stream with dynamic concentration variations. Environ. Pollut. 158(3): 641-648.

Braeutigam, A., D. Schaumloeffel, H. Preud'homme, I. Thondorf and D. Wesenberg. 2011. Physiological characterization of cadmium-exposed *Chlamydomonas reinhardtii*. Plant Cell Environ. 34(12): 2071-2082.

Braginskly, L.P. and E.P. Shcherban. 1978. Acute toxicity of heavy metals to aquatic invertebrates at different temperatures. Hydrobiol. J. 14(6): 78.

Branco, D., A. Lima, S.F.P. Almeida and E. Figueira. 2010. Sensitivity of biochemical markers to evaluate cadmium stress in the freshwater diatom *Nitzschia palea* (Kuetzing) W. Smith. Aquat. Toxicol. 99(2): 109-117.

Brand, L.E., W.G. Sunda and R.R.L. Guillard. 1986. Reduction of marine phytoplankton reproduction rates by copper and cadmium. J. Exp. Mar. Biol. Ecol. 96: 225-250.

Brandao, J.C., H.H.L. Bohets, I.E. Van de Vyver and P.J. Dierickx. 1992. Correlation between the *in vitro* cytotoxicity to cultured fathead minnow fish cells and fish lethality data for 50 chemicals. Chemosphere 25(4): 553-562.

Brauwers, C. 1983. Comparison of Zn and Cd toxicity on *Chlorella*. Aquat. Sci. Fish. Abstr. Pt. 1, 13(5): 161-162.

Brauwers, C. 1985. Algae and heavy metal pollution. C. A. Sel. Environ. Pollut. 14, 1-(ABS NO. 103:1579C).

Brent, R.N. and E.E. Herricks. 1998. Postexposure effects of brief cadmium, zinc, and phenol exposures on freshwater organisms. Environ. Toxicol. Chem. 17(10): 2091-2099.

Bresler, V. and V. Yanko. 1995. Acute toxicity of heavy metals for benthic epiphytic foraminifera *Pararotalia spinigera* (Le Calvez) and influence of seaweed-derived DOC. Environ. Toxicol. Chem. 14(10): 1687-1695.

Bressan, M. and R. Brunetti. 1988. The effects of nitriloacetic acid, Cd and Hg on the marine algae *Dunaliella tertiolecta* and *Isochrysis galbana*. Water Res. 22(5): 553-556.

Bringmann, G. 1975. Determination of the biologically harmful effect of water pollutants by means of the retardation of cell proliferation of the blue algae *Microcystis*. Gesundheits-Ing. 96: 238.

Bringmann, G. 1978. Determination of the biological toxicity of waterbound substances towards protozoa. I. bacteriovorous flagellates (model organism: *Entosiphon sulcatum* Stein). Z. Wasser Abwasser Forsch. 11: 210.

Bringmann, G. 1979. Determination of the biological toxicity of water pollutants on protozoa. Z. Wasser-Abwasser-Forsch. 11(6): 210-215.

Bringmann, G. and R. Kuhn. 1959a. The toxic effects of waste water on aquatic bacteria, algae, and small crustaceans. Gesundheits-Ing. 80: 115.

Bringmann, G. and R. Kuhn. 1959b. Water toxicology studies with protozoans as test organisms. Gesundheits-Ing. 80: 239.

Bringmann, G. and R. Kuhn. 1976. Comparative results of the damaging effects of water pollutants against bacteria (*Pseudomonas putida*) and blue algae (*Microcystis aeruginosa*). Gas-Wasserfach, Wasser-Abwasser 117: 410.

Bringmann, G. and R. Kuhn. 1977a. Limiting values for the damaging action of water pollutants to bacteria (*Pseudomonas putida*) and green algae *(Scenedesmus quadricauda*) in the cell multiplication inhibition test. Z. Wasser Abwasser Forsch. 10: 87.

Bringmann, G. and R. Kuhn. 1977b. Results of damaging effect of water pollutants on *Daphnia magna*. Z. Wasser Abwasser Forsch. 10: 161.

Bringmann, G. and R. Kuhn. 1977c. Toxicity threshold for eater pollutants in the cell multiplication test with respect to bacteria (*Pseudomonas putida*) and green algae (*Scenedesmus quadricauda*). Z. Wasser-Abwasser-Forsch. 10(3-4): 87-98.

Bringmann, G. and R. Kuhn. 1978a. Limiting values for the noxious effects of water pollutant material to blue algae (*Microcystis aeruginosa*) and green algae (*Scenedesmus quadricauda*) in cell propagation inhibition test. Vom Wasser 50: 45.

Bringmann, G. and R. Kuhn. 1978b. Testing of substances for their toxicity threshold: model organisms *Microcystis (Diplocystis) aeruginosa* and *Scenedesmus quadricauda*. Mitt. Int. Ver. Theor. Angew. Limnol. 21: 275.

Bringmann, G. and R. Kuhn. 1979. Comparison of toxic limiting concentrations of water contaminants toward bacteria, algae, and protozoa in the cell-growth inhibition test. Haustech. Bauphys. Umwelttech. 100: 249.

Bringmann, G. and R. Kuhn. 1980a. Determination of the harmful biological effect of water pollutants on protozoa. II. bacteriovorous ciliates. Z. Wasser Abwasser Forsch. 13: 26.

Bringmann, G. and R. Kuhn. 1980b. Comparison of the toxicity thresholds of water pollutants to bacteria, algae, and protozoa in the cell multiplication inhibition test. Water Res. 14: 231.

Bringmann, G. and R. Kuhn. 1981. Comparison of the effects of harmful substances on flagellates as well as ciliates and on halozoic bacteriophagous and saprozoic protozoa. Gas-Wasserfach, Wasser-Abwasser 122: 308.

Bringmann, G. and R Kuhn. 1982. Results of toxic action of water pollutants on *Daphnia magna* Straus tested by an improved standardized procedure. Z. Wasser Abwasser Forsch. 15: 1.

Bringmann, G., R. Kuhn and A. Winter. 1980. Determination of biological damage from water pollutants to protozoa. III. Saprozoic flagellates. Z. Wasser Abwasser Forsch. 13(5): 170-173.

Bringolf, R.B., M.C. Barnhardt, and W.G. Cope. 2013. Determining the appropriate duration of toxicity tests with glochidia of native freshwater mussels. Final Completion Report for the period August 1, 2010 through July 31, 2012. U.S. EPA Region V

Brinke, M., K. Ristau, M. Bergtold, S. Hoss, E. Claus, P. Heininger and W. Traunspurger. 2011. Using meiofauna to assess pollutants in freshwater sediments: a microcosm study with cadmium. Environ. Toxicol. Chem. 30(2): 427-438.

Brinkhurst, R.O., P.M Chapman and M.A. Farrell. 1983. A comparative study of respiration rates of some aquatic oligochaetes in relation to sublethal stress. Int. Rev. Gesamten Hydrobiol. 68(5): 683-699.

Brinkman, S.F. 2012. Water pollution studies. Federal Aid Project F-243R-19. Job Progress Report, Colorado Div. of Wildlife, Fort Collins, CO, 27 pp.

Brinkman, S.F. and D.L. Hansen. 2004a. Effect of hardness on cadmium toxicity to brown trout (*Salmo trutta*) embryos, larvae, and fry. Water Pollution Studies, Federal Aid in Fish and Wildlife Restoration Project F-243-R11. Colorado Division of Wildlife Fort Collins, CO, p. 4-20.

Brinkman, S.F. and D.L. Hansen. 2004b, Effect of hardness on zinc toxicity to Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) and rainbow trout (*Oncorhynchus mykiss*) embryos and fry. Water Pollution Studies, Federal Aid in Fish and Wildlife Restoration Project F-243-R11. Colorado Division of Wildlife Fort Collins, CO, p. 22–35.

Brinkman, S.F. and D.L. Hansen. 2007. Toxicity of cadmium to early life stages of brown trout (*Salmo trutta*) at multiple water hardnesses. Environ. Toxicol. Chem. 26(8): 1666-1671.

Brinkman, S.F. and W.D. Johnston. 2008. Acute toxicity of aqueous copper, cadmium, and zinc to the mayfly *Rhithrogena hageni*. Arch. Environ. Contam. Toxicol. 54(3): 466-472.

Brinkman, S.F. and N. Vieira. 2007. Water pollution studies. Federal Aid Project F-243-R14, Job Progress Report, Colorado Div. of Wildlife, Fort Collins, CO, 98 p.

Brinkman, S.F. and N. Vieira. 2008. Water pollution studies. Federal Aid Project F-243-R15, Job Progress Report, Colorado Div. of Wildlife, Fort Collins, CO, 38 p.

Brinza, L., C.A. Nygard, M.J. Dring, M. Gavrilescu and L.G. Benning. 2009. Cadmium tolerance and adsorption by the marine brown alga *Fucus vesiculosus* from the Irish Sea and the Bothnian Sea. Bioresour. Technol. 100(5): 1727-1733.

British Columbia Ministry of Environment (BC-MOE). 2014. Ambient water quality guidelines for cadmium. Technical Report. Water Protection and Sustainability Branch, Environmental Sustainability and Strategic Policy Division, BC Ministry of Environment, 93 pp.

Brix, K.V., R.M. Gerdes, W.J. Adams and M. Grosell. 2006. Effects of copper, cadmium, and zinc on the hatching success of brine shrimp (*Artemia franciscana*). Arch. Environ. Contam. Toxicol. 51(4): 580-583.

Brix, K.V., D.K. DeForest and W.J. Adams. 2011. The sensitivity of aquatic insects to divalent metals: a comparative analysis of laboratory and field data. Sci. Total Environ. 409(20): 4187-4197.

Brkovic-Popovic, I. and M. Popovic. 1977a. Effects of heavy metals on survival and respiration rate of tubificid worms: Part I-effects on survival. Environ. Pollut. 13:65.

Brkovic-Popovic, I. and M. Popovic. 1977b. Effects of heavy metals on survival and respiration rate of tubificid worms: Part II-effects on respiration rate. Environ. Pollut. 13: 93.

Brooks, A.C., P.N. Gaskell and L.L. Maltby. 2009. Sublethal effects and predator-prey interactions: implications for ecological risk assessment. Environ. Toxicol. Chem. 28(11): 2449-2457.

Brooks, A.W., L. Maltby, A.J. Saul and P. Calow. 1996. A simple indoor artificial stream system designed to study the effects of toxicant pulses on aquatic organisms. Water Res. 30(2): 285-290.

Brooks, B.W., J.K. Stanley, J.C. White, P.K. Turner, K.B. Wu and T.W. La Point. 2004. Laboratory and field responses to cadmium: an experimental study in effluent-dominated stream mesocosms. Environ. Toxicol. Chem. 23(4): 1057-1064.

Brouwer, M, D.W. Engel, J. Bonaventura and G.A. Johnson. 1992. In vivo magnetic resonance imaging of the blue crab, *Callinectes sapidus*: effect of cadmium accumulation in tissues on proton relaxation properties. J. Exp. Zool. 263: 32-40.

Brown, A.F. and D. Pascoe. 1988. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates: V. The acute toxicity of cadmium to twelve species of predatory macroinvertebrates. Arch. Hydrobiol. 114(2): 311-319.

Brown, B. and M. Ahsanullah. 1971. Effect of heavy metals on mortality and growth. Mar. Pollut. Bull. 2: 182.

Brown, D.A. S.M. Bay, J.F. Alfafara, G.P. Hershelman and K.D. Rosenthal. 1984. Detoxification/toxification of cadmium in scorpionfish (*Scorpaena quttata*): acute exposure. Aquat. Toxicol. 5(2): 93-107.

Brown, G.W.J. 1976. Effects of polluting substances on enzymes of aquatic organisms. J. Fish. Res. Board Can. 33(9): 2018-2022.

Brown, M.W., D.G. Thomas, D. Shurben, J.F. De L.G. Solbe, J. Kay and A. Cryer. 1986. A comparison of the differential accumulation of cadmium in the tissues of three species of freshwater fish, *Salmo Gairdneri*, *Rutilus rutilus* and *Noemacheilus barbatulus*. Comp. Biochem. Physiol. 84C(2): 213-217.

Brown, V., D. Shurben, W. Miller and M. Crane. 1994. Cadmium toxicity to rainbow trout *Oncorhynchus mykiss* Walbaum and brown trout *Salmo trutta* L. over extended exposure periods. Ecotoxicol. Environ. Safety. 29: 38-46.

Brucka-Jastrzebska, E. and M. Protasowicki. 2004. Elimination dynamics of cadmium, administered by a single intraperitoneal injection, in common carp, *Cyprinus carpio* L. Acta Ichthyol. Piscatoria 34(2): 167-179.

Brumbaugh, W.G., C.J. Schmitt and T.W. May. 2005. Concentrations of cadmium, lead, and zinc in fish from mining-influenced waters of northeastern Oklahoma: sampling of blood, carcass, and liver for aquatic biomonitoring. Arch. Environ. Contam. Toxicol. 49(1): 76-88.

Brunelli, E., A. Mauceri, M. Maisano, I. Bernabn, A. Giannetto, E. De Domenico, B. Corapi, S. Tripepi and S. Fasulo. 2011. Ultrastructural and immunohistochemical investigation on the gills of the teleost, *Thalassoma pavo* L., exposed to cadmium. Acta Histochem. 113(2): 201-213.

Brunetti, R., M. Marin, M. Bressan, M. Zordan and A. Soggia. 1991. Effects of the chelating agent nitrilotriacetic acid (NTA) on the toxicity of metals (Cd, Cu, Zn and Pb) in the sea urchin *Paracentrotus lividus* LMK. Vie Milieu. 41(1): 39-43.

Brunham, W. and L.I. Bendell. 2011. The effect of temperature on the accumulation of cadmium, copper, zinc, and lead by *Scirpus acutus* and *Typha latifolia*: a comparative analysis. Water Air Soil Pollut. 219(1-4): 417-428.

Bryan, G.W. 1971. The effects of heavy metals (other than mercury) on marine and estuarine organisms. Proc. R. Soc. London B. 177: 389.

Bryan, G.W. and W.J. Langston. 1992. Bioavailability, accumulation and effects of heavy metals in sediments with special reference to united kingdom estuaries: a review. Environ. Pollut. 76: 89-131.

Bryan, G.W., W.J. Langston, L.G. Hummerstone, G.R. Burt and Y.B. Ho. 1983. An assessment of the gastropod, *Littorina littorea*, as an indicator of heavy metal contamination in United Kingdom estuaries. J. Mar. Biol. Assoc. U.K. 63(2): 327-345.

Bryan, M.D., G.J. Atchison and M.B. Sandheinrich. 1995. Effects of cadmium on the foraging behavior and growth of juvenile bluegill, *Lepomis macrochirus*. Can. J. Fish. Aquat. Sci. 53: 1630-1638.

Bryson, W.T., W.R. Garrett, M.A. Mallin, K.A. MacPherson, W.E. Partin and S.E. Woock. 1984b. Roxboro steam electric plant 1982 environmental monitoring studies volume II Hyco Reservoir bioassay studies. Carolina Power and Light Company, New Hill, NC, 82 p.

Bryson, W.T., W.R. Garrett, M.A. Mallin, K.A. MacPherson, W.E. Partin andS.E. Woock. 1984a. Roxboro steam electric plant preliminary hyco bioassay report for 1983. Carolina Power and Light Company, New Hill, NC, 88 p.

Buchwalter, D.B., D.J. Cain, W.H. Clements and S.N. Luoma. 2007. Using biodynamic models to reconcile differences between laboratory toxicity tests and field biomonitoring with aquatic insects. Environ. Sci. Technol. 41(13): 4821-4828.

Buckley, J.A., G.A. Yoshida, N.R. Wells and R.T. Aquino. 1985. Toxicities of total and chelex-labile cadmium to salmon in solutions of natural water and diluted sewage with potentially different cadmium complexing capacities. Water Res. 19(12): 1549-1554.

Budambula, N.L.M. and E.C. Mwachiro. 2006. Metal status of Nairobi River waters and their bioaccumulation in *Labeo cylindricus*. Water Air Soil Pollut. 169: 275-291.

Buhl, K.J. 1997. Relative sensitivity of three endangered fishes, Colorado squawfish, bonytail, and razorback sucker, to selected metal pollutants. Ecotoxicol. Environ. Safety. 37: 186-192.

Buhl, K.J. and S.J. Hamilton. 1991. Relative sensitivity of early life stages of arctic grayling, coho salmon, and rainbow trout to nine inorganics. Ecotoxicol. Environ. Safety. 22: 184-197.

Buikema, A.L., J. Cairns and G.W. Sullivan. 1973. Development and assessment of acute bioassay techniques for the littoral rotifer, *Philodina acuticornis*. Office Water Res.and Technol., Washington D.C. 35 p. (U.S.NTIS PB-290937).

Buikema, A.L.Jr., C.L. See and J. Cairns Jr. 1974a. Rotifers as monitors of heavy metal pollution in water. Bulletin 71. Virginia Water Resources Research Center, Blacksburg, Virginia.

Buikema, A.L.Jr. J. Cairns Jr. and G.W. Sullivan. 1974b. Evaluation of *Philodina acuticornis* (Rotifera) as a bioassay organism for heavy metals. Water Res. Bull. 10(4): 648-661.

Buikema, A.L.Jr., C.L. See and J. Cairns Jr. 1977. Rotifer sensitivity to combinations of inorganic water pollutants. Bulletin 92. Virginia Water Resources Research Center, Blacksburg, Virginia.

Bulus Rossini, G.D. and A.E. Ronco. 2004. Sensitivity of *Cichlasoma facetum* (Cichlidae, Pisces) to metals. Bull. Environ. Contam. Toxicol. 72(4): 763-768.

Bunluesin, S., P. Pokethitiyook, G.R. Lanza, J.F. Tyson, M. Kruatrachue, B. Xing and S. Upatham. 2007. Influences of cadmium and zinc interaction and humic acid on metal accumulation in *Ceratophyllum demersum*. Water Air Soil Pollut. 180:(1-4): 225-235.

Bu-Olayan, A.H. and B.V. Thomas. 2008. Trace metals toxicity and bioaccumulation in mudskipper *Periophthalmus waltoni* Koumans 1941 (Gobiidae: Perciformes). Turk. J. Fish. Aquat.Sci. 8(2): 215-218

Bu-Olayan, A.H., B.V.Thomas and M.S. Husaini. 2008. Trace metals toxicity to the body structures of mullet *Liza klunzingeri* (Mugilidae: Perciformes). Int. J. Environ. Res. 2(3): 249-254.

Burdin, K.S. and K.T. Bird. 1994. Heavy metal accumulation by carrageenan and agar producing algae. Bot. Mar. 37: 467-470.

Burger, J. 2007. A framework and methods for incorporating gender-related issues in wildlife risk assessment: Gender-related differences in metal levels and other contaminants as a case study. Environ. Res. 104: 153-162.

Burger, J. 2008. Assessment and management of risk to wildlife from cadmium. Sci. Total Environ. 389(1): 37-45.

Burger, J. and K.R. Campbell. 2004. Species differences in contaminants in fish on and adjacent to the Oak Ridge Reservation, Tennessee. Environ. Res. 96(2): 145-155.

Burger, J. and M. Gochfeld. 2005. Heavy metals in commercial fish in New Jersey. Environ. Res. 99(3): 403-412. A

Burger, J., K. Cooper and M. Gochfeld. 1992. Exposure assessment for heavy metal ingestion from a sport fish in Puerto Rico: estimating risk for local fishermen. J. Toxicol. Environ. Health 36(4): 355-365.

Burger, J., K.F. Gaines, C.S. Boring, W.L. Stephens, J. Snodgrass, C. Dixon, M. McMahon, S. Shukla, T. Shukla and M. Gochfeld. 2002a. Metal levels in fish from the Savannah River: potential hazards to fish and other receptors. Environ. Res. 89(1): 85-97.

Burger, J., C. Dixon, T. Shukla, N. Tsipoura and M. Gochfeld. 2002b. Metal levels in horseshoe crabs (*Limulus polyphemus*) from Maine to Florida. Environ. Res. 90(3): 227-236.

Burger, J., E.F. Orlando, M. Gochfeld, G.A. Binczik and L.J. Guillette Jr. 2004. Metal levels in tissues of Florida gar (*Lepisosteus platyrhincus*) from Lake Okeechobee. Environ. Monit. Assess. 90(1-3): 187-201.

Burger, J., K.R. Campbell, S. Murray, T.S. Campbell, K.F. Gaines, C. Jeitner, T. Shukla, S. Burke, and M. Gochfeld. 2007a. Metal levels in blood, muscle and liver of water snakes (*Nerodia spp*.) from New Jersey, Tennessee and South Carolina. Sci.Total Environ. 373: 556-563.

Burger, J., M. Gochfeld, C. Jeitner, S. Burke and T. Stamm. 2007b. Metal levels in flathead sole (*Hippoglossoides elassodon*) and great sculpin (*Myoxocephalus polyacanthocephalus*) from Adak Island, Alaska: potential risk to predators and fishermen. Environ. Res. 103(1): 62-69.

Burger, J., M. Gochfeld, T. Shukla, C. Jeitner, S. Burke, M. Donio, S. Shukla, R. Snigaroff, D. Snigaroff, T. Stamm and C. Volz. 2007c. Heavy metals in pacific cod (*Gadus macrocephalus*) from the Aleutians: location, age, size, and risk. J. Toxicol. Environ. Health 70A(22): 911.

Burgos, M.G. and P.S. Rainbow. 2001. Availability of cadmium and zinc from sewage sludge to the flounder, *Platichthys flesus*, via a marine food chain. Mar. Environ. Res. 51(5): 417-439.

Burke, J., R.D. Handy and S.D. Roast. 2003. Effect of low salinity on cadmium accumulation and calcium homeostasis in the shore crab (carcinus maenas) at fixed free Cd2+ concentrations. Environ. Toxicol. Chem. 22(11): 2761-2767.

Burnison, B.K., T. Meinelt, R. Playle, M. Pietrock, A. Wienke and C.E.W. Steinberg. 2006. Cadmium accumulation in zebrafish (*Danio rerio*) eggs is modulated by dissolved organic matter (DOM). Aquat.Toxicol. 79(2):185-191.

Burnison, G., P.T.S. Wong, Y.K. Chau and B. Silverberg. 1975. Toxicity of cadmium to freshwater algae. Proc. Can. Fed. Biol. Soc. 18(182): 46.

Burrell, D.C. and D. Weihs. 1983. Uptake of cadmium by marine bacteria and transfer to a deposit feeding clam. Sea Grant Report 83-5. University of Alaska, Fairbanks, AK.

Burt, A., W. Maher, A. Roach, F. Krikowa, P. Honkoop and B. Bayne. 2007. The accumulation of Zn, Se, Cd, and Pb and physiological condition of *Anadara trapezia* transplanted to a contamination gradient in Lake Macquarie, New South Wales, Australia. Mar. Environ. Res. 64: 54-78.

Burton, D.T. and D.J. Fisher. 1990. Acute toxicity of cadmium, copper, zinc, ammonia, 3,3'-dichlorobenzidine, 2,6-dichloro-4-nitroaniline, methylene chloride, and 2,4,6-trichlorophenol to juvenile grass shrimp and killifish. Bull. Environ. Contam. Toxicol. 44: 776-783.

Burton, W.H. and A.E. Pinkney. 1994. Yellow perch larval survival in the Zekiah Swamp Watershed (Wicomico River, Maryland) relative to the potential effects of a coal ash storage facility. Water Air Soil Pollut. 72(1-4): 235-249.

Busch, D, T. Lucker and W. Wosniok. 1998. Effects of changing salt concentrations and other physical-chemical parameters on bioavailability and bioaccumulation of heavy metals in exposed *Dreissena polymorpha* (Pallas, 1771). Limnologica. 28(3): 263-274.

Bustamante, P., J.L. Teyssie, S.W. Fowler, O. Cotret, B. Danis, P. Miramand and M. Warnau. 2002. Biokinetics of zinc and cadmium accumulation and depuration at different stages in the life cycle of the cuttlefish *Sepia officinalis*. Mar. Ecol. Prog. Ser. 231: 167-177.

Bustamante, P., P. Bocher, Y. Cherel, P. Miramand and F. Caurant. 2003. Distribution of trace elements in the tissues of benthic and pelagic fish from the Kerguelen Islands. Sci. Total Environ. 313(1-3): 25-39.

Byzitter, J., K. Lukowiak, V. Karnik and S. Dalesman. 2012. Acute Combined Exposure to Heavy Metals (Zn, Cd) blocks memory formation in a freshwater snail. Ecotoxicol. 21(3): 860-868.

Cadena-Cardenas, L., L.I.A. Mendez-Rodriguez, T. Zenteno-Savin, J. Garcia-Hernandez and B. Acosta-Vargas. 2009. Heavy metal levels in marine mollusks from areas with, or without, mining activities along the Gulf of California, Mexico. Arch. Environ. Contam. Toxicol. 57(1): 96-102.

Cain, D.J., S.N. Luoma and W.G. Wallace. 2004. Linking metal bioaccumulation of aquatic insects to their distribution patterns in a mining-impacted river. Environ. Toxicol. Chem. 23(6): 1463-1473.

Cain, D.J., D.B. Buchwalter and S.N. Luoma. 2006. Influence of metal exposure history on the bioaccumulation and subcellular distribution of aqueous cadmium in the insect *Hydropsyche californica*. Environ. Toxicol. Chem. 25(4): 1042-1049.

Cain, D.J, M.N. Croteau and S.N. Luoma. 2011. Bioaccumulation dynamics and exposure routes of Cd and Cu among species of aquatic mayflies. Environ. Toxicol. Chem. 30(11): 2532-2541.

Cairns, J. Jr., A.G. Heath and B.C. Parker. 1975. The effects of temperature upon the toxicity of chemicals to aquatic organisms. Hydrobiologia 47(1):135-171.

Cairns, J. Jr., J.R. Pratt, B.R. Niederlehner and P.V. McCormick. 1986. A simple, cost-effective multispecies toxicity test using organisms with a cosmopolitan distribution. Environ. Monit. Assess. 6: 207-220.

Calabrese, A., R.S. Collier, D.A. Nelson and J.R. MacInnes. 1973. The toxicity of heavy metals to embryos of the American oyster *Crassostrea virginica*. Mar. Biol. 18: 162-166.

Calabrese, F.P., F.P. Thurberg, M.A. Dawsonet and D.R. Wenzloff. 1975. Sublethal physiological stress induced by cadmium and mercury in the winter flounder, *Pseudopleuronectes americanus*. *In:* J.H. Koeman and J.J.T.W.A. Strik (*Eds*.), Sublethal Effects of Toxic Chemicals in Aquatic animals. Elsevier, New York. p. 15.

Calabro, P., G. Ziino, A. Corrao and A. Panebianco. 2006. Survey on the presence of heavy metals in Patella caerulea specimens collected along coastlines in Messina Province (Italy). Arch. Lebensmittelhyg. 57(9-10): 148-152.

Calevro, F., S. Campani, M. Ragghianti, S. Bucci and G. Mancino. 1998a. Tests of toxicity and teratogenicity in biphasic vertebrates treated with heavy metals (Cr^{3+}, Al^{3+}, Cd^{2+}). Chemosphere. 37(14-15): 3011-3017

Calevro, F., C. Filippi, P. Deri, C. Albertosi and R. Batistoni. 1998b. Toxic effects of aluminum, chromium and cadmium in intact and regenerating freshwater planarians. Chemosphere. 37(4): 651-659.

Calfee, R.D., E.E. Little, H.J. Puglis, E. Scott, W.G. Brumbaugh and C.A. Mebane. 2014. Acute sensitivity of white sturgeon (*Acipenser transmontanus*) and rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium or zinc in water-only laboratory exposures. Environ. Toxicol. Chem. 33(10): 2259-2272.

Caliceti, M., E. Argese, A. Sfriso and B. Pavoni. 2002. Heavy metal contamination in the seaweeds of the Venice Lagoon. Chemosphere 47(4): 443-454.

Call, D.J., L.T. Brooke, D.H. Hammermeister, C.E. Northcott and A.D. Hoffman. 1983. Variation of acute toxicity with water source. Center for Lake Superior Environmental Studies, Report No. LSRI0273, 58 p.

Callaghan. 2008. Linking molecular and population stress responses in *Daphnia magna* exposed to cadmium. Environ. Sci. Technol. 42(6): 2181-2188.

Callahan, M.A., M.W. Slimak, N.W. Gabel, I.P. May, C.F. Fowler, J.R. Freed, P. Jennings, R.L. Durfee, F.C. Whitmore, B. Maestri, W.R. Mabey, B.R. Holt and C. Gould. 1979. Water-related environmental fate of 129 priority pollutants. Volume 1: Introduction and technical background, metals and inorganics, pesticides and PBCs. Washington, D.C. 20460, Office of Water Planning and Standards Office of Water and Waste Management, U.S. Environmental Protection Agency. EPA-440/4-79-029a.

Cambier, S., P. Gonzalez, G. Durrieu and J.P. Bourdineaud. 2010. Cadmium-induced genotoxicity in zebrafish at environmentally relevant doses. Ecotoxicol. Environ. Saf. 73(3): 312-319.

Campbell, J. and R.D. Evans. 1991. Cadmium concentrations in the freshwater mussel (*Elliptio complanata*) and their relationship to water chemistry. Arch. Environ. Contam. Toxicol. 20: 125-131.

Campbell, P.G.C., A. Giguere, E. Bonneris and L. Hare. 2005. Cadmium-handling strategies in two chronically exposed indigenous freshwater organisms-the yellow perch (*Perca flavescens*) and the floater mollusc (*Pyganodon grandis*). Aquat. Toxicol. 72(1/2): 83-97.

Campos, N.H. 1985. Heavy metal concentrations in some oyster species of the Caribbean Coast of Columbia. Govt Reports Announcements & Index, Issue 12.

Camusso, M., L. Vigano and R. Balestrini. 1995. Bioconcentration of trace metals in rainbow trout: a field study. Ecotoxicol. Environ. Safety. 31: 133-141.

Canli, M. and F. Kargin. 1995. A comparative study on heavy metal (Cd, Cr, Pb and Ni) accumulation in the tissue of the carp *Cyprinus carpio* and the Nile fish *Tilapia nilotica*. Turk. J. Zool. 19: 165-171.

Canli, M. and R.W. Furness. 1993. Toxicity of heavy metals dissolved in sea water and influences of sex and size on metal accumulation and tissue distribution in the Norway lobster *Nephrops norvegicus*. Mar. Environ. Res. 36: 217-236.

Canli, M. and R.W. Furness. 1995. Mercury and cadmium uptake from seawater and from food by the Norway lobster *Nephrops norvegicus*. Environ. Toxicol. Chem. 14(5): 819-828.

Canli, M., R.M. Stagg and G. Rodger. 1997. The induction of metallothionein in tissues of the Norway lobster *Nephrops norvegicus* following exposure to cadmium, copper and zinc: the relationships between metallothionein and the metals. Environ. Pollut. 96(3): 343-350.

Canli, M., M. Kalay and O.E. Ay. 2001. Metal (Cd, Pb, Cu, Zn, Fe, Cr, Ni) concentrations in tissues of a fish *Sardina pilchardus* and a prawn *Penaeus japonicus* from three stations on the Mediterranean Sea. Bull. Environ. Contam. Toxicol. 67(1): 75-82.

Cannicci, S., F. Bartolini, F. Dahdouh-Guebas, S. Fratini, C. Litulo, A. Macia, E.J. Mrabu, G. Penha-Lopes and J. Paula. 2009. Effects of urban wastewater on crab and mollusc assemblages in equatorial and subtropical mangroves of East Africa. Estuar. Coast. Shelf Sci. 84(3): 305-317.

Canterford, G.S. and D.R. Canterford. 1980. Toxicity of heavy metals to the marine diatom *Ditylum brightwellii* (West) Grunow: correlation between toxicity and metal speciation. J. Mar. Biol. Assoc. U.K. 60: 227.

Canton, J.H. and D.M.M. Adema. 1978. Reproducibility of short-term and reproduction toxicity experiments with *Daphnia magna* and comparison of the sensitivity of *Daphnia magna* with *Daphnia pulex* and *Daphnia cucullata* in short-term experiments. Hydrobiol. 59: 135.

Canton, J.H. and W. Slooff. 1979. A proposal to classify compounds and to establish water quality based on laboratory data. Ecotoxicol. Environ. Safety 3: 126.

Canton, J.H. and W. Slooff. 1982. Toxicity and accumulation studies of cadmium (Cd^{2+}) with freshwater organisms of different trophic levels. Ecotoxicol. Environ. Safety 6: 113.

Cao, L., W. Huang, X. Shan, Z. Xiao, Q. Wang and S. Dou. 2009. Cadmium toxicity to embryonic-larval development and survival in red sea bream *Pagrus major*. Ecotoxicol. Environ. Saf. 72(7): 1966-74.

Cao, L., W. Huang, J. Liu, X. Yin and S. Dou. 2010. Accumulation and oxidative stress biomarkers in japanese flounder larvae and juveniles under chronic cadmium exposure. Comp. Biochem. Physiol. 151C(3): 386-392.

Cao, L., W. Huang, X. Shan, Z. Ye and S. Dou. 2012. Tissue-specific accumulation of cadmium and its effects on antioxidative responses in japanese flounder juveniles. Environ. Toxicol. Pharmacol. 33(1): 16-25.

Capelli, R., K. Das, R.D. Pellegrini, G. Drava, G. Lepoint, C. Miglio, V. Minganti and R. Poggi. 2008. Distribution of trace elements in organs of six species of cetaceans from the Ligurian Sea (Mediterranean), and the relationship with stable carbon and nitrogen ratios. Sci Total Environ. 390(2-3): 569-78.

Caplat, C., R. Oral, M.L. Mahaut, A. Mao, D. Barillier, M. Guida, C. Della Rocca and G. Pagano. 2010. Comparative toxicities of aluminum and zinc from sacrificial anodes or from sulfate salt in sea urchin embryos and sperm. Ecotoxicol. Environ. Saf. 73(6): 1138-1143.

Carattino, M.D., S. Peralta, C. Perez-Coll, F. Naab, A. Burlon, A.J. Kreiner, A.F. Preller and T.M. Fonovich de Schroeder. 2004. Effects of long-term exposure to Cu2+ and Cd2+ on the pentose phosphate pathway dehydrogenase activities in the ovary of adult *Bufo arenarum*: possible role as biomarker for Cu2+ toxicity. Ecotoxicol. Environ. Saf. 57(3): 311-318.

Cardin, J.A. 1982. Memorandum to J.H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Cardin, J.A. 1985. Memorandum to D. Hansen. U.S. EPA, Narragansett, Rhode Island.

Cardwell, A.J., D.W. Hawker and M. Greenway. 2002. Metal accumulation in aquatic macrophytes from southeast Queensland, Australia. Chemosphere 48(7): 653-663.

Cardwell, R.D., C.E. Woelke, M.I. Carr and E.W. Sanborn. 1979. Toxic substance and water quality effects on larval marine organisms. Tech. Rep. No. 45, State of Washington, Dept. of Fish, Olympia, WA, 71 p.

Carline, R.F., A.J. Benson and H. Rothenbacher. 1987. Long-term effects of treated domestic wastewater on brown trout. Water Res. 21(11): 1409-1415.

Carlisle, D.M. and W.H. Clements. 1999. Sensitivity and variability of metrics used in biological assessments of running waters. Environ. Toxicol. Chem. 18(2): 285-291.

Carlson, A.R., J.A. Tucker, V.R. Mattson, G.L. Phipps, P.M. Cook and F.A. Puglisi. 1982. Cadmium and endrin toxicity to fish in waters containing mineral fibers. EPA-600/3-82-053. National Technical Information Service, Springfield, VA.

Carmichael, N.G. and B.A. Fowler. 1981. Cadmium accumulation and toxicity in the kidney of the bay scallop *Argopecten irradians*. Mar. Biol. 65: 35.

Carpene, E. and L. Boni. 1992. Effects of heavy metals on the algae *Nitzschia closterium* and *Prorocentrum micans*. Sci. Total Environ. Supplemental Vol.: 921-927.

Carpene, E., P. Cartesi, G. Crisetig and G.P. Serrazanetti. 1980. Cadmium-binding proteins from the mantle of *Mytilus edulis* (L.) after exposure to cadmium. Thalassia Jugosl. 16: 317-323.

Carr, R.S. and J.M. Neff. 1982. Biochemical indices of stress in the sandworm *Neanthes virens* (Sars). II. sublethal responses to cadmium. Aquat. Toxicol. 2: 319.

Carr, R.S., J.W. Williams, F.I. Saksa, R.L. Buhl and J.M. Neff. 1983. Dose-dependent bioenergetic alterations correlated with reduced growth, fecundity and body burden of cadmium for *Mysidopsis bahia* during a life-cycle exposure. SETAC Proc., Nov.1983.

Carr, R.S., J.W. Williams, F.I. Saksa, R.L. Buhl and J.M. Neff. 1985. Bioenergetic alterations correlated with growth, fecundity and body burden of cadmium for mysids (*Mysidopsis bahia*). Environ. Toxicol. Chem. 4: 181-188.

Carranza-Alvarez, C., A.J. Alonso-Castro, M.C.A.D. La Torre and R.F. Garcia-De La Cruz. 2008. Accumulation and distribution of heavy metals in *Scirpus americanus* and *Typha latifolia* from an artificial lagoon in San Luis Potosi, Mexico. Water Air Soil Pollut. 188: 297-309.

Carrier, R. 1987. Temperature tolerance of freshwater fish exposed to water-borne cadmium. M.S.Thesis, University of North Texas, Denton, TX.

Carrier, R. and T.L. Beitinger. 1988a. Reduction in thermal tolerance of *Notropis lutrensis* and *Pimephales promelas* exposed to cadmium. Water Res. 22(4): 511-515.

Carrier, R. and T.L. Beitinger. 1988b. Resistance of temperature tolerance ability of green sunfish to cadmium exposure. Bull. Environ. Contam. Toxicol. 40: 475-480.

Carriquiriborde, P. and A. Ronco. 2002. Sensitivity of the neotropical teleost *Odonthestes bonariensis* (Pisces, Atherinidae) to chromium(VI), copper(II), and cadmium(II). Bull. Environ. Contam. Toxicol. 69(2): 294-301.

Carriquiriborde, P. and A.E. Ronco. 2008. Distinctive accumulation patterns of Cd(II), Cu(II), and Cr(VI) in tissue of the South American teleost, pejerrey (*Odontesthes bonariensis*). Aquat. Toxicol. 86(2): 313-322.

Carroll, J.J., S.J. Ellis and W.S. Oliver. 1979. Influences of hardness constituents on the acute toxicity of cadmium to brook trout (*Salvelinus fontinalis*). Bull. Environ. Contam. Toxicol. 22:575-581.

Casado-Martinez, M.C., B.D. Smith, T.A. DelValls, S.N. Luoma and P.S. Rainbow. 2009. Biodynamic modelling and the prediction of accumulated trace metal concentrations in the polychaete *Arenicola marina*. Environ. Pollut. 157(10): 2743-2750.

Casas, S., J.L. Gonzalez, B. Andral and D. Cossa. 2008. Relation between metal concentration in water and metal content of marine mussels (*Mytilus galloprovincialis*): impact of physiology. Environ. Toxicol. Chem. 27(7): 1543-1552.

Casini, S. and M.H. Depledge. 1997. Influence of copper, zinc, and iron on cadmium accumulation in the Talitrid amphipod, *Platorchestia platensis*. Bull. Environ. Contam. Toxicol. 59: 500-506.

Casiot, C., M. Egal, F. Elbaz-Poulichet, O. Bruneel, C. Bancon-Montigny, M.A. Cordier, E. Gomez and C. Aliaume. 2009. Hydrological and geochemical control of metals and arsenic in a Mediterranean River contaminated by acid mine drainage (the Amous River, France); preliminary assessment of impacts on fish (*Leuciscus cephalus*). Appl. Geochem. 24(5): 787-799.

Cassini, A, L. Tallandini, N. Favero and V. Albergoni. 1986. Cadmium bioaccumulation studies in the freshwater molluscs *Anodonta cygnea* and *Unio elongatulus*. Comp. Biochem. Physiol. 84C(1): 35-41.

Cassis, D., P. Lekhi, C.M. Pearce, N. Ebell, K.Orians and M.T. Maldonado. 2011. The role of phytoplankton in the modulation of dissolved and oyster cadmium concentrations in Deep Bay, British Columbia, Canada. Sci. . Tot. Environ. 409(20): 4415-4424.

Castano, A., M.J. Cantarino, P. Castillo and J.V. Tarazona. 1996. Correlations between the RTG-2 cytotoxicity test EC50 and *in vivo* LC50 rainbow trout bioassay. Chemosphere. 32(11): 2141-2157.

Castille, F.L. Jr. and A.L. Lawrence. 1981. The effects of EDTA (ethylenedinitrotetraacetic acid) on the survival and development of shrimp nauplii (*Penaeus stylirostris* Stimpson) and the interactions of EDTA and the toxicities of cadmium, calcium, and phenol. J. World Maricul. Soc. 12: 292.

Cavas, T., N.N. Garanko and V.V. Arkhipchuk. 2005. Induction of micronuclei and binuclei in blood, gill and liver cells of fishes subchronically exposed to cadmium chloride and copper sulphate. Food Chem. Toxicol. 43(4): 569-574.

Cearley, J.E. and R.L. Coleman. 1973. Cadmium toxicity and accumulation in southern naiad. Bull. Environ. Contam. Toxicol. 9: 100.

Cearley, J.E. and R.L. Coleman. 1974. Cadmium toxicity and bioconcentration in largemouth bass and bluegill. Bull. Environ. Contam. Toxicol. 11: 146.

Cebrian, E. and M.J. Uriz. 2007. Contrasting effects of heavy metals and hydrocarbons on larval settlement and juvenile survival in sponges. Aquat. Toxicol. 81(2):137-143.

Celik, U., S. Cakli and J. Oehlenschlaeger. 2004. Determination of the lead and cadmium burden in some northeastern Atlantic and Mediterranean fish species by DPSAV. Eur. Food Res. Technol. 218(3): 298-305.

Centeno, M.D.F., L. Brendonck and G. Persoone. 1993. Cyst-based toxicity tests. III. Development and standardization of an acute toxicity test with the freshwater anostracan crustacean *Streptocephalus proboscideus*. *In:* A.M.V.M. Soares and P. Calow (eds.). Progress in Standardization of Aquatic Toxicity Tests. Lewis Publishers. pp 37-55.

Centeno, M.D.F., G. Persoone and M.P.Goyvaerts. 1995. Cyst-based toxicity tests. IX. The potential of Thamnocephalus platyurus as test species in comparison with *Streptocephalus proboscideus* (Crustacea: branchiopoda: anostraca). Environ. Toxicol. Water Qual. 10(4): 275-282.

Cesar, A., L. Marin-Guirao, R. Vita and A. Marin. 2002. Sensitivity of mediterranean amphipods and sea urchins to reference toxicants. Cienc. Mar. 28(4): 407-417.

Cevik, U., N. Damla, A.I. Kobya, V.N. Bulut, C. Duran, G. Dalgic and R. Bozaci. 2008. Assessment of metal element concentrations in mussel (*M. galloprovincialis*) in Eastern Black Sea, Turkey. J. Hazard. Mater. 160: 396-401.

Chadwick Ecological Consultants, Inc. 2003. Acute and chronic toxicity of cadmium to freshwater crustaceans at different water hardness values. Report Prepared for Thompson Creek Mining Compnay, Challis, ID .

Chadwick Ecological Consultants, Inc. 2004a. Chronic toxicity of cadmium to freshwater crustaceans at different water hardness concentrations, Prepared for Thompson Creek Mining, Challis, Idaho by Chadwick Ecological Consultants, Littleton, CO, 62 p.

Chadwick Ecological Consultants, Inc. 2004b. U.S. EPA cadmium water quality criteria document - technical review and crtieria update. Report Prepared for Association of Metropolian Sewerage Agencies (AMSA).

Chadwick Ecological Consultants, Inc. 2004c. Addendum to U.S. EPA cadmium water quality criteria document - technical review and crtieria update. Report Prepared for Association of Metropolian Sewerage Agencies (AMSA).

Chagnon, N.L. and S.I. Guttman. 1989. Differential survivorship of allozyme genotypes in mosquitofish populations exposed to copper or cadmium. Environ. Toxicol. Chem. 8: 319-326.

Chaharlang, B.H., A.R. Bakhtiari and V. Yavari. 2012. Assessment of cadmium, copper, lead and zinc contamination using oysters (*Saccostrea cucullata*) as biomonitors on the coast of the Persian Gulf, Iran. Bull. Environ. Contam. Toxicol. 88(6): 956-961.

Champeau, O., M.P. Auffret, M. Cajaraville, A. Basseres and J.F. Narbonne. 2007. Immunological and cytotoxicological responses of the asian clam, *Corbicula fluminea* (M.), experimentally exposed to cadmium. Biomarkers 12(2): 173-187.

Chan, H.M. 1988. Accumulation and tolerance to cadmium, copper, lead and zinc by the green mussel *Perna viridis*. Mar. Ecol. Prog. Ser. 48: 295-303.

Chan, H.M., P. Bjerregaard, P.S. Rainbow, M.H. Depledge. 1992. Uptake of zinc and cadmium by two populations of shore crabs *Carcinus maenas* at different salinities. Mar. Ecol. Prog. Ser. 86: 91-97.

Chan, K.Y., K.H. Wong and S.L. Ng. 1981. Effects of polyethylene glycol on growth and cadmium accumulation of *Chlorella salina* CU-1. Chemosphere 10(8): 985-991.

Chan, P.K. and S.H. Cheng. 2003. Cadmium-induced ectopic apoptosis in zebrafish embryos. Arch. Toxicol. 77(2): 69-79.

Chan, S.M., W.X. Wang and I.H. Ni. 2003. The uptake of Cd, Cr, and Zn by the macroalga *Enteromorpha crinita* and subsequent transfer to the marine herbivorous rabbitfish, *Siganus canaliculatus*. Arch. Environ. Contam. Toxicol. 44(3): 298-306.

Chander, G.P., N.V. Madhav and Vidyavati. 1991. Response of *Pithophora oedogonia* to cadmium. Acta Botanica Indica. 19: 240-242.

Chandini, T. 1988a. Changes in food (*Chlorella*) levels and the acute toxicity of cadmium to *Daphnia carinata* (daphnidae) and *Echinisca triserialis* (macrothricidae) (Crustacea: cladocera). Bull. Environ. Contam. Toxicol. 41: 398-403.

Chandini, T. 1988b. Effects of different food (*Chlorell*a) concentrations on the chronic toxicity of cadmium to survivorship, growth and reproduction of *Echinisca triserialis* (crustacea: cladocera). Environ. Pollut. 54: 139-154.

Chandini, T. 1989. Survival, growth and reproduction of *Daphnia carinata* (crustacea: cladocera) exposed to chronic cadmium stress at different food (*Chlorella*) levels. Environ. Pollut. 60: 29-45.

Chandini, T. 1991. Reproductive value and the cost of reproduction in *Daphnia carinata* and *Echinisca triserialis* (crustacea: cladocera) exposed to food and cadmium stress. Bull. Environ. Contam. Toxicol. 47: 76-83.

Chandra, P. and P. Garg. 1992. Absorption and toxicity of chromium and cadmium in *Limnanthemum cristatum* Griseb. Sci. Total Environ. 125: 175-183.

Chandra, P. and A.R. Khuda-Bukhsh. 2004. Genotoxic effects of cadmium chloride and azadirachtin treated singly and in combination in fish. Ecotoxicol. Environ. Saf. 58(2): 194-201.

Chandrudu, M.V. and K. Radhakrishnaiah. 2008. Effect of cadmium on the histology of hepatopancreas and foot of the freshwater mussel *Lamellidens marginalis* (Lam.). Nature Environ. Pollut. Technol. 7(3): 397-402.

Chandrudu, M.V., A.S. Reddy and K. Radhakrishnaiah. 2007. Effect of subacute concentration of cadmium on the energetics of freshwater mussel *Lamellidens marginalis* (Lam.) and fish *Labeo rohita* (Ham.). Nature Environ. Pollut. Technol. 6(3): 387-392.

Chandurvelan, R., I.D. Marsden, S. Gaw and C.N. Glover. 2012. Impairment of green-lipped mussel (*Perna canaliculus*) physiology by waterborne cadmium: relationship to tissue bioaccumulation and effect of exposure duration. Aquat.Toxicol.124/125(0): 114-124.

Chandurvelan, R., I.D. Marsden, S. Gaw and C.N. Glover. 2013a. Waterborne cadmium impacts immunocytotoxic and cytogenotoxic endpoints in green-lipped mussel, *Perna canaliculus*. Aquat. Toxicol. 142-143: 283-293.

Chandurvelan, R., I.D. Marsden, S. Gaw and C.N. Glover. 2013b. Biochemical biomarker responses of green-lipped mussel, *Perna canaliculus*, to acute and subchronic waterborne cadmium toxicity. Aquat. Toxicol. 140-141: 303-313.

Chang, F., G. Li, M. Haws and T.Niu. 2007. Element concentrations in shell of *Pinctada margaritifera* from French Polynesia and evaluation for using as a food supplement. Food Chem. 104(3): 1171-1176.

Chang, M., H.C. Lin and P. Hwang. 1998. Ca^{2+} uptake and Cd^{2+} accumulation in larval tilapia (*Oreochromis mossambicus*) acclimated to waterborne Cd^{2}. Am. J. Physiol. 27(6): 1570-1577.

Chang, M., W.N. Wang, A.L. Wang, T.T. Tian, P. Wang, Y. Zheng and Y. Liu, Y. 2009. Effects of cadmium on respiratory burst, intracellular Ca2+ and dna damage in the white shrimp *Litopenaeus vannamei*. Comp. Biochem. Physiol.149C(4): 581-586.

Chang, Z., M. Lu, K.W. Lee, B.S. Oh, M.J. Bae and J.S. Park. 2011. Influence of divalent metal ions on e2-induced er pathway in goldfish (*Carassius auratus*) hepatocytes. Ecotoxicol. Environ. Saf. 74(8): 2233-2239.

Chao, M.R. and C.Y. Chen. 2001. Discrepancies between different response parameters in batch and continuous algal toxicity tests. J. Hazard. Mater. 82(2): 129-36.

Chapman, G.A. 1973 Progress, Roap 16-Aad. Nov.29th Memo to K.Biesinger, NWQL, from G.A.Chapman, U.S. EPA, West. Fish Toxicol. Stn., Corvallis, OR.

Chapman, G.A. 1975. Toxicity of copper, cadmium and zinc to Pacific Northwest salmonids. U.S. EPA, Corvallis, Oregon.

Chapman, G.A. 1978. Toxicities of cadmium, copper, and zinc to four juvenile stages of chinook salmon and steelhead. Trans. Am. Fish. Soc. 107: 841.

Chapman, G.A. 1982. Letter to C.E. Stephan. U.S. EPA, Corvallis, Oregon. December 6.

Chapman, G.A. and D.G. Stevens. 1978. Acutely lethal levels of cadmium, copper, and zinc to adult male coho salmon and steelhead. Trans. Am. Fish. Soc. 107: 837.

Chapman, G.A., S. Ota and F. Recht. Manuscript. Effects of water hardness on the toxicity of metals to *Daphnia magna*. U.S. EPA, Corvallis, Oregon.

Chapman, G.A., S. Ota and F. Recht. 1980. Effect of water hardness on the toxicity of metals to *Daphnia magna*: Status Report - January 1980. Corvallis Environmental Research Laboratory. 28 pages

Chapman, P.M. 1995. Extrapolating laboratory toxicity test results to the field. Environ. Toxicol. Chem. 14: 927-930.

Chapman, P.M., M.A. Farrell and R.O. Brinkhurst. 1982. Relative tolerances of selected aquatic oligochaetes to individual pollutants and environmental factors. Aquat. Toxicol. 2(1): 47-67.

Chapman, P. M., H. Bailey and E. Canaria. 2000. Toxicity of total dissolved solids associated with two mine effluents to chironomid larvae and early life stages of rainbow trout. Environ. Toxicol. Chem. 19: 210-214.

Chapman, P.M., B.G. McDonald, P.E. Kickham and S. McKinnon. 2006. Global geographic differences in marine metals toxicity. Mar. Pollut. Bull. 52(9): 1081-1084.

Chapman, W.H., H.L. Fisher and M.W. Pratt. 1968. Concentration factors of chemical elements in edible aquatic organisms. UCRL-50564. National Technical Information Service, Springfield, Virginia.

Charpentier, S., J. Garnier and R. Flaugnatti. 1987. Toxicity and bioaccumulation of cadmium in experimental cultures of duckweed, *Lemna polyrrhiza* L. Bull. Environ. Contam. Toxicol. 38: 1055-1061.

Chassard-Bouchaud, C. 1982. Ultrastructural study of cadmium concentration by the digestive gland of the crab *Carcinus maenas* (crustacea decapoda). C. R. Seances Acad. Sci. Ser. III Sci. Vie 294:153-157.

Chattopadhyay, S. K. Anam and A.K. Aditya. 1995. Bioassay evaluation of acute toxicity levels of mercuric chloride and cadmium chloride on the early growing stages of *Labeo rohita*. J. Ecobiol. 7(1): 41-47.

Chaumot, A., P. Gos, J. Garric O. Geffard. 2009. Additive vs non-additive genetic components in lethal cadmium tolerance of Gammarus (Crustacea): novel light on the assessment of the potential for adaptation to contamination. Aquat. Toxicol. 94(4): 294-299.

Chawla, G., J. Singh and P.N. Viswanathan. 1991. Effect of pH and temperature on the uptake of cadmium by *Lemna minor* L. Bull. Environ. Contam. Toxicol. 47: 84-90.

Chelomin, V.P., M.V. Zakhartsev, A.V. Kurilenko and N.N. Belcheva. 2005. An in vitro study of the effect of reactive oxygen species on subcellular distribution of deposited cadmium in digestive gland of mussel *Crenomytilus grayanus*. Aquat. Toxicol. 73(2): 181-189.

Chen, C.M., S.C. Yu and M.C. Liu. 2001. Use of Japanese medaka (*Oryzias latipes*) and tilapia (*Oreochromis mossambicus*) in toxicity tests on different industrial effluents in Taiwan. Arch. Environ. Contam. Toxicol. 40(3): 363-370.

Chen, C.Y., K.C. Lin and D.T. Yang. 1997. Comparison of the relative toxicity relationships based on batch and continuous algal toxicity tests. Chemosphere 35(9): 1959-1965.

Chen, F., J. Gao and Q. Zhou. 2012. Toxicity assessment of simulated urban runoff containing polycyclic musks and cadmium in *Carassius auratus* using oxidative stress biomarkers. Environ. Pollut. 162: 91-97.

Chen, G.Z. and Z.Q. Fang. 2011. Safety assessment and acute toxicity of copper, zinc and cadmium to the embryo and larval fish of *Tanichthys albonubes*. Shengwuxue Zazhi 28(2): 28-31.

Chen, H.G., X.P. Jia, Q. Lin, S.W. Ma, W.G. Cai and Z.H. Wang. 2008. Accumulation and release characteristics of heavy metals in *Crassostrea rivalaris* under mixed exposure. J. Appl. Ecol. 19(4): 922-927.

Chen, J., J. Liu, S. Xiao and Z. Yu. 2011b. molecular cloning, characterization and expression analysis of receptor for activated c kinase 1 (rack1) from pearl oyster (*Pinctada martensii*) challenged with bacteria and exposed to cadmium. Fish and Shellfish Immunol. 31(6): 781-787.

Chen, N., X.B. Liu, S.Y. Tian, Z.G. Liu, L.N. Sun and G.F. Li. 2010. Accumulation and elimination characteristics of heavy metal cadmium in *Bullacta exarata* from intertidal zone of Tianjin, China. J. Agro-Environment Sci. 29(9): 1687-1692.

Chen, Q.L., Y. Gong, Z. Luo, J.L. Zheng and Q.L. Zhu. 2013. Differential effect of waterborne cadmium exposure on lipid metabolism in liver and muscle of yellow catfish *Pelteobagrus fulvidraco*. Aquat. Toxicol. 142-143: 380-386.

Chen, W.Y., J.A.C. John, C.H. Lin and C.Y. Chang. 2007. Expression pattern of metallothionein, MTF-1 nuclear translocation, and its DNA-binding activity in zebrafish (Danio rerio) induced by zinc and cadmium. Environ. Toxicol. Chem. 26(1): 110-117.

Chen, W.Y., Y.R. Ju, B.C. Chen, J.W. Tsai, C.J. Lin and C.M. Liao. 2011a. Assessing abalone growth inhibition risk to cadmium and silver by linking toxicokinetics/toxicodynamics and subcellular partitioning. Ecotoxicol. 20(4): 912-24.

Chen, X., C. Lu and Y. Ye. 2009. Effects of Cd and Zn on oxygen consumption and ammonia excretion in sipuncula (*Phascolosoma esculenta*). Ecotoxicol. Environ. Saf. 72(2): 507-515.

Cherkasov, A.S., P.K. Biswas, D.M. Ridings, A.H. Ringwood and I.M. Sokolova. 2006. Effects of acclimation temperature and cadmium exposure on cellular energy budgets in the marine mollusk *Crassostrea virginica*: linking cellular and mitochondrial responses. J. Exp. Biol. 209(7): 1274-1284.

Cherkasov, A.S., S. Grewal and I.M. Sokolova. 2007. Combined effects of temperature and cadmium exposure on *Haemocyte apoptosis* and cadmium accumulation in the eastern oyster *Crassostrea virginica* (Gmelin). J. Therm. Biol. 32(3): 162-170.

Cherkasov, A.S., C. Taylor and I.M. Sokolova. 2010. Seasonal variation in mitochondrial responses to cadmium and temperature in eastern oysters *Crassostrea virginica* (Gmelin) from different latitudes. Aquat. Toxicol. 97(1): 68-78.

Chernova, E.N. and O.S. Sergeeva. 2008. Metal concentrations in sargassum algae from coastal waters of Nha Trang Bay (South China Sea). Russ. J. Mar. Biol. 34(1): 57-63.

Cherry, D.S. and R.K. Guthrie. 1977. Toxic metals in surface waters from coal ash. Water Resour. Bull. 13(6): 1227-1236.

Cherry, D.S., R.K. Guthrie, E.M. Davis and R.S. Harvey. 1984. Coal ash basin effects (particulates, metals, acidic pH) upon aquatic biota: an eight-year evaluation. Water Resour. Bull. 20(4): 535-544.

Cheung, C.C.C. and P.K.S. Lam. 1998. Effect of cadmium on the embryos and juveniles of a tropical freshwater snail, *Physa acuta* (Draparnaud, 1805). Water Sci. Tech. 38(7): 263-270.

Cheung, K.C. and M.H. Wong. 2006. Risk assessment of heavy metal contamination in shrimp farming in Mai Po Nature Reserve, Hong Kong. Environ. Geochem. Health 28(1-2): 24-33.

Cheung, K.C., H.M. Leung and M.H. Wong. 2008. Metal concentrations of common freshwater and marine fish from the Pearl River Delta, South China. Arch. Environ. Contam. Toxicol. 54(4): 705-15.

Cheung, S.G., K.K. Tai, C.K. Leung and Y.M. Siu. 2002. Effects of heavy metals on the survival and feeding behaviour of the sandy shore scavenging gastropod *Nassarius festivus* (Powys). Mar. Pollut. Bull. 45(1-12): 107-113. 2002.

Chevreuil, M., A.M. Carru, A. Chesterikoff, P. Boet, E. Tales and J. Allardi. 1995. Contamination of fish from different areas of the river Seine (France) by organic (PCB and pesticides) and metallic (Cd, Cr, Cu, Fe, Mn, Pb and Zn) micropollutants. Sci. Total Environ. 162: 31-42.

Chevreuil, M., M. Blanchard, M.J. Teil, A.M. Carru, P. Testard and A. Chesterikoff. 1996. Evaluation of the pollution by organochlorinated compounds (polychlorobiphenyls and pesticides) and metals (Cd, Cr, Cu and Pb) in the water and in the zebra mussel (*Dreissena polymorpha* Pallas) of the River Seine. Water Air Soil Pollut. 88(3-4): 371-381.

Chiarelli, R., M. Agnello and M.C. Roccheri. 2011. Sea urchin embryos as a model system for studying autophagy induced by cadmium stress. Autophagy 7(9): 1028-1034.

Chiarelli, R., M. Agnello, L. Bosco and M.C. Roccheri. 2013. Sea urchin embryos exposed to cadmium as an experimental model for studying the relationship between autophagy and apoptosis. Mar. Environ. Res. (In Press).

Chigbo, F.E., R.W. Smith and F.L. Shore. 1982. Uptake of arsenic, cadmium, lead and mercury form polluted waters by the water hyacinth *Eichornia crassipes*. Environ. Pollut. 27A: 31-36.

Chiodi Boudet, L., P. Polizzi, M.B. Romero, A. Robles and M. Gerpe. 2013. Lethal and sublethal effects of cadmium in the white shrimp *Palaemonetes argentinus*: A comparison between populations from contaminated and reference sites. Ecotoxicol. Environ. Saf. 89: 52-58.

Chishty, N., A. Tripathi and M. Sharma. 2012. Evaluation of acute toxicity of zinc, lead and cadmium to zooplanktonic community in upper Berach river system, Rajasthan, India. S. Asian J. Exp. Biol. 2(1): 20-26.

Chitguppa, R., K.H. Chu and M.A. Hashim. 1997. Reusability of seaweed biosorbent in multiple cycles of cadmium adsorption and desorption. Biotech. Techniques 11(6): 371-373.

Choi, C.Y., K.W. An, E.R. Nelson and H.R. Habibi. 2007b. Cadmium affects the expression of metallothionein (MT) and glutathione peroxidase (GPX) mRNA in goldfish, *Carassius auratus*. Comp. Biochem. Physiol.145C(4): 595-600.

Choi, H.J., I.Y. Ahn, Y.S. Lee, K.W. Kim and K.H. Jeong. 2003. Histological responses of the antarctic bivalve *Laternula elliptica* to a short-term sublethal-level Cd exposure. Ocean Polar Res. 25(2): 147-154.

Choi, H.J., J. Ji., K.H. Chung and I.Y. Ahn. 2007a. Cadmium Bioaccumulation and Detoxification in the Gill and Digestive Gland of the Antarctic Bivalve Laternula elliptica. Comp. Biochem. Physiol. 145C(2): 227-235.

Choi, J.H. and M.H. Ha. 2009. Effect of cadmium exposure on the globin protein expression in 4th instar larvae of *Chironomus riparius* Mg. (Diptera: Chironomidae): an ecotoxicoproteomics approach. Proteomics 9(1): 31-39.

Choi, J., J.Y. Lee and J.S. Yang. 2009. Biosorption of heavy metals and uranium by starfish and *Pseudomonas putida*. J. Hazard. Mater. 161(1): 157-162.

Choi, Y.K., P.G. Jo and C.Y. Choi. 2008. Cadmium affects the expression of heat shock protein 90 and metallothionein mRNA in the pacific oyster, *Crassostrea gigas*. Comp. Biochem. Physiol. 147C(3): 286-292.

Chojnacka, K., A. Chojnacki and H. Gorecka. 2005. Biosorption of Cr3+, Cd2+ and Cu2+ ions by blue-green algae *Spirulina sp.*: kinetics, equilibrium and the mechanism of the process. Chemosphere 59(1): 75-84.

Chora, S., M. Starita-Geribaldi, J.M. Guigonis, M. Samson, M. Romeo and M.J.Bebianno. 2009. Effect of cadmium in the clam *Ruditapes decussatus* assessed by proteomic analysis. Aquat. Toxicol. 94(4): 300-308.

Chou, C.L. and J.F. Uthe. 1991. Effect of starvation on trace metal levels in blue mussels (*Mytilus edulis*). Bull. Environ. Contam. Toxicol. 46: 473-478.

Chou, C.L., J.F. Uthe, J.D. Castell and J.C. Kean. 1987. Effect of dietary cadmium on growth, survival, and tissue concentrations of cadmium, zinc, copper, and silver in juvenile american lobster (*Homarus americanus*). Can. J. Fish. Aquat. Sci. 44: 1443-1450.

Chou, C.L., L.A. Paon and J.D. Moffatt. 2002. Cadmium, copper, manganese, silver, and zinc in rock crab (*Cancer irroratus*) from highly copper contaminated sites in the Inner Bay of Fundy, Atlantic Canada. Bull. Environ. Contam. Toxicol. 68(6): 885-892.

Chou, T.S., Y.Y. Chao, W.D. Huang, C.Y. Hong and C.H. Kao. 2011. Effect of magnesium deficiency on antioxidant status and cadmium toxicity in rice seedlings. J. Plant Physiol. 168(10): 1021-1030.

Chouchene, L., M. Banni, A. Kerkeni, K. Said and I. Messaoudi. 2011. Cadmium-induced ovarian pathophysiology is mediated by change in gene expression pattern of zinc transporters in zebrafish (*Danio rerio*). Chem.-Biol. Interact. 193(2): 172-179.

Chowdhury, M.J., D.G. McDonald and C.M. Wood. 2004. gastrointestinal uptake and fate of cadmium in rainbow trout acclimated to sublethal dietary cadmium. Aquat. Toxicol. 69: 149-163.

Christoffers, D. and D.E.W. Ernst. 1983. The *in-vivo* fluorescence of *Chlorella fusca* as a biological test for the inhibition of photosynthesis. Toxicol. Environ. Chem. 7: 61-71.

Chu, K.W. and K.L. Chow. 2002. Synergistic toxicity of multiple heavy metals is revealed by a biological assay using a nematode and its transgenic derivative. Aquat.Toxicol. 61(1/2): 53-64.

Chung, K.S. 1978. Cadmium tolerance of the white mullet (*Mugil curema*) and its use to predict survival probability in polluted sea waters. Bol. Inst. Oceanogr. Univ. Oriente 17(1-2): 105-107.

Chung, K.S. 1983. Lethal effects of cadmium in tropical fishes. Bull. Japan. Soc. Sci. Fish. 49(10): 1565-1568.

Chung, K.W., M.H. Fulton and G.I. Scott. 2007. Use of the juvenile clam, *Mercenaria mercenaria*, as a sensitive indicator of aqueous and sediment toxicity. Ecotoxicol.Environ.Saf. 67(3): 333-340.

Ciardullo, S., F. Aureli, E. Coni, E. Guandalini, F. Iosi, A. Raggi, G. Rufo and F. Cubadda. 2008. Bioaccumulation potential of dietary arsenic, cadmium, lead, mercury, and selenium in organs and tissues of rainbow trout (*Oncorhyncus mykiss*) as a function of fish growth. J. Agric. Food Chem. 56(7): 2442-2451.

Cicik, B., O. Ay and F. Karayakar. 2004. Effects of lead and cadmium interactions on the metal accumulation in tissue and organs of the Nile Tilapia (*Oreochromis niloticus*). Bull. Environ. Contam. Toxicol. 72(1): 141-148.

Cid, B.P, C. Boiab, L. Pomboc and E. Rebeloc. 2001. Determination of trace metals in fish species of the Ria de Aveiro (Portugal) by electrothermal atomic absorption spectrometry. Food Chem. 75(1): 93-100.

Ciliberti, A., P. Berny, M.L. Delignette-Muller and V. De Buffrenil. 2011. The Nile monitor (*Varanus niloticus*; Squamata: Varanidae) as a sentinel species for lead and cadmium contamination in sub-Saharan wetlands. Sci. Tot. Environ. 409(22): 4735-4745.

Cincinelli, A., T. Martellini, M. Del Bubba, L. Lepri, S. Corsolini, N. Borghesi, M.D. King and R.M. Dickhut. 2009. Organochlorine pesticide air-water exchange and bioconcentration in krill in the Ross Sea. Environ. Pollut. 157(7): 2153-2158.

Ciocan, C.M. and J.M. Rotchell. 2004. Cadmium induction of metallothionein isoforms in juvenile and adult mussel (*Mytilus edulis*). Environ. Sci. Technol. 38(4): 1073-1078.

Cirillo, T., R.A. Cocchieri, E. Fasano, A. Lucisano, S. Tafuri, M.C. Ferrante, E., G. Andreani and G. Isani. 2012. Cadmium accumulation and antioxidant responses in *Sparus aurata* exposed to waterborne cadmium. Arch. Environ. Contam. Toxicol. 62(1): 118-126.

Ciutat, A. and A. Boudou. 2003. Bioturbation effects on cadmium and zinc transfers from a contaminated sediment and on metal bioavailability to benthic bivalves. Environ.Toxicol.Chem. 22(7): 1574-1581.

Ciutat, A., M. Gerino, N. Mesmer-Dudons, P. Anschutz and A. Boudou. 2005. Cadmium bioaccumulation in tubificidae from the overlying water source and effects on bioturbation. Ecotoxicol.Environ.Saf. 60(3): 237-246.

Clark, G.M. 2002. Occurrence and transport of cadmium, lead, and zinc in the Spokane River basin, Idaho and Washington, water years 1999-2001: U.S. Geological Survey Water-Resources Investigations Report 02-4183, 37 p., accessed October 2003 at http://id.water.usgs.gov/public/reports.html.

Clason, B., S. Duquesne, M. Liess, R. Schulz and G.P. Zauke. 2003. Bioaccumulation of trace metals in the antarctic amphipod *Paramoera walkeri* (Stebbing, 1906): comparison of two-compartment and hyperbolic toxicokinetic models. Aquat. Toxicol. 65(2): 117-140.

Clausen, P.S., P. Bjerregaard and M.H. Depledge. 1993. Passive and active cadmium uptake in the isolated gills of the shore crab, *Carcinus maenas* (L.). Chemosphere. 26(12): 2209-2219.

Clements, W.H., D.M. Carlisle, L.A. Courtney and E.A. Harrahy. 2002. Integrating observational and experimental approaches to demonstrate causation in stream biomonitoring studies. Environ. Toxicol. Chem. 21(6): 1138-1146.

Clements, W.H. and P.M. Kiffney. 1996. Validation of whole effluent toxicity tests: Integrated studies using field assessments, microcosms, and mesocosms. In: D.L. Grothe, K.L. Dickson and D.K. Reed-Judkins (*Eds*.). *Whole effluent toxicity testing: an evaluation of methods and prediction of receiving system impacts*. Pensacola, FL., Society of Environmental Toxicology and Chemistry (SETAC), p. 229-244.

Clifford, M.S.A. 2009. A study of waterborne and dietary toxicity of cadmium to *Hydra attenuata* and *Daphnia pulex* in soft waters and the development of biotic ligand models to predict such toxicity. M.S. Thesis, Wilfrid Laurier University, Canada.

Clifford, M. and J. McGeer. 2009. Waterborne and dietary effects of cadmium on *Hydra attenuate*. NSERC - Industry Proj.on Metal Bioavailability, Research Newsletter, McMaster Univ., Hamilton, Ontario, Canada , 9 p. 2009.

Clifford, M. and J.C. McGeer. 2010. Development of a biotic ligand model to predict the acute toxicity of cadmium to *Daphnia pulex*. Aquat. Toxicol. 98(1): 1-7.

Clubb, R.W., A.R. Gaufin and J.L. Lords. 1975. Acute cadmium toxicity studies upon nine species of aquatic insects. Environ. Res. 9(3): 332-341.

Coban, B., N. Balkis, A. Aksu, D. Gueray and A. Tekinay. 2009. Heavy metals in livers, gills and muscle of *Dicentrarchus labrax* (Linnaeus, 1758) fish species grown in the dardanelles. J. Black Sea/Mediterr. Environ. 15(1): 61-67.

Coeurdassier, M., A. De Vaufleury and P.M. Badot. 2003. Bioconcentration of cadmium and toxic effects on life-history traits of pond snails (*Lymnaea palustris* and *Lymnaea stagnalis*) in laboratory bioassays. Arch. Environ. Contam. Toxicol. 45(1): 102-109.

Coeurdassier, M., A. De Vaufleury, R. Scheifler, E. Morhain and P.M. Badot. 2004. Effects of cadmium on the survival of three life-stages of the freshwater pulmonate *Lymnaea stagnalis* (Mollusca: Gastropoda). Bull. Environ. Contam. Toxicol. 72(5): 1083-1090.

Cogun, H.Y., T.A. Yuzereroglu and F. Kargin. 2003. Accumulation of copper and cadmium in small and large Nile Tilapia *Oreochromis niloticus*. Bull. Environ. Contam. Toxicol. 71(6): 1265-1271.

Cogun, H.Y., T.A.Yuzereroglu, O. Firat, G. Gok and F. Kargin. 2006. Metal concentrations in fish species from the Northeast Mediterranean Sea. Environ. Monit. Assess. 121: 431-438.

Cohen, T., S.S. Que Hee and R.F. Ambrose. 2001. Trace metals in fish and invertebrates of three California Coastal Wetlands. Mar. Pollut. Bull. 42(3): 224-232.

Cole, R.H., R.E. Frederick and R.P. Healy. 1984. Preliminary findings of the priority pollutant monitoring project of the nationwide urban runoff program. J. Water Pollut. Contr. Fed. 56:898-908.

Collado, C., R. Ramirez, O. Bergasa, J.J. Hernandez-Brito, M.D. Gelado-Caballero and R.J. Haroun. 2006. Heavy metals (Cd, Cu, Pb and Zn) in two species of limpets (*Patella rustica* and *Patella candei* crenata) in the Canary Islands, Spain. Trans. Ecol. Environ. 95: 45-53

Collard, J.M. and R.F. Matagne. 1994. Cd^{2+} resistance in wild-type and mutant strains of *Chlamydomonas reinhardtii*. Environ. Exp. Bot. 34(2): 235-244.

Collier, R.S., J.E. Miller, M.A. Dawson and F.P. Thurberg. 1973. Physiological response of the mud crab *Eurypanopeus depressis* to cadmium. Bull. Environ. Contam. Toxicol. 10(6): 378-382.

Collyard, S.A., G.T. Ankley, R.A. Hoke and T. Goldenstein. 1994. Influence of age on the relative sensitivity of *Hyalella azteca* to diazinon, alkylphenol ethoxylates, copper, cadmium, and zinc. Arch. Environ. Contam. Toxicol. 26: 110-113.

Company, R., A. Serafim, M.J. Bebianno, R. Cosson, B. Shillito and A. Fiala-Medioni. 2004. Effect of cadmium, copper and mercury on antioxidant enzyme activities and lipid peroxidation in the gills of the hydrothermal vent mussel *Bathymodiolus azoricus*. Mar. Environ. Res. 58(2-5: 377-381.

Company, R., A. Serafim, R.P. Cosson, A. Fiala-Medioni, L. Camus, R. Serrao-Santos and M. Joao Bebianno. 2010. Sub-lethal effects of cadmium on the antioxidant defence system of the hydrothermal vent mussel *Bathymodiolus azoricus*. Ecotoxicol. Environ. Saf. 73(5): 788-795.

Connon, R., H.L. Hooper, R.M. Sibly, F.L. Lim, L.H. Heckmann, D.J. Moore, H. Watanabe, A. Soetaert, K. Cook, S.J. Maund, T.H. Hutchinson, J. Moggs, W. De Coen, T. Iguchi and A. Callaghan. 2008. Linking molecular and population stress responses in *Daphnia magna* exposed to cadmium. Environ. Sci. Technol. 42: 2181-2188.

Conti, M.E. and G.Cecchetti. 2003. A biomonitoring study: trace metals in algae and molluscs from Tyrrhenian coastal areas. Environ. Res. 93(1): 99-112.

Conway, H.L. 1978. Sorption of arsenic and cadmium and their effects on growth, micronutrient utilization, and photosynthetic pigment composition of *Asterionella formosa*. J. Fish. Res. Board Can. 35: 286.

Conway, H.L. and S.C. Williams. 1977. Sorption and desorption of cadmium by *Asterionella formosa* and *Fragilaria crotonensis*. In: Argonne Natl. Lab., Radiol.and Environ.Res.Div., Annu.Rep.on Ecol., Argonne, IL, 51-53. 1

Conway, L. 1981. Ecological impact of cadmium on aquatic organisms. Report BNL-51472, Brookhaven Natl. Lab., Upton, NY, 21 p.

Cook, M.E. and H. Morrow. 1995. Anthropogenic sources of cadmium in Canada. National Workshop on Cadmium Transport into Plants. Canadian Network of Toxicology Centres, Ottawa, Ontario, Canada. June 20-21, 1995.

Cooke, J.A and M.S. Johnson. 1996. Cadmium in small mammals. In: W.N. Beyer, G.H. Heinz, A.W. Redmon-Norwood (*Eds.*). Environmental contaminants in wildlife: Interpreting tissue concentrations. Lewis Publishers, New York, pp. 377-388.

Cooke, M., G. Nickless, R.E. Lawn and D.J. Roberts. 1979. Biological availability of sediment-bound cadmium to the edible cockle, *Cerastoderma edule*. Bull. Environ. Contam. Toxicol. 23: 381-386.

Cooper, C.A., R.D. Handy and N.R. Bury. 2006. The effects of dietary iron concentration on gastrointestinal and branchial assimilation of both iron and cadmium in zebrafish (*Danio rerio*). Aquat. Toxicol. 79(2): 167-175.

Cooper, S., L. Hare and P.G.C. Campbell. 2010b. Modeling cadmium uptake from water and food by the freshwater bivalve *Pyganodon grandis*. Can. J. Fish. Aquat. Sci. 67(11): 1874-1888.

Cooper, S., L. Hare and P.G.C. Campbell. 2010a. Subcellular partitioning of cadmium in the freshwater bivalve, *Pyganodon grandis*, after separate short-term exposures to waterborne or diet-borne metal. Aquat. Toxicol. 100 (4): 303-312.

Cooper, V.A. and L.G.S. De. 1978. Reducing the toxicity of cadmium sulphate to rainbow trout (*Salmo gairdneri*) by preliminary exposure of fish to zinc sulphate, with and without intermittent exposure to cadmium. A Progress Report. Int. Lab. Rep. Water Res. Ctr. 750, 8 p.

Cope, W.G., J.G. Wiener and G.J. Atchison. 1994. Hepatic cadmium, metal-binding proteins and bioaccumulation in bluegills exposed to aqueous cadmium. Environ. Toxicol. Chem. 13(4): 553-562.

Cope, W.G., R.B. Bringolf, D.B. Buchwalter, T.J. Newton, C.G. Ingersoll, N. Wang, T. Augspurger, F.J. Dwyer, M.C. Barnhart, R.J. Neves and E. Hammer. 2008. Differential exposure, duration, and sensitivity of unionoidean bivalve life stages to environmental contaminants. J. N. Am. Benthol. Soc. 27(2): 451-462.

Copes, R., N.A. Clark, K. Rideout, J. Palaty and K. Teschke. 2008. Uptake of cadmium from Pacific oysters (*Crassostrea gigas*) in British Columbia oyster growers. Environ. Res. 107(2): 160-169.

Coppellotti, O. 1994. Effects of cadmium on *Uronema marinum* (Ciliophora, Scuticociliatida) from Antarctica. Acta Protozool. 33: 159-167.

Corami, F., G. Capodaglio, C. Turetta, M. Bragadin, N. Calace and B.M. Petronio. 2007. Complexation of cadmium and copper by fluvial humic matter and effects on their toxicity. Ann. Chim. 97(1-2): 25-37.

Cordero, J., M. Guevara, E. Morales and C. Lodeiros. 2005. Effect of heavy metals on the growth of the tropical microalgae *Tetrasermis chuii* (Prasinophyceae). Rev. Biol. Trop. 53(3/4): 325-330.

Cornellier, P. 2010. Cinetique De Bioaccumulation Et Distribution Tissulaire Du Cadmium-109 Par La Nourriture Et Par L'eau Chez Le Petoncle Geant (Placopecten Magellanicus) Et Le Petoncle D'islande (Chlamys Islandica). M.Sc. Thesis, Universite du Quebec a Rimouski, Canada.

Costa, P.M., M.S. Diniz, S. Caeiro, J. Lobo, M. Martins, A.M. Ferreira, M. Caetano, C. Vale, T.A. DelValls and M.H. Costa. 2009b. Histological biomarkers in liver and gills of juvenile *Solea senegalensis* exposed to contaminated estuarine sediments: a weighted indices approach. Aquat. Toxicol. 92(3): 202-212.

Costa, P.M., S. Caeiro, M.S. Diniz, J. Lobo, M. Martins, A.M. Ferreira, M. Caetano, C. Vale, T.A. DelValls and M.H. Costa. 2009a. Biochemical endpoints on juvenile *Solea senegalensis* exposed to estuarine sediments: the effect of contaminant mixtures on metallothionein and CYP1A induction. Ecotoxicology. 18(8): 988-1000.

Costa, P.M., S. Caeiro and M.H. Costa. 2013. Multi-organ histological observations on juvenile Senegalese soles exposed to low concentrations of waterborne cadmium. Fish Physiol. Biochem. 39(2): 143-158.

Coteur, G., D. Gillan, P. Pernet and P. Dubois. 2005. Alteration of cellular immune responses in the seastar *Asterias rubens* following dietary exposure to cadmium. Aquat.Toxicol. 73(4): 418-421.

Couch, J.A. 1977. Ultrastructural study of lesions in gills of a marine shrimp exposed to cadmium. J. Invertebr. Pathol. 29: 267-288.

Couillard, Y., P. Ross and B. Rinel-Alloul. 1989. Acute toxicity of six metals to the rotifer *Brachionus calyciflorus*, with comparisons to other freshwaer organisms. Toxic. Assess. 4(4): 451-462.

Couture, P. and P.R. Kumar. 2003. Impairment of metabolic capacities in copper and calcium contaminated wild yellow perch (*Perca flavescens*). Aquat.Toxicol. 64(1): 107-120.

Cox, A.D. 2011. Interactions of cadmium, zinc, and phosphorus in marine synechococcus: field uptake, physiological and proteomic studies. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Craig, A., L. Hare, P.M. Charest and A. Tessier. 1998. Effect of exposure regime on the internal distribution of cadmium in *Chironomus staegeri* larvae (insecta, diptera). Aquat. Toxicol. 41: 265-275.

Craig, A., L. Hare and A. Tessier. 1999. Experimental evidence for cadmium uptake via calcium channels in the aquatic insect *Chironomus staegeri*. Aquat. Toxicol. 44: 255-262.

Cravo, A., P. Foster, C. Almeida, M.J. Bebianno and R. Company. 2008. Metal concentrations in the shell of *Bathymodiolus azoricus* from contrasting hydrothermal vent fields on the mid-Atlantic ridge. Mar. Environ. Res. 65(4): 338-348.

Creighton, N. and J. Twining. 2010. Bioaccumulation from food and water of cadmium, selenium and zinc in an estuarine fish, *Ambassis jacksoniensis*. Mar. Pollut. Bull. 60(10): 1815-1821.

Cressman III, C.P. and P.L. Williams. 1997. Reference toxicants for toxicity testing using *Caenorhabditis elegans* in aquatic media. In: F.J. Dwyer, T.R. Doane and M.L. Hinman (*Eds.*), Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment (Sixth Volume), ASTM STP 1317, Philadelphia, PA: 518-532.

Crichton, C.A., A.U. Conrad and D.J. Baird. 2004. Assessing stream grazer response to stress: a post-exposure feeding bioassay using the freshwater snail *Lymnaea peregra* (Muller). Bull. Environ. Contam. Toxicol. 72(3): 564-570.

Cripe, G.M. 1994. Comparative acute toxicities of several pesticides and metals to *Mysidopsis bahia* and postlarval *Penaeus duorarum*. Environ. Toxicol. Chem. 13(11): 1867-1872.

Crisinel, A., L. Delaunay, D. Rossel, J. Tarradellas, H. Meyer, H. Saiah, P. Vogel, C. Delisle and C. Blaise. 1994. Cyst-based ecotoxicological tests using anostracans: comparison of two species of *Streptocephalus*. Environ. Toxicol. Water Qual. 9(4): 317-326.

Croisetiere, L., L. Hare and A. Tessier. 2006. A field experiment to determine the relative importance of prey and water as sources of As, Cd, Co, Cu, Pb, and Zn for the aquatic invertebrate *Sialis velata*. Environ. Sci. Technol. 40: 873-879.

Croteau, M.N. and S.N. Luoma. 2008. A biodynamic understanding of dietborne metal uptake by a freshwater invertebrate. Environ. Sci. Technol. 42(5): 1801-1806.

Croteau, M.N., L. Hare and A. Tessier. 2001. Differences in Cd accumulation among species of the lake-dwelling biomonitor chaoborus. Can. J. Fish. Aquat. Sci. 58(9): 1737-1746.

Cruz Rodriguez, L.A. 2002. Heat shock protein (HSP70) response in the eastern oyster, *Crassostrea virginica*, exposed to various contaminants (PAHs, PCBs and Cadmium). Ph.D. Thesis, The College of William and Mary, Williamsburg, VA.

Cruz, C.C.V., A.C.A. Da Costa, C.A. Henriques and A.S. Luna. 2004. Kinetic modeling and equilibrium studies during cadmium biosorption by dead *Sargassum sp.* biomass. Bioresour. Technol. 91(3): 249-257.

Cubadda, F., M.E. Conti and L. Campanella. 2001. Size-dependent concentrations of trace metals in four Mediterranean gastropods. Chemosphere 45(4-5): 561-569.

Cullen, J.T. and M.T. Maldonado. 2013. Biogeochemistry of cadmium and its release to the environment. *In*: A. Sigel, H. Sigel and R.K.O. Sigel (*Eds*.), Cadmium: From Toxicity to Essentiality, Metal Ions in Life Sciences 11, DOI 10.1007/978-94-007-5179-8_2, Springer Science Business Media Dordrecht.

Culshaw, C., L.C. Newton, I. Weir and D.J. Bird. 2002. Concentrations of Cd, Zn and Cu in sediments and brown shrimp (*Crangon crangon* L.) from the Severn Estuary and Bristol Channel, UK. Mar. Environ. Res. 54(3-5): 331-334.

Cunha, I., E. Mangas-Ramirez and L. Guilhermino. 2007. Effects of copper and cadmium on cholinesterase and glutathione S-transferase activities of two marine gastropods (*Monodonta lineata* and *Nucella lapillus*). Comp. Biochem. Physiol. 145C(4): 648-657.

Cunningham, J.L. 2012. The effect of cadmium exposure on repeat swimming performance and recovery in rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and lake whitefish (*Coregonus clupeaformis*). M.S. Thesis, Wilfrid Laurier University, Canada.

Currie, R.S., D.C.G. Muir, W.L. Fairchild, M.H. Holoka and R.E. Hecky. 1998. Influence of nutrient additions on cadmium bioaccumulation by aquatic invertebrates in littoral enclosures. Environ. Toxicol. Chem. 17(12): 2435-2443.

Cusimano, R.F., D.F. Brakke and G.A. Chapman. 1986. Effects of pH on the toxicities of cadmium, copper, and zinc to steelhead trout (*Salmo gairdneri*). Can. J. Fish. Aquat. Sci. 43: 1497-1503.

Cuthbert, K.C., A.C. Brown and M.J. Orren. 1976. Toxicity of cadmium to *Bullia digitalis* (prosobranchiata: nassaridae). Trans. R. Soc. S. Afr. 42: 203-208.

Cuvin-Aralar, MLA. 1994. Survival and heavy metal accumulation of two Oreochromis niloticus (L.) strains exposed to mixtures of zinc, cadmium and mercury. Sci. Tot. Environ., 148: 31-38.

Cuvin-Aralar, M.L. and Aralar, E.V. 1993 Effects of long-term exposure to a mixture of cadmium, zinc, and inorganic mercurey on two strains of Tilapia *Oreochromis niloticus (L.).* Bull. Environ. Toxicol. 50: 891-897.

Cyrille, Y.D., K. Victor, T.A. Sanogo, S. Boukary and W. Joseph. 2012. Cadmium accumulation in tissues of *Sarotherodon melanotheron* (Ruppel, 1852) from the Aby Lagoon system in Cote d'Ivoire. Int. J. Environ. Res. Public Health 9(3): 821-30.

D’Agostino, A. and C. Finney. 1974. The effect of copper and cadmium on the development of *Tigriopus japonicus*. *In:* F.J. Vernberg and W.B. Vernberg (eds.), Pollution and Physiology of Marine Organisms. Academic Press, New York. p. 445.

D’Aniello, A., M. Pischetola, F. Vanacore, M. De Nicola and M. Denuce. 1990. Effect of mercury, cadmium and copper on the development and viability of *Loligo vulgaris* and *Sepia officinalis* embryos. Ital. J. Biochem. 39(2): 130A-132A.

Da Cruz, A.C.S., B.C. Couto, I.A. Nascimento, S.A. Pereira, M.B.N.L. Leite, E. Bertoletti and P. Zagatto. 2007. Estimation of the critical effect level for pollution prevention based on oyster embryonic development toxicity test: The search for reliability. Environ. Int. 33(4): 589-595.

da Silva, E.T., M. Ridd and D. Klumpp. 2005. Can body burden in the barnacle *Balanus amphitrite* indicate seasonal variation in cadmium concentrations? Estuar. Coast. Shelf Sci. 65(1-2): 159-171.

da Silva, E.T., M.K. Ridd, D. Klumpp and P. Ridd. 2004. Relative contribution of food and water to the Cd burden in *Balanus amphitrite* in an urban tidal creek discharging into the Great Barrier Reef lagoon. Estuar. Coast. Shelf Sci. 60(2): 313-324.

Dabas, A., N.S. Nagpure, R. Kumar, B. Kushwaha, P. Kumar and W.S. Lakra. 2012. Assessment of tissue-specific effect of cadmium on antioxidant defense system and lipid peroxidation in freshwater murrel, *Channa punctatus*. Fish Physiol. Biochem. 38(2): 469-482.

Daka, E.R. and S.J. Hawkins. 2006. interactive effects of copper, cadmium and lead on zinc accumulation in the gastropod mollusc *Littorina saxatilis*. Water Air Soil Pollut. 171(1-4): 19-28.

Daka, E.R., S.J. Hawkins and E.R. Daka. 2004. Tolerance to heavy metals in *Littorina saxatilis* from a metal contaminated estuary in the Isle of Man. J. Mar. Biol. Assoc. U.K. 84(2): 393-400.

Dallinger, R. and H. Kautzky. 1985. The importance of contaminated food for the uptake of heavy metals by rainbow trout (*Salmo gairdneri*): a field study. Oecologia 67(1):82-89.

Dallinger, R., E. Carpene, G.J. Dalla Via and P. Cortesi. 1989. Effects of cadmium on *Murex trunculus* from the Adriatic Sea. I. Accumulation of metal and binding to a metallothionein-like protein. Arch. Environ. Contam. Toxicol. 18: 554-561.

Dallinger, R., M. Egg, G. Kock and R. Hofer. 1997. The role of metallothionein in cadmium accumulation of Arctic char (*Salvelinus alpinus*) from high alpine lakes. Aquat. Toxicol. 38: 47-66.

Damiens, G., C. Mouneyrac, F. Quiniou, E. His, M. Gnassia-Barelli and M. Romeo. 2006. Metal bioaccumulation and metallothionein concentrations in larvae of *Crassostrea gigas*. Environ. Pollut. 140(3): 492-499.

Dang, F. and W.X. Wang. 2009. Assessment of tissue-specific accumulation and effects of cadmium in a marine fish fed contaminated commercially produced diet. Aquat. Toxicol. 95(3): 248-255.

Dang, Z.C., M.H.G. Berntssen, A.K. Lundebye, G. Flik, S.E. Wendelaar Bonga and R.A.C. Lock. 2001. Metallothionein and cortisol receptor expression in gills of atlantic salmon, *Salmo salar*, exposed to dietary cadmium. Aquat. Toxicol. 53(2): 91-101.

Dangre, A.J., S. Manning and M. Brouwer. 2010. Effects of cadmium on hypoxia-induced expression of hemoglobin and erythropoietin in larval sheepshead minnow, *cyprinodon variegatus*. Aquat. Toxicol. 99(2):168-175.

Darmono, D. 1990. Uptake of cadmium and nickel in banana prawn (*Penaeus merguiensis* de Man). Bull. Environ. Contam. Toxicol. 45: 320-328.

Darmono, D., G.R.W. Denton and R.S.F. Campbell. 1990. The pathology of cadmium and nickel toxicity in the banana shrimp (*Penaeus merguiensis* de Man). Asian Fish. Sci. 3(3): 287-297.

Das, M. and K. Maiti Subodh. 2007. Metal accumulation in *A. baccifera* growing naturally on abandoned copper tailings pond. Environ. Monit. Assess. 127(1-3): 119-125.

Das, S. and A. Gupta. 2012. Effects of cadmium chloride on oxygen consumption and gill morphology of Indian flying barb, *Esomus danricus*. J. Environ. Biol. 33(6): 1057-1061.

Das, S. and B.S. Khangarot. 2010. Bioaccumulation and toxic effects of cadmium on feeding and growth of an Indian pond snail *Lymnaea luteola* L. under laboratory conditions. J. Hazard. Mater. 182(1/3): 763-770.

Das, S., A.K. Sharma and T. Ahmad. 2012. The temperature dependence of the acute toxicity of heavy metals (cadmium, copper and mercury) to a freshwater pond snail, *Lymnae aluteola* L. Environ. Conserv. J. 13(1/2): 11-15.

Datta, D.K and G.M. Sinha. 1987. Estimation of acute toxicity of cadmium, a heavy metal, in a carnivorous freshwater teleost, *Mystus vittatus* (Bloch). *In*: Proc. Indian Natl. Sci. Acad. Part B 53(1): 43-45.

Datta, S., S.H. Masala and R.C. Das. 2003. Influence of some abiotic factors on the acute toxicity of cadmium to *Cyprinus carpio*. J. Indian Fish. Assoc. 30: 41-52.

Dautremepuits, C., D.J. Marcogliese, A.D. Gendron and M. Fournier. 2009. Gill and head kidney antioxidant processes and innate immune system responses of yellow perch (*Perca flavescens*) exposed to different contaminants in the St. Lawrence River, Canada. Sci. Total Environ. 407(3): 1055-64.

Dauvin, J.C. 2008. Effects of heavy metal contamination on the macrobenthic fauna in estuaries: the case of the Seine Estuary. Mar. Pollut. Bull. 57,(1-5): 160-169.

Dave, G., K. Andersson, R. Berglind and B. Hasselrot. 1981. Toxicity of eight solvent extraction chemicals and of cadmium to water fleas, *Daphnia magna*, rainbow trout, *Salmo gairdneri*, and zebrafish, *Brachydanio rerio*. Comp. Biochem. Physiol. 69C(1): 83-98.

Daverat, F., N. Tapie, L. Quiniou, R. Maury Brachet, R. Riso., M. Eon, J. Laroche and H. Budzinski. 2011. Otolith microchemistry interrogation of comparative contamination by Cd, Cu and PCBs of eel and flounder, in a large SW France catchment. Est. Coast Shelf Sci. 92(3): 332-338.

Davies, I.M., G. Topping, W.C. Graham, C.R. Falconer, A.D. McIntosh and D. Saward. 1981. Field and experimental studies on cadmium in the edible crab *Cancer pagurus*. Mar. Biol. 64: 291-297.

Davies, N.A., M.G. Taylor and K. Simkiss. 1997. The influence of particle surface characteristics on pollutant metal uptake by cells. Environ. Pollut. 96(2): 179-184.

Davies, P.H. 1976a. Use of dialysis tubing in defining the toxic fractions of heavy metals in natural water. *In:* R.W. Andrew, P.V. Hodson and D.E. Konasewich (*Eds*.), Toxicity to Biota of Metal Forms in Natural Water. International Joint Commission, Windsor, Ontario. p. 110.

Davies, P.H. 1976b. The need to establish heavy metal standards on the basis of dissolved metals. *In:* R.W. Andrew, P.V. Hodson and D.E. Konasewich (*Eds*.), Toxicity to Biota of Metal Forms in Natural Water, Proceedings of a Workshop held in Duluth, MN: 93-126.

Davies, P.H. and S.F. Brinkman. 1994a. Appendix I: Effects of pre-exposure to sublethal waterborne cadmium on cadmium toxicity, metallothionein concentrations, and subcellular distribution of cadmium in the gill and kidney of brown trout. In: P.H. Davies (*Ed.*), Water Pollution Studies, Federal Aid in Fish and Wildlife Restoration, Project #F-33. Colorado Division of Wildlife, Fort Collins, CO, p. I-11-I-31.

Davies, P.H. and S.F. Brinkman. 1994b, Appendix II: Cadmium toxicity to rainbow trout: Bioavailability and kinetics in waters of high and low complexing capacities. In: P.H. Davies (*Ed.*), Water Pollution Studies, Federal Aid in Fish and Wildlife Restoration, Project #F-33. Colorado Division of Wildlife, Fort Collins, CO, p. II-33-II-59.

Davies, P.H. and S.F. Brinkman. 1994c, Toxicology and chemical data on unregulated pollutants. Water Pollution Studies, Federal Aid in Fish and Wildlife Restoration, Project #F-33. Colorado Division of Wildlife, Fort Collins, CO, p. 5-10.

Davies, P.H. and W.C. Gorman. 1987. Effects of chemical equilibria and kinetics on the bioavailability and toxicity of cadmium to rainbow trout. Am. Chem. Soc. Natl. Meeting. 194: 646-650.

Davies, P. H. and Woodling, J. D. 1980. Importance of laboratory-derived metal toxicity results in predicting in-stream response of resident salmonids. *In:* J.G.Eaton, P.R.Parrish and A.C. Hendricks (*Eds*.), Aquatic Toxicology, ASTM STP 707, Philadelphia, PA: 281-299.

Davies, P.H., W.C. Gorman, C.A. Carlson and S.F. Brinkman. 1993. Effect of hardness on bioavailability and toxicity of cadmium to rainbow trout. Chem. Spec. Bioavail. 5(2): 67-77.

Davies, R.W., R.N. Singhal and D.D. Wicklum. 1995. Changes in reproductive potential of the leech *Nephelopsis obscura* (Erpobdellidae) as biomarkers for cadmium stress. Can. J. Zool. 73: 2192-2196.

Davis, A., C. Sellstone, S. Clough, R. Barrick and B. Yare. 1996. Bioaccumulation of arsenic, chromium and lead in fish: constraints imposed by sediment geochemistry. Appl. Geochem. 11: 409-423.

Davis, A.P., M. Shokouhian and S. Ni. 2001. Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. Chemosphere. 44: 997-1009.

Davis, T.A., F.E.C. Alli, E. Giannitti, B. Volesky and A. Mucci, A. 2004. Cadmium biosorption by *S. Fluitans*: Treatment, resilience and uptake relative to other *Sargassum spp*. and brown algae. Water Qual. Res. J. Can. 39(3): 183-189.

Dawson, M.A., E. Gould. F.P. Thurberg and A. Calabrese. 1977. Physiological response of juvenile striped bass, *Morone saxatilis*, to low levels of cadmium and mercury. Chesapeake Sci. 18(4): 353-.359.

Dayeh, V R., D.H. Lynn and N.C. Bols. 2005. Cytotoxicity of metals common in mining effluent to rainbow trout cell lines and to the ciliated protozoan, *Tetrahymena thermophila*. Toxicol. In Vitro 19(3): 399-410.

De Boeck, G., M. Eyckmans, I. Lardon, R. Bobbaers, A.K. Sinha and R. Blust. 2010. Metal accumulation and metallothionein induction in the spotted dogfish *Scyliorhinus canicula*. Comp. Biochem. Physiol.155A(4): 503-508.

De Coninck, D.I.M., C.R. Janssen and K.A.C. De Schamphelaere. 2013. An investigation of the inter-clonal variation of the interactive effects of cadmium and *Microcystis aeruginosa* on the reproductive performance of *Daphnia magna*. Aquat. Toxicol. 140-141: 425-431.

De Conto Cinier, C., M. Petit-Ramel, R. Faure and D. Garin. 1997. Cadmium bioaccumulation in carp (*Cyprinus carpio*) tissues during long-term high exposure: analysis by inductively coupled plasma-mass spectrometry. Ecotoxicol. Environ. Safety. 38: 137-143.

De Conto Cinier, C, M. Petit-Ramel, R. Faure and M. Bortolato. 1998. Cadmium accumulation and metallothionein biosynthesis in *Cyprinus carpio* tissues. Bull. Environ. Contam. Toxicol. 61: 793-799.

De Lange, H.J., J. Lahr, J.J.C. Van der Pol, Y. Wessels and J.H. Faber. 2009. Ecological vulnerability in wildlife: an expert judgement and multicriteria analysis tool using ecological traits to assess relative impact of pollutants. Environ. Toxicol. Chem. 28(10): 2233-2240.

De Lisle, P.F. and M.H. Roberts, Jr. 1988. The effect of salinity on cadmium toxicity to the estuarine mysid *Mysidopsis bahia*: role of chemical speciation. Aquat. Toxicol. 12: 357-370.

De Lisle, P.F. and M.H. Roberts, Jr. 1994. The effect of salinity on cadmium toxicity in the estuarine mysid *Mysidopsis bahia*: roles of osmoregulation and calcium. Mar. Environ. Res. 37: 47-62.

De March, B.G.E. 1988. Acute toxicity of binary mixtures of five cations (Cu^{2+}, Cd^{2+}, Zn^{2+}, Mg^{2+} and K^+) to the freshwater amphipod *Gammarus lacustris* (Sars): alternative descriptive models. Can. J. Fish. Aquat. Sci. 45: 625-633.

de Mora, S., S.W. Fowler, E. Wyse and S. Azemard. 2004. Distribution of heavy metals in marine bivalves, fish and coastal sediments in the Gulf and Gulf of Oman. Mar. Pollut. Bull. 49(5-6): 410-424.

De Nicloa Guidici, M. and L. Migliore. 1988. Long term effect of cadmium of copper on *Asellus aquaticus* (L.) (Crustacea, isopoda). Verh.- Int. Ver. Theor. Angew. Limnol. 23: 1660-1662.

De Nicola Giudici, M. and S.M. Guarino. 1989. Effects of chronic exposure to cadmium or copper on *Idothea baltica* (crustacea, isopoda). Mar. Pollut. Bull. 20(2): 69-73.

De Nicola, M., N. Cardellicchio, C. Gambardella, S.M. Guarino and C. Marra. 1993. Effects of cadmium on survival, bioaccumulation, histopathology, and PGM polymorphism in the marine isopod *Idotea baltica*. Ecotoxicol. Met. Invert. Proc. Sess. 1993. 1st Meet.: 103-116.

De Nicola, M., C. Gambardella and S.M. Guarino. 1996. Ecotoxicological assessment of pollutants by chemico-biological analysis: a minireview. Ann. Chim. 86(11-12): 515-526.

De Smet, H. and R. Blust. 2001. Stress responses and changes in protein metabolism in carp *Cyprinus carpio* during cadmium exposure. Ecotoxicol. Environ. Saf. 48(3): 255-262.

De Smet, H., B. De Wachter, R. Lobinski and R. Blust. 2001. Dynamics of (Cd,Zn)-metallothioneins in gills, liver and kidney of common carp *Cyprinus carpio* during cadmium exposure. Aquat. Toxicol. 52(3/4): 269-281.

de Vlaming, V. and T.J. Norberg-King. 1999. A review of single species toxicity tests: Are the tests reliable predictors of aquatic ecosystem community response? Duluth, MN, U.S. Environmental Protection Agency, EPA 600/R/97/114.

De Vries, W., P.F.A.M. Romkens and G. Schutze. 2007. Critical soil concentrations of cadmium, lead, and mercury in view of health effects on humans and animals. Rev. Environ. Contam. Toxicol. 191: 91-130.

De Wolf, H. and R. Rashid. 2008. Heavy metal accumulation in *Littoraria scabra* along polluted and pristine mangrove areas of Tanzania. Environ. Pollut. 152(3): 636-643.

De Wolf, H., T. Backeljau and R. Blust. 2004. Sensitivity to cadmium along a salinity gradient in populations of the periwinkle, *Littorina littorea*, using time-to-death analysis. Aquat. Toxicol. 66(3): 241-253.

Debelak, R.W. 1975. Acute toxicity of mixtures of copper, chromium, and cadmium to *Daphnia magna*. Thesis. Miami University, Oxford, Ohio.

Decho, A.W. and S.N. Luoma. 1994. Humic and fulvic acids: ink or source in the availability of metals to the marine bivalves *Macoma balthica* and *Potamocorbula amurensis*? Mar. Ecol. Prog. Ser. 108: 133-145.

De Filippis, L.F., R. Hampp and H. Ziegler. 1981. The effects of sublethal concentrations of zinc, cadmium and mercury on *Euglena*. II. Respiration, photosynthesis and photochemical activities. Arch. Microbiol. 128: 407-411.

Defo, M.A., F. Pierron, P.A. Spear, L. Bernatchez, P.G. Campbell and P. Couture. 2012. evidence for metabolic imbalance of vitamin A2 in wild fish chronically exposed to metals. Ecotoxicol. Environ. Saf. 85(0): 88-95.

DeForest, D.K., K.V. Brix and W.J. Adams. 2007. Assessing metal bioaccumulation in aquatic environments: the inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. Aquat. Toxicol. 84: 236-246.

Dekker, T., O.E. Krips and W. Admiraal. 2002. Life history changes in the benthic cladoceran *Chydorus piger* induced by low concentrations of sediment-bound cadmium. Aquat. Toxicol. 56(2): 93-101.

Dekker, T., G.D. Greve, T.L. Ter Laak, M.E. Boivin, B. Veuger, G. Gortzak, S. Dumfries, S.M.G. Lucker, M.H.S. Kraak, W. Admiraal and H.G. Van der Geest. 2006. Development and application of a sediment toxicity test using the benthic cladoceran *Chydorus sphaericus*. Environ. Pollut. 140(2): 231-238.

Del Castillo Arias, E. and W.E. Robinson. 2009. Nuclear and cytosolic distribution of metallothionein in the edible blue mussel, *Mytilus edulis* Linnaeus exposed to cadmium and benzo[a]pyrene and in gill tissue from three natural populations along the Massachusetts coast. Ph.D. Thesis, University of Massachusetts Boston, Boston, MA.

Del Ramo, J, J. Diaz-Mayans, A. Torreblanca and A. Nunez. 1987. Effects of temperature on the acute toxicity of heavy metals (Cr, Cd, and Hg) to the freshwater crayfish, *Procambarus clarkii* (Girard). Bull. Environ. Contam. Toxicol. 38: 736-741.

DeLisle, P. F. and M.H. Roberts Jr. 1988. The effect of salinity of cadmium toxicity to the estuarine *Mysidopsis bahia*: role of chemical speciation. Aquat. Toxicol. 12: 357-370.

Delmail, D., P. Labrousse, P. Hourdin, L. Larcher, C. Moesch and M. Botineau. 2011. Physiological, anatomical and phenotypical effects of a cadmium stress in different-aged chlorophyllian organs of *Myriophyllum alterniflorum* DC (Haloragaceae). Environ. Exp. Bot. 72(2): 174-181.

Delmotte, S., F.J.R. Meysman, A. Ciutat, A. Boudou, S. Sauvage and M. Gerino. 2007. Cadmium transport in sediments by tubificid bioturbation: an assessment of model complexity. Geochim. Cosmochim. Acta. 71(4): 844-862.

Delval, C., M.A. Janquin and A. Richard. 1988. Responses of a flat fish, the flounder (*Platichtys flesus* L.) to metal pollutions by elaborating metallothioneins; competition between zinc, copper. Oceanis 14(4): 519-524.

Demirak A., F. Yilmaz, A.L. Tuna and N. Ozdemir. 2006. Heavy metals in water, sediment and tissues of *Leuciscus cephalus* from a stream in Southwestern Turkey. Chemosphere 63(9): 1451-1458.

Demon, A., M. De Bruin and H. Wolterbeek. 1988. The influence of pH on trace element uptake by an alga (*Scenedesmus pannonicus* subsp. Berlin) and fungus (*Aureobasidium pullulans*). Environ. Monit. Assess. 10-2: 165-173.

Demon, A., M. De Bruin and H. Wolterbeek. 1989. The influence of pre-treatment, temperature and calcium ions on trace element uptake by an alga (*Scenedesmus pannonicus* subsp. Berlin) and fungus (*Aureobasidium pullulans*). Environ. Monit. Assess. 13: 21-33.

Den Besten, P.J., H.J. Herwig, D.I. Zandee and P.A. Voogt. 1989. Effects of cadmium and PCBs on reproduction of the sea star *Asterias rubens*: aberrations in the early development. Ecotoxicol. Environ. Safety. 18(2): 173-180.

Den Besten, P.J., E.G. van Donselaar, H.J. Herwig, D.I. Zandee and P.A. Voogt. 1991. Effects of cadmium on gametogenesis in the sea star *Asterias rubens* L. Aquat. Toxicol. 20: 83-94.

Deng, H., Z. Zhang, C. Chang and Y. Wang. 2007. Trace metal concentration in great tit (*Parus major*) and greenfinch (*Carduelis sinica*) at the Western Mountains of Beijing, China. Environ. Pollut. 148(2): 620-626.

Deniseger, J., A. Austin and W.P. Lucey. 1986. Periphyton communities in a pristine mountain stream above and below heavy metal mining operations. Freshw. Biol. 16: 209-218.

Denton, G.R.W. and C. Burdon-Jones. 1981. Influence of temperature and salinity on the uptake, distribution, and depuration of mercury, cadmium, and lead by the black-lip oyster *Saccostrea echinata*. Mar. Biol. 64: 317.

Denton, G.R.W. and C. Burdon-Jones. 1986a. Trace metals in corals from the Great Barrier Reef. Mar. Pollut. Bull. 17(5): 209-213.

Denton, G.R.W. and C. Burdon-Jones. 1986b. Environmental effects on toxicity of heavy metals to two species of tropical marine fish from northern Australia. Chem. Ecol. 2: 233-249.

Department of the Environment. 1973. Water Pollut. Res. 1972. London. p. 37.

Desouky, M.M.A. 2012. Metallothionein is up-regulated in molluscan responses to cadmium, but not aluminum, exposure. J. Basic Appl. Zool. 65(2): 139-143.

Desouky, M.M., C.R. McCrohan, R. Jugdaohsingh, J.J. Powell, J. J. and K.N. White. 2003. Effect of orthosilicic acid on the accumulation of trace metals by the pond snail *Lymnaea stagnalis*. Aquat. Toxicol. 64(1): 63-71.

Desrosiers, M., C. Gagnon, S. Masson, L. Martel and M.P. Babut. 2008. Relationships among total recoverable and reactive metals and metalloid in St. Lawrence River sediment: bioaccumulation by chironomids and implications for ecological risk assessment. Sci. Total Environ. 389(1): 101-114.

Dethlefsen, V. 1978. Uptake, retention and loss of cadmium by brown shrimp (*Crangon crangon*). Meeresforschung 26: 137-152.

Deveau, A. 2011. Kwakwaka'wakw use of the edible seaweed taqq'astan (*Porphyra abbottiae* Krishnamurthy: Bangiaceae) and metal bioaccumulation at traditional harvesting sites in Queen Charlotte Strait and Broughton Strait. M.Sc. Thesis, University of Victoria, Canada.

Devi Prasad, P.V. and P.S. Devi Prasad. 1982. Effect of cadmium, lead and nickel on three freshwater green algae. Water Air Soil Pollut. 17: 263.

Devi, C.A. and A.K. Kumaraguru. 2008. Toxicity of heavy metals copper and cadmium on the brown macroalgal species of Pudumadam Coast, Gulf of Mannar. Seaweed Res. Util., Spec. Issue 30: 203-211.

Devi, M., D.A. Thomas, J.T. Barber and M. Fingerman. 1996. Accumulation and physiological and biochemical effects of cadmium in a simple aquatic food chain. Ecotoxicol. Environ. Safety. 33: 38-43.

Devi, V.U. 1987. Heavy metal toxicity to fiddler crabs, *Uca annulipes* Latreille and *Uca triangularis* (Milne Edwards): tolerance to copper, mercury, cadmium, and zinc. Bull. Environ. Contam. Toxicol. 39: 1020-1027.

Devi, V.U. 1996. Bioaccumulation and metabolic effects of cadmium on marine fouling dressinid bivalve, *Mytilopsis sallei* (Recluz). Arch. Environ. Contam. Toxicol. 31: 47-53.

Devi. V.U. 1997. Heavy metal toxicity to an intertidal gastropod *Morula granulata* (Duclos): Tolerance to copper, mercury, cadmium and zinc. J. Environ. Biol. 18(3): 287-290.

Devi, V.U. and Y.P. Rao. 1989. Cadmium accumulation in fiddler crabs *Uca annulipes* latelle and *Uca triangularis* (Milne Edwards). Water, Air, Soil Pollut. 43: 309-321.

Devier, M.H., S. Augagneur, H. Budzinski, K. Le Menach, P. Mora, J.F. Narbonne and P. Garrigues. 2005. One-year monitoring survey of organic compounds (PAHs, PCBs, TBT), heavy metals and biomarkers in blue mussels from the Arcachon Bay, France. J. Environ. Monit. 7(3): 224-240.

Devineau, J. and C.A. Triquet. 1985. Patterns of bioaccumulation of an essential trace element (zinc) and a pollutant metal (cadmium) in larvae of the prawn *Palaemon serratus*. Mar. Biol. 86: 139-143.

Dhamotharan, R., S. Murugesan, S. and M. Yoganandam. 2009. Bioremediation of tannery effluent using cyanobacterium. Biosci. Biotechnol. Res. Asia 5(1): 201-206.

Di Giulio, R.T. and R.F. Scanlon. 1984. Sublethal effects of cadmium ingestion on mallard ducks. Arch. Environ. Contam. Toxicol. 13: 765.

Diamond, J.M., D.E. Koplish, J. McMahon III and R. Rost. 1997. Evaluation of the water-effect ratio procedure for metals in a riverine system. Environ. Toxicol. Chem. 16(3): 509-520.

Diamond, J., M. Bowersox, H. Latimer, C. Barbour, J. Bearr and J. Butcher. 2005. Effects of pulsed contaminant exposures on early life stages of the fathead minnow. Arch. Environ. Contam. Toxicol. 49(4): 511-519.

Dickson, G.W., J.P. Giesy and L.A. Briese. 1982. The effect of chronic cadmium exposure on phosphoadenylate concentrations and adenylate energy charge of gills and dorsal muscle tissue of crayfish. Environ. Toxicol. Chem. 1(2): 147-156.

Dierickx, P.J. and E. Bredael-Rozen. 1996. Correlation between the *in vitro* cytotoxicity of inorganic metal compounds to cultured fathead minnow fish cells and the toxicity to *Daphnia magna*. Bull. Environ. Contam. Toxicol. 57: 107-110.

Dierking, J., E. Wafo, T. Schembri, V. Lagadec, C. Nicolas, Y. Letourneur and M. Harmelin-Vivien. 2009. Spatial patterns in PCBs, pesticides, mercury and cadmium in the common sole in the NW Mediterranean Sea, and a novel use of contaminants as biomarkers. Mar. Pollut. Bull. 58(11): 1605-1614.

Dietrich, G.J., M. Dietrich, R.K. Kowalski, S. Dobosz, H. Karol, W. Demianowicz and J. Glogowski. 2010. Exposure of rainbow trout milt to mercury and cadmium alters sperm motility parameters and reproductive success. Aquat. Toxicol. 97(4): 277-284.

Dietrich, M.A., G.J. Dietrich, P. Hliwa and A. Ciereszko. 2011. Carp transferrin can protect spermatozoa against toxic effects of cadmium ions. Comp. Biochem. Physiol. 153C(4): 422-429.

Dillon, T.M. and B.C. Suedel. 1986. The relationship between cadmium bioaccumulation and survival, growth, and reproduction in the freshwater crustacean, *Daphnia magna*. Environ. Contam., 2nd Conf., CEP Consult., Edinburgh, U.K.: 21-23.

Dinnel, P.A., J.M. Link, Q.J. Stober, M.W. Letourneau and W.E. Roberts. 1989. Comparative sensitivity of sea urchin sperm bioassays to metals and pesticides. Arch. Environ. Contam. Toxicol. 18: 748-755.

Dive, D., N. Pommery, M. Lalande and F. Erb. 1982. Cadmium complexation by humic substances: chemical and ecotoxicological study with ciliate protozoan *Colpidium campylum*. Can. Tech. Rep. Fish. Aquat. Sci. 1163: 9-21.

Dive, D., S. Robert, E. Angrand, C. Bel, H. Bonnemain, L. Brun, Y. Demarque, A. Le Du, R. El Bouhouti, M.N. Fourmaux, L. Guery, O. Hanssens and M. Murat. 1989. A bioassay using the measurement of the growth inhibition of a ciliate protozoan: *Colpidium campylum* Stokes. Hydrobiol. 188/189: 181-188.

Dixon, J.L., P.J. Statham, C.E. Widdicombe, R.M. Jones, S. Barquero-Molina, B. Dickie, M. Nimmo and C.M. Turley. 2006. Cadmium uptake by marine micro-organisms in the English Channel and Celtic Sea. Aquat. Microb. Ecol. 44(1): 31-43.

Dixon, W.J. and M.B. Brown (*Eds.*) 1979. BMDP Biomedical Computer Programs, P-series. University of California, Berkeley, California. p. 521.

Dobrovoljc, K., Z. Jeran and B. Bulog. 2003. Uptake and elimination of cadmium in *Rana dalmatina* (Anura, Amphibia) tadpoles. Bull. Environ. Contam. Toxicol. 70(1): 78-84.

Doganlar, Z.B. 2013. Metal accumulation and physiological responses induced by copper and cadmium in *Lemna gibba*, *L. minor* and *Spirodela polyrhiza*. Chem. Spec. Bioavail. 25(2): 79-88.

Domal-Kwiatkowska, D., B. Sosak-Swiderska, U. Mazurek and D. Tyrawska. 1994. The effect of cadmium on the survival and filtering rate of *Daphnia magna*, Straus 1820. Pol. Arch. Hydrobiol. 41(4): 465-473.

Dong, X.Y., Z.D. Sun, X.Y. Qi and B.J. Xie. 2006. Concentrations of heavy metals and safe assessments of fishes in main lakes from Wuhan City. J. Hygiene Res. 35(6): 719-21

Dorfman, D. 1977. Tolerance of *Fundulus heteroclitus* to different metals in salt waters. Bull. New Jersey Acad. Sci. 22: 21.

Dorgelo, J., H. Meester and C. van Velzen. 1995. Effects of diet and heavy metals on growth rate and fertility in the deposit-feeding snail *Potamopyrgus jenkinsi* (Smith) (Gastropoda: Hydrobiidae). Hydrobiol. 316: 199-210.

Dorts, J., A. Bauwin, P. Kestemont, S. Jolly, W. Sanchez and F. Silvestre. 2012. Proteasome and antioxidant responses in cottus gobio during a combined exposure to heat stress and cadmium. Comp. Biochem. Physiol.155C(2): 318-324.

Dorts, J., P. Kestemont, M. Dieu, M. Raes and F. Silvestre. 2009. Sub-lethal cadmium toxicity in bullhead *Cottus gobio*. Biochemical and proteomic approaches. Comp. Biochem.Physiol. 154A (Suppl. 1): S17.

Dorts, J., P. Kestemont, M. Dieu, M. Raes and F. Silvestre. 2011. Proteomic response to sublethal cadmium exposure in a sentinel fish species, *Cottus gobio*. J. Proteome Res. 10(2): 470-478.

Douben, P.E.T. 1989. Uptake and elimination of waterborne cadmium by the fish *Noemacheilus barbatulus* L. (stone loach). Arch. Environ. Contam. Toxicol. 18: 576-586.

Dovzhenko, N.V., A.V. Kurilenko, N.N. Bel'cheva, N. N. and V.P. Chelomin. 2005. Cadmium-induced oxidative stress in the bivalve mollusk *Modiolus modiolus*. Russ. J. Mar. Biol.31(5): 309-313.

Downs, C.A., J.E. Fauth and C.M. Woodley. 2001a. Assessing the health of grass shrimp (*Palaeomonetes pugio*) exposed to natural and anthropogenic stressors: a molecular biomarker system. Mar. Biotechnol. 3(4): 380-397.

Downs, C.A., R.T. Dillon Jr., J.E. Fauth and C.M. Woodley. 2001b. A molecular biomarker system for assessing the health of gastropods (*Ilyanassa obsoleta*) exposed to natural and anthropogenic stressors. J. Exp. Mar. Biol. Ecol. 259(2): 189-214.

Dragun, Z., B. Raspor and M. Podrug. 2007. The influence of the season and the biotic factors on the cytosolic metal concentrations in the gills of the european chub (*Leuciscus cephalus* L.). Chemosphere 69(6): 911-919.

Dragun, Z., M. Erk, D. Ivankovic, R. Zaja, V. Filipovic Marijic and B. Raspor, B. 2010. Assessment of low-level metal contamination using the Mediterranean mussel gills as the indicator tissue. Environ. Sci. Pollut. Res. Int. 17(4): 977-986.

Drastichova, J., Z. Svobodova, V. Luskova and J. Machova. 2004a. Effect of cadmium on hematological indices of common carp (*Cyprinus carpio* L.). Bull. Environ. Contam. Toxicol. 72(4): 725-732.

Drastichova, J., Z. Svobodova, V. Luskova, O. Celechovska and P. Kalab. 2004b. Effect of cadmium on blood plasma biochemistry in carp (*Cyprinus carpio* L.). Bull. Environ. Contam. Toxicol. 72(4): 733-740.

Drastichova, J., E. Svestkova, V. Luskova and Z. Svobodova. 2005. Cytochemical study of carp neutrophil granulocytes after acute exposure to cadmium. J. Appl. Ichthyol. 21(3): 215-219.

Drava, G., R. Apelli, V. Minganti, R. De Pellegrini, L.O. Relini and M. Ivaldi. 2004. Trace elements in the muscle of red shrimp *Aristeus antennatus* (Risso, 1816) (Crustacea, Decapoda) from Ligurian sea (NW Mediterranean): variations related to the reproductive cycle. Sci. Total Environ. 321(1-3): 87-92.

Drazkiewicz, M. and T. Baszynski. 2008. Calcium protection of PS2 complex of *Phaseolus coccineus* from cadmium toxicity: in vitro study. Environ. Exp. Bot. 64(1): 8-14.

Drbal, K., K. Veber and J. Zahradnik. 1985. Toxicity and accumulation of copper and cadmium in the alga *Scenedesmus obliquus* LH. Bull. Environ. Contam. Toxicol. 34: 904-908.

Dressing, S.A. 1980. The effect of chemical speciation on the equilibrium, whole-body cadmium content of larvae of the caddisfly, *Hydropsyche sp.* M.S.Thesis, University of North Carolina, Chapel Hill, NC.

Dressing, S.A., R.P. Maas and C.M. Weiss. 1982. Effect of chemical speciation on the accumulation of cadmium by the caddisfly, *Hydropsyche* sp. Bull. Environ. Contam. Toxicol. 28: 172-180.

Drinovec, L., D. Drobne, I. Jerman and A. Zrimec. 2004. Delayed fluorescence of *Lemna minor*: A biomarker of the effects of copper, cadmium, and zinc. Bull. Environ. Contam. Toxicol. 72(5): 896-902.

Drost, W., M. Matzke and T. Backhaus. 2007. Heavy metal toxicity to *Lemna minor*: Studies on the time dependence of growth inhibition and the recovery after exposure. Chemosphere 67(1): 36-43.

Drummond, R.A. and D.A. Benoit. Manuscript. Toxicity of cadmium to fish: some observations on the influence of experimental procedures. U.S. EPA, Duluth, Minnesota.

Drummond, R.A. and D.A. Benoit. 1976. Importance of test procedures on the toxicity of cadmium to brook trout (*Salvelinus fontinalis*). Unpublished paper. National Water Quality Laboratory, U.S. Environmental Protection Agency, Duluth, MN, 10 p.

Du Laing, G., A.M.K. Van de Moortel, W. Moors, W., P. De Grauwe, E. Meers, F.M.G. Tack and M.G. Verloo. 2009. Factors affecting metal concentrations in reed plants (*Phragmites australis*) of intertidal marshes in the Scheldt Estuary. Ecol. Eng. 35(2): 310-318.

Duan, Y., S.I. Guttman., J.T. Oris and A.J. Bailer. 2001. Differential survivorship among allozyme genotypes of *Hyalella azteca* exposed to cadmium, zinc or low pH. Aquat. Toxicol. 54(1/2): 15-28.

Dugmonits, K., A. Ferencz, Z. Jancso, R. Juhasz and E. Hermesz. 2013. Major distinctions in the antioxidant responses in liver and kidney of Cd^{2+}-treated common carp (*Cyprinus carpio*). Comp. Biochem. Physiol. Part C Toxicol. Pharmacol. 158(4): 225-230.

Dulymamode, R., N. Sukhoo and I. Bhugun. 2001. Evaluation of *Padina boergesenii* (phaeophyceae) as a bioindicator of heavy metals: Some preliminary results from Mauritius. S. Afr. J. Bot. 67(3): 460-464.

Duman, F. and M. Kar. 2012. Temporal variation of metals in water, sediment and tissues of the European chup (*Squalius cephalus* L.). Bull. Environ. Contam. Toxicol. 89: 428-433.

Duman, F., M. Cicek and G. Sezen. 2007. Seasonal changes of metal accumulation and distribution in common club rush (*Schoenoplectus lacustris*) and common reed (*Phragmites australis*). Ecotoxicology 16(6): 457-463.

Duman, F., Z. Leblebici and A. Aksoy. 2009. Bioaccumulation of nickel, copper, and cadmium by *Spirodela polyrhiza* and *Lemna gibba*. J. Freshw. Ecol. 24(1): 177-179.

Duman, F., A. Aksoy, Z. Aydin and R. Temizgul. 2011. Effects of exogenous glycinebetaine and trehalose on cadmium accumulation and biological responses of an aquatic plant (*Lemna Gibba* L.). Water Air Soil Pollut. 217(1-4): 545-556.

Duncan, D.A. and J.F. Klaverkamp. 1983. Tolerance and resistance to cadmium in white suckers (*Catostomus commersoni*) previously exposed to cadmium, mercury, zinc, or selenium. Can. J. Fish. Aquat. Sci. 40: 128.

Duong, T.T., S. Morin, O. Herlory, A. Feurtet-Mazel, M. Coste and A. Boudou. 2008. Seasonal effects of cadmium accumulation in periphytic diatom communities of freshwater biofilms. Aquat. Toxicol. 90(1): 19-28.

Duong, T.T., S. Morin, M. Coste, O. Herlory, A. Feurtet-Mazel and A. Boudou. 2010. Experimental toxicity and bioaccumulation of cadmium in freshwater periphytic diatoms in relation with biofilm maturity. Sci. Total Environ. 408(3): 552-562.

Duquesne, S.J. and J.C. Coll. 1995. Metal accumulation in the clam *Tridacna crocea* under natural and experimental conditions. Aquat. Toxicol. 32: 239-253.

Duquesne, S., M. Liess and D.J. Bird. 2004. Sub-lethal effects of metal exposure: physiological and behavioural responses of the estuarine bivalve *Macoma balthica*. Mar. Environ. Res. 58(2-5): 245-250.

Dural M., M.Z. Goöksu, A.A. Ozak and B. Derici. 2006. Bioaccumulation of some heavy metals in different tissues of *Dicentrarchus labrax* L, 1758, *Sparus aurata* L, 1758 and *Mugil cephalus* L, 1758 from the Camlik Lagoon of the Eastern Coast of Mediterranean (Turkey). Environ. Monit. Assess. 118(1-3): 65-74.

Durum, W.H., J.D. Hem and S.G. Heidel. 1971. Reconnaissance of selected minor elements in surface waters of the United States, October 1970. U.S. Geological Survey Circular 643, 49 p.

Dutta, T.K. and A. Kaviraj. 2001. Acute toxicity of cadmium to fish *Labeo rohita* and copepod *Diaptomus forbesi* pre-exposed to CaO and $KMnO_4$. Chemosphere 42(8): 955-958.

Dutton, J. and N.S. Fisher. 2011a. Salinity effects on the bioavailability of aqueous metals for the estuarine killifish *Fundulus heteroclitus*. Environ. Toxicol. Chem. 30(9): 2107-2114.

Dutton, J. and N.S. Fisher. 2011b. Bioaccumulation of As, Cd, Cr, Hg(II), and MeHg in killifish (*Fundulus heteroclitus*) from amphipod and worm prey. Sci. Tot. Environ. 409(18): 3438-3447.

Dutton, J. and N.S. Fisher. 2012. Influence of humic acid on the uptake of aqueous metals by the killifish *Fundulus heteroclitus*. Environ. Toxicol. Chem. 31(10): 2225-2232.

Dyer, S.D., S.E. Belanger and G.J. Carr. 1997. An initial evaluation of the use of Euro/North American fish species for tropical effects assessments. Chemosphere. 35(11): 2767-2781.

Eaton, J.G. 1973. Chronic toxicity of a copper, cadmium and zinc mixture to the fathead minnow (*Pimephales Promelas* Rafinesque). Water Res. 7(11): 1723-1736.

Eaton, J.G. 1974. Chronic cadmium toxicity to the bluegill (*Lepomis macrochirus* Rafinesque). Trans. Am. Fish. Soc. 4: 729.

Eaton, J.G. 1980. Memorandum to C.E. Stephan. U.S. EPA, Duluth, Minnesota. August 5.

Eaton, J.G., J.M. McKim and G.W. Holcombe. 1978. Metal toxicity to embryos and larvae of seven freshwater fish species-I. Cadmium. Bull. Environ. Contam. Toxicol. 19(1): 95-103.

Ebau, W., C.S.M. Rawi, Z. Din and S.A. Al-Shami. 2012. Toxicity of cadmium and lead on tropical midge larvae, *Chironomus kiiensis* Tokunaga and *Chironomus javanus* Kieffer (Diptera: Chironomidae). Asian Pacific J. Tropical Biomed. 2(8): 631-634.

Ebrahimi, M. 2005. Using computer assisted sperm analysis (CASA) to monitoring the effects of zinc and cadmium pollution on fish sperm. Iran. J. Fish.Sci. 4(2): 81-100.

Ebrahimi, M. 2007. Effects of in vivo and in vitro zinc and cadmium treatment on sperm steroidogenesis of the African catfish *Clarias gairepinus*. Pak. J. Biol. Sci. 10(17): 2862-2867.

Ebrahimi, M. and M. Taherianfard. 2010. Concentration of four heavy metals (cadmium, lead, mercury, and arsenic) in organs of two cyprinid fish (*Cyprinus carpio* and *Capoeta sp.*) from the Kor River (Iran). Environ. Monit. Assess. 168(1-4): 575-585.

Ebrahimpour, M. and I. Mushrifah. 2008. Heavy metal concentrations (Cd, Cu and Pb) in five aquatic plant species in Tasik Chini, Malaysia. Environ. Geol. 54(4): 689-698.

Ebrahimpour, M. and I. Mushrifah. 2010. Seasonal variation of cadmium, copper, and lead concentrations in fish from a freshwater lake. Biol. Trace Elem. Res.138(1-3): 190-201.

Echeveste, P., S. Agusti and A. Tovar-Sanchez. 2012. Toxic thresholds of cadmium and lead to oceanic phytoplankton: Cell size and ocean basin-dependent effects. Environ. Toxicol. Chem. 31(8): 1887-1894.

Echols, B.S., R. Currie and D.S. Cherry. 2010. Preliminary results of laboratory toxicity tests with the mayfly, *Isonychia bicolor* (Ephemeroptera: Isonychiidae) for development as a standard test organism for evaluating streams in the Appalachian coalfields of Virginia and West Virginia. Environ. Monit. Assess. 169(1-4): 487-500.

Edema, C.U. and A.B.M. Egborge. 2001. Heavy metal content of crabs from Warri River, Nigeria. Ind. J. Entomol. 63(2): 151-157.

Edge, K.J., E.L. Johnston, A.C. Roach and A.H. Ringwood. 2012. Indicators of environmental stress: Cellular biomarkers and reproductive responses in the Sydney rock oyster (*Saccostrea glomerata*). Ecotoxicol. 21(5): 1415-1425.

Edgren, M. and M. Notter. 1980. Cadmium uptake by fingerlings of perch (*Perca fluviatilis*) studied by Cd-115m at two different temperatures. Bull. Environ. Contam. Toxicol. 24: 647-651.

EIFAC Working Party on Water Quality Criteria for European Freshwater Fish. 1978. Report on cadmium and freshwater fish. Water Res. 12: 281-283.

Eimers, M.C., R.D. Evans and P.M. Welbourn. 2001. Cadmium accumulation in the freshwater isopod *Asellus racovitzai*: The relative importance of solute and particulate sources at trace concentrations. Environ. Pollut. 111(2): 247-253.

Eisler, R. 1971. Cadmium poisoning in *Fundulus heteroclitus* (Pisces: Cyprinodontidae) and other marine organisms. J. Fish. Res. Board Can. 28: 1225.

Eisler, R. 1974. Radio cadmium exchange with seawater by *Fundulus heteroclitus* (L.) (Pisces: Cyprinodontidae). J. Fish Biol. 6: 601.

Eisler, R. 1977. Acute toxicities of selected heavy metals to the soft-shell clam, *Mya arenaria*. Bull. Environ. Contam. Toxicol. 17: 137.

Eisler, R. 1981. Trace metal concentrations in marine organisms. Pergamon Press, NY.

Eisler, R. 1985. Cadmium hazards to fish, wildlife and invertebrates: A synoptic review. U.S. Fish and Wildlife Service Biological Report 85 (1.2), Contaminant Hazard Reviews Report.

Eisler, R. and G.R. Gardner. 1973. Acute toxicology to an estuarine teleost of mixtures of cadmium, copper, and zinc salts. J. Fish Biol. 5: 131.

Eisler, R. and R. Hennekey. 1977. Acute toxicities of Cd^{+2}, Cr^{+6}, Hg^{+2}, Ni^{+2}, and Zn^{+2} to estuarine macrofauna. Arch. Environ. Contam. Toxicol. 6: 315.

Eisler, R., G.E. Zaroogian and R.J. Hennekey. 1972. Cadmium uptake by marine organisms. J. Fish. Res. Board Can. 29(9): 1367-1369.

Eisler, R., M.M. Barry, R.L. Lapan, Jr., G. Telek, E.W. Davey and A.E. Soper. 1978. Metal survey of the marine clam *Pitar morrhauna* collected near a Rhode Island (USA) electroplating plant. Mar. Biol. 45: 311-417.

Eisler, R., R.M. Rossoll and G.A. Gaboury. 1979. Fourth annotated bibliography on biological effects of metals in aquatic environments. EPA-600/3-79-084. National Technical Information Service, Springfield, VA.

Eissa, B.L., A. Salibian and L. Ferrari. 2006. Behavioral alterations in juvenile *Cyprinus carpio* (Linnaeus, 1758) exposed to sublethal waterborne cadmium. Bull. Environ. Contam. Toxicol. 77(6): 931-937.

Eissa, B.L., N.A. Ossana, L. Ferrari and A. Salibian. 2010. Quantitative behavioral parameters as toxicity biomarkers: fish responses to waterborne cadmium. Arch. Environ. Contam. Toxicol. 58(4): 1032-1039.

Elder, J.F. and H.C. Mattraw Jr. 1984. Accumulation of trace elements, pesticides, and polychlorinated biphenyls in sediments and the clam *Corbicula manilensis* of the Apalachicola River, Florida. Arch. Environ. Contam. Toxicol. 13: 453-469.

Eletta, O.A.A., F.A. Adekola and J.S. Omotosho. 2004. Determination of concentration of heavy metals in two common fish species from Asa River, Ilorin, Nigeria. Toxicol. Environ. Chem. 85(1-3): 7-12.

Elinder, C.G. 1992. Cadmium as an environmental hazard. IARC Sci. Publ. 118:123-132.

Elinder, C.G. 1985. Cadmium: Uses, occurrence and intake. In: Friberg, L., C.G. Elinder and T. Kjellström(*Eds.*). Cadmium and health: A toxicological and epidemiological appraisal. Vol. I. Exposure, dose, and metabolism. Effects and response. Boca Raton, FL: CRC Press. pp. 23-64.

Elliott, N.G., R. Swain and D.A. Ritz. 1985. The influence of cyclic exposure on the accumulation of heavy metals by *Mytilus edulis planulatus* (Lamarck). Mar. Environ. Res. 15: 17-30.

Elliott, N.G., R. Swain and D.A. Ritz. 1986. Metal interaction during accumulation by the mussel *Mytilus edulis planulatus*. Mar. Biol. 395-399.

Elnabarawy, M.T., A.N. Welter and R.R. Robideau. 1986. Relative sensitivity of three daphnid species to selected organic and inorganic chemicals. Environ. Toxicol. Chem. 5: 393-398.

Engel, D.W. 1999. Accumulation and cytosolic partitioning of metals in the american oyster *Crassostrea virginica*. Mar. Environ. Res. 47: 89-102.

Engel, D.W. and B.A. Fowler. 1979. Copper and cadmium induced changes in the metabolism and structure of molluscan gill tissue. In: W.B.Vernberg, F.P.Thurberg, A.Calabrese, and F.J.Vernberg (*Eds*.), Marine Pollution: Functional Responses, Acad., NY, 239-256.

Enserink, L., W. Luttmer and H. Maas-Diepeveen. 1990. Reproductive strategy of *Daphnia magna* affects the sensitivity of its progeny in acute toxicity tests. Aquat. Toxicol. 17: 15-26.

Enserink, L., J.L. Maas-Diepeveen and C.J. Van Leeuwen. 1991. Combined effects of metals; an ecotoxicological evaluation. Water Res. 25(6): 679-687.

Enserink, L., M. De la Haye and H. Maas. 1993. Reproductive strategy of *Daphnia magna*: Implications for chronic toxicity test. Aquat Toxicol. 25: 111-124.

Erdogrul, O. and D.A. Ates. 2006. Determination of cadmium and copper in fish samples from Sir and Menzelet Dam Lake Kahramanmaras, Turkey. Environ. Monit. Assess. 117(1-3): 281-290.

Erickson, R.J., and C.E. Stephan. 1988. Calculation of the final acute value for water quality criteria for aquatic organisms. Duluth, MN., Environmental Research Laboratory-Duluth, EPA/600/3-88/018. 62 p.

Erickson, R.J., D.R. Mount, T.L. Highland, J.R. Hockett, E.N. Leonard, V.R. Mattson, T.D. Dawson and K.G. Lott. 2010. Effects of copper, cadmium, lead, and arsenic in a live diet on juvenile fish growth. Can. J. Fish. Aquat. Sci. 67: 1816-1826.

Errecalde, O., M. Seidl and P.G.C. Campbell. 1998. Influence of a low molecular weight metabolite (citrate) on the toxicity of cadmium and zinc to the unicellular green alga *Selenastrum capricornutum*: and exception to the free-ion model. Water Res. 32(2): 419-429.

Escobedo-Fregoso, C., L. Mendez-Rodriguez, P. Monsalvo-Spencer, R. Llera-Herrera, T. Zenteno-Savin and B. Acosta-Vargas. 2010. Assessment of metallothioneins in tissues of the clam *Megapitaria squalida* as biomarkers for environmental cadmium pollution from areas enriched in phosphorite. Arch. Environ. Contam. Toxicol. 59(2): 255-263.

Eslami, S., A. Hajizadeh Moghaddam, N. Jafari, S.F. Nabavi, S.M. Nabavi and M.A. Ebrahimzadeh. 2011. Trace element level in different tissues of *Rutilus frisii* kutum collected from Tajan River, Iran. Biol. Trace Elem. Res. 143(2): 965-73.

Espana, M.S.A., E.M.R. Rodriguez and C.D. Romero. 2004. Manganese, nickel, selenium and cadmium in molluscs from the Magellan Strait, Chile. Food Add. Contam. 21(8): 768-773.

Espinoza, H.M., C.R. Williams and E.P. Gallagher. 2012. Effect of cadmium on glutathione s-transferase and metallothionein gene expression in coho salmon liver, gill and olfactory tissues. Aquat. Toxicol. 110: 37-44.

Esposito, S., S. Sorbo, B. Conte and A. Basile. 2012. Effects of heavy metals on ultrastructure and HSP70s induction in the aquatic moss *Leptodictyum riparium* Hedw. Int. J. Phytoremediat. 14(4): 443-455.

Essumang, D.K. 2009. Analysis and human health risk assessment of arsenic, cadmium, and mercury in *Manta birostris* (manta ray) caught along the Ghanaian coastline. Human Ecolog. Risk Assess.15(5): 985-998.

Estabrook, G.F., D.W. Burk, D.R. Inman, P.B. Kaufman, J.R. Wells, J.D. Jones and N. Ghosheh. 1985. Comparison of heavy metals in aquatic plants on Charity Island, Saginaw Bay, Lake Huron, USA, with plants along the shoreline of Saginaw Bay. Am. J. Bot. 72(2): 209-216.

Esvelt, L.A., W.J. Kaufman and R.E. Selleck. 1971. Toxicity removal from municipal wastewaters. Volume IVof a study of toxicity and biostimulation in San Francisco Bay-Delta waters. Rep. No. 71-7, Sanitary Engineering Research Laboratory, University of California, Berkeley, CA, 236 p.

Etnier, E.L., R.E. Meyer, E.B. Lewis and L.C. Folmar. 1987. Update of acute and chronic aquatic toxicity data for heavy metals and organic chemicals found at hazardous waste sites. ORNL-6392, Oak Ridge Natl.Lab., Oak Ridge, TN, 207 p.

European Commission (EC). 2001. Ambient air pollution by As, Cd and Ni compounds. Position paper. Working Group on Arsenic, Cadmium and Nickel Compounds. European Commission, Directorate-General Environment.

Eustace, I.J. 1974. Zinc, cadmium, copper and manganese in species of finfish and sellfish caught in the Derwent estuary, Tashmania. Aust. J. Mar. Fresh. Res.25(2): 209-220.

Evans, D.H. 1987. The fish gill: site of action and model for toxic effects of environmental pollutants. Environ. Health Perspect. 71:47-58.

Evans, R.D., G.C. Balch, H.E. Evans and P.M. Welbourn. 2002. Simultaneous measurement of uptake and elimination of cadmium by caddisfly (Trichoptera: Hydropsychidae) larvae using stable isotope tracers. Environ. Toxicol. Chem. 21(5): 1032-1039.

Everaarts, J.M. 1990. Uptake and release of cadmium in various organs of the common mussel, *Mytilus edulis* (L.). Bull. Environ. Contam. Toxicol. 45: 560-567.

Everaarts, J.M. and C.V. Fischer. 1991. Micro contaminants in surface sediments and macrobenthic invertebrates of the North Sea. Govt. Report. Announ. Index Issue 08

NMED Exhibit 70

Everard, L.B. and R. Swain. 1983. Isolation, charaterization and induction of metallothionein in the stonefly *Eusthenia spectabilis* following exposure to cadmium. Comp. Biochem. Physiol.75(C): 275-280.

EVS Environment Consultants. 1996. Site-Specfic Toxicity Testing Methods for the South Fork Coeur D'Alene River-Results and Recommendations

Evtushenko, Z.S., N.N. Belcheva and O.N. Lukyanova. 1986. Cadmium accumulation in organs of the scallop *Mizuhopecten yessoensis* - I. activities of phosphatases and composition and amount of lipids. Comp. Biochem. Physiol. 83C: 371-376.

Evtushenko, Z.S., O.N. Lukyanova and N.N. Belcheva. 1990. Cadmium bioaccumulation in organs of the scallop *Mizuhopecten yessoensis*. Mar. Biol. 104: 247-250.

Ezemonye, L.I.N. and A. Enuneku. 2005. Evaluation of acute toxicity of cadmium and lead to amphibian tadpoles (toad: *Bufo Maculatus* and frog: *Ptychadena Birroni*). J. Aquat. Sci. 20(1): 33-38.

Fabacher, D.L. 1982. Hepatic microsomes from freshwater fish - I. *In vitro* cytochrome P-450 chemical interactions. Comp. Biochem. Physiol. 73(C), 277-283.

Fabris, G., N.J. Turoczy and F. Stagnitti. 2006. Trace metal concentrations in edible tissue of snapper, flathead, lobster, and abalone from coastal waters of Victoria, Australia. Ecotoxicol. Environ. Saf. 63: 286-292.

Faggio, C., A. Torre, D. Alberghina, G. Piccione and F. Trischitta. 2010. Cadmium impairs RVD in the digestive cells of *Mytilus galloprovincialis*. Comp. Biochem. 157A, Suppl. 1(0): S37-S38.

Faimali, M., F. Garaventa, V. Piazza, E. Costa, G. Greco, V. Mazzola, M. Beltrandi, E. Bongiovanni, S. Lavorano and G. Gnone. 2013. Ephyra jellyfish as a new model for ecotoxicological bioassays. Mar. Environ. Res. (In Press).

Fair, P.A. and L.V. Sick. 1983. Accumulations of naphthalene and cadmium after simultaneous ingestion by the Black Sea Bass, *Centropristis striata*. Arch. Environ. Contam. Toxicol. 12: 551.

Falfushynska, H.I., L.L. Gnatyshyna and O.B. Stoliar. 2012. Population-related molecular responses on the effect of pesticides in *Carassius auratus* gibelio. Comp. Biochem. Physiol. 155C(2): 396-406.

Fan, W.H., G. Tang, C.M. Zhao, Y. Duan and R. Zhang. 2009. Metal accumulation and biomarker responses in *Daphnia magna* following cadmium and zinc exposure. Environ. Toxicol. Chem. 28(2): 305-310.

Fang, J.K.H., R.S.S. Wu, A.K.Y. Chan and P.K.S. Shin. 2008. Metal concentrations in green-lipped mussels (*Perna viridis*) and rabbitfish (*Siganus oramin*) from Victoria Harbour, Hong Kong after pollution abatement. Mar. Pollut. Bull. 56(8): 1486-1491.

Fang, T.H., J.S. Hwang, S.H. Hsiao and H.Y. Chen. 2006. Trace metals in seawater and copepods in the ocean outfall area off the northern Taiwan Coast. Mar. Environ. Res. 61: 224-243.

Fang, Y., H. Yang, T. Wang, B. Liu, H. Zhao and M. Chen. 2010. Metallothionein and superoxide dismutase responses to sublethal cadmium exposure in the clam *Mactra veneriformis*. Comp. Biochem. Physiol. 151C(3): 325-333.

Fang, Z. 2006. Comparative studies on uptake pathway of cadmium by *Perna viridis*. J. Ocean Univ. China. 5(1): 49-54.

Fang, Z.Q., R.Y.H. Cheung and M.H. Wong. 2003. Heavy metals in oysters, mussels and clams collected from coastal sites along the Pearl River Delta, South China. J. Environ. Sci. 15(1): 9-24.

Faraday, W.E. and A.C. Churchill. 1979. Uptake of cadmium by the eelgrass *Zostera marina*. Mar. Biol. 53: 293.

Farag, A.M., C.J. Boese, D.F. Woodward and H.L. Bergman. 1994. Physiological changes and tissue metal accumulation in rainbow trout exposed to foodborne and waterborne metals. Environ. Toxicol. Chem. 13(12): 2021-2029.

Farag, A.M., D.F. Woodward, J.N. Goldstein, W. Brumbaugh and J.S. Meyer. 1998. Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River basin, Idaho. Arch. Environ. Contam. Toxicol. 34: 19-127.

Farag, A.M., D. Skaar, D.A. Nimick, E. MacConnell and C. Hogstrand. 2003. Characterizing aquatic health using salmonid mortality, physiology, and biomass estimates in streams with elevated concentrations of arsenic, cadmium, copper, lead, and zinc in the Boulder River Watershed, Montana. Trans. Am. Fish. Soc. 132(3): 450-467.

Farag, A.M., D.A. Nimick, B.A. Kimball, S.E. Church, D.D. Harper and W.G. Brumbaugh. 2007. Concentrations of metals in water, sediment, biofilm, benthic macroinvertebrates, and fish in the Boulder River Watershed, Montana, and the role of colloids in metal uptake. Arch. Environ. Contam. Toxicol. 52: 397-409.

Fargasova, A. 1993. Effect of five toxic metals on the alga *Scenedesmus quadricauda*. Biologia, Bratislava. 48(3): 301-304.

Fargasova, A. 1994a. Toxicity of metals on *Daphnia magna* and *Tubifex tubifex*. Ecotoxicol Environ. Safety. 27: 210-213.

Fargasova, A. 1994b. Comparative toxicity of five metals on various biological subjects. Bull. Environ. Contam. Toxicol. 53: 317-324.

Fargasova, A. 2001. Winter third- to fourth-instar larvae of *Chironomus plumosus* as bioassay tools for assessment of acute toxicity of metals and their binary combinations. Ecotoxicol. Environ. Saf. 48(1): 1-5.

Fargasova, A. 2003. Cd, Cu, Zn and their binary combination acute toxicity for *Chironomus pulmosus* larvae. Fresenius Environ. Bull. 12(8): 830-834.

Faria, M.S., R.J. Lopes, A.J. Nogueira and A.M. Soares. 2007. In situ and laboratory bioassays with *Chironomus riparius* larvae to assess toxicity of metal contamination in rivers: The relative toxic effect of sediment versus water contamination. Environ. Toxicol. Chem. 26(9): 1968-1977.

Faria, M., D. Huertas, D.X. Soto, J.O. Grimalt, J. Catalan, M.C. Riva and C. Barata. 2010. Contaminant accumulation and multi-biomarker responses in field collected zebra mussels (*Dreissena polymorpha*) and crayfish (*Procambarus clarkii*), to evaluate toxicological effects of industrial hazardous dumps in the Ebro river (NE Spain). Chemosphere 78(3): 232-40.

Farkas, A., J. Salanki and A. Specziar. 2003. Age- and size-specific patterns of heavy metals in the organs of freshwater fish *Abramis brama* L. populating a low-contaminated site. Water Res. 37(5): 959-964.

Fattorini, D., A. Notti, R. Di Mento, A.M. Cicero, M. Gabellini, A. Russo and F. Regoli. 2008. Seasonal, spatial and inter-annual variations of trace metals in mussels from the Adriatic Sea: a regional gradient for arsenic and implications for monitoring the impact of off-shore activities. Chemosphere 72(10): 1524-1533.

Faucher, K., D. Fichet, P. Miramand and J.P. Lagardere. 2006. Impact of acute cadmium exposure on the trunk lateral line neuromasts and consequences on the "C-Start" response behaviour of the sea bass (*Dicentrarchus labrax* L.; Teleostei, Moronidae). Aquat. Toxicol. 76(3/4): 278-294.

Faucher, K., D. Fichet, P. Miramand and J.P. Lagardere. 2008. Impact of chronic cadmium exposure at environmental dose on escape behaviour in sea bass (*Dicentrarchus labrax* L.; Teleostei, Moronidae). Environ. Pollut. 151(1): 148-157.

Faupel, M. and W. Traunspurger. 2012. Secondary production of a zoobenthic community under metal stress. Water Res. 46(10): 3345-3352.

Faupel, M., K. Ristau and W. Traunspurger. 2012. The functional response of a freshwater benthic community to cadmium pollution. Environ. Pollut. 162: 104-109.

Fava, J.A., J.J. Gift, A.F. Maciorowski, W.L. McCulloch and H.J. Reisinger II. 1985. Comparative toxicity of whole and liquid phase sewage sludges to marine organisms. In: R. Cardwell, R. Purdy and R. Bahner (*Eds*.), Aquatic Toxicology and Hazard Assessment: 7th Symposium, ASTM STP 854, Philadelphia, PA, 229-252.

Favorito, R., G. Chiarelli, M.C. Grimaldi, S. De Bonis, M. Lancieri and I. Ferrandino. 2011. Bioaccumulation of cadmium and its cytotoxic effect on zebrafish brain. Chem. Ecol. 27(S2): 39-46.

Fayed, S.E. and H.I. Abdel-Shafy. 1986. Accumulation of Cu, Cd, and Pb by algae. Egypt. J. Microbiol. 21(2): 263-274.

Fdil, M.A., A. Mouabad, A. Outzourhit, A. Benhra, A. Maarouf and J.C. Pihan. 2006. Valve movement response of the mussel *Mytilus galloprovincialis* to metals (Cu, Hg, Cd and Zn) and phosphate industry effluents from moroccan atlantic coast. Ecotoxicol. 15(5): 477-486.

Felten, V., G. Charmantier, R. Mons, A. Geffard, P. Rousselle, M. Coquery, J. Garric and O. Geffard. 2008. Physiological and behavioural responses of *Gammarus pulex* (Crustacea: Amphipoda) exposed to cadmium. Aquat. Toxicol. 86(3): 413-425.

Feng, C.X., J. Cao and L. Bendell. 2011. Exploring spatial and temporal variations of cadmium concentrations in pacific oysters from British Columbia. Biometrics 67(3): 1142-52.

Feng, T., C. Song and J. Chen. 2012. Indication function of aquatic algae for environment. Agricult. Sci. Technol. 13(5): 1060-1066.

Fennikoh, K.B., H.I. Hirshfield and T.J. Kneip. 1978. Cadmium toxicity in planktonic organisms of a freshwater food web. Environ. Res. 15(3): 357-367.

Ferencz, A., R. Juhasz, M. Butnariu, A.K. Deer, I.S. Varga and J. Nemcsok. 2012. Expression analysis of heat shock genes in the skin, spleen and blood of common carp (*Cyprinus carpio*) after cadmium exposure and hypothermia. Acta Biol. Hung. 63(1): 15-25.

Fernandez, B., J.A. Campillo, C. Martinez-Gomez and J. Benedicto. 2012. Assessment of the mechanisms of detoxification of chemical compounds and antioxidant enzymes in the digestive gland of mussels, *Mytilus galloprovincialis*, from Mediterranean coastal sites. Chemosphere 87(11): 1235-45.

Fernandez, N. and R. Beiras. 2001. Combined toxicity of dissolved mercury with copper, lead and cadmium on embryogenesis and early larval growth of the *Paracentrotus lividus* sea-urchin. Ecotoxicol. 10(5): 263-271.

Fernandez-Leborans, G. and M.T. Antonio-Garcia. 1988. Effects of lead and cadmium in a community of protozoans. Acta Protozool. 27(2): 141-159.

Fernandez-Leborans, G. and A. Novillo-Villajos. 1993. Changes in trophic structure of a freshwater protozoan community subjected to cadmium. Ecotoxicol. Environ. Safety. 25: 271-279.

Fernandez-Leborans, G. and A. Novillo. 1996. Toxicity and bioaccumulation of cadmium in *Olisthodiscus Leteus*. Water Res. 30(1): 57-62.

Fernandez-Pinas, F, P. Mateo and I. Bonilla. 1995. Cadmium toxicity in *Nostoc* UAM208: protection by calcium. New Phytol. 131: 403-407.

Fernández-Severini, M.D., S.E. Botté, M.S. Hoffmeyer and J.E. Marcovecchio. 2009. Spatial and temporal distribution of cadmium and copper in water and zooplankton in the Bahía Blanca estuary, Argentina. Estuar. Coast. Shelf Sci. 85(1): 57-66.

Ferrari, L, A. Salibian and C.V. Muino. 1993. Selective protection of temperature against cadmium acute toxicity to *Bufo arenarum* tadpoles. Bull. Environ. Contam. Toxicol. 50: 212-218.

Ferrari, L., B.L. Eissa and A. Salibian. 2011. Energy balance of juvenile *Cyprinus carpio* after a short-term exposure to sublethal water-borne cadmium. Fish Physiol. Biochem. 37(4): 853-862.

Ferreira da Silva, E., S.F.P. Almeida, M.L. Nunes, A.T. Luis, F. Borg, M. Hedlund, C.M. de Sa, C. Patinha and P. Teixeira. 2009. Heavy metal pollution downstream the abandoned Coval Da Mo mine (Portugal) and associated effects on epilithic diatom communities. Sci. Total Environ. 407(21): 5620-5636.

Ferreira, A.L.G., S. Loureiro and A.M.V.M. Soares. 2008a. Toxicity prediction of binary combinations of cadmium, carbendazim and low dissolved oxygen on *Daphnia magna*. Aquat. Toxicol. 89: 28-39.

Ferreira, M., M. Caetano, J. Costa, P. Pousao-Ferreira, C. Vale and M.A. Reis-Henriques. 2008b. Metal accumulation and oxidative stress responses in, cultured and wild, white seabream from Northwest Atlantic. Sci. Total Environ. 407: 638-646.

Ferrer, L., S. Andrade, R. Asteasuain and J. Marcovecchio. 2006. Acute toxicities of four metals on the early life stages of the crab *Chasmagnathus granulata* from Bahia Blanca Estuary, Argentina. Ecotoxicol. Environ. Saf. 65(2): 209-217.

Fialkowski, W., P.S. Rainbow, B.D. Smith and L. Zmudzinski. 2003. Seasonal variation in trace metal concentrations in three talitrid amphipods from the Gulf of Gdansk, Poland. J. Exp. Mar. Biol. Ecol. 288(1): 81-93.

Figueira, E., P. Cardoso and R. Freitas. 2012. *Ruditapes decussatus* and *Ruditapes philippinarum* exposed to cadmium: Toxicological effects and bioaccumulation patterns. Comp. Biochem. Physiol. 156C(2): 80-86.

Filazi, A., R. Baskaya, C. Kum and S.E. Hismiogullari. 2003. Metal concentrations in tissues of the Black Sea fish *Mugil auratus* from Sinop-Icliman, Turkey. Hum. Exp. Toxicol. 22(2): 85-87.

Filosto, S., M.C. Roccheri, R. Bonaventura and V. Matranga. 2008. Environmentally relevant cadmium concentrations affect development and induce apoptosis of *Paracentrotus lividus* larvae cultured *in vitro*. Cell Biol. Toxicol. 24(6): 603-10

Findlay, D.L., S.E.M. Kasian and E.U. Schindler. 1996. Long-term effects of low cadmium concentrations on a natural phytoplankton community. Can. J. Fish. Aquat. Sci. 53: 1903-1912.

Finger, S.E. and J.S. Bulak. 1988. Toxicity of water from three South Carolina rivers to larval striped bass. Trans. Am. Fish. Soc. 117(6): 521-528.

Finlayson, B.J. and K.M. Verrue. 1982. Toxicities of copper, zinc and cadmium mixtures to juvenile chinook salmon. Trans. Am. Fish. Soc. 111: 645-650.

Finlayson, B., R. Fujimura and Z.Z. Huang. 2000. Toxicity of metal-contaminated sediments from Keswick Reservoir, California, USA. Environ. Toxicol. Chem. 19(2): 485-494.

Firat, O. and F. Kargin. 2010a. Biochemical alterations induced by Zn and Cd individually or in combination in the serum of *Oreochromis niloticus*. Fish Physiol. Biochem. 36(3): 647-653.

Firat, O. and F. Kargin. 2010b. Effects of zinc and cadmium on erythrocyte antioxidant systems of a freshwater fish *Oreochromis niloticus*. J. Biochem. Mol. Toxicol. 24(4): 223-229.

Firat, O. and F. Kargin. 2010c. Individual and combined effects of heavy metals on serum biochemistry of Nile *Tilapia oreochromis* Niloticus. Arch. Environ. Contam. Toxicol. 58(1): 151-157.

Firat, O. and F. Kargin. 2010d. Protein intensity changes in the hemoglobin and plasma electrophoretic patterns of *Oreochromis niloticus* in response to single and combined Zn and Cd exposure. J. Biochem. Mol. Toxicol. 24(6): 395-401.

Fisher, N.S. and J.G. Fabris. 1982. Complexation of Cu, Zn and Cd by metabolites excreted from marine diatoms. Mar. Chem. 11: 245.

Fisher, N.S. and G.J. Jones. 1981. Heavy metals and marine phytoplankton: Correlation of toxicity and sulfhydryl-binding. J. Phycol. 17: 108.

Fisher, N.S., J.L. Teyssie, S.W. Fowler and W.X. Wang. 1996. Accumulation and retention of metals in mussels from food and water: a comparison under field and laboratory conditions. Environ. Sci. Technol. 30(11): 3232-3242.

Fisher, N.S., I. Stupakoff, S. Sanudo-Wilhelmy, W.X. Wang, J.L. Teyssie, S.W. Fowler and J. Crusius. 2000. Trace metals in marine copepods: A field test of a bioaccumulation model coupled to laboratory uptake kinetics data. Mar. Ecol. Prog. Ser. 194: 211-218.

Fitzsimons, J.D., S. Huestis and B. Williston. 1995. Occurrence of a swim-up syndrome in Lake Ontario lake trout in relation to contaminants and cultural practices. J. Great Lakes Res. 21(Suppl. 1): 277-285.

Flament, S., S. Kuntz, A. Chesnel, I. Grillier-Vuissoz, C. Tankozic, M. Penrad-Mobayed, G. Auque, P. Shirali, H. Schroeder and D. Chardard. 2003. Effect of cadmium on gonadogenesis and metamorphosis in *Pleurodeles waltl* (Urodele Amphibian). Aquat. Toxicol. 64(2): 143-153.

Fleeger, J.W., G. Tita, K.R. Carman, R.N. Millward, E.B. Moser, R.J. Portier and R.P. Gambrell. 2006. Does bioturbation by a benthic fish modify the effects of sediment contamination on saltmarsh benthic microalgae and meiofauna? J. Exp. Mar. Biol. Ecol. 330(1): 180-194.

Flegal, A.R. 1978. Trace element concentrations of the rough limpet, *Acmaea scabra*, in California. Bull. Environ. Contam. Toxicol. 20: 834-839.

Flick, D.F., H.F. Kraybill and J.M. Dimitroff. 1971. Toxic effects of cadmium: a review. Environ. Res. 4: 71-85.

Florence, T.M., G.M. Morrison and J.L. Stauber. 1992. Determination of trace element speciation and the role of speciation in aquatic toxicity. Sci. Total Environ. 125: 1-13.

Fokina, N.N. and N.N. Nemova. 2012. Fatty acid composition of blue mussels *Mytilus edulis* changes in response to cadmium and copper effects. Comp. Biochem. Physiol. 163A(Suppl.): S16.

Food and Agriculture Organization of the United Nations. 1977. Report on cadmium and freshwater fish. EIFAC Tech.Pap.No.30, EIFAC Worksin Party on Water Qual. Crit. for Eur. Freshw. Fish with Cooperation of the United Nations Environment Programme (UNEP), Food and Agric.Org.of the United Nations, Rome, 21 p.

Foran, C.M., B.N. Peterson and W.H. Benson. 2002. Influence of parental and developmental cadmium exposure on endocrine and reproductive function in Japanese medaka (*Oryzias latipes*). Comp. Biochem. Physiol.133C(3): 345-354.

Foran, J.A., R.A. Hites, D.O. Carpenter, C. Hamilton, A. Mathews-Amos and S.J. Schwager. 2004. A survey of metals in tissues of farmed Atlantic and wild Pacific salmon. Environ. Toxicol. Chem. 23(9): 2108-2110.

Forbes, V.E. 1991. Response of *Hydrobia ventrosa* (Montagu) to environmental stress: Effects of salinity fluctuations and cadmium exposure on growth. Funct. Ecol. 5(5): 642-648.

Forget, J., J.F. Pavillon, M.R. Menasria and G. Bocquene. 1998. Mortality and LC50 values for several stages of the marine copepod *Tigriopus brevicornis* (Muller) exposed to the metals arsenic and cadmium and the pesticides atrazine, carbofuran, dichlorvos, and malathion. Ecotoxicol. Environ. Safety. 40: 239-244.

Forget, J., J.F. Pavillon, B. Beliaeff and G. Bocquene. 1999. Joint action of pollutant combinations (pesticides and metals) on survival (LC50 values) and acetylcholinesterase activity of *Tigriopus brevicornis* (Copepoda, Harpacticoida). Environ. Toxicol. Chem 18(5): 912-918.

Formicki, G., R. Stawarz, N. Lukac, A. Putala and A. Kuczkowska. 2008. Combined effects of cadmium and ultraviolet radiation on mortality and mineral content in common frog (*Rana temporaria*) larvae. J. Environ. Sci. Health 43A(10): 1174-1183.

Formicki, G., R. Stawarz, P. Massanyi, M. Guzik, T. Laciak, Z. Goc and K. Kilian. 2009. Cadmium availability to freshwater mussel (*Unio tumidus*) in the presence of organic matter and UV radiation. J. Environ. Sci. Health 44A(8): 808-819.

Fort, D.J., E.L. Stover, J.A. Bantle, J.N. Dumont and R.A. Finch. 2001. Evaluation of a reproductive toxicity assay using *Xenopus laevis*: boric acid, cadmium and ethylene glycol monomethyl ether. J. Appl. Toxicol. 2: 41-52.

Foster, P.L. 1982. Metal resistances of chlorophyta from rivers polluted by heavy metals. Freshwater Biol. 12: 41.

Fowler, B.A., R.C. Fay, R.L. Walter, R.D. Willis and W.F. Gutknecht. 1975. Levels of toxic metals in marine organisms collected from southern California coastal waters. Environ. Health Perspect. 12: 71-76.

Fracacio, R., B.K. Rodrigues, A.F. Campagna, N.E. Verani, C.B. Dornfeld and E.L.G. Espindola. 2009. In situ and laboratory evaluation of toxicity with *Danio Rerio* Buchanan (1822) and *Poecilia Reticulata* Peters (1859). Acta Limnol. Brasil. 21(1): 111-122.

France, R.L. 1987. Calcium and trace metal composition of crayfish (*Orconectes virilis*) in relation to experimental lake acidification. Can. J. Fish. Aquat. Sci. 44(Suppl.): 107-113.

Francesconi, D.A. 1989. Distribution of cadmium in the pearl oyster, *Pinctada albina albina* (Lamarck), following exposure to cadmium in seawater. Bull. Environ. Contam. Toxicol. 43: 321-328.

Francesconi, K.A., E.J. Moore and L.M. Joll. 1993. Cadmium in the saucer scallop, *Amusium balloti*, from western Australian waters: Concentrations in adductor muscle and redistribution following frozen storage. Aust. J. Mar. Freshwat. Res. 44(6): 787-797.

Francesconi, K.A., E.J. Moore and J.S. Edmonds. 1994. Cadmium uptake from seawater and food by the western rock lobster *Panulirus cygnus*. Bull. Environ. Contam. Toxicol. 53: 219-223.

Franchi, M., A.A. Menegario, A.L. Brossi-Garcia, G.C. Chagas, M.V. Silva, A.C.S. Piao and J.S. Govone. 2011. Bioconcentration of Cd and Pb by the river crab *Trichodactylus fluviatilis* (Crustacea: Decapoda). J. Braz. Chem. Soc. 22(2): 230-238.

Francis, P.C., W.J. Birge and J.A. Black. 2004. Effects of cadmium enriched sediment on fish and amphibian embryo-larval stages. Fish. Physiol. Biochem. 36: 403-409.

Frank, P.M. and P.B. Robertson. 1979. The influence of salinity on toxicity of cadmium and chromium to the blue crab, *Callinectes sapidus*. Bull. Environ. Contam. Toxicol. 21: 74.

Frankenne, F., F. Noel-Lambot and A. Disteche. 1980. Isolation and characterization of metallothioneins from cadmium-loaded mussel *Mytilus edulis*. Comp. Biochem. Physiol. 66C: 179-182.

Franklin, N.M., M.S. Adams, J.L. Stauber and R.P. Lim. 2001. Development of an improved rapid enzyme inhibition bioassay with marine and freshwater microalgae using flow cytometry. Arch. Environ. Contam. Toxicol. 40(4): 469-480.

Franklin, N.M., J.L. Stauber, R.P. Lim and P. Petocz. 2002. Toxicity of metal mixtures to a tropical freshwater alga (*Chlorella sp.*): The effect of interactions between copper, cadmium, and zinc on metal cell binding and uptake. Environ. Toxicol. Chem. 21(11): 2412-2422.

Franzellitti, S., C. Locatelli, G. Gerosa, C. Vallini and E. Fabbri. 2004. Heavy metals in tissues of loggerhead turtles (*Caretta caretta*) from the northwestern Adriatic Sea. Comp. Biochem. Physiol. 138C(2): 187-194.

Franzin, W.G. and G.A. McFarlane. 1980. An Analysis of the aquatic macrophyte, *Myriophyllum exalbescens*, as an indicator of metal contamination of aquatic ecosystems near a base metal smelter. Bull. Environ. Contam. Toxicol. 24: 597-605.

Fraser, M., C. Surette and C. Vaillancourt. 2011. Spatial and temporal distribution of heavy metal concentrations in mussels (*Mytilus edulis*) from the Baie Des Chaleurs, New Brunswick, Canada. Mar. Pollut. Bull. 62(6): 1345-1351.

Fraysse, B., R. Mons and J. Garric. 2006. Development of a zebrafish 4-day embryo-larval bioassay to assess toxicity of chemicals. Ecotoxicol. Environ. Saf. 63(2): 253-267.

Frazier, J.M. 1979. Bioaccumulation of cadmium in marine organisms. Environ. Health Perspect. 28: 75.

Frazier, J.M. and S.G. George. 1983. Cadmium kinetics in oyster - a comparative study of *Crassostrea gigas* and *Ostrea edulis*. Mar. Biol. 76: 55.

Freeman, B.J. 1978. Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress. SRO-757-6. National Technical Information Service, Springfield, Virginia.

Freeman, B.J. 1980. Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress. Thesis. University of Georgia, Athens, Georgia.

Freitas, E.C. and O. Rocha. 2011. Acute toxicity tests with the tropical cladoceran *Pseudosida ramosa*: The importance of using native species as test organisms. Arch. Environ. Contam. Toxicol. 60(2): 241-249.

Frias-Espericueta, M.G., D. Voltolina, D. and J.I. Osuna-Lopez. 2001. Acute toxicity of cadmium, mercury, and lead to whiteleg shrimp (*Litopenaeus vannamei*) postlarvae. Bull. Environ. Contam. Toxicol. 67(4): 580-586.

Frias-Espericueta, M.G., G. Izaguirre-Fierro, F. Valenzuela-Quinonez, J.I. Osuna-Lopez, D. Voltolina, G. Lopez-Lopez, M.D. Muy-Rangel and W. Rubio-Castro. 2007. Metal content of the Gulf of California blue shrimp *Litopenaeus stylirostris* (Stimpson). Bull. Environ. Contam. Toxicol. 79: 214-217.

Frias-Espericueta, M.G., J.I. Osuna-López, A. Ruiz-Telles, J.M. Quintero-Alvarez, G. López-López, G. Izaguirre-Fierro and D. Voltolina. 2006. Heavy metals in the tissues of the sea turtle *Lepidochelys olivacea* from a nesting site of the Northwest Coast of Mexico. Bull. Environ. Contam. Toxicol. 77(2): 179-185.

Frias-Espericueta, M.G., S. Abad-Rosales, A.C. Nevarez-Velazquez, I. Osuna-Lopez, F. Paez-Osuna, R. Lozano-Olvera and D. Voltolina. 2008a. Histological effects of a combination of heavy metals on pacific white shrimp *Litopenaeus vannamei* juveniles. Aquat. Toxicol. 89(3): 152-157.

Frias-Espericueta, M.G., J.I. Osuna-Lopez, D. Voltolina, G. Lopez-Lopez, G. Izaguirre-Fierro and M.D. Muy-Rangel. 2008b. The metal content of bivalve molluscs of a coastal lagoon of NW Mexico. Bull. Environ. Contam. Toxicol. 80: 90-92.

Frias-Espericueta, M.G., J.I. Osuna-Lopez, M.A. Jimenez-Vega, D. Castillo-Bueso, M.D. Muy-Rangel, W. Rubio-Carrasco, G. Lopez-Lopez, G. Izaguirre-Fierro and D. Voltolina. 2011. Cadmium, copper, lead, and zinc in *Mugil cephalus* from seven coastal lagoons of NW Mexico. Environ. Monit. Assess. 182(1-4): 133-9.

Friberg, L., M. Piscator and G. Nordberg. 1971. Cadmium in the environment. CRC Press. Cleveland, OH. 168 pp.

Fridman, O., L. Corro and J. Herkovits. 2004. Estradiol uptake, toxicity, metabolism, and adverse effects on cadmium-treated amphibian embryos. Environ. Health Perspect. 112(8): 862-866.

Friedrich, L.A. and N.M. Halden. 2010. Determining exposure history of northern pike and walleye to tailings effluence using trace metal uptake in otoliths. Environ. Sci. Technol. 44(5): 1551-1558.

Fritioff, A. and M. Greger. 2006. Uptake and distribution of Zn, Cu, Cd, and Pb in an aquatic plant *Potamogeton natans*. Chemosphere 63(2): 220-227.

Fritioff, A., L. Kautsky and M. Greger. 2005. Influence of temperature and salinity on heavy metal uptake by submersed plants. Environ.Pollut. 133(2): 265-274.

Fritts, A.K., M.C. Barnhart, M. Bradley, N. Liu, W.G. Cope, E. Hammer and R.B. Bringolf. 2014. Assessment of toxicity test endpoints for freshwater mussel larvae (glochidia). Environ. Toxicol. Chem. 33(1): 199-207.

Fu, H., R.A.C. Lock and S.E. Wendelaar Bonga. 1989. Effect of cadmium on prolactin cell activity and plasma electrolytes in the freshwater teleost *Oreochromis mossambicus*. Aquat. Toxicol. 14(4): 295-306.

Fujii, K. and M. Sugiyama. 1983. Toxic effect of cadmium to early life stages of fishes and a simple method for toxicity evaluation of environmental pollutants. Ecol. Chem. 6(1): 9-16.

Fulkerson, W. and H.E. Goeller. 1973. Cadmium: The dissipated element, ORNL NSF-EP-21. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Fulladosa, E., J.C. Murat and I. Villaescusa. 2005. Study on the toxicity of binary equitoxic mixtures of metals using the luminescent bacteria *Vibrio fischeri* as a biological target. Chemosphere 58(5): 551-557.

Fulladosa, E., E. Deane, A.H.Y. Ng, N.Y.S. Woo, J.C. Murat and I. Villaescusa. 2006. Stress proteins induced by exposure to sublethal levels of heavy metals in sea bream (*Sparus Sarba*) blood cells. Toxicol. In Vitro. 20(1): 96-100.

Furness, R.W. 1996. Cadmium in birds. In: W.N. Beyer, G.H. Heinz, A.W. Redmon-Norwood (*Eds.*). Environmental contaminants in wildlife: Interpreting tissue concentrations. CRC Press, pp. 398-404.

Gaal, S., I. Fuzesi and B. Penzes. 1984. The heavy metal content of fish in Lake Balaton the Danube and the Tisza From 1979-1982. Allattani Kozl 71(1-4): 77-84.

Gachter, R. 1976. Heavy metal toxicity and synergism to natural phytoplankton. In: Aquatic Sciences - Research Across Boundaries, Birkhauser, Basel 38(2): 97-119.

Gachter, R. and W. Geiger. 1979. Melimex, an experimental heavy metal pollution study: Behaviour of heavy metals in an aquatic food chain. Schweiz. Z. Hydrol. 41(2): 277-290.

Gachter, R. and A. Mares. 1979. Melimex, an experimental heavy metal pollution study: Effects of increased heavy metal loads on phytoplankton communities. Schweiz. Z. Hydrol. 41(2): 228-246.

Gadkari, A.S. and V.B. Marathe. 1983. Toxicity of cadmium and lead to a fish and a snail from two different habitats. IAWPC Tech. Annual. X: 141-148.

Gaete, H. and K. Paredes. 1996. Toxicity of chemical pollutant mixtures towards *Daphnia magna*. Rev. Int. Contam. Ambiental. 12(1): 23-28

Gagnaire, B., H. Thomas-Guyon and T. Renault. 2004. In vitro effects of cadmium and mercury on Pacific oyster, *Crassostrea gigas* (Thunberg), haemocytes. Fish Shellfish Immunol. 16(4): 501-512.

Gagne, F., C. Blaise, I. Aoyama, R. Luo, C. Gagnon, Y. Couillard, P. Campbell and M. Salazar. 2002. Biomarker study of a municipal effluent dispersion plume in two species of freshwater mussels. Environ. Toxicol. 17(3): 149-159.

Gagne, F., M. Fortier, L. Yu, H.L. Osachoff, R.C. Skirrow, G. Van Aggelen, C. Gagnon and M. Fournier. 2010. Immunocompetence and alterations in hepatic gene expression in rainbow trout exposed to Cds/Cdte quantum dots. J. Environ. Monit. 12(8): 1556-1565.

Gagnon, C., F. Gagne, P. Turcotte, I. Saulnier, C. Blaise, M.H. Salazar and S.M. Salazar. 2006. Exposure of caged mussels to metals in a primary-treated municipal wastewater plume. Chemosphere 62(6): 998-1010.

Gaikwad, S.A. 1989. Effects of mixture and three individual heavy metals on susceptibility of three freshwater fishes. Pollut. Res. 8(1): 33-35.

Gale, N.L., B.G. Wixson, M.G. Hardie and J.C. Jennett. 1973. Aquatic organisms and heavy metals in Missouri's new lead belt. Water Res. Bull. 9(4): 673-688.

Gale, N.L., C.D. Adams, B.G. Wixson, K.A. Loftin and Y.W. Huang. 2004. Lead, zinc, copper, and cadmium in fish and sediments from the Big River and Flat River Creek of Missouri's old lead belt. Environ. Geochem. Health 26(1): 37-49.

Gale, S.A., C.K. King and R.V. Hyne. 2006. Chronic sublethal sediment toxicity testing using the estuarine amphipod, *Melita plumulosa* (Zeidler): Evaluation using metal-spiked and field-contaminated sediments. Environ. Toxicol. Chem. 25(7): 1887-1898.

Galic, M., L. Sipos and B. Raspor. 1987. Toxicity of cadmium and nitrilotriacetic acid in sea water to the photobacteria *Vibrio fisheri*. Sci. Total Environ. 60: 173-184.

Gallego, A., A. Martin-Gonzalez, R. Ortega and J.C. Gutierrez. 2007. Flow cytometry assessment of cytotoxicity and reactive oxygen species generation by single and binary mixtures of cadmium, zinc and copper on populations of the ciliated protozoan *Tetrahymena Thermophila*. Chemosphere 68(4): 647-661.

Gallo, A., F. Silvestre, A. Cuomo, F. Papoff and E. Tosti. 2011. The impact of metals on the reproductive mechanisms of the ascidian *Ciona intestinalis*. Mar. Ecol. 32(2): 222-231.

Galvao, P., J. Torres, O. Malm and M. Rebelo. 2010. Sudden cadmium increases in the digestive gland of scallop, *Nodipecten nodosus* L., farmed in the tropics. Bull. Environ. Contam. Toxicol. 85(5): 463-466.

Gama-Flores, J.L., M.D.J. Ferrara-Guerrero, S.S.S. Sarma and S. Nandini. 2007c. Prey (*Brachionus calyciflorus* and *Brachionus havanaensis*) exposed to heavy metals (Cu and Cd) for different durations and concentrations affect predator's (*Asplanchna brightwellii*) population growth. J. Environ. Sci. Health 42A(10): 1483-1488.

Gama-Flores, J.L., M.E. Castellanos-Paez, S.S.S. Sarma and S. Nandini. 2007b. Effect of pulsed exposure to heavy metals (copper and cadmium) on some population variables of *Brachionus calyciflorus* Pallas (Rotifera: Brachionidae: Monogononta). Hydrobiologia 593(1): 201-208.

Gama-Flores, J.L., S.S.S. Sarma and S. Nandini. 2007a. Exposure time-dependent cadmium toxicity to *Moina macrocopa* (Cladocera): A life table demographic study. Aquat. Ecol. 41(4): 639-648.

Gao, A., L. Wang and H. Yuan. 2012. Expression of metallothionein cDNA in a freshwater crab, *Sinopotamon yangtsekiense*, exposed to cadmium. Exp. Toxicol. Pathol. 64(3): 253-258.

Garceau, N., N. Pichaud and P. Couture. 2010. Inhibition of goldfish mitochondrial metabolism by *in vitro* exposure to Cd, Cu and Ni. Aquat. Toxicol. 98(2): 107-112.

Garcia, G.G., S. Nandini and S.S.S. Sarma. 2004. Effect of cadmium on the population dynamics of *Moina macrocopa* and *Macrothrix triserialis* (Cladocera). Bull. Environ. Contam. Toxicol. 72(4): 717-724.

Garcia, K., J.B.R. Agard and A. Mohammed. 2008. Comparative sensitivity of a tropical mysid metamysidopsis insularis and the temperate species *Americamysis bahia* to six toxicants. Toxicol. Environ. Chem. 90(4): 779-785.

Garcia, M.E., A. Rodrigues Capitulo and L. Ferrari. 2010. Age-related differential sensitivity to cadmium in *Hyalella curvispina* (Amphipoda) and implications in ecotoxicity studies. Ecotoxicol. Environ. Saf. 73(5): 771-778.

Garcia, M.E., A.R. Capitulo and L. Ferrari. 2012. Age differential response of *Hyalella curvispina* to a cadmium pulse: Influence of sediment particle size. Ecotoxicol. Environ. Saf. 80: 314-320.

Garcia-Fernandez, A.J., P. Gomez-Ramirez, E. Martinez-Lopez, A. Hernandez-Garcia, P. Maria-Mojica, D. Romero, P. Jimenez, J.J. Castillo and J.J. Bellido. 2009. Heavy metals in tissues from loggerhead turtles (*Caretta caretta*) from the Southwestern Mediterranean (Spain). Ecotoxicol. Environ. Saf. 72(2): 557-563.

Garcia-Hernandez, J., L. Garcia-Rico, M.E. Jara-Marini, R. Barraza-Guardado and A. Hudson Weaver. 2005. Concentrations of heavy metals in sediment and organisms during a harmful algal bloom (HAB) at Kun Kaak Bay, Sonora, Mexico. Mar. Pollut. Bull. 50(7): 733-739.

Garcia-Medina, S., L. Garcia-Medina, M. Galar-Martinez, I. Alvarez-Gonzalez, O. Madrigal-Santillan, C. Razo-Estrada, L.M. Gomez-Olivan and E. Madrigal-Bujaidar. 2013. Genotoxicity and oxidative stress induced by cadmium and zinc in the planarian, *Dugesia dorotocephala*. African J. Biotechnol. 12(25): 4028-4038.

Garcia-Santos, S., A. Fontainhas-Fernandes and J.M. Wilson. 2006. Cadmium tolerance in the Nile tilapia (*Oreochromis niloticus*) following acute exposure: assessment of some ionoregulatory parameters. Environ. Toxicol. 21(1): 33-46.

Garcia-Santos, S., J. Mancera, A. Fontaínhas-Fernandes and J. Wilson. 2008. Metabolic and osmoregulatory alterations and cell proliferation in gilthead sea bream (*Sparus aurata*) exposed to cadmium. Comp.Biochem. Physiol. 150A(3, Suppl.1): S105-S106

Garcia-Santos, S., L. Vargas-Chacoff, I. Ruiz-Jarabo, J.L. Varela, J.M. Mancera, A. Fontainhas-Fernandes and J.M. Wilson. 2011. Metabolic and osmoregulatory changes and cell proliferation in gilthead sea bream (*Sparus aurata*) exposed to cadmium. Ecotoxicol. Environ. Saf. 74(3): 270-278.

Garg, P. and P. Chandra. 1994. The duckweed *Wolffia globosa* as an indicator of heavy metal pollution: sensitivity to Cr and Cd. Environ. Monit. Assess. 29(1): 89-95.

Garg, S., R.K. Gupta and K.L. Jain. 2009. Sublethal effects of heavy metals on biochemical composition and their recovery in Indian major carps. J. Hazard. Mater. 163(2/3): 1369-1384.

Gargiulo, G., P. De Girolamo, L. Ferrara, O. Soppelsa, G. Andreozzi, R. Antonucci and P. Battaglini. 1996. Action of cadmium on the gills of *Carassius auratus* L. in the presence of catabolic NH_3. Arch. Environ. Contam. Toxicol. 30: 235-240.

Garofano, J.S. 1979. The effects of cadmium on the peripheral blood and head kidney of the brown bullhead *Ictalurus nebulosus* (Lesueur). Thesis. New York University.

Gauley, J. and J.J. Heikkila. 2006. Examination of the expression of the heat shock protein gene, hsp110, in *Xenopus laevis* cultured cells and embryos. Comp. Biochem. Physiol. 145A(2): 225-234.

Gaur, J.P., N. Noraho, Y.S. Chauhan. 1994. Relationship between heavy metal accumulation and toxicity in *Spirodela polyrhiza* (L.) Schleid. and *Azolla pinnata* R. Br. Aquat. Bot. 49(2/3): 183-192.

Gauthier, C., P. Couture and G.G. Pyle. 2006. Metal effects on fathead minnows (*Pimephales Promelas*) under field and laboratory conditions. Ecotoxicol. Environ. Saf. 63(3): 353-364.

Gauthier, C., P.G.C. Campbell and P. Couture. 2009. Condition and pyloric caeca as indicators of food web effects in fish living in metal-contaminated lakes. Ecotoxicol. Environ. Saf. 72(8): 2066-2074.

Geffard, A., O. Geffard, E. His and J.C. Amiard. 2002. Relationships between metal bioaccumulation and metallothionein levels in larvae of *Mytilus galloprovincialis* exposed to contaminated estuarine sediment elutriate. Mar. Ecol. Prog. Ser. 233: 131-142.

Geffard, A., O. Geffard, J.C. Amiard, E. His and C. Amiard-Triquet. 2007. Bioaccumulation of metals in sediment elutriates and their effects on growth, condition index, and metallothionein contents in oyster larvae. Arch. Environ. Contam. Toxicol. 53: 57-65.

Geffard, O., A. Geffard, A. Chaumot, B. Vollat, C. Alvarez, M.H. Tusseau-Vuillemin and J. Garric. 2008. Effects of chronic dietary and waterborne cadmium exposures on the contamination level and reproduction of *Daphnia magna*. Environ. Toxicol. Chem. 27(5): 1128-1134.

Geffard, O., B. Xuereb, A. Chaumot, A. Geffard, S. Biagianti, C. Noel, K. Abbaci, J. Garric, G. Charmantier and M. Charmantier-Daures. 2010. Ovarian cycle and embryonic development in *Gammarus fossarum*: Application for reproductive toxicity assessment. Environ. Toxicol. Chem. 29(10): 2249-2259.

Gentile, J.H. and M. Johnson. 1982. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Gentile, S.M. 1982. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Gentile, S.M., J.H. Gentile, J. Walker and J.F. Heltshe. 1982. Chronic effects of cadmium on two species of mysid shrimp: *Mysidopsis bahia* and *Mysidopsis bigelowi*. Hydrobiol. 93: 195.

George, S.G. and T.L. Coombs. 1977. The effects of chelating agents on the uptake and accumulation of cadmium by *Mytilus edulis*. Mar. Biol. 39: 261.

George, S.G., B.J.S. Pirie and J.M. Frazier. 1983. Effects of cadmium exposure on metal-containing amoebocytes of the oyster *Ostrea edulis*. Mar. Biol. 76: 63-66.

Geraci, F., A. Pinsino, G. Turturici, R. Savona, G. Giudice and G. Sconzo. 2004. Nickel, lead, and cadmium induce differential cellular responses in sea urchin embryos by activating the synthesis of different HSP70s. Biochem. Biophys. Res. Commun. 322(3): 873-877.

Gerbron, M., P. Geraudie, B. Xuereb, E.M. Hill, J.R. Rotchell and C. Minier. 2012. Combined effect of cadmium and estradiol on the endocrine system of roach (*Rutilus rutilus*): *in vitro* and *in vivo* approaches. Comp. Biochem. Physiol. 163A, Suppl.(0): S34.

Geret, F. and R.P. Cosson. 2002. Induction of specific isoforms of metallothionein in mussel tissues after exposure to cadmium or mercury. Arch. Environ. Contam. Toxicol. 42(1): 36-42.

Geret, F., A. Jouan, V. Turpin, M.J. Bebianno and R.P. Cosson. 2002b. Influence of metal exposure on metallothionein synthesis and lipid peroxidation in two bivalve mollusks: The oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*). Aquat. Living Res. 15(1): 61-66.

Geret, F., A. Serafim, L. Barreira and M.J. Bebianno. 2002a. Effect of cadmium on antioxidant enzyme activities and lipid peroxidation in the gills of the clam *Ruditapes decussatus*. Biomarkers 7(3): 242-256.

Gerhardt, A. 1990. Effects of subacute doses of cadmium on pH-stressed *Leptophlebia marginata* (L.) and *Baetis rhodani* Pictet (Insecta: Ephemeroptera). Environ. Pollut. 67: 29-42.

Gerhardt, A. 1992. Acute toxicity of Cd in stream invertebrates in relation to pH and test design. Hydrobiol. 239: 93-100.

Gerhardt, A. 1993. Review of impact of heavy metals on stream invertebrates with special emphasis on acid conditions. Water Air Soil Pollut. 66(3/4): 289-314.

Gerhardt, A. 1995. Joint and single toxicity of Cd and Fe related to metal uptake in the mayfly *Leptophlebia marginata* (L.) (Insecta). Hydrobiol. 306: 229-240.

Gerhardt, A. 2009. Screening the toxicity of Ni, Cd, Cu, ivermectin, and imidacloprid in a short-term automated behavioral toxicity test with *Tubifex tubifex* (Muller 1774) (Oligochaeta). Hum. Ecol. Risk Assess. 15(1): 27-40.

Gharbi-Bouraoui, S., M. Gnassia-Barelli, M. Romeo, M. Dellali and P. Aissa. 2008. Field study of metal concentrations and biomarker responses in the neogastropod, *Murex trunculus*, from Bizerta Lagoon (Tunisia). Aquat. Living Resour. 21(2): 213-220.

Ghedira, J., J. Jebali, Z. Bouraoui, M. Banni, H. Guerbej and H. Boussetta. 2010. Metallothionein and metal levels in liver, gills and kidney of *Sparus aurata* exposed to sublethal doses of cadmium and copper. Fish Physiol. Biochem. 36(1): 101-107.

Ghiasi, F, S.S. Mirzargar, H. Badakhshan, S. Shamsi and F. Ghiasi. 2010. Effects of low concentration of cadmium on the level of lysozyme in serum, leukocyte count and phagocytic index in *Cyprinus carpio* under the wintering conditions. J. Fish. Aquat. Sci. 5(2): 113-119.

Ghidini, S., G. Delbono and G. Campanini. 2003. Cd, Hg and As concentrations in fish caught in the North Adriatic Sea. Vet. Res. Commun. 27(Suppl. 1): 297-299.

Ghnaya, T., I. Slama, D. Messedi, C. Grignon, M.H. Ghorbel and C. Abdelly, C. 2007. Cd-induced growth reduction in the halophyte *Sesuvium portulacastrum* is significantly improved by NaCl. J. Plant Res. 120(2): 309-316.

Ghosal, T.K. and A. Kaviraj. 2002. Combined effects of cadmium and composted manure to aquatic organisms. Chemosphere 46(7): 1099-1105.

Ghosh, A.R. and P. Chakrabarti. 1990. Toxicity of arsenic and cadmium to a freshwater fish. Environ. Ecol. 8(2): 576-579.

Ghosh, T.K., J.P. Kotangale and K.P. Krishnamoorthi. 1990. Toxicity of selective metals to freshwater algae, ciliated protozoa and planktonic crustaceans. Environ. Ecol. 8(1): 356-360.

Gianazza, E., R. Wait, A. Sozzi, S. Regondi, D. Saco, M. Labra, and E. Agradi. 2007. Growth and protein profile changes in *Lepidium sativum* L. plantlets exposed to cadmium. Environ. Experiment. Bot. 59(2): 179-187.

Giari, L., M. Manera, E. Simoni and B.S. Dezfuli, 2007. Cellular alterations in different organs of European sea bass *Dicentrarchus labrax* (L.) exposed to cadmium. Chemosphere 67(6): 1171-1181.

Giarratano, E., L. Comoglio and O. Amin. 2007. Heavy metal toxicity in *Exosphaeroma gigas* (Crustacea, Isopoda) from the coastal zone of beagle channel. Ecotoxicol. Environ. Saf. 68(3): 451-462.

Giesy Jr., J.P. 1978. Cadmium inhibition of leaf decomposition in an aquatic microcosm. Chemosphere 6: 467.

Giesy Jr., J.P. and J.G. Wiener. 1977. Frequency distributions of trace metal concentrations in five freshwater fishes. Trans. Am. Fish. Soc. 106(4): 393-403.

Giesy Jr., J.P., G.J. Leversee and D.R. Williams. 1977. Effects of naturally occurring aquatic organic fractions on cadmium toxicity to *Simocephalus cerrulatus* (Daphnidae) and *Gambusia affinis* (Poeciliidae). Water Research 11: 1013-1020.

Giesy Jr., J.P., H.J. Kania, J.W. Bowling, R.L. Knight, S. Mashburn and S. Clarkin. 1979. Fate and biological effects of cadmium introduced into channel microcosms. EPA-600/3-79-039. National Technical Information Service, Springfield, Virginia.

Giguere, A., P.G.C. Campbell, L. Hare, D.G. McDonald and J.B. Rasmussen. 2004. Influence of lake chemistry and fish age on cadmium, copper, and zinc concentrations in various organs of indigenous yellow perch (*Perca flavescens*). Can. J. Fish. Aquat. Sci. 61(9): 1702-1716.

Giguere, A., P.G.C. Campbell, L. Hare and C. Cossu-Leguille. 2005. Metal bioaccumulation and oxidative stress in yellow perch (*Perca flavescens*) collected from eight lakes along a metal contamination gradient (Cd, Cu, Zn, Ni). Can. J. Fish. Aquat. Sci. 62(3): 563-577.

Gil, F., L.F. Capitán-Vallvey, E. De Santiago, J. Ballesta, A. Pla, A.F. Hernández, M. Gutiérrez-Bedmar, J. Fernández-Crehuet, J. Gómez, O. López-Guarnido, L. Rodrigo and E. Villanueva. 2006. Heavy metal concentrations in the general population of Andalusia, south of Spain: A comparison with the population within the area of influence of Aznalcóllar mine spill (SW Spain). Sci. Total Environ. 372(1): 49-57.

Giles, M.A. 1988. Accumulation of cadmium by rainbow trout, *Salmo gairdneri*, during extended exposure. Can. J. Fish. Aquat. Sci. 45: 1045-1053.

Gill, T.S. and A. Epple. 1992. Impact of cadmium on the mummichog *Fundulus heteroclitus* and the role of calcium in suppressing heavy metal toxicity. Comp. Biochem. Physiol. 101C(3): 519-523.

Gillespie, R., T. Reisine and E.J. Massaro. 1977. Cadmium uptake by the crayfish, *Orconectes propinquus propinquus* (Girard). Environ. Res. 13(3): 364-368.

Gillis, P.L. and C.M. Wood. 2008. The effect of extreme waterborne cadmium exposure on the internal concentrations of cadmium, calcium, and sodium in *Chironomus riparius* larvae. Ecotoxicol. Environ. Saf. 71(1): 56-64. 2008.

Gillis, P.L., L.C. Diener, T.B. Reynoldson and D.G. Dixon. 2002. Cadmium-induced production of a metallothioneinlike protein in *Tubifex tubifex* (Oligochaeta) and *Chironomus riparius* (Diptera): Correlation with reproduction and growth. Environ. Toxicol. Chem. 21(9): 1836-1844.

Gillis, P.L., D.G. Dixon, U. Borgmann and T.B. Reynoldson. 2004. Uptake and depuration of cadmium, nickel, and lead in laboratory-exposed tubefix tubifex and corresponding changes in the concentration of a metallothionein-like protein. Environ. Toxicol. Chem. 23(1): 76-85.

Gillis, P.L., T.B. Reynoldson and D.G. Dixon. 2006a. Metallothionein-like protein and tissue metal concentrations in invertebrates (oligochaetes and chironomids) collected from reference and metal contaminated field sediments. J. Great Lakes Res. 32(3): 565-577.

Gillis, P.L., C.M. Wood, J.F. Ranville, and P. Chow-Fraser. 2006b. Bioavailability of sediment-associated Cu and Zn to *Daphnia magna*. Aquat. Toxicol. 77(4): 402-411.

Gingrich, D.J., D.H. Petering and C.F. Shaw III. 1984. Zinc and cadmium metabolism in *Euglena gracilis*: Metal distribution in normal and zinc-deficient cells. Mar. Environ. Res. 14(1-4): 89-102.

Gismondi, E., C. Cossu-Leguille and J.N. Beisel. 2012b. Acanthocephalan parasites: Help or burden in gammarid amphipods exposed to cadmium? Ecotoxicol. 21(4): 1188-1193.

Gismondi, E., T. Rigaud, J.N. Beisel and C. Cossu-Leguille. 2012a. Microsporidia parasites disrupt the responses to cadmium exposure in a gammarid. Environ. Pollut. 160: 17-23.

Gismondi, E., C. Cossu-Leguille and J.N. Beisel. 2013. Do male and female gammarids defend themselves differently during chemical stress? Aquat. Toxicol. 140-141: 432-438.

Giusto, A., L.A. Somma and L. Ferrari. 2012. Cadmium toxicity assessment in juveniles of the Austral South America amphipod *Hyalella curvispina*. Ecotoxicol. Environ. Saf. 79: 163-169.

Glubokov, A.I. 1990. Growth of three species of fish during early ontogeny under normal and toxic conditions. Voprosy Ikhtiologii. 30(1): 137-143.

Glynn, A.W. 1996. The concentration dependency of branchial intracellular cadmium distribution and influx in the zebrafish (*Brachydanio rerio*). Aquat. Toxicol. 35: 47-58.

Glynn, A.W. 2001. The influence of zinc on apical uptake of cadmium in the gills and cadmium influx to the circulatory system in zebrafish (*Danio rerio*). Comp. Biochem. Physiol. 128C(2): 165-172.

Glynn, A.W., C. Haux and C. Hogstrand. 1992. Chronic toxicity and metabolism of Cd and Zn in juvenile minnows (*Phoxinus phoxinus*) exposed to a Cd and Zn mixture. Can. J. Fish. Aquat. Sci. 49: 2070-2079.

Glynn, A.W., L. Norrgren and A. Mussener. 1994. Differences in uptake of inorganic mercury and cadmium in the gills of the zebrafish, *Brachydanio rerio*. Aquat. Toxicol. 30: 13-26.

Gnandi, K., G. Tchangbedji, K. Killi, G. Baba and K. Abbe. 2006. The impact of phosphate mine tailings on the bioaccumulation of heavy metals in marine fish and crustaceans from the coastal zone of Togo. Mine Water Environ. 25: 56-62.

Goatcher, L.J., A.A. Qureshi and I.D. Gaudet. 1984. Evaluation and refinement of the *Spirillum volutans* test for use in toxicity screening. In: D. Liu and B.J. Dutka (*Eds*.), Toxicity Screening Procedures Using Bacterial Systems, Marcel Dekker Inc., NY, 89-108.

Gobel P, C. Dierkes and W.G. Coldewey. 2007. Storm water runoff concentration matrix for urban areas. J. Contam. Hydrol. 91(1-2): 26-42

Gold, C., A. Feurtet-Mazel, M. Coste and A. Boudou, A. 2003. Effects of cadmium stress on periphytic diatom communities in indoor artificial streams. Freshw. Biol. 48(2): 316-328.

Golding, L.A., U. Borgmann and D.G. Dixon. 2011a. Validation of a chronic dietary cadmium bioaccumulation and toxicity model for *Hyalella azteca* exposed to field-contaminated periphyton and lake water. Environ. Toxicol. Chem. 30(11): 2628-2638.

Golding, L.A., U. Borgmann and D.G. Dixon. 2011b. Modeling chronic dietary cadmium bioaccumulation and toxicity from periphyton to *Hyalella azteca*. Environ. Toxicol. Chem. 30(7): 1709-1720.

Golding, L.A., U. Borgmann and D.D. George. 2013. Cadmium bioavailability to *Hyalella azteca* from a periphyton diet compared to an artificial diet and application of a biokinetic model. Aquat Toxicol. 126: 291-298.

Gomez-Mendikute, A. and M.P. Cajaraville. 2003. Comparative effects of cadmium, copper, paraquat and benzo[a]pyrene on the actin cytoskeleton and production of reactive oxygen species (ROS) in mussel haemocytes. Toxicol. In Vitro 17(5/6): 539-546.

Gomot, A. 1997. Dose-dependent effects of cadmium on the growth of snails in toxicity bioassays. Arch. Environ. Contam. Toxicol. 33: 209-216.

Gomot, A. 1998. Toxic effects of cadmium on reproduction, development, and hatching in the freshwater snail *Lymnaea stagnalis* for water quality monitoring. Ecotoxicol. Environ. Safety. 41: 288-297.

Gonzalez, P., M. Baudrimont, A. Boudou and J.P. Bourdineaud. 2006. Comparative effects of direct cadmium contamination on gene expression in gills, liver, skeletal muscles and brain of the zebrafish (*Danio rerio*). Biometals 19: 225-235.

Gopal, V. and K.M. Devi. 1991. Influence of nutritional status on the median tolerance limits (LC50) of *Ophiocephalus striatus* for certain heavy metal and pesticide toxicants. Indian. J. Environ. Health. 33: 393-394.

Gopalakrishnan, S., H. Thilagam and P.V. Raja. 2008. Comparison of heavy metal toxicity in life stages (spermiotoxicity, egg toxicity, embryotoxicity and larval toxicity) of *Hydroides elegans*. Chemosphere 71(3): 515-528.

Gordon, M., G.A. Knauer and J.H. Martin. 1980. *Mytilus californianus* as a bioindicator of trace metal pollution: Variability and statistical considerations. Mar. Pollut. Bull. 11(7): 195-198.

Gorman Jr., W.C. and R.K. Skogerboe. 1987. Speciation of cadmium in natural waters and their effect on rainbow trout. Preprint extended abstract, presented before the Division of Environ. Chem., Am. Chem. Soc., Aug. 30 - Sept. 4, 1987. New Orleans, LA: 664-645.

Gorski, J. and D. Nugegoda. 2006a. Sublethal toxicity of trace metals to larvae of the blacklip abalone, *Haliotis rubra*. Environ. Toxicol. Chem. 25(5): 1360-1367.

Gorski, J. and D. Nugegoda. 2006b. Toxicity of trace metals to juvenile abalone, *Haliotis rubra* following short-term exposure. Bull. Environ. Contam. Toxicol. 77(5): 732-740.

Gosselin, A. and L. Hare. 2004. Effect of sedimentary cadmium on the behavior of a burrowing mayfly (Ephemeroptera, *Hexagenia limbata*). Environ. Toxicol. Chem. 23(2): 383-387.

Gossiaux, D.C., P.F. Landrum and V.N. Tsymbal. 1992. Response of the amphipod *Diporeia spp*. to various stressors: Cadmium, salinity, and temperature. J. Great Lakes Res. 18(3): 364-371.

Goto, D. and W.G. Wallace. 2007. Interaction of Cd and Zn during uptake and loss in the polychaete *Capitella capitata*: Whole body and subcellular perspectives. J. Exp. Mar. Biol. Ecol. 352(1): 65-77.

Goto, D. and W.G. Wallace. 2009a. Relevance of intracellular partitioning of metals in prey to differential metal bioaccumulation among populations of mummichogs (*Fundulus heteroclitus*). Mar. Environ. Res. 68(5): 257-267.

Goto, D. and W.G. Wallace. 2009b. Influences of prey- and predator-dependent processes on cadmium and methylmercury trophic transfer to mummichogs (*Fundulus heteroclitus*). Can. J. Fish. Aquat. Sci. 66(5): 836-846.

Gottofrey, J. and H. Tjalve. 1991. Axonal transport of cadmium in the olfactory nerve of the pike. Pharmacol. Toxicol. 19: 242-252.

Gottofrey, J., I. Bjorklund and H. Tjalve. 1986. Effect of sodium isopropylxanthate, potassium amylxanthate and sodium diethyldithiocarbamate or the uptake and distribution of cadmium in the brown trout (*Salmo trutta*). Aquat. Toxicol. 12: 171-184.

Gould, E. and J. Karolus. 1974. Physiological response of the cunner, *Tautogolabrus adspersus*, to cadmium. Observations on the biochemistry. NOAA Technical Report SSRF-681, Part V.

Gould, E., R.S. Collier, J.J. Karolus and S. Givens. 1976. Heart transaminase in the rock crab, *Cancer irroratus*, exposed to cadmium salts. Bull. Environ. Contam. Toxicol. 15(6): 635-643.

Goulet, R.R., S. Krack, P.J. Doyle, L. Hare, B. Vigneault and J.C. McGeer. 2007. Dynamic multipathway modeling of Cd bioaccumulation in *Daphnia magna* using waterborne and dietborne exposures. Aquat. Toxicol. 81(2): 117-125.

Govindarajan, S., C.P. Valsaraj, R. Mohan, V. Hariprasad and R. Ramasubramanian. 1993. Toxicity of heavy metals in aquaculture organisms: *Penaeus indicus*, *Perna viridis*, *Artemia salina* and *Skeletonema costatum*. Pollut. Res. 12(3): 187-189.

Goyer, R.A., C.R. Miller, S. Zhu and W. Victery. 1989. Non-metallothionein-bound cadmium in the pathogenesis of cadmium nephrotoxicity in the rat. Toxicol. Appl. Pharmacol. 101(2): 232-244.

Grabowski, J. and K. Trybus. 2001. Some results on toxcicity of heavy metals, fly ash and chemical solvents as measured by the method of a substrate (FDA) with fluorogenic product. In: VII Ogolnopolskie Sympozjum Naukowo-Techniczne, Biotechnologia Srodowiskowa, 263-275.

Grajeda Y Ortega, E. Lopez-Lopez, L. Favari-Perozzi, L. Garduno-Siciliano and M. Galar-Martinez. 2008. Cadmium, iron and zinc uptake individually and as a mixture by *Limnodrillus hoffmeisteri* and impact on adenosin-triphosphate content. Environ. Toxicol. Chem. 27(3): 612-616.

Graney Jr., R.L., D.S. Cherry and J. Cairns Jr. 1983. Heavy metal indicator potential of the Asiatic clam (*Corbicula fluminea*) in artificial stream systems. Hydrobiol. 102(2): 81-88.

Graney Jr., R.L., D.S. Cherry and J. Cairns Jr. 1984. The influence of substrate, pH, diet and temperature upon cadmium accumulation in the asiatic clam (*Corbicula fluminea*) in laboratory artificial streams. Water Res. 18: 833-842.

Green, A.S., G.T. Chandler and E.R. Blood. 1993. Aqueous-, pore-water and sediment-phase cadmium: toxicity relationships for a meiobenthic copepod. Environ. Toxicol. Chem. 12: 1497-1506.

Green, D. W. J. and K.A. Williams. 1983. A continuous flow toxicity testing apparatus for macroinvertebrates. Lab. Pract. 32(11): 74-76.

Green, D.W.J., K.A. Williams and D. Pascoe. 1986. The acute and chronic toxicity of cadmium to different life history stages of the freshwater crustacean *Asellus aquaticus* (L). Arch. Environ. Contam. Toxicol. 15(5): 465-471.

Greenwood, J.G. and D.R. Fielder. 1983. Acute toxicity of zinc and cadmium to zoeae of three species of portnid crabs (Crustacea: Brachyura). Comp. Biochem. Physiol. 75C: 141.

Greichus, Y.A., A. Greichus, H.A. Draayer and B. Marshall. 1978. Insecticides, polychlorinated biphenyls and metals in African lake ecosystems. II. Lake Mcilwaine, Rhodesia. Bull. Environ. Contam. Toxicol. 19: 444-453.

Greig, R.A. 1979. Trace metal uptake by three species of mollusks. Bull. Environ. Contam. Toxicol. 22: 643.

Greig, R.A. and D.R. Wenzloff. 1978. Metal accumulation and depuration by the american oyster, *Crassostrea virginica*. Bull. Environ. Contam. Toxicol. 20: 499.

Griscom, S.B. and N.S. Fisher. 2002. Uptake of dissolved Ag, Cd, and Co by the clam, *Macoma balthica*: relative importance of overlying water, oxic pore water, and burrow water. Environ. Sci. Technol. 36(11): 2471-2478.

Griscom, S.B., N.S. Fisher and S.N. Luoma. 2002b. Kinetic modeling of Ag, Cd and Co bioaccumulation in the clam *Macoma balthica*: Quantifying dietary and dissolved sources. Mar. Ecol. Prog. Ser. 240: 127-141.

Griscom, S.B., N.S. Fisher, R.C. Aller and B.G. Lee. 2002a. Effects of gut chemistry in marine bivalves on the assimilation of metals from ingested sediment particles. J. Mar. Res. 60(1): 101-120.

Gross, J.A., T.H. Chen and W.H. Karasov. 2007. Lethal and sublethal effects of chronic cadmium exposure on northern leopard frog (*Rana pipiens*) tadpoles. Environ. Toxicol. Chem. 26(6): 1192-1197.

Gross, J.A., P.T.J. Johnson, L.K. Prahl and W.H. Karasov. 2009. Critical period of sensitivity for effects of cadmium on frog growth and development. Environ. Toxicol. Chem. 28(6): 1227-1232.

Gstoettner, E.M. and N.S. Fisher. 1997. Accumulation of cadmium, chromium, and zinc by the moss *Sphagnum papillosum* Lindle. Water Air Soil Pollut. 93: 321-330.

Gu, W., G. Shi, Y. Hao, K. Du and N. Xu. 2001. Toxic effects of Hg^{2+} and Cd^{2+} combined pollution on *Myriophyllum verticillatum* L. J. Nat. Sci. Nanjing Normal Univ. 3: 72-77.

Guan, R. and W.X. Wang. 2004a. Cd and Zn uptake kinetics in *Daphnia magna* in relation to Cd exposure history. Environ. Sci. Technol. 38(22): 6051-6058.

Guan, R. and W.X. Wang. 2004b. Dietary assimilation and elimination of Cd, Se, and Zn by *Daphnia magna* at different metal concentrations. Environ. Toxicol. Chem. 23(11): 2689-2698.

Guan, R. and W.X. Wang. 2006b. Comparison between two clones of *Daphnia magna*: Effects of multigenerational cadmium exposure on toxicity, individual fitness, and biokinetics. Aquat. Toxicol. 76(3/4): 217-229.

Guan, R. and W.X. Wang. 2006a. Multigenerational cadmium acclimation and biokinetics in *Daphnia magna*. Environ. Pollut. 141(2): 343-352.

Guan, R. and W.X. Wang. 2006c. Multiphase biokinetic modeling of cadmium accumulation in *Daphnia Magna* from dietary and aqueous sources. Environ. Toxicol. Chem. 25(11): 2840-2846.

Guanzon Jr., N.G., H. Nakahara and Y. Yoshida. 1994. Inhibitory effects of heavy metals on growth and photosynthesis of three freshwater microalgae. Fish. Sci. 60(4): 379-384.

Guardiola, F.A., A. Cuesta, J. Meseguer, S. Martinez, M.J. Martinez-Sanchez, C. Perez-Sirvent and M.A. Esteban. 2013. Accumulation, histopathology and immunotoxicological effects of waterborne cadmium on gilthead seabream (*Sparus aurata*). Fish Shell. Immunol. 35(3): 792-800.

Gueguen, C., B. Koukal, J. Dominik and M. Pardos. 2003. Competition between alga (*Pseudokirchneriella subcapitata*), humic substances and EDTA for Cd and Zn control in the algal assay procedure (AAP) medium. Chemosphere 53(8): 927-934.

Guerin, C., N. Giani and M. Sire. 1994. A study of the sensitivity of *Enchytraeus variatus* (Oligochaeta, Enchytraeidae) to certain salts of heavy metals in relation to its use as a test organism. Ann. Limnol. 30(3): 167-178.

Guerin, J.L. and W.B. Stickle. 1995. Effects of cadmium on survival, osmoregulatory ability and bioenergetics of juvenile blue crabs *Callinectes sapidus* at different salinities. Mar. Environ. Res. 40(3): 227-246.

Guilhermino, L., M.C. Lopes, A.P. Carvalho and A.M.V.M. Soares. 1996. Inhibition of acetylcholinesterase activity as effect criterion in acute tests with juvenile *Daphnia magna*. Chemosphere. 32(4): 727-738.

Guilhermino, L., T.C. Diamantino, R. Ribeiro, F. Goncalves and A.M.V.M. Soares. 1997. Suitability of test media containing EDTA for the evaluation of acute metal toxicity to *Daphnia magna* Straus. Ecotoxicol. Environ. Safety. 38: 292-295.

Gul, A., M. Yilmaz, S. Benzer and L. Tasdemir. 2011. Investigation of zinc, copper, lead and cadmium accumulation in the tissues of *Sander lucioperca* (L., 1758) living in Hirfanli Dam Lake, Turkey. Bull. Environ. Contam. Toxicol. 87(3): 264-266.

Gully, J.R. and A.Z. Mason. 1993. Cytosolic redistribution and enhanced accumulation of Cu in gill tissue of *Littorina littorea* as a result of Cd exposure. Mar. Environ. Res. 35(1-2): 53-57.

Guner, U. 2008. Effects of copper and cadmium interaction on total protein levels in liver of *Carassius carassius*. J. Fish. Sci. 2(1): 54-65.

Guner, U. 2010. Cadmium bioaccumulation and depuration by freshwater crayfish, *Astacus leptodactylus*. Ekoloji 19(77): 23-28.

Gungordu, A., A. Birhanli and M. Ozmen. 2010. Assessment of embryotoxic effects of cadmium, lead and copper on *Xenopus laevis*. Fresenius Environ. Bull. 19(11): 2528-2535.

Gunkel, G., C. Hoppe, M. Koswig, M. Voll and G. Axt. 1983. A fish test on the basic of the avoidance reaction. Vom Wasser 61: 199-215.

Guo, L., B.J. Hunt, P.H. Santschi and S.M. Ray. 2001. effect of dissolved organic matter on the uptake of trace metals by american oysters. Environ. Sci. Technol. 35(5): 885-893.

Guo, L., Y. Qiu, G. Zhang, G.J. Zheng, P.K.S. Lam and X. Li. 2008. Levels and bioaccumulation of organochlorine pesticides (OCPS) and polybrominated diphenyl ethers (PBDES) in fishes from the Pearl River Estuary and Daya Bay, South China. Environ. Pollut. 152(3): 604-611.

Guo, Y., Y. Yang and D. Wang. 2009. Induction of reproductive deficits in nematode *Caenorhabditis Elegans* exposed to metals at different developmental stages. Reprod. Toxicol. 28(1): 90-95.

Gupta, A.K. and V.K. Rajbanshi. 1991. Toxicity of copper and cadmium to *Heteropneustes fossilis* (Bloch). Acta Hydrochim. Hydrobiol. 19(3): 331-340.

Gupta, A., D.K. Rai, R.S. Pandey and B. Sharma. 2009. Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. Environ. Monit. Assess. 157(1-4): 449-58.

Gupta, M. and S. Devi. 1995. Uptake and toxicity of cadmium in aquatic ferns. J. Environ. Biol. 16(2): 131-136.

Gupta, M., S. Devi and J. Singh. 1992. Effects of long-term low-dose exposure to cadmium during the entire life cycle of *Ceratopteris thalictroides*, a water fern. Arch. Environ. Contam. Toxicol. 23(2): 184-189.

Gust, K.A. 2006. Joint toxicity of cadmium and phenanthrene in the freshwater amphipod *Hyalella azteca*. Arch. Environ. Contam. Toxicol. 50(1): 7-13.

Gust, K.A. and J.W. Fleeger. 2005. Exposure-related effects on Cd bioaccumulation explain toxicity of Cd-phenanthrene mixtures in *Hyalella azteca*. Environ. Toxicol. Chem. 24(11): 2918-2926.

Gust, K.A. and J.W. Fleeger. 2006. Exposure to cadmium-phenanthrene mixtures elicits complex toxic responses in the freshwater tubificid oligochaete*, Ilyodrilus templetoni*. Arch. Environ. Contam. Toxicol. 51(1): 54-60.

Guthrie, R.K. and D.S. Cherry. 1979. Trophic level accumulation of heavy metals in a coal ash basin drainage system. Water Res. Bull. 15(1): 244-248.

Guven, K. and D.I. De Pomerai. 1995. Differential expression of HSP70 proteins in response to heat and cadmium in *Caenorhabditis elegans*. J. Therm. Biol. 20(4): 355-363.

Guven, K., S. Topcuoglu, N. Balkis, H. Ergul and A. Aksu. 2007. Heavy metals concentrations in marine algae from the Turkish Coast of the Black Sea. Rapp. Comm. Int. Mer Medit. 38.

Guzman-Garcia, X., A.V. Botello, L. Martinez-Tabche and H. Gonzalez-Marquez. 2009. Effects of heavy metals on the oyster (*Crassostrea virginica*) at Mandinga Lagoon, Veracruz, Mexico. Rev. Biol. Trop. 57(4): 955-962.

Ha, M.H. and J. Choi. 2008. Chemical-induced alteration of hemoglobin expression in the 4th instar larvae of *Chironomus tentans* Mg. (Diptera: Chironomidae). Environ. Toxicol. Pharmacol. 25(3): 393-398.

Haap, T. and H.R. Kohler. 2009. Cadmium tolerance in seven *Daphnia magna* clones is associated with reduced hsp70 baseline levels and induction. Aquat. Toxicol. 94(2): 131-137.

Hackstein, E. 1988. Changes in the population dynamics of gammarus *Tigrinus sexton* (Crustacea: Amphipoda) as expression of sublethal effects by reciprocal interactions of temperature and cadmium enriched food. Int. Rev. Gesamten Hydrobiol. 73(2): 213-227.

Hader, D.P., M. Lebert, H. Tahedl and P. Richter. 1997. The Erlanger flagellate test (EFT): photosynthetic flagellates in biological dosimeters. J. Photochem. Photobiol. B. Biol. 40: 23-28.

Hadjispyrou, S., A. Kungolos and A. Anagnostopoulos. 2001. Toxicity, bioaccumulation, and interactive effects of organotin, cadmium, and chromium on *Artemia franciscana*. Ecotoxicol. Environ.Saf. 49(2): 179-186.

Haesloop, U. and M. Schirmer. 1985. Accumulation of orally administered cadmium by the eel (*Anguilla anguilla*). Chemosphere 14: 1627-1634.

Haines, T.A. and W.G. Brumaugh. 1994. Metal concentration in the gill, gastrointestinal tract, and carcass of white suckers (*Catostomus commersoni*) in relation to lake acidity. Water Air Soil Pollut. 73: 265-274.

Hakanson, L. 1984. Metals in fish and sediments from the River Kolbacksan water system, Sweden. Arch. Hydrobiol. 101(3): 373-400.

Hale, J.G. 1977. Toxicity of metal mining wastes. Bull. Environ. Contam. Toxicol. 17: 66.

Hall Jr., L.W. 1988. Studies of striped bass in three Chesapeake Bay spawning habitats. Mar. Pollut. Bull. 19(9): 478-487.

Hall Jr., L.W., L.O. Horseman and S. Zeger. 1984. Effects of organic and inorganic chemical contaminants on fertilization, hatching success, and prolarval survival of striped bass. Arch. Environ. Contam. Toxicol. 13: 723-729.

Hall Jr., L.W, A.E. Pinkney, R.L. Herman and S.E. Finger. 1987a. Survival of striped bass larvae and yearlings in relation to contaminants and water quality in the Upper Chesapeake Bay. Arch. Environ. Contam. Toxicol. 16: 391-400.

Hall Jr., L.W., W.S. Hall, S.J. Bushong and R.L. Herman. 1987b. *In situ* striped bass (*Morone saxatilis*) contaminant and water quality studies in the Potomac River. Aquat. Toxicol. 19: 73-99.

Hall Jr., L.W., S.J. Bushong, M.C. Ziegenfuss, W.S. Hall and R.L. Herman. 1988. Concurrent mobile on-site and *in situ* striped bass contaminant and water quality studies in the Choptank River and upper Chesapeake Bay. Environ. Toxicol. Chem. 7: 815-830.

Hall Jr., L.W., M.C. Ziegenfuss and S.A. Fischer. 1992. Ambient toxicity testing in the Chesapeake Bay watershed using freshwater and estuarine water column tests. Environ. Toxicol. Chem. 11(10): 1409-1425.

Hall Jr., L.W., M.C. Ziegenfuss, R.D. Anderson and B.L. Lewis. 1995. The effect of salinity on the acute toxicity of total and free cadmium to a Chesapeake Bay copepod and fish. Mar. Pollut. Bull. 30(6): 376-384.

Hall Jr., L.W., R.D. Anderson and R.W. Alden III. 2002. A ten-year summary of concurrent ambient water column and sediment toxicity tests in the Chesapeake Bay watershed: 1990-1999. Environ. Monit. Assess. 76(3): 311-352.

Hall, M.J. and M.T. Brown. 2002. Copper and manganese influence the uptake of cadmium in marine macroalgae. Bull. Environ. Contam. Toxicol. 68(1): 49-55.

Hall, W.S., R.L. Paulson, L.W. Hall Jr. and D.T. Burton. 1986. Acute toxicity of cadmium and sodium pentachlorophenate to daphnids and fish. Bull. Environ. Contam. Toxicol. 37: 308-316.

Ham, L., R. Quinn and D. Pascoe. 1995. Effects of cadmium on the predator-prey interaction between the turbellarian *Dendrocoelum lacteum* (Muller, 1774) and the isopod crustacean *Asellus aquaticus* (L.). Arch. Environ. Contam. Toxicol. 29: 358-365.

Hamed, M.A. and A.M. Emara. 2006. Marine molluscs as biomonitors for heavy metal levels in the Gulf of Suez, Red Sea. J. Mar. Syst. 60(3-4): 220-234.

Hameed, S.V.S.A and K.K. Muthukumaravel. 2006. Impact of cadmium on the biochemical constituents of fresh water fish *Oreochromis mossambicus*. Indian J. Environ. Sci.10(1): 63-65.

Hamilton, S.J. and K.J. Buhl. 1990. Safety assessment of selected inorganic elements to fry of chinook salmon (*Oncorhynchus tshawytscha*). Ecotoxicol. Environ. Saf. 20: 307-324.

Hammock, D., C.C. Huang, G. Mort and J.H. Swinehart. 2003. The effect of humic acid on the uptake of mercury(II), cadmium(II), and zinc(II) by chinook salmon (*Oncorhynchus tshawytscha*) eggs. Arch. Environ. Contam. Toxicol. 44(1): 83-88.

Han, T. and G.W. Choi. 2005. A novel marine algal toxicity bioassay based on sporulation inhibition in the green macroalga *Ulva pertusa* (Chlorophyta). Aquat. Toxicol. 75(3): 202-212.

Han, T., Y.S. Han, C.Y. Park, Y.S. Jun, M.J. Kwon, S.H. Kang and M.T. Brown. 2008. Spore release by the green alga *Ulva*: A quantitative assay to evaluate aquatic toxicants. Environ. Pollut. 153(3): 699-705.

Han, Y.S., M.T. Brown, G.S. Park and T. Han. 2007. Evaluating aquatic toxicity by visual inspection of thallus color in the green macroalga *Ulva*: Testing a novel bioassay. Environ. Sci. Technol. 41(10): 3667-3671.

Hanafy, S. and M.E. Soltan. 2007. Comparative changes in absorption, distribution and toxicity of copper and cadmium chloride in toads during the hibernation and the role of vitamin C against their toxicity. Toxicol. Environ. Chem. 89(1-4): 89-110.

Handy, R.D. 1993. The effect of acute exposure to dietary Cd and Cu organ toxicant concentrations in rainbow trout, *Oncorhynchus mykiss*. Aquat. Toxicol. 27: 1-14.

Handy, R.D. 1996. Dietary exposure to toxic metals in fish. In: E.W. Taylor (*Ed*.), Soc.Exp.Biol., Seminar Ser.No.57, Toxicology of Aquatic Pollution: Physiological, Molecular and Cellular Approaches; Symp.on Aquatic Toxicology at the Easter Meeting of the Society for Exp.Biol., University Press, U.K. 57: 29-60.

Hannam, M.L., S.D. Bamber, R.C. Sundt and T.S. Galloway. 2009. Immune modulation in the blue mussel *Mytilus edulis* exposed to North Sea produced water. Environ. Pollut. 157(6): 1939-1944.

Hannas, B.R., Y.H. Wang, S. Thomson, G. Kwon, H. Li and G.A. LeBlanc. 2011. Regulation and dysregulation of vitellogenin mRNA accumulation in daphnids (*Daphnia magna*). Aquat. Toxicol. 101(2): 351-357.

Hansen, B.H., O.A. Garmo, P.A. Olsvik and R.A. Andersen. 2007a. Gill metal binding and stress gene transcription in brown trout (*Salmo trutta*) exposed to metal environments: The effect of pre-exposure in natural populations. Environ. Toxicol. Chem. 26(5): 944-953.

Hansen, B.H., S. Romma, O.A. Garmo, S.A. Pedersen, P.A. Olsvik and R.A. Andersen. 2007b. Induction and activity of oxidative stress-related proteins during waterborne Cd/Zn-exposure in brown trout (*Salmo trutta*). Chemosphere 67(11): 2241-2249.

Hansen, I.V., J.M. Weeks and M.H. Depledge. 1995 Accumulation of copper, zinc, cadmium and chromium by the marine sponge *Halichondria panicea* Pallas and the implications for biomonitoring. Mar. Pollut. Bull. 31(3-1): 133-138.

Hansen, J.A., D.F. Woodward, E.E. Little, A.J. DeLonay and H.L. Bergman. 1999. Behavioral acoidance: Possible mechanism for explaining abundance and distribution of trout species in a metal-impacted river. Environ. Toxicol. Chem. 18(2): 313-317.

Hansen, J.A., P.G. Welsh, J. Lipton, D. Cacela and A.D. Dailey. 2002a. Relative sensitivity of bull trout (*Salvelinus confluentus*) and rainbow trout (*Oncorhynchus mykiss*) to acute exposures of cadmium and zinc. Environ. Toxicol. Chem. 21(1), 67-75.

Hansen, J.A., P.G. Welsh, J. Lipton and M.J. Suedkamp. 2002b. The effects of long-term cadmium exposure on the growth and survival of juvenile bull trout (*Salvelinus confluentus*). Aquat. Toxicol. 58(3/4): 165-174.

Hanson, P.J. and D.W. Evans. 1992. Metal contaminant assessment for the Southeast Atlantic and Gulf Of Mexico coasts: Results of the national benthic surveillance project over the first four years 1984-87. Govt. Reports Announcements & Index (GRA&I), Issue 08.

Hansten, C., M. Heino and K. Pynnonen. 1996. Viability of glochidia of *Anodonta anatina* (Unionidae) exposed to selected metals and chelating agents. Aquat. Toxicol. 34: 1-12.

Harada, H., M. Kurauchi, R. Hayashi and T. Eki. 2007. Shortened lifespan of nematode *Caenorhabditis elegans* after prolonged exposure to heavy metals and detergents. Ecotoxicol. Environ. Saf. 66(3): 378-83.

Hardy, J.K. and D.H. O'Keeffe. 1985. Cadmium uptake by the water hyacinth: Effects of root mass, solution volume, complexers and other metal ions. Chemosphere 14(5): 417-426.

Hardy, J.K. and N.B. Raber. 1985. Zinc uptake by the water hyacinth: Effect of solution factors. Chemosphere 14(9): 1155-1166.

Hare, L. 1992. Aquatic insects and trace metals: bioavailability, bioaccumulation, and toxicity. Critic. Rev. Toxicol. 22(5/6): 327-369.

Hare, L., E. Saouter, P.G.C. Campbell, A. Tessier, F. Ribeyre and A. Boudou. 1991b. Dynamics of cadmium, lead, and zinc exchange between nymphs of the burrowing mayfly *Hexagenia rigida* (Ephemeroptera) and the environment. Can. J. Fish. Aquat. Sci. 48: 39-47.

Hare, L., A. Tessier and P.G.C. Campbell. 1991a. Trace element distributions in aquatic insects: Variations among genera, elements, and lakes. Can. J. Fish. Aquat. Sci. 48: 1481-1491.

Hare, L., R. Carignan and M.A. Huerta-Diaz. 1994. A field study of metal toxicity and accumulation by benthic invertebrates; implications for the acid-volatile sulfide (AVS) model. Limnol. Oceanogr. 39(7): 1653-1668.

Hare, L., A. Tessier and L. Warren. 2001. Cadmium accumulation by invertebrates living at the sediment-water interface. Environ. Toxicol. Chem. 20(4): 880-889.

Haritonidis, S., J.W. Rijstenbil, P. Malea, J. van Drie and J.A. Wijnholds. 1994. Trace metal interactions in the macroalga *Enteromorpha prolifera* (O.F. Muller) grown in water of the Scheldt estuary (Belgium and SW Netherlands), in response to cadmium exposure. BioMetals 7: 61-66.

Harper, D.D., A.M. Farag and W.G. Brumbaugh. 2008. Effects of acclimation on the toxicity of stream water contaminated with zinc and cadmium to juvenile cutthroat trout. Arch. Environ. Contam. Toxicol. 54(4): 697-704.

Harper, D.D., A.M. Farag, C. Hogstrand and E. Macconnell. 2009. Trout density and health in a stream with variable water temperatures and trace element concentrations: Does a cold-water source attract trout to increased metal exposure? Environ. Toxicol. Chem. 28(4): 800-808.

Harrahy, E.A. and W.H. Clements. 1997. Toxicity and bioaccumulation of a mixture of heavy metals in *Chironomus tentans* (Diptera: Chironomidae) in synthetic sediment. Environ. Toxicol. Chem. 16(2): 317-327.

Harrison, S.E. and J.F. Klaverkamp. 1989. Uptake, elimination and tissue distribution of dietary and aqueous cadmium by rainbow trout (*Salmo gairdneri* Richardson) and lake whitefish (*Coregonus clupeaformis* Mitchell). Environ. Toxicol. Chem. 8: 87-97.

Hart, B.A. and B.D. Schaife. 1977. Toxicity and bioaccumulation of cadmium in *Chlorella pyrenoidosa*. Environ. Res. 14: 401.

Harter, V.L. and R.A. Matthews. 2005. Acute and chronic toxicity test methods for *Nematostella vectensis* Stephenson. Bull. Environ. Contam. Toxicol. 74(5): 830-836.

Hartmann, L. 1980. Synergistic effects of heavy metal ions on the activity of bacteria and other aquatic microorganisms. In: 2nd Environ. Res. Prog., 1976-1980, Environment and Quality of Life, Rep. on Res. Sponsored Under the First Phase, Luxembourg, 16-20.

Hartmann, N.B., F. Der Kammer, T. Hofmann, M. Baalousha, S. Ottofuelling and A. Baun. 2010. Algal testing of titanium dioxide nanoparticles - testing considerations, inhibitory effects and modification of cadmium bioavailability. Toxicol. 269(2/3): 190-197.

Hartmann, N.B., S. Legros, F. Von Der Kammer, T. Hofmann and A. Baun. 2012. The potential of TiO_2 nanoparticles as carriers for cadmium uptake in *Lumbriculus variegatus* and *Daphnia magna*. Aquat. Toxicol. 118-119: 1-8.

Hartwell, S.I. 1997. Demonstration of a toxicological risk ranking method to correlate measures of ambient toxicity and fish community diversity. Environ. Toxicol. Chem. 16(2): 361-371.

Hartwell, S.I., D.S. Cherry and J. Cairns Jr. 1987. Avoidance responses of schooling fathead minnows (*Pimephales promelas*) to a blend of metals during a 9-month exposure. Environ. Toxicol. Chem. 6(3): 177-187.

Hartwell, S.I., D. Cherry and J. Cairns Jr. 1988. Fish behavioral assessment of pollutants. In: J.Cairns Jr.and J.R. Pratt (*Eds*.), Functional Testing of Aquatic Biota for Estimating Hazards of Chemicals, ASTM STP 988, Philadelphia, PA, 138-165.

Harvey, J., L. Harwell and J.K. Summers. 2008. Contaminant concentrations in whole-body fish and shellfish from US estuaries. Environ. Monit. Assess. 137(1-3): 403-412.

Harvey, R.W. and S.N. Luoma. 1985a. Separation of solute and particulate vectors of heavy metal uptake in controlled suspension-feeding experiments with *Macoma balthica*. Hydrobiol. 21: 97-102.

Harvey, R.W and S.N. Luoma. 1985b. Effect of adherent bacteria and bacterial extracellular polymers upon assimilation by *Macoma balthica* of sediment-bound Cd, Zn and Ag. Mar. Ecol. Prog. Ser. 22: 281-289.

Hasan, S.H., M. Talat and S. Rai. 2007. Sorption of cadmium and zinc from aqueous solutions by water hyacinth (*Eichchornia crassipes*). Bioresour. Technol. 98(4): 918-928.

Hashemi, F., G.G. Leppard and D.J. Kushner. 1994. Copper resistance in *Anabaena variabilis*: Effects of phosphate nutrition and polyphosphate bodies. Microb. Ecol. 27: 159-176.

Hashim, M.A. and K.H. Chu. 2004. Biosorption of cadmium by brown, green, and red seaweeds. Chem. Eng. J. 97(2/3): 249-255.

Hashim, M.A., K.H. Chu, S.M. Phang and G.S. Ong. 1997. Adsorption equilibria of cadmium on algal biomass. Adsorpt. Sci. Technol. 15(6): 445-453.

Has-Schön E., I. Bogut and I. Strelec. 2006. Heavy metal profile in five fish species included in human diet, domiciled in the end flow of river Neretva (Croatia). Arch. Environ. Contam. Toxicol. 50(4): 545-551.

Has-Schön E., I. Bogut, G. Kralik, S. Bogut, J. Horvatić and M. Cacić M. 2008a. Heavy metal concentration in fish tissues inhabiting waters of "Busko Blato" Reservoir (Bosnia and Herzegovina). Environ. Monit. Assess. 144(1-3): 15-22.

Has-Schön E., I. Bogut, V. Rajković, S. Bogut, M. Cacić and J. Horvatić J. 2008b. Heavy metal distribution in tissues of six fish species included in human diet, inhabiting freshwaters of the Nature Park "Hutovo Blato" (Bosnia and Herzegovina). Arch. Environ. Contam. Toxicol. 54(1): 75-83.

Hatakeyama, S. 1984. Accumulation and chronic effects of cadmium on the guppy (*Poecilia reticulata*) fed the cadmium-accumulated midge larvae (*Chironomus yuoshimatsui*). Res. Rep. Natl. Inst. Environ. Stud. 62: 99-120.

Hatakeyama, S. 1987. Chronic effects of Cd on reproduction of *Polypedilum nubifer* (Chironomidae) through water and food. Environ. Pollut. 48: 249-261.

Hatakeyama, S. and M. Yasuno. 1981a. The effects of cadmium-accumulated *Chlorella* on the reproduction of *Moina macrocopa* (Cladocera). Ecotoxicol. Environ. Safety 5: 341.

Hatakeyama, S. and M. Yasuno. 1981b. Effects of cadmium on the periodicity of parturation and brood size of *Moina macrocopa* (Cladocera). Environ. Pollut. (Series A) 26: 111.

Hatakeyama, S., K. Satake and S. Fukushima. 1986. Flora and fauna in heavy metal polluted rivers. I. Density of *Epeorus latifolium* (Ephemeroptera) and heavy metal concentrations of *Baetis spp*. (Ephemeroptera) relating to Cd, Cu and Zn concentrations. Res. Rep. Natl. Inst. Environ. Stud. 99: 15-33.

Hatano, A. and R. Shoji. 2008. Toxicity of copper and cadmium in combinations to duckweed analyzed by the biotic ligand model. Environ. Toxicol. 23(3): 372-378.

Hattink, J., G. De Boeck and R. Blust. 2005. The toxicokinetics of cadmium in carp under normoxic and hypoxic conditions. Aquat. Toxicol. 75(1): 1-15.

Haye, J.M., P.H. Santschi, K.A. Roberts and S. Ray. 2006. Protective role of alginic acid against metal uptake by american oyster (*Crassostrea virginica*). Environ. Chem. 3(3): 172-183.

Haynes, G.J., A.J. Stewart and B.C. Harvey. 1989. Gender-dependent problems in toxicity tests with *Ceriodaphnia dubia*. Bull. Environ. Contam Toxicol. 43: 271-279.

Hazen, R.E. and T.J. Kneip. 1980. Biogeochemical cycling of cadmium in a marsh ecosystem. *In:* J.O. Nriagu (*Ed*.), Cadmium in the Environment, Part I. Wiley, New York. p. 399.

Hedouin, L., M. Metian, J.L. Teyssie, S.W. Fowler, R. Fichez and M. Warnau. 2006. Allometric relationships in the bioconcentration of heavy metals by the edible tropical clam *Gafrarium tumidum.* Sci. Total Environ. 366(1): 154-163.

Hedouin, L., P. Bustamante, C. Churlaud, O. Pringault, R. Fichez and M. Warnau. 2009. Trends in concentrations of selected metalloid and metals in two bivalves from the coral reefs in the SW Lagoon of New Caledonia. Ecotoxicol. Environ. Saf. 72(2): 372-381.

Heimann, K., J.M. Matuszewski and P.L. Klerks. 2002. Effects of metals and organic contaminants on the recovery of bioluminescence in the marine dinoflagellate *Pyrocystis lunula* (Dinophyceae). J. Phycol. 38(3): 482-492.

Heininger, P., S. Hoess, E. Claus, J. Pelzer and W. Traunspurger. 2006. Nematode communities in contaminated river sediments. Environ. Pollut. 146(1): 64-76.

Heinis, F., K.R. Timmermans and W.R. Swain. 1990. Short-term sublethal effects of cadmium on the filter feeding chironomid larva *Glyptotendipes pallens* (Meigen) (Diptera). Aquat. Toxicol. 16: 73-86.

Heit, M. and C.S. Klusek. 1985. Trace element concentrations in the dorsal muscle of white suckers and brown bullheads from two acidic Adirondack lakes. Water Air Soil Pollut. 25: 87-96.

Heit, M., C.S. Klusek and K.M. Miller. 1980. Trace element, radionuclide, and polynuclear aromatic hydrocarbon concentrations in unionidae mussels from Northern Lake George. Environ. Sci. Technol. 14(4): 465-468.

Hem, J. D. 1972. Chemistry and occurrence of cadmium and zinc in surface water and groundwater. Water Res. Res. 8(3): 661-679.

Hem, J.D. 1992. Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hendriks, J.A. 1995. Modelling equilibrium concentrations of microcontaminants in organisms of the Rhine delta: Can average field residues in the aquatic food chain be predicted from laboratory accumulation? Aquat. Toxicol. 31: 1-25.

Hendrix, P.F., C.L. Langner, E.P. Odum and C.L. Thomas. 1981. Microcosms as test systems for the ecological effects of toxic substances: An appraisal with cadmium. Grant No. R805860010, U.S. EPA, Athens, GA, 184 p.

Henebry, M.S. and P.E. Ross. 1989. Use of protozoan communities to assess the ecotoxicological hazard of contaminated sediments. Toxic. Assess. 4(2): 209-227.

Heng, L.Y., K. Jusoh, C.H. Ling and M. Idris. 2004. Toxicity of single and combinations of lead and cadmium to the cyanobacteria *Anabaena flos-aquae*. Bull. Environ. Contam. Toxicol. 72(2): 373-379.

Henke, R., M. Eberius and K.J. Appenroth. 2011. Induction of frond abscission by metals and other toxic compounds in *Lemna minor*. Aquat. Toxicol. 101(1): 261-265.

Henriksen, A. and R.F. Wright. 1978. Concentrations of heavy metals in small Norwegian lakes. Water Res. 12: 101-112.

Henry, F., R. Amara, L. Courcot, D. Lacouture and M.L. Bertho. 2004. Heavy metals in four fish species from the French coast of the eastern English Channel and southern bight of the North Sea. Environ. Int. 30(5): 675-683.

Henry M., Huang W., Cornet C., Belluau M. and Durbec J.-P. 1984. Contamination accidentelle par le cadmium d'un mollusque Rudifapes decussatus: bioaccumulation et toxicite. (CL50, 96 h). Oceanol. Acta 7, 329-335.

Henson, M.C. and J. Chedrese. 2004. Endocrine disruption by cadmium, a common environmental toxicant with paradoxical effects on reproduction. Exp. Bio. Med. 229: 383-392.

Herkovits, J. and C.S. Perez-Coll. 1990. Zinc protection against delayed development produced by cadmium. Biol. Trace Elem. Res. 24: 217-221.

Herkovits, J. and C.S. Perez-Coll. 1993. Stage-dependent susceptibility of *Bufo arenarum* embryos to cadmium. Bull. Environ. Contam. Toxicol. 50: 608-611.

Herkovits, J. and C.S. Perez-Coll. 1995. Increased resistance against cadmium toxicity by means of pretreatment with low cadmium-zinc concentrations in *Bufo arenarum* embryos. Biol. Trace Elem. Res. 49: 171-175.

Herkovits, J., P. Cardellini, C. Pavanati and C.S. Perez-Coll. 1997. Susceptibility of early life stages of *Xenopus laevis* to cadmium. Environ. Toxicol. Chem. 16(2): 312-316.

Herkovits, J., P. Cardellini, C. Pavanati and C.S. Perez-Coll. 1998. Cadmium uptake and bioaccumulation in *Xenopus laevis* embryos at different developmental stages. Ecotoxicol. Environ. Safety. 39: 21-26.

Hermesz, E., M. Abraham and J. Nemcsok. 2001. Tissue-specific expression of two metallothionein genes in common carp during cadmium exposure and temperature shock. Comp. Biochem. Physiol. 128C(3): 457-465.

Hernandez, O.D., A.J. Gutierrez, D. Gonzalez-Weller, G. Lozano, E.G. Melon, C. Rubio and A. Hardisson. 2010. Accumulation of toxic metals (Pb and Cd) in the sea urchin *Diadema aff. antillarum* Philippi, 1845, in an oceanic island (Tenerife, Canary Islands). Environ. Toxicol. 25(3): 227-33.

Hernández, P.P. and M.L. Allende. 2008. Zebrafish (*Danio rerio*) as a model for studying the genetic basis of copper toxicity, deficiency, and metabolism. Am. J. Clin. Nutr. 88(3): 835S-839S.

Herve-Fernandez, P., F. Houlbreque, F. Boisson, S. Mulsow, J.L. Teyssie, F. Oberhaensli, S. Azemard and R. Jeffree. 2010. Cadmium bioaccumulation and retention kinetics in the Chilean blue mussel *Mytilus chilensis*: Seawater and food exposure pathways . Aquat. Toxicol. 99(4): 448-456.

Herwig, H.J., F. Brands, E. Kruitwagen and D.I. Zandee. 1989. Bioaccumulation and histochemical localization of cadmium in *Dreissena polymorpha* exposed to cadmium chloride. Aquat. Toxicol. 15: 269-286.

Herzi, F., N. Jean, H. Zhao, S. Mounier, H.H. Mabrouk and A.S. Hlaili. 2013. Copper and cadmium effects on growth and extracellular exudation of the marine toxic dinoflagellate *Alexandrium catenella*: 3D-fluorescence spectroscopy approach. Chemosphere 93(6): 1230-1239.

Heugens, E.H.W., T. Jager, R. Creyghton, M.H.S. Kraak, A.J. Hendriks, N.M. Van Straalen and W. Admiraal. 2003. Temperature-dependent effects of cadmium on *Daphnia magna*: Accumulation versus sensitivity. Environ. Sci. Technol. 37(10): 2145-2151.

Heugens, E.H.W., L.T.B. Tokkie, M.H.S. Kraak, A.J. Hendriks, N.M. Van Straalen and W. Admiraal. 2006. Population growth of *Daphnia magna* under multiple stress conditions: Joint effects of temperature, food, and cadmium. Environ. Toxicol. Chem. 25(5): 1399-1407.

Heumann, H.G. 1987. Effects of heavy metals on growth and ultrastructure of *Chara vulgaris*. Protoplasma 136: 37-48.

Hewitt, A.H., W.G. Cope, T.J. Kwak, T. Augspurger, P.R. Lazaro and D. Shea. 2006. Influence of water quality and associated contaminants on survival and growth of the endangered Cape Fear shiner (*Notropis mekistocholas*). Environ. Toxicol. Chem. 25(9): 2288-2298.

Heydari, S., J. Imanpour Namin, M. Mohammadi and F.M. Rad. 2011. Cadmium and lead concentrations in muscles and livers of stellate sturgeon (*Acipenser stellatus*) from several sampling stations in the southern Caspian Sea. J. Appl. Ichthyol. 27(2): 520-523.

Hickey, C.W. and W.H. Clements. 1998. Effects of heavy metals on benthic macroinvertebrate communities in New Zealand streams. Environ. Toxicol. Chem. 17(11): 2338-2346.

Hickey, C.W. and M.L. Martin. 1995. Relative sensitivity of five benthic invertebrate species to reference toxicants and resin-acid contaminated sediments. Environ. Toxicol. Chem. 14(8): 1401-1409.

Hickey, C.W. and D.S. Roper. 1992. Acute toxicity of cadmium to two species of infaunal marine amphipods (tube-dwelling and burrowing) from New Zealand. Bull. Environ. Contam. Toxicol. 49: 165-170.

Hickey, C.W. and M.L. Vickers. 1992. Comparison of the sensitivity to heavy metals and pentachlorophenol of the mayflies *Deleatidium spp*. and the cladoceran *Daphnia magna*. New Zealand J. Mar. Freshwater Res. 26: 87-93.

Hildebrand, S.G., R.M. Cushman and J.A. Carter. 1976. The potential toxicity and bioaccumulation in aquatic systems of trace elements present in aqueous coal conversion effluents. In: D.D. Hemphill (*Ed*.), Proc. Univ. of Missouri's Tenth Annu. Conf. on Trace Subst. in Environ. Health, June 8-10, 1976, Univ.of Missouri, Columbia, MO, 305-312.

Hilmy, A.M., M.B. Shabana and A.Y. Daabees. 1985. Bioaccumulation of cadmium: Toxicity in *Mugil cephalus*. Comp. Biochem. Physiol. 81(1): 139-143.

Hinck, J.E., V.S. Blazer, N.D. Denslow, K.R. Echols, T.S. Gross, T.W. May, P.J. Anderson, J.J. Coyle and D.E. Tillitt. 2007. Chemical contaminants, health indicators, and reproductive biomarker responses in fish from the Colorado River and its tributaries. Sci. Total Environ. 378: 376-402.

Hinrichsen, R.D. and J.R. Tran. 2010. A circadian clock regulates sensitivity to cadmium in *Paramecium tetraurelia*. Cell Biol. Toxicol. 26(4): 379-389.

Hiraoka, Y., S. Ishizawa, T. Kamada and H. Okuda. 1985. Acute toxicity of 14 different kinds of metals affecting medaka (*Oryzias latipes*) fry. Hiroshima J. Med. Sci. 34: 327-30.

Hiraoka, Y. 1991. Reduction of heavy metal content in Hiroshima Bay oysters (*Crassostrea Gigas*) by purification. Environ. Pollut. 70(3): 209-217.

Hoang, T.C. and S.J. Klaine. 2007. Influence of organism age on metal toxicity to *Daphnia magna.* Environ. Toxicol. Chem. 26(6): 1198-1204.

Hockett, J.R. Unpublished. Personal communication to U.S. EPA.

Hockett, J.R and D.R. Mount. 1996. Use of metal chelating agents to differentiate among sources of acute aquatic toxicity. Environ. Toxicol. Chem. 15: 1687-1693.

Hockner, M., K. Stefanon, D. Schuler, R. Fantur, A. de Vaufleury and R. Dallinger. 2009. Coping with cadmium exposure in various ways: The two helicid snails *Helix pomatia* and *Cantareus aspersus* share the metal transcription factor-2, but differ in promoter organization and transcription of their cd-metallothionein genes. J. Exp. Zool. 311A(10): 776-787.

Hofer, R., R. Lackner, J. Kargl, B. Thaler, D. Tait, L. Bonetti, R. Vistocco and G. Flaim. 2001. Organochlorine and metal accumulation in fish (*Phoxinus phoxinus*) along a north-south transect in the Alps. Water Air Soil Pollut. 125(1-4): 189-200.

Hofslagare, O., G. Samuelsson and S. Sjoberg. 1985. Cadmium effects on photosynthesis and nitrate assimilation in *Scenedesmus obliquus*. A potentiometric study in an open CO_2-system. Environ. Exp. Bot. 25(1): 75-82.

Hogstrand, C. and C.M. Wood. 1996. The physiology and toxicology of zinc in fish. In: E.W. Taylor (*Ed.*) Toxicology of Aquatic Pollution. Cambridge University Press, Cambridge, UK, pp. 61-84.

Hogstrand, C., L. Goran and C. Haux. 1991. The importance of metallothionein for the accumulation of copper, zinc and cadmium in environmentally exposed perch, *Perca fluviatilis*. Pharmacol. Toxicol. 68: 492-501.

Holcombe, G.W., G.L. Phipps and J.T. Fiandt. 1983. Toxicity of selected priority pollutants to various aquatic organisms. Ecotoxicol. Environ. Saf. 7(4): 400-409.

Holcombe, G.W., G.L. Phipps and J.W. Marier. 1984. Methods for conducting snail (*Aplexa hypnorum*) embryo through adult exposures: Effects of cadmium and reduced pH levels. Arch. Environ. Contam. Toxicol. 13(5): 627-634.

Holdway, D.A., K. Lok and M. Semaan. 2001. The acute and chronic toxicity of cadmium and zinc to two hydra species. Environ. Toxicol. 16: 557-565.

Hollibaugh, J.T., D.L.R. Seibert and W.H. Thomas. 1980. A comparison of the acute toxicities of ten heavy metals to the plankton from Sasnick Inlet, B.C., Canada. Estuar. Coast. Mar. Sci. 10(1): 93-105.

Hollis, L, K. Burnison and R.C. Playle. 1996. Does the age of metal-dissolved organic carbon complexes influence binding of metals to fish gills? Aquat. Toxicol. 35: 253-264.

Hollis, L., L. Muench and R.C. Playle. 1997. Influence of dissolved organic matter on copper binding, and calcium on cadmium binding by gills of rainbow trout. J. Fish Biol. 50: 703-720.

Hollis, L., C. Hogstrand and C.M. Wood. 2001. Tissue-specific cadmium accumulation, metallothionein induction, and tissue zinc and copper levels during chronic sublethal cadmium exposure in juvenile rainbow trout. Arch. Environ. Contam. Toxicol. 41(4): 468-474.

Hollis, L., J.C. McGeer, D.G. McDonald and C.M. Wood. 1999. Cadmium accumulation, gill Cd binding, acclimation, and physiological effects during long term sublethal Cd exposure in rainbow trout. Aquat. Toxicol. 46: 101-119.

Hollis, L., J.C. McGeer, D.G. McDonald and C.M. Wood. 2000a. Effects of long term sublethal Cd exposure in rainbow trout during soft water exposure: implications for biotic ligand modelling. Aquat. Toxicol. 51: 93-105

Hollis, L., J.C. McGeer, D.G. McDonald and C.M. Wood. 2000b. Protective effects of calcium against chronic waterborne cadmium exposure to juvenile rainbow trout. Environ. Toxico. Chem 19(11): 2725-2734.

Holmes, C.W, S.E. Ross, N. Buster and A.E. Koenig. 2006. Trace-metal content in antipatharian corals from the Jacksonville Lithoherm, Florida. American Geophysical Union 2000 Florida Ave., N.W., Washington, DC.

Hong, J.S. and D.J. Reish. 1987. Acute toxicity of cadmium to eight species of marine amphipod and isopod crustaceans from southern California. Bull. Environ. Contam. Toxicol. 39: 884-888.

Hongve, D., O.K. Skogheim, A. Hindar and H. Abrahamsen. 1980. Effect of heavy metals in combination with NTA, humic acid, and suspended sediment on natural phytoplankton photosynthesis. Bull. Environ. Contam. Toxicol. 25(4): 594-600.

Hook, S.E. and N.S. Fisher. 2001. Reproductive toxicity of metals in calanoid copepods. Mar. Biol. (Berlin) 138(6): 1131-1140.

Hook, S.E. and N.S. Fisher. 2002. Relating the reproductive toxicity of five ingested metals in calanoid copepods with sulfur affinity. Mar. Environ. Res. 53(2): 161-174.

Hook, S.E. and R.F. Lee. 2004. Interactive effects of UV, benzo(a)pyrene, and cadmium on DNA damage and repair in embryos of the grass shrimp *Paleomonetes pugio*. Mar. Environ. Res. 58(2-5): 735-739.

Hooten, R.L. and R.S. Carr. 1997. Development and application of a marine sediment pore-water toxicity test using *Ulva fasciata* zoospores. Environ. Toxicol. Chem. 17(5): 932-940.

Hopkins, W.A., B.P. Staub, J.W. Snodgrass, B.E. Taylor, A.E. DeBiase, J.H. Roe, B.P. Jackson and J.D. Congdon. 2004. Responses of benthic fish exposed to contaminants in outdoor microcosms--examining the ecological relevance of previous laboratory toxicity tests. Aquat. Toxicol. 68(1): 1-12.

Horike, N., A. Nishikawa, H. Tanaka and S. Nakamura. 2002. Usefulness of flagellar regeneration in *Dunaliella sp.* J. Japan Soc. Water Environ. 25(8): 485-490.

Horng, C.Y., S.L. Wang and I.J. Cheng. 2009. Effects of sediment-bound Cd, Pb, and Ni on the growth, feeding, and survival of *Capitella sp.* I. J. Exp. Mar. Biol. Ecol. 371(1): 68-76.

Hornstrom, E. 1990. Toxicity test with algae - a discussion on the batch method. Ecotoxicol. Environ. Safety. 20: 343-353.

Horvatic, J. and V. Persic. 2007. The effect of Ni^{2+},Co^{2+}, Zn^{2+}, Cd^{2+} and Hg^{2+} on the growth rate of marine diatom *Phaeodactylum tricornutum* Bohlin: Microplate growth inhibition test. Bull. Environ. Contam. Toxicol. 79(5): 494-498.

Hoss, S., T. Henschel, M. Haitzer, W. Traunspurger and C.E.W. Steinberg. 2001. Toxicity of cadmium to *Caenorhabditis elegans* (Nematoda) in whole sediment and pore water - the ambiguous role of organic matter. Environ. Toxicol. Chem. 20(12): 2794-2801.

Hsiao, S.H., T.H. Fang and J.S. Hwang. 2006. The bioconcentration of trace metals in dominant copepod species off the Northern Taiwan Coast. Crustaceana 79(4): 459-474.

Hsu, T., H.T. Tsai, K.M. Huang, M.C. Luan and C.R. Hsieh. 2010. Sublethal levels of cadmium down-regulate the gene expression of DNA mismatch recognition protein MutS homolog 6 (MSH6) in zebrafish (*Danio rerio*) embryos. Chemosphere 81(6): 748-754.

Hu, J.Z., A.Z. Zheng, D.L. Pei and G.X. Shi. 2010. Bioaccumulation and chemical forms of cadmium, copper and lead in aquatic plants. Braz. Arch. Biol. Technol. 53(1): 235-240.

Hu, L., M.B. McBride, H. Cheng, J. Wu, J. Shi, J. Xu and L. Wu. 2011b. Root-induced changes to cadmium speciation in the rhizosphere of two rice (*Oryza sativa* L.) genotypes. Environ. Res. 111(3): 356-361.

Hu, S., C.H. Tang and M. Wu. 1996. Cadmium accumulation by several seaweeds. Sci. Total Environ. 187: 65-71.

Hu, X., Q. Chen, L. Jiang, Z. Yu, D. Jiang and D. Yin. 2011a. Combined effects of titanium dioxide and humic acid on the bioaccumulation of cadmium in zebrafish. Environ. Pollut. 159(5): 1151-1158.

Huang, Q.Y., C.W. Fang and H.Q. Huang. 2011b. Alteration of heart tissue protein profiles in acute cadmium-treated scallops *Patinopecten yessoensis*. Arch. Environ. Contam. Toxicol. 60(1): 90-98.

Huang, X., C. Ke and W.X. Wang. 2008. Bioaccumulation of silver, cadmium and mercury in the abalone *Haliotis diversicolor* from water and food sources. Aquacult. 283: 194-202.

Huang, X., F. Guo, C. Ke and W.X. Wang. 2010b. Responses of abalone *Haliotis diversicolor* to sublethal exposure of waterborne and dietary silver and cadmium. Ecotoxicol. Environ. Saf. 73(6): 1130-1137.

Huang, X.U., C. Ke and W.X. Wang. 2010a. Cadmium and copper accumulation and toxicity in the macroalga *Gracilaria tenuistipitata*. Aquat. Biol. 11(1): 17-26.

Huang, X., C.W. Fang, Y.W. Guo and H.Q. 2011a. Differential protein expression of kidney tissue in the scallop *Patinopecten yessoensis* under acute cadmium stress. Ecotoxicol. Environ. Saf. 74(5): 1232-1237.

Huang, Z., L. Li, G. Huang, Q. Yan, B. Shi and X. Xu. 2009. Growth-inhibitory and metal-binding proteins in *Chlorella vulgaris* exposed to cadmium or zinc. Aquat. Toxicol. 91(1): 54-61.

Huebert, D.B. and J.M. Shay. 1991. The effect of cadmium and its interaction with external calcium in the submerged aquatic macrophyte *Lemna trisulca* L. Aquat. Toxicol. 20: 57-72.

Huebert, D.B. and J.M. Shay. 1992. Zinc toxicity and its interaction with cadmium in the submerged aquatic macrophyte *Lemna trisulca* L. Environ. Toxicol. Chem. 11: 715-720.

Huebert, D.B. and J.M. Shay. 1993. The response of *Lemna trisulca* L. to cadmium. Environ. Pollut. 80: 247-253.

Huebert, D.B., B.S. Dyck and J.M. Shay. 1993. The effect of EDTA on the assessment of Cu toxicity in the submerged aquatic macrophyte, *Lemna trisulca* L. Aquat. Toxicol. 24: 183-194.

Huebner, J.D. and K.S. Pynnonen. 1992. Viability of glochidia of two species of *Anodonta* exposed to low pH and selected metals. Can. J. Zool. 70: 2348-2355.

Huelya, K.A. 2009. Seasonal variations of heavy metals in water, sediments, pondweed (*P. pectinatus* L.) and freshwater fish (*C. c. umbla*) of Lake Hazar (Elazig-Turkey). Fresenius Environ. Bull. 18(4): 511-518.

Hughes, G.M., S.F. Perry and V.M. Brown. 1979. A morphometric study of effects of nickel, chromium and cadmium on the secondary lamellae of rainbow trout gills. Water Res. 13: 665-679.

Hughes, J.S. 1973. Acute toxicity to thirty chemicals to striped bass (*Morone saxatilis*). Western Assoc. State Game Fish Comm., Salt Lake City, UT.

Huiskes, A.H. and J. Nieuwenhuize. 1990. Uptake of heavy metals from contaminated sediments by salt-marsh plants. Govt. Reports Announcements & Index, Issue 14.

Hung, T.C., P.J. Meng, B.C. Han, A. Chuang and C.C. Huang. 2001. Trace metals in different species of mollusca, water and sediments from Taiwan coastal area. Chemosphere 44(4): 833-841.

Hung, Y. 1982. Effects of temperature and chelating agents on cadmium uptake in the American oyster. Bull. Environ. Contam. Toxicol. 28: 546.

Hungspreugs, M., S. Silpipat, C. Tonapong, R.F. Lee, H.L. Windom and K.R. Tenore. 1984. Heavy metals and polycyclic hydrocarbon compounds in benthic organisms of the Upper Gulf of Thailand. Mar. Pollut. Bull. 15(6): 213-218.

Husaini, Y., A.K. Singh and L.C. Rai. 1991. Cadmium toxicity to photosynthesis and associated electron transport system of *Nostoc linckia*. Bull. Environ. Contam. Toxicol. 46: 146-150.

Hutcheson, M.S. 1975. The effects of temperature and salinity on cadmium uptake by the blue crab, *Callinectes sapidus*. Chesapeake Sci. 15: 237.

Hutchins, C.M., D.F. Simon, W. Zerges and K.J. Wilkinson. 2010. Transcriptomic signatures in *Chlamydomonas reinhardtii* as Cd biomarkers in metal mixtures. Aquat. Toxicol. 100(1): 120-127.

Hutchinson, T.C. and F.W. Collins. 1978. Effect of H^+ ion activity and Ca^{2+} on the toxicity of metals in the environment. Environ. Health Perspect. 25: 47-52.

Hutchinson, T.C. and H. Czyrska. 1972. Cadmium and zinc toxicity and synergism to floating aquatic plants. In: Water Pollut. Res. in Canada 1972. Proc. 7th Canadian Symp. Water Pollut. Res., Inst. Environ. Sci. Eng. Publ. No. EI-3. p. 59.

Hutchinson, T.C. and P.M. Stokes. 1975. Heavy metal toxicity and algal bioassays. In: S. Barabos (*Ed*.), Water Quality Parameters. ASTM STP 573. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 320.

Hutchinson, T.H., T.D. Williams and G.J. Eales. 1994. Toxicity of cadmium, hexavalent chromium and copper to marine fish larvae (*Cyprinodon variegatus*) and copepods (*Tisbe battagliai*). Mar. Environ. Res. 38: 275-290.

Hutton, M. 1983. Sources of cadmium in the environment. Ecotoxicol. Environ. Safety. 7:9-24.

Hwang, P.P., S.W. Lin and H.C. Lin. 1995. Different sensitivities to cadmium in tilapia larvae (*Oreochromis mossambicus*; Teleostei). Arch. Environ. Contam. Toxicol. 29: 1-7.

HydroQual. 2003. Phase I development of a Biotic Ligand Model for cadmium. Batl1106, Technical Report, Mahwah, NJ.

Hylland, K., M. Skold, J.S. Gunnarsson and J. Skei. 1997. Interactions between eutrophication and contaminants. IV. Effects on sediment-dwelling organisms. Mar. Pollut. Bull. 33(1-6): 90-99.

Iannacone, O.J.A. and F.L. Alvarino. 1999. Acute ecotoxicity of heavy metals using juveniles of freshwater snail *Physa venustula* (Gould, 1847) (Mollusca). Gayana 63(2): 101-110.

Idardare, Z., J.F. Chiffoleau, A. Moukrim, A.A. Alla, D. Auger, L. Lefrere and E. Rozuel. 2008. Metal concentrations in sediment and *Nereis diversicolor* in two Moroccan lagoons: Khnifiss and Oualidia. Chem. Ecol. 24(5): 329-340.

Ieradi, L.A., F. Meucci, F. Giucca, L. Meucci, E. Ciccotti, E. Cardarelli, R. Grossi and L. Campanella. 1996. Mutagenicity test and heavy metals in teleost fish from Tiber River (Rome, Italy). Ekol. Khim. 5(4): 287-291.

Iftode, F., J.J. Curgy, A. Fleury and G. Fryd-Versavel. 1985. Action of a heavy ion, Cd^{2+}, and the antagonistic effect of Ca^{2+}, on two ciliates *Tetrahymena pyriformis* and *Euplotes vannus*. Acta Protozool. 24(3-4): 273-279.

Ikemoto, T., N.P.C. Tu, N. Okuda, A. Iwata, K. Omori, S. Tanabe, B.C. Tuyen and I. Takeuchi. 2008. Biomagnification of trace elements in the aquatic food web in the Mekong Delta, South Vietnam using stable carbon and nitrogen isotope analysis. Arch. Environ. Contam. Toxicol. 54: 504-515.

Ikuta, K.A 1985a. A comparison on heavy metal contents between *Batillus cornutus* and *Babylonia japonica*. Bull. Fac. Agric. Miyazaki Univ. 32(1): 79-84.

Ikuta, K. 1985b. Distribution and localization of some heavy metals in female and male of a herbivorous gastropod *Haliotis discus*. Bull. Fac. Agric. Miyazaki Univ. 32(1): 103-112.

Ikuta, K. 1985c. Distribution of heavy metals in female and male of a herbivorous gastropod *Batillus cornutus*. Bull. Fac. Agric. Miyazaki Univ. 32(1): 85-92.

Ikuta, K. 1985d. Distribution of heavy metals in female and male of a scallop *Patinopecten yessoensis*. Bull. Fac. Agric. Miyazaki Univ. 32(1): 93-102.

Ikuta, K. 1987. Cadmium accumulation by a top shell *Batillus cornutus*. Nippon Suisan Gakkaishi. 53(7): 1237-1242.

Ilangovan, K., R.O. Canizares-Villanueva, S. Gonzalez Moreno and D. Voltolina. 1998. Effect of cadmium and zinc on respiration and photosynthesis in suspended and immobilized cultures of *Chlorella vulgaris* and *Scenedesmus acutus*. Bull. Environ. Contam. Toxicol. 60: 936-943.

Iliopoulou-Georgudaki, J. and N. Kotsanis. 2001. Toxic effects of cadmium and mercury in rainbow trout (*Oncorhynchus mykiss*): A short-term bioassay. Bull. Environ. Contam. Toxicol. 66(1): 77-85.

Illuminati, S., C. Truzzi, A. Annibaldi, B. Migliarini, O. Carnevali and G. Scarponi. 2010. Cadmium bioaccumulation and metallothionein induction in the liver of the antarctic teleost *Trematomus bernacchii* during an on-site short-term exposure to the metal via seawater. Toxicol. Environ. Chem. 92(3): 617-640.

Ingersoll, C.G. and N. Kemble. 2000. Unpublished. Methods development for long-term sediment toxicity tests with the amphipod *Hyalella azteca* and the midge *Chironomus tentans*.

Ingersoll, C. and N. Kemble, N. 2001. Revised description of toxicity data on cadmium: Chronic water-only exposures with the amphipod *Hyalella azteca* and the midge *Chironomus tentans*. Letter to C. Roberts, U.S.D.I., U.S.Geol.Surv., Columbia Environ.Res.Ctr., Columbia, MO, 5 p.

Ingersoll, C.G. and R.W. Winner. 1982. Effect on *Daphnia pulex* (De Geer) of daily pulse exposures to copper or cadmium. Environ. Toxicol. Chem. 1: 321.

Ingersoll, C.G., N.E. Kemble, J.L. Kunz, W.G. Brumbaugh, D.D. MacDonald and D. Smorong. 2009. Toxicity of sediment cores collected from the Ashtabula River in Northeastern Ohio, USA, to the amphipod *Hyalella azteca*. Arch. Environ. Contam. Toxicol. 57(2): 315-329.

International Cadmium Association. 2013. International Cadmium Association website. Accessed September 2013. www.cadmium.org.

Inza, B., F. Ribeyre and A. Boudou. 1998. Dynamics of cadmium and mercury compounds (inorganic mercury or methylmercury): Uptake and depuration in *Corbicula fluminea*. Effects of temperature and pH. Aquat. Toxicol. 43: 273-285.

Ip, C.C.M., X.D. Li, G. Zhang, C.S.C. Wong and W.L. Zhang. 2005. Heavy metal and Pb isotopic compositions of aquatic organisms in the Pearl River Estuary, South China. Environ. Pollut. 138(3): 494-504.

Irato, P. and E. Piccinni. 1996. Effects of cadmium and copper on *Astasia longa*: Metal uptake and glutathione levels. Acta Protozool. 35: 281-285.

Irving, E.C., D.J. Baird and J.M. Culp. 2003. Ecotoxicological responses of the mayfly *Baetis tricaudatus* to dietary and waterborne cadmium: Implications for toxicity testing. Environ. Toxicol. Chem. 22(5): 1058-1064.

Irving, E.C., D.J. Baird and J.M. Culp. 2009. Cadmium toxicity and uptake by mats of the freshwater diatom: *Navicula pelliculosa* (Breb) Hilse. Arch. Environ. Contam. Toxicol. 57(3): 524-30.

Isani, G., G. Andreani, F. Cocchioni, D. Fedeli, E. Carpene and G. Falcioni. 2009. Cadmium accumulation and biochemical responses in *Sparus aurata* following sub-lethal Cd exposure. Ecotoxicol. Environ. Saf. 72(1): 224-230.

Isherwood, D.M. 2009. Photoinduced toxicity of metals and PAHs to *Hyalella azteca*: UV-mediated toxicity and the effects of their photoproducts. M.S. Thesis, University of Waterloo, Canada.

Ismail, A. and S. Yusof. 2011. Effect of mercury and cadmium on early life stages of java medaka (*Oryzias javanicus*): A potential tropical test fish. Mar. Pollut. Bull. 63(5-12): 347-349.

Ismail, M., S.M. Phang, S.L. Tong and M.T.A. Brown. 2002. Modified toxicity testing method using tropical marine microalgae. Environ. Monit. Assess. 75(2): 145-154.

Issa, A.A., R. Abdel-Basset and M.S. Adam. 1995. Abolition of heavy metal toxicity on *Kirchneriella lunaris* (Chlorophyta) by calcium. Ann. Bot. 75: 189-192.

Issartel, J., V. Boulo, S. Wallon, O. Geffard and G. Charmantier. 2010. Cellular and molecular osmoregulatory responses to cadmium exposure in *Gammarus fossarum* (Crustacea, Amphipoda). Chemosphere 81(6): 701-710.

Ivanina, A.V. and I.M. Sokolova. 2008. Effects of cadmium exposure on expression and activity of p-glycoprotein in eastern oysters, *Crassostrea virginica* Gmelin. Aquat. Toxicol. 88(1): 19-28.

Ivanina, A.V. and I.M. Sokolova. 2013. Interactive effects of pH and metals on mitochondrial functions of intertidal bivalves *Crassostrea virginica* and *Mercenaria mercenaria*. Aquat. Toxicol. 144-145: 303-309.

Ivanina, A.V., E.P. Sokolov and I.M. Sokolova. 2010a. Effects of cadmium on anaerobic energy metabolism and mrna expression during air exposure and recovery of an intertidal mollusk *Crassostrea virginica*. Aquat. Toxicol. 99(3): 330-342.

Ivanina, A.V., S. Eilers, I.O. Kurochkin, J.S. Chung, S. Techa, H. Piontkivska, E.P. Sokolov and I.M. Sokolova. 2010b. Effects of cadmium exposure and intermittent anoxia on nitric oxide metabolism in eastern oysters, *Crassostrea virginica*. J. Exp. Biol. 213(3): 433-444.

Ivanina, A.V., B. Froelich, T. Williams, E.P. Sokolov, J.D. Oliver and I.M. Sokolov. 2011. Interactive effects of cadmium and hypoxia on metabolic responses and bacterial loads of eastern oysters *Crassostrea virginica* Gmelin. Chemosphere 82(3): 377-389.

Ivankovic, D., J. Pavicic, V. Beatovic, R.S. Klobucar and G.I.V. Klobucar. 2010. Inducibility of metallothionein biosynthesis in the whole soft tissue of zebra mussels *Dreissena polymorpha* exposed to cadmium, copper, and pentachlorophenol. Environ. Toxicol. 25(2): 198-211.

Ivey CD, Ingersoll CG. 2016. Influence of bromide on the performance of the amphipod Hyalella azteca in reconstituted waters. Environ Toxicol Chem. In press..

Ivorra, N., C. Barranguet, M. Jonker, M.H.S. Kraak and W. Admiraal. 2002a. Metal-induced tolerance in the freshwater microbenthic diatom *Gomphonema parvulum*. Environ. Pollut. 116(1): 147-157.

Ivorra, N., J. Hettelaar, M.H.S. Kraak, S. Sabater and W. Admiraal. 2002b. Responses of biofilms to combined nutrient and metal exposure. Environ. Toxicol. Chem. 21(3): 626-632.

Iwasaki, Y. and S.J. Ormerod. 2012. Estimating safe concentrations of trace metals from inter-continental field data on river macroinvertebrates. Environ. Pollut. 166: 182-186.

Jaafarzadeh, N., R. Khoshnood, Z. Khoshnood and N. Jaafarzadeh. 2011. Cadmium determination in two flat fishes from two fishery regions in North of the Persian Gulf. Iranian J. Fish. Sci. 10(3): 537-540.

Jackson, B.P., P.J. Lasier, W.P. Miller and P.W. Winger. 2000. Effects of calcium, magnesium, and sodium on alleviating cadmium toxicity to *Hyalella azteca*. Bull. Environ. Contam. Toxicol. 64: 279-286.

Jak, R.G., J.L. Maas and M.C.T. Scholten. 1996. Evaluation of laboratory derived toxic effect concentrations of a mixture of metals by testing freshwater plankton communities in enclosure. Water Res. 30(5): 1215-1227.

Jamers, A.N., R. Blust, W. De Coen, J.L. Griffin and O.A. Jones. 2012. An omics based assessment of cadmium toxicity in the green alga *Chlamydomonas reinhardtii*. Aquat. Toxicol. 126(15): 355-364.

James, R. and K. Sampath. 1999. Effect of zeolite on the reduction of cadmium toxicity in water and a freshwater fish, *Oreochromis mossambicus*. Bull. Environ. Contam. Toxicol. 62(2): 222-229.

James, S.M. and E.E. Little. 2003. The effects of chronic cadmium exposure on american toad (*Bufo americanus*) tadpoles. Environ. Toxicol. Chem. 22(2): 377-380.

James, S.M., E.E. Little and R.D. Semlitsch. 2005. Metamorphosis of two amphibian species after chronic cadmium exposure in outdoor aquatic mesocosms. Environ. Toxicol. Chem. 24(8): 1994-2001.

Jana, S. and S.S. Sahana. 1988. Effects of copper, cadmium and chromium cations on the freshwater fish *Clarias batrachus* L. Physiol. Bohemoslov. 37(1): 79-82.

Jana, S. and S.S. Sahana. 1989. Sensitivity of the freshwater fishes *Clarias batrachus* and *Anabas testudineus* to heavy metals. Environ. Ecol. 7(2): 265-270.

Janati-Idrissi, M., M. Guerbet and J.M. Jouany. 2001. Effect of cadmium on reproduction of daphnids in a small aquatic microcosm. Environ. Toxicol. 16: 361-364.

Jankovska, I., D. Miholova, D. Lukesova, L. Kalous, P. Valek, S. Romocusky, J. Vadlejch, M. Petrtyl, I. Langrova and Z. Cadkova. 2012. Concentrations of Zn, Mn, Cu and Cd in different tissues of perch (*Perca fluviatilis*) and in perch intestinal parasite (*Acanthocephalus lucii*) from the stream near Prague (Czech Republic). Environ. Res. 112: 83-85.

Janssen, C.R. and G. Persoone. 1993. Rapid toxicity screening tests for aquatic biota. I. Methodology and experiments with *Daphnia magna*. Environ. Toxicol. Chem. 12: 711-717.

Janssen, H.H. and N. Scholz. 1979. Uptake and cellular distribution of cadmium in *Mytilus edulis*. Mar. Biol. 55: 133.

Janssen, M.P.M., C. Oosterhoff, G.J.S.M. Heijmans and H. Van der Voet. 1995. The toxicity of metal salts and the population growth of the Ciliate *Colpoda cucculus*. Bull. Environ. Contam. Toxicol. 54: 597-605.

Janssens de Bisthoven, L.G., K.R. Timmerans and F. Ollevier. 1992. The concentration of cadmium, lead, copper and zinc in *Chironomus thummi* larvae (Diptera, Chironomidae) with deformed versus normal menta. Hydrobiol. 239: 141-149.

Janssens de Bisthoven, L., J. Postma, A. Vermeulen, G. Goemans and F. Ollevier. 2001. Morphological deformities in *Chironomus riparius* Meigen larvae after exposure to cadmium over several generations. Water Air Soil Pollut. 129(1-4): 167-179.

Jara-Marini, M.E., M.F. Soto-Jiménez and F. Páez-Osuna. 2009. Trophic relationships and transference of cadmium, copper, lead and zinc in a subtropical coastal lagoon food web from SE Gulf of California. Chemosphere 77(10): 1366-1373.

Jarup, L., M. Berglund, C.G. Elinder, G. Nordberg and M. Vahter. 1998. Health effects of cadmium exposure – a review of the literature and a risk estimate. Scandinavian J. Work Environ. Health 24(3): 240.

Jarvinen, A.W. and G.T. Ankley. 1999. Linkage of effects to tissue residues: Development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals. Society of Environmental Toxicology and Chemistry, Pensacola, FL, 364 pp.

Javanshir, A., M. Shapoori and F. Moezzi. 2011. Impact of water hardness on cadmium absorption by four freshwater mollusks *Physa fontinalis*, *Anodonta cygnea*, *Corbicula fluminea* and *Dreissena polymorpha* from south Caspian Sea region. J. Food Agric. Environ. 9(2): 763-767.

Javed, M.T. and M. Greger. 2011. Cadmium triggers *Elodea canadensis* to change the surrounding water pH and thereby Cd uptake. Int. J. Phytoremediat. 13(1): 95-106.

Jaworska, M., A. Gorczyca, J. Sepiol and P. Tomasik. 1997. Effect of metal ions on the entomopathogenic nematode *Heterorhabditis bacteriophora poinar* (Nematoda: Heterohabditidae) under laboratory conditions. Water Air Soil Pollut. 93: 157-166.

Jay, F.B. and R.J. Muncy. 1979. Toxicity to channel catfish of wastewater from an Iowa coal beneficiation plant. Iowa State J. Res. 54(1): 45-50.

Jebali, J., M. Banni, H. Guerbej, E.A. Almeida, A. Bannaoui and H. Boussetta. 2006. Effects of malathion and cadmium on acetylcholinesterase activity and metallothionein levels in the fish *Seriola dumerilli*. Fish Physiol. Biochem. 32(1): 93-98.

Jeitner, C. and J. Burger. 2009. Metal concentrations (arsenic, cadmium, chromium, lead, mercury and selenium) in dolly varden (*Salvelinus malma*) from the Aleutian Islands, Alaska. M.S. Thesis, Rutgers The State University of New Jersey - New Brunswick, NJ.

Jemec, A., D. Drobne, T. Tisler, P. Trebse, M. Ros and K. Sepcic. 2007. The applicability of acetylcholinesterase and glutathione s-transferase in *Daphnia Magna* toxicity test. Comp. Biochem. Physiol. 144C (4): 303-309.

Jemec, A., T. Tisler, D. Drobne, K. Sepcic, P. Jamnik and M. Ros. 2008. Biochemical biomarkers in chronically metal-stressed daphnids. Comp. Biochem. Physiol. 147C(1): 61-68.

Jenkins, K.D. and A.Z. Mason. 1988. Relationships between subcellular distributions of cadmium and perturbations in reproduction in the polychaete *Neanthes arenaceodentata*. Aquat. Toxicol. 12: 229-244.

Jenkins, K.D. and B.M. Sanders. 1986. Relationships between free cadmium ion activity in seawater, cadmium accumulation and subcellular distibution, and growth in polychaetes. Environ. Health Perspect. 65: 205-210.

Jenner, H.A. and T. Bowmer. 1990. The accumulation of metals and their toxicity in the marine intertidal invertebrates *Cerastoderma edule*, *Macoma balthica*, and *Arenicola marina* exposed to pulverized fuel ash in mesocosms. Environ. Pollut. 66(2): 139-156.

Jenner, H.A. and J.P.M. Janssen-Mommen. 1989. Phytomonitoring of pulverized fuel ash leachates by the duckweed (*Lemna minor*). Hydrobiologia 188/189: 361-366.

Jenner, H.A. and J.P.M. Janssen-Mommen. 1993. Duckweed *Lemna minor* as a tool for testing toxicity of coal residues and polluted sediments. Arch. Environ. Contam. Toxicol. 25: 3-11.

Jennett, J.C., B.G. Wixson and R.L. Kramer. 1981. Some effects of century old abandoned lead mining operations on streams in Missouri, USA. Miner. Environ. 3: 17-20.

Jennings, J.R. and P.S. Rainbow. 1979a. Studies on the uptake of cadmium by the crab *Carcinus maenas* in the laboratory. I. Accumulation from seawater and a food source. Mar. Biol. 50: 131.

Jennings, J.R. and P.S. Rainbow. 1979b. Accumulation of cadmium by *Dunaliella tertiolecta* Butcher. J. Plankton Res. 1: 67.

Jensen, A. and F. Bro-Rasmussen. 1992. Environmental contamination in Europe. Rev. Environ. Contam. Toxicol. 125: 101-181.

Jensen, A. and V.E. Forbes. 2001. Interclonal variation in the acute and delayed toxicity of cadmium to the European prosobranch gastropod *Potamopyrgus antipodarum* (Gray). Arch. Environ. Contam. Toxicol. 40(2): 230-235.

Jensen, A., V.E. Forbes and E.D. Parker Jr. 2001. Variation in cadmium uptake, feeding rate, and life-history effects in the gastropod *Potamopyrgus antipodarum*: Linking toxicant effects on individuals to the population level. Environ. Toxicol. Chem. 20(11): 2503-2513.

Jerez, S., M. Motas, R.A. Canovas, J. Talavera, R.M. Almela and A.B. Del Rio. 2010. Accumulation and tissue distribution of heavy metals and essential elements in loggerhead turtles (*Caretta caretta*) from Spanish Mediterranean coastline of Murcia. Chemosphere 78(3): 256-264.

Jezierska, B. and P. Sarnowski. 2002. The effect of mercury, copper and cadmium during single and combined exposure on oxygen consumption of *Oncorhynchus mykiss* Wal. and *Cyprinus carpio* L. larvae. Arch. Pol. Fish. 10(1): 15-22.

Jezierska, B., K. Lugowska and M. Witeska. 2002. The effect of temperature and heavy metals on heart rate changes in common carp *Cyprinus carpio* L. and grass carp *Ctenopharyngodon idella* (Val.) during embryonic development. Arch. Pol. Fish. 10(2): 153-165.

Jia, X., H. Zhang and X. Liu. 2011. Low levels of cadmium exposure induce DNA damage and oxidative stress in the liver of oujiang colored common carp *Cyprinus carpio* var. color. Fish Physiol. Biochem. 37(1): 97-103.

Jiang, L. 1986. Avoidance reaction of fishes to twenty-five pollutants. Fresh. Fish. 1: 29-34.

Jiang, X.D., G.Z. Wang, S.J. Li and J.F. He. 2007. Heavy metal exposure reduces hatching success of *Acartia pacifica* resting eggs in the sediment. J. Environ. Sci. 19(6): 733-737.

Jindal, R. and A. Verma. 1990. Heavy metal toxicity to *Daphnia pulex*. Indian J. Environ. Health 32(3): 289-292.

Jing, J., H. Liu, H. Chen, S. Hu, K. Xiao and X. Ma. 2013. Acute effect of copper and cadmium exposure on the expression of heat shock protein 70 in the Cyprinidae fish *Tanichthys albonubes*. Chemosphere 91(8): 1113-1122.

Jiraungkoorskul, W., S. Sahaphong, P. Kosai and M.H. Kim. 2007a. Micronucleus test: The effect of ascorbic acid on cadmium exposure in fish (*Puntius altus*). Res. J. Environ. Toxicol. 1(1): 27-36.

Jiraungkoorskul, W., S. Sahaphong, P. Kosai and M.H. Kim. 2007b. The effect of ascorbic acid on cadmium exposure in the gills of *Puntius altus*. Int. J. Zool. Res. 3(2): 77-85.

Jiraungkoorskul, W., S. Sahaphong, P. Kosai and M.H. Kim. 2010. Micronucleus Test: The effect of ascorbic acid on cadmium exposure in fish (*Puntius altus*). Res. J. Environ. Toxicol. 4(2): 103-112.

Jofre, M.B., R.I. Anton and E. Caviedes-Vidal. 2011. Lead and cadmium accumulation in anuran amphibians of a permanent water body in arid midwestern Argentina. Environ. Sci. Pollut. Res. Int. 19(7): 2889-2897.

John, J., E.T. Gjessing, M. Grande and B. Salbu. 1987. Influence of aquatic humus and pH on the uptake and depuration of cadmium by the Atlantic salmon (*Salmo salar* L.). Sci. Total Environ. 62: 253-265.

Johns, C. 2001. Spatial distribution of total cadmium, copper, and zinc in the zebra mussel (*Dreissena polymorpha*) along the upper St. Lawrence River. J. Great Lakes Res. 27(3): 354-366.

Johns, C. 2012. Trends of total cadmium, copper, and zinc in the zebra mussel (*Dreissena polymorpha*) along the upper reach of the St. Lawrence River: 1994-2005. Environ. Monit. Assess. 184(9): 5371-5385.

Johns, D.M. and D.C. Miller. 1982. The use of bioenergetics to investigate the mechanisms of pollutant toxicity in crustacean larvae. *In*: W.B. Vernberg, et al. (*Eds*.), Physiological Mechanisms of Marine Pollutant Toxicity. Academic Press, New York. p. 261.

Johnson, G.D., A.W. McIntosh and G.J. Atchison. 1978. The use of periphyton as a monitor of trace metals in two contaminated Indiana lakes. Bull. Environ. Contam. Toxicol. 19: 733-740.

Johnson, M. and J. Gentile. 1979. Acute toxicity of cadmium, copper, and mercury to larval American lobster (*Homarus americanus*). Bull. Environ. Contam. Toxicol. 22: 258.

Jones, I., P. Kille and G. Sweeney. 2001. Cadmium delays growth hormone expression during rainbow trout development. J. Fish Biol. 59(4): 1015-1022.

Jones, K.C., P.J. Peterson and B.E. Davies. 1985. Silver and other metals in some aquatic bryophytes from streams in the lead mining district of Mid-Wales, Great Britain. Water Air Soil Pollut. 24: 329-338.

Jones, M.B. 1975. Synergistic effects of salinity, temperature and heavy metals on mortality and osmoregulation in marine and estuarine isopods (Crustacea). Mar. Biol. 30: 13.

Jonker, M.J., A.M. Piskiewicz, N.I. Castella and J.E. Kammenga. 2004. Toxicity of binary mixtures of cadmium-copper and carbendazim-copper to the nematode *Caenorhabditis elegans*. Environ. Toxicol. Chem. 23(6): 1529-1537.

Jonnalagadda, S.B. and P.V.V.P. Rao. 1993. Toxicity, bioavailability and metal speciation. Comp. Biochem. Physiol. 106C(3): 585-595.

Jop, K.M. 1991. Concentration of metals in various larval stages of four *Ephemeroptera* species. Bull. Environ. Contam. Toxicol. 46: 901-905.

Jop, K.M., A.M. Askew and R.B. Foster. 1995. Development of a water-effect ratio for copper, cadmium, and lead for the Great Works River in Maine using *Ceriodaphnia dubia* and *Salvelinus fontinalis*. Bull. Environ. Contam. Toxicol. 54: 29-33.

Jop, K.M., R.C. Biever, J.R. Hoberg and S.P. Shepherd. 1997. Analysis of metals in blue crabs, *Callinectes sapidus*, from two connecticut estuaries. Bull. Environ. Contam. Toxicol. 58(2): 311-317.

Jost, C. and G.P. Zauke. 2008. Trace metal concentrations in Antarctic sea spiders (*Pycnogonida, pantopoda*). Mar. Pollut. Bull. 56(8): 1396-1399.

Juarez-Franco, M.F., S.S.S. Sarma and S. Nandini. 2007. Effect of cadmium and zinc on the population growth *of Brachionus havanaensis* (Rotifera: Brachionidae). J. Environ. Sci. Health 42A(10): 1489-1493.

Juchelka, C.M. and T.W. Snell. 1994. Rapid toxicity assessment using rotifer ingestion rate. Arch. Environ. Contam. Toxicol. 26: 549-554.

Jude, D.J. 1973. Sublethal effects of ammonia and cadmium on growth of green sunfish. Ph.D. Thesis. Michigan State University.

Juhasza, R., A. Ferencz, Z. Jancsć, K. Dugmonits and E. Hermesz. 2012. Comparative study on the expression of glutathione peroxidase, glutathione reductase, glutathione synthetase and metallothionein genes in common carp during cadmium exposure. Free Radical Biology and Medicine: Society for Free Radical Research International 16th Biennial Meeting 53, Supplement 1(0): S220.

Julshamn, K., A. Andersen, O. Ringdal and J. Morkore. 1987. Trace elements intake in the Faroe Islands I. Element levels in edible parts of pilot whales (*Globicephalus meleanus*). Sci. Total Environ. 65: 53-62.

Julshamn, K., E.K. Torpe, C. Boernes, L.J. Saethre and A. Maage. 2001. Cadmium, lead, copper and zinc in blue mussels (*Mytilus edulis*) sampled in the Hardangerfjord, Norway. J. Environ. Monit. 3(5): 539-542.

Julshamn, K., A. Mage, I.M. Tyssebotn and L.J. Saethre. 2011. Concentrations of mercury and other toxic elements in orange roughy, *Hoplostethus atlanticus*, from the Mid-Atlantic Ridge. Bull. Environ. Contam. Toxicol. 87(1): 70-73.

Jun, B.H., S.I. Lee, H.D. Ryu and Y.J. Kim. 2006. Temperature-based rapid toxicity test using *Ceriodaphnia dubia*. Water Sci. Technol. 53(4/5): 347-355.

Jung, K. and G.P. Zauke. 2008. Bioaccumulation of trace metals in the brown shrimp *Crangon crangon* (Linnaeus, 1758) from the German Wadden Sea. Aquat. Toxicol. 88(4): 243-249.

Jung, K., V. Stelzenmueller and G.P. Zauke. 2006. Spatial distribution of heavy metal concentrations and biomass indices in *Cerastoderma edule* Linnaeus (1758) from the German Wadden Sea: An integrated biomonitoring approach. J. Exp. Mar. Biol. Ecol. 338(1): 81-95.

Jurewa, D. and M. Blanuwa. 2003. Mercury, arsenic, lead and cadmium in fish and shellfish from the Adriatic Sea. Food Addit. Contam. 20(3): 241-246.

Kadioglu, A. and O. Ozbay. 1995. Effects of heavy metals on chlorophyll content and cell colony number in *Chlamydomonas reinhardii*. Tr. J. Eng. Environ. Sci. 19: 71-74.

Kahle, J. 2002. Bioaccumulation of trace metals in the copepod *Calanoides acutus* from the Weddell Sea (Antarctica): Comparison of two-compartment and hyperbolic toxicokinetic models. Aquat. Toxicol. 59(1-2): 115-135.

Kahle, J. and G.P. Zauke. 2002. Bioaccumulation of trace metals in the calanoid copepod *Metridia gerlachei* from the Weddell Sea (Antarctica). Sci. Total Environ. 295(1-3): 1-16.

Kahle, J. and G.P. Zauke. 2003a. Bioaccumulation of trace metals in the Antarctic amphipod *Orchomene plebs*: Evaluation of toxicokinetic models. Mar. Environ. Res. 55(5): 359-384.

Kahle, J. and G.P. Zauke. 2003b. Trace metals in Antarctic copepods from the Weddell Sea (Antarctica). Chemosphere 51(5): 409-417.

Kaitala, S., J. Kuparinen and V.N. Maximov. 1983. The effect of copper, cadmium, zinc and pentachlorophenolate on heterotrophic activity and primary production. In: B.J.Dutka and D.Liu (*Eds*.), Symp. Abstr. Canada Centre for Inland Waters, Burlington,Toxicity Screening Tests.

Kalafatic, M., N. Kopjar and V. Besendorfer. 2004. The impairments of neoblast division in regenerating planarian *Polycelis felina* (Daly.) caused by in vitro treatment with cadmium sulfate. Toxicol. In Vitro 18(1): 99-107.

Kallqvist, T. 2009. Effect of water hardness on the toxicity of cadmium to the green alga *Pseudokirchneriella subcapitata* in an artificial growth medium and nutrient-spiked natural lake waters. J. Toxicol. Environ. Health 72A(3): 277-283.

Kalman, J., B.D. Smith, I. Riba, J. Blasco and P.S. Rainbow. 2010b. Biodynamic modelling of the accumulation of Ag, Cd and Zn by the deposit-feeding polychaete *Nereis diversicolor*: Inter-population variability and a generalised predictive model. Mar. Environ. Res. 69(5): 363-373.

Kalman, J., I. Riba, T.A. DelValls and J. Blasco. 2010a. Comparative toxicity of cadmium in the commercial fish species *Sparus aurata* and *Solea senegalensis*. Ecotoxicol. Environ. Saf. 73(3): 306-311.

Kamala-Kannan, S., B. Prabhu Dass Batvari, K.J. Lee, N. Kannan, R. Krishnamoorthy, K. Shanthi and M. Jayaprakash. 2008. Assessment of heavy metals (Cd, Cr and Pb) in water, sediment and seaweed (*Ulva lactuca*) in the Pulicat Lake, south east India. Chemosphere 71(7): 1233-1240.

Kamaruzzaman, B.Y., M.C. Ong, K. Zaleha and S. Shahbudin. 2008. Levels of heavy metals in green-lipped mussel *Perna veridis* (Linnaeus) from Muar Estuary, Johore, Malaysia. Pakistan J. Biol. Sci. 11(18): 2249-2253.

Kamunde, C. 2009. Early subcellular partitioning of cadmium in gill and liver of rainbow trout (*Oncorhynchus mykiss*) following low-to-near-lethal waterborne cadmium exposure. Aquat. Toxicol. 91(4): 291-301.

Kamunde, C. and R. MacPhail. 2011a. Subcellular interactions of dietary cadmium, copper and zinc in rainbow trout (*Oncorhynchus mykiss*). Aquat. Toxicol. 105(3/4): 518-527.

Kamunde, C. and R. Macphail. 2011b. Metal-metal interactions of dietary cadmium, copper and zinc in rainbow trout, *Oncorhynchus mykiss*. Ecotoxicol. Environ. Saf. 74(4): 658-667.

Kamunde, C., R. Macphail and C. Kamunde. 2011. Effect of humic acid during concurrent chronic waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium and zinc. Ecotoxicol. Environ. Saf. 74(3): 259-269.

Kangwe, J.W., F. Hellblom, A.K. Semesi, M.S.P. Mtolera and M. Bjork. 2001. Heavy metal inhibition of calcification and photosynthetic rates of the geniculate calcareous alga *Amphiroa tribulus*. In: M.D.Richmond and J.Francis (Eds.), Proc.of the Conf.on Advances on Marine Sciences in Tanzania (1): 147-157.

Kaonga, C.C., J. Kumwenda and H.T. Mapoma. 2010. Accumulation of lead, cadmium, manganese, copper and zinc by sludge worms; *Tubifex tubifex* in sewage sludge. Int. J. Environ. Sci. Tech. 7(1): 119-126.

Kaoud, H.A. and A. Rezk. 2011. Effect of exposure to cadmium on the tropical freshwater prawn *Macrobrachium rosenbergii*. Afr. J. Aquat. Sci. 36(3): 253-260.

Kapauan, P.A., L.A. Salamat, F.P. Verceluz and P.G. Beltran. 1982. Cadmium, lead, copper and zinc in Philippine aquatic life. Govt. Report. Announ. Index 14.

Kaplan, D., Y.M. Heimer, A. Abeliovich and P.B. Goldsbrough. 1995. Cadmium toxicity and resistance in *Chlorella sp*. Plant Sci. 109: 129-137.

Kapur, K. and N.A. Yadav. 1982. The effects of certain heavy metal salts on the development of eggs in common carp, *Cyprinus carpio* var. *communis*. Acta Hydrochim. Hydrobiol. 10: 517.

Kar, S. and A.K. Aditya. 2010. Impact of heavy metal and pesticide on total protein content in intact and regenerating *Hydra*. Environ. Ecol. 28(3B): 2003-2007.

Kara, Y. 2010. Physiological and toxicological effects of lead plus cadmium mixtures on rainbow trout (*Oncorhynchus mykiss*) in soft acidic water. M.S. Thesis, Wilfrid Laurier University, Waterloo, Ontario, Canada.

Kara, Y. and A. Zeytunluoglu. 2007. Bioaccumulation of toxic metals (Cd and Cu) by *Groenlandia densa* (L.) Fourr. Bull. Environ. Contam. Toxicol. 79(6): 609-612.

Karadede-Akin, H. and E. Unlu. 2007. Heavy metal concentrations in water, sediment, fish and some benthic organisms from Tigris River, Turkey. Environ. Monit. Assess. 131: 323-337.

Karakas, S.B. and B. Otludil. 2011. Healing effect on cadmium toxicity of EDTA in *Lymnaea stagnalis*. Curr. Opin. Biotechnol. 22: S79-S79.

Karasov, W.H., R.E. Jung, S.V. Langenberg and T.L.E. Bergeson. 2005. Field exposure of frog embryos and tadpoles along a pollution gradient in the Fox River and Green Bay ecosystem in Wisconsin, USA. Environ. Toxicol. Chem. 24(4): 942-953.

Karayakar, F., C. Erdem and B. Cicik. 2007. Seasonal variation in copper, zinc, chromium, lead and cadmium levels in hepatopancreas, gill and muscle tissues of the mussel *Brachidontes pharaonis* Fischer, collected along the Mersin Coast, Turkey. Bull. Environ. Contam. Toxicol. 79(3): 350-355.

Karez, C.S., S. Bonotto and S. Puiseux-Dao. 1989. Response of the unicellular giant alga *Acetabularia acetabulum* to cadmium toxicity and accumulation. Toxicol. Environ. Chem. 19: 223-232.

Kargin, F., A. Doenmez and H.Y. Cogun. 2001. Distribution of heavy metals in different tissues of the shrimp *Penaeus semiculatus* and *Metapenaeus monocerus* from the Iskenderun Gulf, Turkey: Seasonal variations. Bull. Environ. Contam. Toxicol. 66(1): 102-109.

Karlsson-Norrgren, L. and P. Runn. 1985. Cadmium dynamics in fish: Pulse studies with ^{109}Cd in female zebrafish, *Brachydanio rerio*. J. Fish Biol. 27: 571-581.

Karntanut, W. and D. Pascoe. 2000. A comparison of methods for measuring acute toxicity to *Hydra vulgaris*. Chemosphere 41: 1543-1548.

Karntanut, W. and D. Pascoe. 2002. The toxicity of copper, cadmium and zinc to four different hydra (Cnidaria: Hydrozoa). Chemosphere 47(10): 1059-1064.

Karntanut, W. and D. Pascoe. 2005. Effects of removing symbiotic green algae on the response of *Hydra viridissima* (Pallas 1776) to metals. Ecotoxicol. Environ. Saf. 60(3): 301-305.

Karouna-Renier, N.K., R.A. Snyder, J.G. Allison, M.G. Wagner and K. Ranga Rao. 2007. Accumulation of organic and inorganic contaminants in shellfish collected in estuarine waters near Pensacola, Florida: Contamination profiles and risks to human consumers. Environ. Pollut. 145(2): 474-488.

Karthik, A., D.G. Sekhar, M.A. Raju, S. Adam and S.D.S. Murthy. 2011. Synergistic effect of cadmium in combination with UV-B radiations in PS II photochemistry of the cyanobacterium *Spirulina platensis*. Bioscan 6(1): 81-82.

Karuppasamy, R., S. Subathra and S. Puvaneswari. 2005. Haematological responses to exposure to sublethal concentration of cadmium in air breathing fish, *Channa punctatus* (Bloch). J. Environ. Biol. 26(1): 123-128.

Kasherwani, D., R.S. Verma, S. Shukla and U.D. Sharma. 2007. Cadmium induced skeletal deformities in freshwater catfish, *Heteropneustes fossilis* (Bloch). Environ. Ecol. 25(2): 348-351.

Kasherwani, D., H.S. Lodhi, K.J. Tiwari and S. Shukla. 2009. Cadmium toxicity to freshwater catfish, *Heteropneustes fossilis* (Bloch). Asian J. Exp. Sci. 23(1): 149-156.

Kaska, Y. and R.W. Furness. 2001. Heavy metals in marine turtle eggs and hatchlings in the Mediterranean. Zool. Middle East. 24: 127-132.

Kasuga, S. 1980. Sexual differences of medaka, *Oryzias latipes* in the acute toxicity test of cadmium. Bull. Jap. Soc. Sci. Fish. 46(9): 1073-1076.

Kato, T. 1973. Studies on toxicity of chemical substances (heavy metals etc.) to fish and animal. Nagoya Shiritsu Daigaku Igakkai Zasshi 24(1): 11-34.

Katsikatsou, M., A. Anestis, H.O. Portner, T. Kampouris and B. Michaelidis. 2011. Field studies on the relation between the accumulation of heavy metals and metabolic and HSR in the bearded horse mussel *Modiolus barbatus*. Comp. Biochem. Physiol. 153C(1): 133-140.

Katsumiti, A., F.X.V. Domingos, M. Azevedo, M.D. Silva, R.C. Damian, M.I.M. Almeida, H.C.S. Assis, M.M. Cestari, M.A.F. Randi, C.A.O. Ribeiro and C.A. Freire. 2009. An assessment of acute biomarker responses in the demersal catfish *Cathorops spixii* after the Vicuna oil spill in a harbour estuarine area in southern Brazil. Environ. Monit. Assess. 152(1-4): 209-222.

Katti, S.R. and A.G. Sathyanesan. 1985. Chronic effects of lead and cadmium on the testis of the catfish *Clarias batrachus*. Environ. Ecol. 3(4): 596-598.

Kaur, M., A.S. Ahluwalia and S. Chaudhary. 2002. Effect of bimetallic combinations of heavy metals on growth and development of a cyanobacterium *Anabaena doliolum*. Phykos 41(1/2): 27-34.

Kavun, V.Y.A. 2008. Content of microelements in the grass shrimp *Pandalus kessleri* (Decapoda: Pandalidae) from coastal waters of the lesser Kurilskaya Ridge. Russ. J. Mar. Biol./Biol. Morya 34(1): 64-72.

Kavun, V.Y., V.M. Shulkin and N.K. Khristoforova. 2002. Metal accumulation in mussels of the Kuril Islands, northwest Pacific Ocean. Mar. Environ. Res. 53(3): 219-226.

Kawamata, S., Y. Yamaura, H. Hayashi and S. Komiyama. 1983. Contents of heavy metals in fishes in Nagano Prefecture. CA Selects Environ. Pollut. Issue 7: 4.

Kay, J., D.G. Thomas, M.W. Brown, A. Cryer, D. Shurben, J.F. deLong.G. Solbe and J.S. Garvey. 1986. Cadmium accumulation and protein binding patterns in tissues of the rainbow trout, *Salmo gairdneri*. Environ. Health Perspect. 65: 133-139.

Kayhan, F.E., N. Gulsoy, N. Balkis and R. Yuce. 2007. Cadmium (Cd) and lead (Pb) levels of Mediterranean mussel (*Mytilus galloprovincialis* Lamarck, 1819) from Bosphorus, Istanbul, Turkey. Pak. J. Biol. Sci. 10(6): 915-919.

Kayser, H. 1982. Cadmium effects in food chain experiments with marine plankton algae (Dinophyta) and benthic filter-feeders (Tunicata). Neth. J. Sea Res. 16: 444-454.

Ke, C. and W.X. Wang. 2001. Bioaccumulation of Cd, Se, and Zn in an estuarine oyster (*Crassostrea rivularis*) and a coastal oyster (*Saccostrea glomerata*). Aquat. Toxicol. 56(1): 33-51.

Ke, C. and W.X. Wang. 2002. Trace metal ingestion and assimilation by the green mussel *Perna viridis* in a phytoplankton and sediment mixture. Mar. Biol. (Berlin) 140(2): 327-335.

Keduo, C. L. Yumei and H. Lanying. 1987. Effects os six heavy metals on hatching eggs and survival of larval of marine fish. Oceanol. Limol. Sin. (Haiyang Yu Huzhao). 18(2): 138-144.

Keenan, S. and M.A. Alikhan. 1991. Comparative study of cadmium and lead accumulations in *Cambarus bartoni* (Fab.) (Decapoda, Crustacea) from an acidic and a neutral lake. Bull. Environ. Contam. Toxicol. 47: 91-96.

Keil, S., C. De Broyer and G.P. Zauke. 2008. Significance and interspecific variability of accumulated trace metal concentrations in Antarctic benthic crustaceans. Internat. Rev. Hydrobiol. 93(1): 106-126.

Keller, A.E. Unpublished. Personal communication to U.S. EPA.

Keller, A.E. and S.G. Zam. 1991. The acute toxicity of selected metals to the freshwater mussel, *Anodonta imbecilis*. Environ. Toxicol. Chem. 10: 539-546.

Kelly, M.G. and B.A. Whitton. 1989. Interspecific differences in Zn, Cd and Pb accumulation by freshwater algae and bryophytes. Hydrobiol. 17: 1-11.

Kemble, N.E., W.G. Brumbaugh, E.L. Brunson, F.J. Dwyer, C.G. Ingersoll, D.P. Monda and D.F. Woodward. 1994. Toxicity of metal-contaminated sediments from the Upper Clark Fork River, Montana, to aquatic invertebrates and fish in laboratory exposures. Environ. Toxicol. Chem. 13(12): 1985-1997.

Kemble NE, Hardesty DK, Ingersoll CG, Kunz JL, Sibley PK, Calhoun DL, Gilliom RJ, Kuivila KM, Nowell LH, Moran PW. 2013. Contaminants in stream sediments from seven U.S. metropolitan areas: II. Sediment toxicity to the amphipod *Hyalella azteca* and the midge *Chironomus dilutus.* Arch Environ Contam Toxicol 64:52-64.

Kennedy, C.J. and A.P. Farrell. 2008. Immunological alterations in juvenile Pacific herring, *Clupea pallasi*, exposed to aqueous hydrocarbons derived from crude oil. Environ. Pollut. 153(3): 638-648.

Kennedy, K.M. and R.J. Benson. 1994. Report of heavy metal analysis conducted on mussel *Mytilus edulis* samples collected at 55 sites in Newfoundland. Govt. Reports Announ. Index 9.

Keppler, C.J. and A.H. Ringwood. 2002. Effects of metal exposures on juvenile clams, *Mercenaria mercenaria*. Bull. Environ. Contam. Toxicol. 68(1): 43-48.

Kerfoot, W.B. and S.A. Jacobs. 1976. Cadmium accrual in combined waste-treatment aquaculture system. Environ. Sci. Technol. 10: 662.

Keskin, Y., R. Baskaya, O. Oezyaral, T. Yurdun, N.E. Lueleci and O. Hayran. 2007. Cadmium, lead, mercury and copper in fish from the Marmara Sea, Turkey. Bull. Environ. Contam. Toxicol. 78(3-4): 258-261.

Kessler, E. 1985. An extremely cadmium-sensitive strain of *Chlorella*. Experientia. 41: 1621.

Kessler, E. 1986. Limits of growth of five *Chlorella* species in the presence of toxic heavy metals. Arch. Hydrobiol. 71(1): 123-128.

Keteles, K.A. and J.W. Fleeger. 2001. The contribution of ecdysis to the fate of copper, zinc and cadmium in grass shrimp, *Palaemonetes pugio* Holthius. Mar. Pollut. Bull. 42(12): 1397-1402.

Kettle, W.D. and F. deNoyelles Jr. 1986. Effects of cadmium stress on the plankton communities of experimental ponds. J. Fresh. Ecol. 3(4): 433-443.

Khaled, A. 2009. Trace metals in fish of economic interest from the west of Alexandria, Egypt. Chem. Ecol. 29(4): 229-246.

Khaleghzadeh-Ahangar, H., M. Malek and K. McKenzie. 2011. The parasitic nematodes *Hysterothylacium sp*. type MB larvae as bioindicators of lead and cadmium: A comparative study of parasite and host tissues. Parasitol. 138(11): 1400-1405.

Khalil, M., D.N. Furness, V. Zholobenko and D. Hoole. 2014. Effect of tapeworm parasitisation on cadmium toxicity in the bioindicator copepod, *Cyclops strenuus*. Ecol. Indicat. 37 Part A: 21-26.

Khan, A.T. and J.S. Weis. 1993. Bioaccumulation of heavy metals in two populations of mummichog (*Fundulus heteroclitus*). Bull. Environ. Contam. Toxicol. 51: 1-5.

Khan, A.T., J.S. Weis and L. D'Andrea. 1988. Studies of cadmium tolerance in two populations of grass shrimp, *Palaemonetes pugio*. Bull. Environ. Contam. Toxicol. 40: 30-34.

Khan, A.T., J.S. Weis and L. D'Andrea. 1989. Bioaccumulation of four heavy metals in tow populations of grass shrimp, *Palaemonetes pugio*. Bull. Environ. Contam. Toxicol. 42: 339-343.

Khan, A.T., J. Barbieri, S. Khan and F. Sweeney. 1992. A new short-term mysid toxicity test using sexual maturity as an endpoint. Aquat. Toxicol. 23: 97-105.

Khan, F.R., N.R. Bury and C. Hogstrand. 2010. Cadmium bound to metal rich granules and exoskeleton from *Gammarus pulex* causes increased gut lipid peroxidation in zebrafish following single dietary exposure. Aquat. Toxicol. 96(2): 124-129.

Khan, M.A.Q., S.A. Ahmed, B. Catalin, A. Khodadoust, O. Ajayi and M. Vaughn. 2006b. Effect of temperature on heavy metal toxicity to juvenile crayfish, *Orconectes immunis* (Hagen). Environ. Toxicol. 21(5): 513-520.

Khan, S. and D. Nugegoda. 2007. Sensitivity of juvenile freshwater crayfish *Cherax destructor* (Decapoda: Parastacidae) to trace metals. Ecotoxicol. Environ. Saf. 68(3): 463-469.

Khan, S.M.M.K., C. Yoshimura, M. Arikawa, G. Omura, S. Nishiyama, Y. Suetomo, S. Kakuta, and T. Suzaki. 2006a. Axopodial degradation in the heliozoon *Raphidiophrys contractilis*: A novel bioassay system for detecting heavy metal toxicity in an aquatic environment. Environ. Sci. 13(4): 193-200.

Khangarot, B.S. 1991. Toxicity of metals to a freshwater tubificid worm, *Tubifex tubifex* (Muller). Bull. Environ. Contam. Toxicol. 46: 906-912.

Khangarot, B.S. and P.K. Ray. 1987a. Correlation between heavy metal acute toxicity values in *Daphnia magna* and fish. Bull. Environ. Contam. Toxicol. 38: 722-726.

Khangarot, B.S. and P.K. Ray. 1987b. Sensitivity of toad tadpoles, *Bufo melanostictus* (Schneider), to heavy metals. Bull. Environ. Contam. Toxicol. 38(3): 523-527.

Khangarot, B.S. and P.K. Ray. 1989a. Investigation of correlation between physicochemical properties of metals and their toxicity to the water flea *Daphnia magna* Straus. Ecotoxicol. Environ. Safety. 18: 109-120.

Khangarot, B.S. and P.K. Ray. 1989b. Sensitivity of midge larvae of *Chironomus tentans* Fabricius (Diptera: Chironomidea) to heavy metals. Bull. Environ. Contam. Toxicol. 1989. 42: 325-330.

Khangarot, B.S., P.K. Ray and H. Chandra. 1987. *Daphnia magna* as a model to assess heavy metal toxicity: Comparative assessment with mouse system. Acta Hydrochim. Hydrobiol. 15(4): 427-432.

Khoshmanesh, A., F. Lawson and I.G. Prince. 1996. Cadmium uptake by unicellular green microalgae. Chem. Eng. J. 62: 81-88.

Khoshmanesh, A., F. Lawson and I.G. Prince. 1997. Cell surface area as a major parameter in the uptake of cadmium by unicellular green microalgae. Chem. Eng. J. 65: 13-19.

Khosravi, M., M.T. Ganji and R. Rakhshaee. 2005. Toxic effect of Pb, Cd, Ni and Zn on *Azolla filiculoides* in the international Anzali wetland. Int. J. Environ. Sci. Technol. 2(1): 35-40.

Khoury, J.N., E. Powers, P. Patnaik, and W.G. Wallace. 2009. Relating disparity in competitive foraging behavior between two populations of fiddler crabs to the subcellular partitioning of metals. Arch. Environ. Contam. Toxicol. 56(3): 489-99.

Khristoforova, N.K., S.M. Gnezdilova and G.A. Vlasova. 1984. Effect of cadmium on gametogenesis and offspring of the sea urchin *Strongylocentrotus intermedius*. Mar. Ecol. Prog. Ser. 17: 9-14.

Khristoforova, N.K., V.Y Kavun, Y.Y. Latypov, D.D. Tien, E.V. Zhuravel and N.X. Tuyan. 2007. Heavy metals in mass species of bivalves in Ha Long Bay (South China Sea, Vietnam). Russ. Acad. Sci. Oceanol. 47(5): 685-690.

Kiffney, P.M. and W.H. Clements. 1994. Effects of heavy metals on a macroinvertebrate assemblage from a rocky mountain stream in experimental microcosms. J. North Am. Benthol. Soc. 13(4): 511-523.

Kiffney, P.M. and W.H. Clements. 1996. Size-dependent response of macroinvertebrates to metals in experimental streams. Environ. Toxicol. Chem. 15(8): 1352-1356.

Kilemade, M., M. Hartl, D. Sheehan, C. Mothersill, F. Van Pelt, J. O'Halloran and N. O'Brien. 2004. Genotoxicity of field-collected inter-tidal sediments from Cork Harbor, Ireland, to juvenile turbot (*Scophthalmus maximus* L.) as measured by the comet assay. Environ. Mol. Mutagen. 44(1): 56-64.

Kim, B.M., J.S. Rhee, J.S. Seo, I.C. Kim, Y.M. Lee and J.S. Lee. 2012b. 8-Oxoguanine DNA glycosylase 1 (OGG1) from the copepod *Tigriopus japonicus*: Molecular characterization and its expression in response to UV-B and heavy metals. Comp. Biochem. Physiol 155C(2): 290-299.

Kim, J., M. Lee, S. Oh, J.L. Ku., K.H. Kim and K. Choi. 2009. acclimation to ultraviolet irradiation affects UV-B sensitivity of *Daphnia magna* to several environmental toxicants. Chemosphere 77(11): 1600-1608.

Kim, J., S. Kim, K.W. An, C.Y. Choi, S. Lee and K. Choi. 2010a. Molecular cloning of *Daphnia magna* catalase and its biomarker potential against oxidative stresses. Comp. Biochem. Physiol. 152C(3): 263-269.

Kim, J.H., H.U. Dahms, J.S. Rhee, Y.M. Lee, J. Lee, K.N. Han and J.S. Lee. 2010b. Expression profiles of seven glutathione s-transferase (GST) genes in cadmium-exposed river pufferfish (*Takifugu obscurus*). Comp. Biochem. Physiol. 151C(1): 99-106.

Kim, J.H., J.S. Rhee, J.S. Lee, H.U. Dahms, J. Lee and K.N. Han. 2010c. Effect of cadmium exposure on expression of antioxidant gene transcripts in the river pufferfish, *Takifugu obscurus* (Tetraodontiformes). Comp. Biochem. Physiol. 152C(4): 473-479.

Kim, K.Y., T. Lee and S.I. Lee. 2012a. One-hour temperature-based toxicity test with *Daphnia magna*. Environ. Eng. Sci. 29(7): 573-579.

Kim, S.G., J.H. Jee, and J.C. Kang. 2004b. Cadmium accumulation and elimination in tissues of juvenile olive flounder, *Paralichthys olivaceus* after sub-chronic cadmium exposure. Environ. Pollut. 127(1): 117-123.

Kim, S.G., J.W. Kim and J.C. Kang. 2004a. Effect of dietary cadmium on growth and haematological parameters of juvenile rockfish, *Sebastes schlegeli* (Hilgendorf). Aquac. Res. 35(1): 80-86.

Kim, S.G., K.H. Eom, S.S. Kim, H.G. Jin and J.C. Kang. 2006. Kinetics of Cd accumulation and elimination in tissues of juvenile rockfish (*Sebastes schlegeli*) exposed to dietary Cd. Mar. Environ. Res. 62(5): 327-340.

Kim, S.G., W. Dai, Z. Xu and G. Li. 2011a. Effects of montmorillonite on alleviating dietary Cd-induced oxidative damage in carp (*Carassius auratus*). Biol. Trace Elem. Res. 141(1-3): 200-206.

Kim, S., K. Ji, S. Lee, J. Lee, J. Kim, Y. Kho and K. Choi. 2011b. Perfluorooctane sulfonic acid exposure increases cadmium toxicity in early life stage of zebrafish, *Danio rerio*. Environ. Toxicol. Chem. 30(4): 870-877.

Kim, Y., E.N. Powell, T.L. Wade, B.J. Presley and J.M. Brooks. 2001. The geographic distribution of population health and contaminant body burden in Gulf of Mexico oysters. Arch. Environ. Contam. Toxicol. 41(1): 30-46.

King, C.K. and M.J. Riddle. 2001. Effects of metal contaminants on the development of the common antarctic sea urchin *Sterechinus neumayeri* and comparisons of sensitivity with tropical and temperate echinoids. Mar. Ecol. Prog. Ser. 215: 143-154.

King, C.K., S.L. Simpson, S.V. Smith, J.L. Stauber and G.E. Batley. 2005. Short-term accumulation of Cd and Cu from water, sediment and algae by the amphipod *Melita plumulosa* and the bivalve *Tellina deltoidalis*. Mar. Ecol. Prog. Ser. 287: 177-188.

King, C.K., S.A. Gale and J.L. Stauber. 2006. Acute toxicity and bioaccumulation of aqueous and sediment-bound metals in the estuarine amphipod *Melita plumulosa*. Environ. Toxicol. 21(5): 489-504.

King, C.K., M.C. Dowse and S.L. Simpson. 2010. Toxicity of metals to the bivalve *Tellina deltoidalis* and relationships between metal bioaccumulation and metal partitioning between seawater and marine sediments. Arch. Environ. Contam. Toxicol. 58(3): 657-665.

Kir, I., S. Tekin-Oezan and M. Barlas. 2006. Heavy metal concentrations in organs of rudd, *Scardinus erythrophthalmus* L.,1758 populating Lake Karatas-Turkey. Fresenius Environ. Bull. 15(1): 25-29.

Kiran, B.R., T.R.S. Shekhar, E.T. Puttaiah and Y. Shivaraj. 2006. Trace metal levels in the organs of finfish *Oreochromis mossambicus* (Peter) and relevant water of Jannapura Lake, India. J. Environ. Sci. Eng. 48(1): 15-20.

Kirby, J., W. Maher and D. Harasti. 2001a. Changes in selenium, copper, cadmium, and zinc concentrations in mullet (*Mugil cephalus*) from the southern basin of Lake Macquarie, Australia, in response to alteration of coal-fired power station fly ash handling procedures. Arch. Environ. Contam. Toxicol. 41(2): 171-181.

Kirby, J., W. Maher and F. Krikowa. 2001b. Selenium, cadmium, copper, and zinc concentrations in sediments and mullet (*Mugil cephalus*) from the southern basin of Lake Macquarie, NSW, Australia. Arch. Environ. Contam. Toxicol. 40(2): 246-256.

Kiser, T., J. Hansen and B. Kennedy. 2010. Impacts and pathways of mine contaminants to bull trout (*Salvelinus confluentus*) in an Idaho watershed. Arch. Environ. Contam. Toxicol. 59(2): 301-311.

Klass, E., D.W. Rowe and E.J. Massaro. 1974. The effect of cadmium on population growth of the green alga *Scenedesmus quadricauda*. Bull. Environ. Contam. Toxicol. 12: 442.

Klaverkamp, J.F. and D.A. Duncan. 1987. Acclimation to cadmium toxicity by white suckers: Cadmium binding capacity and metal distribution in gill and liver cytosol. Environ. Toxicol. Chem. 6: 275-289.

Kleinert, S.J., P.E. Degurse and J. Ruhland. 1974. Concentration of metals in fish. Tech. Bull. No. 74, Surveys of Toxic Metals in Wisconsin, Dep. of Nat. Resour., Madison, WI, 8-13.

Klerks, P.J. and P.R. Bartholomew. 1991. Cadmium accumulation and detoxification in a Cd-resistant population of the oligochaete *Limnodrilus hoffmeisteri*. Aquat. Toxicol. 19: 97-112.

Klerks, P.L., D.L. Felder, K. Strasser and P.W. Swarzenski. 2007. Effects of ghost shrimp on zinc and cadmium in sediments from Tampa Bay, Fl. Mar. Chem. 104(1-2): 17-26.

Klinck, J.S. and C.M. Wood. 2011. *In vitro* characterization of cadmium transport along the gastro-intestinal tract of freshwater rainbow trout (*Oncorhynchus mykiss*). Aquat. Toxicol. 102(1-2): 58-72.

Klinck, J.S., W.W. Green, R.S. Mirza, S.R. Nadella, M.J. Chowdhury, C.M. Wood and G. Pyle. 2007. Branchial cadmium and copper binding and intestinal cadmium uptake in wild yellow perch (*Perca flavescens*) from clean and metal-contaminated lakes. Aquat. Toxicol. 84(2): 198-207.

Klinck, J.S., T.Y. Ng and C.M. Wood. 2009. Cadmium accumulation and in vitro analysis of calcium and cadmium transport functions in the gastro-intestinal tract of trout following chronic dietary cadmium and calcium feeding. Comp. Biochem. Physiol. C 150(3): 349-360.

Kline, E.R., V.R. Mattson, Q.H. Pickering, D.L. Spehar and C.E. Stephan. 1987. Effects of pollution on freshwater organisms. J. Water Pollut. Control Fed. 59(6): 539-572.

Kljakovic-Gaspic, Z., B. Antolic, T. Zvonaric and A. Baric. 2004. Distribution of cadmium and lead in *Posidonia oceanica* (L.) delile from the middle Adriatic Sea. Fresenius Environ. Bull. 13(11): 1210-1215.

Kljakovic-Gaspic, Z., N. Odzak, I. Ujevic, T. Zvonaric and A. Baric. 2006. Biomonitoring of trace metals (Cu, Cd, Cr, Hg, Pb, Zn) in the eastern Adriatic using the Mediterranean blue mussel (2001-2005). Fresenius Environ. Bull. 15(9a): 1041-1048.

Klochenko, P.D., G.V. Kharchenko, I.B. Zubenko and T.F. Shevchenko. 2007. Some peculiarities of accumulation of heavy metals by macrophytes and epiphyton algae in water bodies of urban territories. Hydrobiol. J./Gidrobiol. Zh. 43(6): 46-57.

Klockner, K. 1979. Uptake and accumulation of cadmium by *Ophryotrocha diadema* (Polychaeta). Mar. Ecol. Prog. Ser. 1: 71.

Kluttgen, B. and H.T. Ratte. 1994. Effects of different food doses on cadmium toxicity to *Daphnia magna*. Environ. Toxicol. Chem. 13(10): 1619-1627.

Kluytmand, J.H., D.I. Zandee and E.L. Enserink. 1988. Effects of cadmium on the reproduction of *Mytilus edulis* L. Aquat. Toxicol. 11: 428-428.

Knauer, G.A. and J. Martin. 1973. Seasonal variations of cadmium, copper, manganese, lead and zinc and in water and phytoplankton in Monterey Bay, California. Limnol. Oceanogr. 18: 597-604.

Kneip, T.J. 1978. Effects of cadmium in an aquatic environment. In: Proc. 1st International Cadmium Conf., Cadmium 77, San Francisco, Metal Bulletin Ltd., London, UK, In: Proc.1st Int. Cadmium Conf., Jan.1977, San Francisco, 120-124.

Kneip, T.J. and R.E. Hazen. 1979. Deposit and mobility of cadmium in marsh-cove ecosystem and the relation to cadmium concentration in biota. Environ. Health Perspect. 28: 67.

Knops, M., R. Altenburger and H. Segner. 2001. Alterations of physiological energetics, growth and reproduction of *Daphnia magna* under toxicant stress. Aquat. Toxicol. 53(2): 79-90.

Kobayashi, N. 1971. Fertilized sea urchin eggs as an indicator material for marine pollution bioassay, preliminary experiments. Publ. Seto Mar. Biol. Lab. 18: 379.

Kobayashi, N. and H. Okamura. 2005. Effects of heavy metals on sea urchin embryo development. Part 2. Interactive toxic effects of heavy metals in synthetic mine effluents. Chemosphere 61(8): 1198-1203.

Koca, S., Y.B. Koca, S. Yildiz and B. Gurcu. 2008. Genotoxic and histopathological effects of water pollution on two fish species, *Barbus capito pectoralis* and *Chondrostoma nasus* in the Buyuk Menderes River, Turkey. Biol. Trace Elem. Res. 122(3): 276-291.

Kock, G., R. Hofer and S. Wograth. 1995. Accumulation of trace metals (Cd, Pb, Cu, Zn) in Arctic char (*Salvelinus alpinus*) from oligotrophic alpine lakes: Relation to alkalinity. Can. J. Fish. Aquat. Sci. 52: 2367-2376.

Kock, G., M. Triendl and R. Hofer. 1996. Seasonal patterns of metal accumulation in Arctic char (*Salvelinus alpinus*) from an oligotrophic alpine lake related to temperature. Can. J. Fish. Aquat. Sci. 53: 780-786.

Koelmans, A.A., F. Gillissen and L. Lijklema. 1996. Influence of salinity and mineralization on trace metal sorption to cyanobacteria in natural waters. Water Res. 30(4): 853-864.

Kogan, I.G., I.D. Anikeeva and E.N. Vanlina. 1975. Effect of cadmium ions on *Chlorella* II: Modification of the UV irridation effect. Genetika 11: 84-87.

Kohler, K. and H.U. Riisgard. 1982. Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilus edulis*. Mar. Biol. 66: 53.

Koivisto, S., M. Arner and N. Kautsky. 1997. Does cadmium pollution change trophic interactions in rockpool food webs? Environ. Toxicol. Chem. 16(6): 1330-1336.

Kojadinovic, J., M. Potier, M. Le Corre, R.P. Cosson and P. Bustamante. 2007. Bioaccumulation of trace elements in pelagic fish from the western Indian Ocean. Environ. Pollut. 146(2): 548-566.

Kola, H. and K.J. Wilkinson. 2005. Cadmium uptake by a green alga can be predicted by equilibrium modelling. Environ. Sci. Technol. 39(9): 3040-3047.

Kolok, A.S., E.P. Plaisance and A. Abdelghani. 1998. Individual variation in the swimming performance of fishes: An overlooked source of variation in toxicity studies. Environ. Toxicol. Chem. 17(2): 282-285.

Kolyuchkina, G.A. and A.D. Ismailov. 2011. Morpho-functional characteristics of bivalve mollusks under the experimental environmental pollution by heavy metals. Oceanol. (Washington) 51(5): 804-813.

Komjarova, I. and R. Blust. 2008. Multi-metal interactions between Cd, Cu, Ni, Pb and Zn in water flea *Daphnia magna*, a stable isotope experiment. Aquat. Toxicol. 90(2): 138-144.

Komjarova, I. and R. Blust. 2009. Effect of Na, Ca and pH on simultaneous uptake of Cd, Cu, Ni, Pb, and Zn in the water flea *Daphnia magna* measured using stable isotopes. Aquat. Toxicol. 94(2): 81-86.

Kondera, E. and M. Witeska. 2012. Cadmium-induced alterations in head kidney hematopoietic tissue of common carp. Fres. Environ. Bull. 21(3A): 769-773.

Kooijman, S.A.L.M. and J.J.M. Bedaux. 1996. Analysis of toxicity tests on *Daphnia* survival and reproduction. Water Res. 30(7): 1711-1723.

Koop, U. 1991. Untersuchungen ueber die schwermetallanreicherung in fischen aus schwermetallbelasteten gewaessern im hinblick auf deren fischereiliche nutzung. (Studies on heavy metal enrichment in fish from waters polluted by heavy metals with reference to their use by the fishing industry). Govt. Report. Announ. Index 24.

Kopecka-Pilarczyk, J. 2010. The effect of pesticides and metals on acetylcholinesterase (ACHE) in various tissues of blue mussel (*Mytilus trossulus* L.) in short-term *in vivo* exposures at different temperatures. J. Environ. Sci. Health 45B(4): 336-346.

Kopfler, F.C. and J. Mayer. 1973. Concentrations of five trace metals in the waters and oysters (*Crassostrea virginica*) of Mobile Bay, Alabama. Proc. Nat. Shellfish. Assoc. 63: 27-34.

Korda, R.J., T.E. Henzler, P.A. Helmke, M.M. Jimenez, L.A. Haskin and E.M. Larsen. 1977. Trace elements in samples of fish, sediment and taconite from Lake Superior. J. Great Lakes Res. 3(1-2): 148-154.

Kosakowska, A., L. Falkowski and J. Lewandowska. 1988. Effect of amino acids on the toxicity of heavy metals to phytoplankton. Bull. Environ. Contam. Toxicol. 40: 532-538.

Kosanovic, M., M.Y. Hasan, D. Subramanian, A.A. Al Ahbabi, O.A. Al Kathiri, E.M. Aleassa and A. Adem. 2007. Influence of urbanization of the western coast of the United Arab Emirates on trace metal content in muscle and liver of wild red-spot emperor (*Lethrinus lentjan*). Food Chem. Toxicol. 45(11): 2261-2266.

Koskinen, H., P. Pehkonen, E. Vehniainen, A. Krasnov, C. Rexroad, S. Afanasyev, H. Molsa, and A. Oikari. 2004. Response of rainbow trout transcriptome to model chemical contaminants. Biochem. Biophys. Res. Commun. 320(3): 745-753.

Kostaropoulos, I., D. Kalmanti, B. Theodoropoulou and N.S. Loumbourdis. 2005. Effects of exposure to a mixture of cadmium and chromium on detoxification enzyme (GST, P450-MO) activities in the frog *Rana ridibunda*. Ecotoxicol. 14(4): 439-447.

Koukal, B., C. Gueguen, M. Pardos and J. Dominik. 2003. Influence of humic substances on the toxic effects of cadmium and zinc to the green alga *Pseudokirchneriella subcapitata*. Chemosphere 53(8): 953-961.

Koutsaftis, A. and I. Aoyama. 2006. The interactive effects of binary mixtures of three antifouling biocides and three heavy metals against the marine algae *Chaetoceros gracilis*. Environ. Toxicol. 21(4): 432-439.

NMED Exhibit 70

Kovacik, J., B. Klejdus, F. Stork, J. Hedbavny and M. Backor. 2011. Comparison of methyl jasmonate and cadmium effect on selected physiological parameters in *Scenedesmus quadricauda* (Chlorophyta, Chlorophyceae). J. Phycol. 47(5): 1044-1049.

Kovarova, J., O. Celechovska, R. Kizek, V. Adam, D. Harustiakova and Z. Svobodova. 2009. Effect of metals, with special attention of Cd, content of the Svitava and Svratka Rivers on levels of thiol compounds in fish liver and their use as biochemical markers. Neuro. Endocrinol. Lett. 30(Suppl. 1): 169-176.

Koyama, J., R. Kuroshima and A. Ishimatsu. 1992. The seawater fish for evaluation of the toxicity of pollutants. Mizu Kankyo Gakkaishi. 15(11): 804-813.

Kraak, M.H.S., M. Toussaint, D. Lavy and C. Davids. 1992a. Short-term effects of metals on the filtration rate of the zebra mussel *Dreissena polymorpha*. Environ. Pollut. 84(2): 139-143.

Kraak, M.H.S., D. Lavy, W.H.M. Peeters and C. Davids. 1992b. Chronic ecotoxicity of copper and cadmium to the zebra mussel *Dreissena polymorpha*. Arch. Environ. Contam. Toxicol. 23: 363-369.

Kraak, M.H.S., H. Schoon, W.H.M. Peeters and N.M. Van Straalen. 1993a. Chronic ecotoxicity of mixtures of Cu, Zn, and Cd to the zebra mussel *Dreissena polymorpha*. Ecotoxicol. Environ. Safety. 25: 315-327.

Kraak, M.H.S., D. Lavy, M. Toussaint, H. Schoon, W.H.M. Peeters and C. Davids. 1993b. Toxicity of heavy metals to the zebra mussel (*Dreissena polymorpha*). In: T.F. Nalepa and D.W. Schloessen (*Eds.*), zebra mussels - biology, impacts, and control, chapter 29, Lewis Publishers, Boca Raton. 8: 491-502.

Kraak, M.H.S., M. Toussaint, D. Lavy and C. Davids. 1994a. Short-term effects of metals on the filtration rate of the zebra mussel *Dreissena polymorpha*. Environ. Pollut. 84(2): 139-143.

Kraak, M.H.S., D. Lavy, H. Schoon, M. Toussaint, W.H.M. Peeters and N.M. Van Straalen. 1994b. Ecotoxicity of mixtures of metals to the zebra mussel *Dreissena polymorpha*. Environ. Toxicol. Chem. 13: 109-114.

Kraak, M.H.S., Y.A. Wink, S.C. Stuijfzand, M.C. Buckert-de Jong, C.J. de Groot and W. Admiraal. 1994c. Chronic ecotoxicity of Zn and Pb to the zebra mussel *Dreissena polymorpha*. Aquat. Toxicol. 30: 77-89.

Kraal, M.H., M.H.S. Kraak, C.J. De Groot and C. Davids. 1995. Uptake and tissue distribution of dietary and aqueous cadmium by carp (*Cyprinus carpio*). Ecotoxicol. Environ. Safety. 31: 179-183.

Kraemer, L.D., P.G.C. Campbell and L. Hare. 2005. Dynamics of Cd, Cu and Zn accumulation in organs and sub-cellular fractions in field transplanted juvenile yellow perch (*Perca flavescens*). Environ. Pollut. 138(2): 324-337.

Kraemer, L.D., P.G.C. Campbell and L. Hare. 2008. Modeling cadmium accumulation in indigenous yellow perch (*Perca flavescens*). Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat. 65(08): 1623-1634.

Kramer, J.R., H.E. Allen, W. Davidson, K.L. Godtfredsen, J.S. Meyer, E.M. Perdue, F. Tipping, D. Van de Meent and J.C. Westall. 1997. Chemical speciation and metal toxicity in surface waters. In: Reassessment of Metal Criteria for Aquatic Life Protection. H.L Bergman and E.J. Doward-King (*Eds*.). SETAC Press, Pensacola, FL.

Krantzberg, G. 1989a. Accumulation of essential and nonessential metals by chironomid larvae in relation to physical and chemical properties of the elements. Can. J. Fish. Aquat. Sci. 46: 1755-1761.

Krantzberg, G. 1989b. Metal accumulation by chironomid larvae: the effects of age and body weight on metal body burdens. Hydrobiol. 188/189: 497-506.

Krantzberg, G. and P.M. Stokes. 1988. The importance of surface adsorption and pH in metal accumulation by chironomids. Environ. Toxicol. Chem. 7: 653-670.

Krantzberg, G. and P.M. Stokes. 1989. Metal regulation, tolerance, and body burdens in the larvae of the genus *Chironomus*. Can. J. Fish. Aquat. Sci. 46: 389-398.

Krasnov, A., S. Afanasyev and A. Oikari. 2007. Hepatic responses of gene expression in juvenile brown trout (*Salmo trutta lacustris*) exposed to three model contaminants applied singly and in combination. Environ. Toxicol. Chem. 26(1): 100-109.

Krassoi, F.R. and M. Julli. 1994. Chemical batch as a factor affecting the acute toxicity of the reference toxicant potassium dichromate to the cladoceran *Moina australiensis* (Sars). Bull. Environ. Contam. Toxicol. 53: 153-157.

Kraus, M.L. 1988. Accumulation and excretion of five heavy metals by the saltmarsh cordgrass *Spartina alteriflora*. Bull. N. J. Acad. Sci. 33(2): 39-44.

Krawczynska, W., N.N. Pivovarova and A. Sobota. 1989. Effects of cadmium on growth, ultrastructure and content of chemical elements in *Tetrahymena pyriformis* and *Acanthamoeba castellanii*. Acta Protozool. 28:(3-4): 245-252.

Kremling, K., J. Piuze, K. Von Brockel and C.S. Wong. 1978. Studies on the pathways and effects of cadmium in controlled ecosystem enclosures. Mar. Biol. 48: 1-11.

Krishna Kumari, L., S. Kaisary and V. Rodrigues. 2006. Bio-accumulation of some trace metals in the short-neck clam *Paphia malabarica* from Mandovi Estuary, Goa. Environ. Int. 32(2): 229-234.

Krishnaja, A.P., M.S. Rege and A.G. Joshi. 1987. Toxic effects of certain heavy metals (Hg, Cd, Pb, As and Se) on the intertidal crab *Scylla serrata*. Environ. Res. 21: 109-119.

Kruatrachue, M., N. Rangsayatorn, P. Pokethitiyook, E.S. Upatham and S. Singhakaew. 2003. Histopathological changes in the gastrointestinal tract of fish, *Puntius gonionotus*, fed on dietary cadmium. Bull. Environ. Contam. Toxicol. 71(3): 561-569.

Krumschnabel, G., H.L. Ebner, M.W. Hess and A. Villunger. 2010. Apoptosis and necroptosis are induced in rainbow trout cell lines exposed to cadmium. Aquat. Toxicol. 99(1): 73-85.

Krywult, M., M. Klich and E. Szarek-Gwiazda. 2008. Metal concentrations in chub *Leuciscus cephalus* from a submontane river (Poland). Acta Ichthyol. Pisc. 38(1): 47-53.

Kucuksezgin, F., O. Altay, E. Uluturhan and A. Kontas. 2001. Trace metal and organochlorine residue levels in red mullet (*Mullus barbatus*) from the eastern Aegean, Turkey. Water Res. 35(9): 2327-2332.

Kuehl, D.W. and R. Haebler. 1995. Organochlorine, organobromine, metal, and selenium residues in bottlenose dolphins (*Tursiops truncatus*) collected during an unusual mortality event in the Gulf of Mexico, 1990. Arch. Environ. Contam. Toxicol. 28(4): 494-499.

Kuehl, D.W., R. Haebler and C. Potter. 1994. Coplanar PCB and metal residues in dophins from the U.S. Atlantic Coast including Atlantic bottlenose obtained during the 1987/88 mass mortality. Chemosphere 28(6): 1245-1253.

Kuhn, R. and M. Pattard. 1990. Results of the harmful effects of water pollutants to green algae (*Scenedesmus subspicatus*) in the cell multiplication inhibition test. Water Res. 24(1): 31-38.

Kuhn, R., M. Pattard, K.D. Pernak and A. Winter. 1989. Results of the harmful effects of water pollutants to *Daphnia magna* in the 21 day reproduction test. Water Res. 23(4): 501-510.

Kumada, H., S. Kimura, M. Yokote and Y. Matida. 1973. Acute and chronic toxicity, uptake and retention of cadmium in freshwater organisms. Bull. Freshwater Fish. Res. Lab. 22: 157.

Kumada, H., S. Kimura and M. Yokote. 1980. Accumulation and biological effects of cadmium in rainbow trout. Bull. Jap. Soc. Sci. Fish. 46(1): 97-103.

Kumar, B.M., R.J. Katti, K.S.V. Moorthy and R.K. D'Souza, R. K. 2003. Selected heavy metals in the sediment and macrobenthos of the coastal waters off mangalore. Indian J. Fish. 50(2): 263-268.

Kumar, K.A. and H. Achyuthan. 2007. Heavy metal accumulation in certain marine animals along the east coast of Chennai, Tamil Nadu, India. J. Environ. Biol. 28(3): 637-643.

Kumar, M. 1991. Accumulation of Pb, Cd, and Zn in aquatic snails from four freshwater sites in Steuben County, Indiana. Bios. 62(1): 2-8.

Kumar, M., A.J. Bijo, R.S. Baghel, C. Reddy and B. Jha. 2012. Selenium and spermine alleviate cadmium induced toxicity in the red seaweed *Gracilaria dura* by regulating antioxidants and DNA methylation. Plant Physiol. Biochem. 51: 129-138.

Kumar, P., Y. Prasad, A.K. Patra and D. Swarup. 2007. Levels of cadmium and lead in tissues of freshwater fish (*Clarias batrachus* L.) and chicken in western up (India). Bull. Environ. Contam. Toxicol. 79(4): 396-400.

Kumarasamy,P., K. Muthuvel, S.V.S.A. Hameed and A. Rajendran. 2006. Effect of some heavy metals on the filtration rate of an estuarine clam *Martrix casta* (Chemnitz). Ind. J. Environ. Sci. 10(1): 79-80.

Kumari, L.K., K. Sujata and R. Veera. 2006. Bio-accumulation of some trace metals in the short-neck clam *Paphia malabarica* from Mandovi Estuary, Goa. Environ. Int. 32(2): 229-234.

Kurochkin, I.O., A.V. Ivanina, S. Eilers, C.A. Downs, L.A. May and I.M. Sokolova. 2009. Cadmium affects metabolic responses to prolonged anoxia and reoxygenation in eastern oysters (*Crassostrea virginica*). Am. J. Physiol., Regul. Integr. Comp. Physiol. 297(5): R1262-R1272.

Kurochkin, I.O., M. Etzkorn, D. Buchwalter, L. Leamy, I.M. Sokolova and I.O. Kurochkin. 2011. Top-down control analysis of the cadmium effects on molluscan mitochondria and the mechanisms of cadmium-induced mitochondrial dysfunction. Am. J. Physiol., Regul. Integr. Comp. Physiol. 300(1): R21-31.

Kuroshima, R. 1987. Cadmium accumulation and it effect on calcium metabolism in the girella *Girella punctata* during a long term exposure. Bull. Japan. Soc. Sci. Fish. 53(3): 445-450.

Kuroshima, R. 1992. Cadmium accumulation in the mummichog, *Fundulus heteroclitus*, adapted to various salinities. Bull. Environ. Contam. Toxicol. 49: 680-685.

Kuroshima, R. and S. Kimura. 1990. Changes in toxicity of Cd and its accumulation in girella and goby with their growth. Bull. Japan. Soc. Sci. Fish. 56(3): 431-453.

Kuroshima, R., S. Kimura, K. Date and Y. Yamamoto. 1993. Kinetic analysis of cadmium toxicity to red sea bream, *Pagrus major*. Ecotoxicol. Environ. Saf. 25: 300-314.

Kurun, A., H. Balkis and N. Balkis. 2007. Accumulations of total metal in dominant shrimp species (*Palaemon adspersus*, *Palaemon serratus*, *Parapenaeus longirostris*) and bottom surface sediments obtained from the northern inner shelf of the Sea of Marmara. Environ. Monit. Assess. 135(1-3): 353-367.

Kurun, A., N. Balkis, M. Erkan, H. Balkis, A. Aksu and M.S. Ersan. 2010. Total metal levels in crayfish *Astacus leptodactylus* (Eschscholtz, 1823), and surface sediments in Lake Terkos, Turkey. Environ. Monit. Assess. 169(1-4): 385-395.

Kusch, R.C., P.H. Krone and D.P. Chivers. 2007. Chronic exposure to low concentrations of water-borne cadmium during embryonic and larval development results in the long-term hindrance of anti-predator behavior in zebrafish. Environ. Toxicol. Chem. 27(3): 705-710.

Kwan, K.H.M. 2007. Comparative study on the whole plant toxicity, uptake kinetics and accumulated forms of thallium and cadmium in *Lemna minor* L. Ph.D.Thesis, Univ. of London, 402 p.

Kwan, K.H.M. and S. Smith. 1991. Some aspects of the kinetics of cadmium and thallium uptake by fronds of *Lemna minor* L. New Phytologist. 117(1): 91-102.

Kwong, R.W.M. and S. Niyogi. 2009. The interactions of iron with other divalent metals in the intestinal tract of a freshwater teleost, rainbow trout (*Oncorhynchus mykiss*). Comp. Biochem. Physiol. Part C: Toxicol. Pharmacol. 150(4): 442-449.

Kwong, R.W. and S. Niyogi. 2012. Cadmium transport in isolated enterocytes of freshwater rainbow trout: Interactions with zinc and iron, effects of complexation with cysteine, and an atpase-coupled efflux. Comp. Biochem. Physiol.155C(2): 238-246.

Kwong, R.W., J.A. Andres, S. Niyogi and R. Kwong. 2010. Molecular evidence and physiological characterization of iron absorption in isolated enterocytes of rainbow trout (*Oncorhynchus mykiss*): Implications for dietary cadmium and lead absorption. Aquat. Toxicol. 99(3): 343-350.

Kwong, R.W., J.A. Andres and S. Niyogi. 2011. Effects of dietary cadmium exposure on tissue-specific cadmium accumulation, iron status and expression of iron-handling and stress-inducible genes in rainbow trout: Influence of elevated dietary iron. Aquat. Toxicol. 102(1-2): 1-9.

La Touche, Y.D. and M.C. Mix. 1982. Seasonal variations of arsenic and other trace elements in bay mussels (*Mytilus edulis*). Bull. Environ. Contam. Toxicol. 29(6): 665-670.

Labonne, M., D.B. Othman and J.M. Luck. 2002. Use of non-radioactive, mono-isotopic metal tracer for studying metal (Zn, Cd, Pb) accumulation in the mussel *Mytilus galloprovincialis*. Appl. Geochem. 17(10): 1351-1360.

Lacoue-Labarthe, T., E. Le Bihan, D. Borg, N. Koueta and P. Bustamante. 2010. Acid phosphatase and cathepsin activity in cuttlefish (*Sepia officinalis*) eggs: The effects of Ag, Cd, and Cu exposure. ICES J. Mar. Sci. 67(7): 1517-1523.

Lacroix, A. and A.A. Hontela. 2004. Comparative assessment of the adrenotoxic effects of cadmium in two teleost species, rainbow trout, *Oncorhynchus mykiss*, and yellow perch, *Perca flavescens*. Aquat. Toxicol. 67(1): 13-21. 2004.

Laegreid, M., Alstad, J., D. Klaveness and H.M. Seip. 1983. Seasonal variation of cadmium toxicity toward the alga *Selenastrum capricornutum* Printz in two lakes with different humus content. Environ. Sci. Technol. 17(6): 357-361.

Lagerwerff, J.V. and A.W. Specht. 1970. Contamination of roadside soil and vegetation with cadmium, nickel, lead and zinc. Environ. Sci. Technol. 4: 583-586.

Lahnsteiner, F. 2008. The sensitivity and reproducibility of the zebrafish (*Danio Rerio*) embryo test for the screening of waste water quality and for testing the toxicity of chemicals. Altern. Lab Anim. 36(3): 299-311.

Lahnsteiner, F., N. Mansour and B. Berger. 2004. The effect of inorganic and organic pollutants on sperm motility of some freshwater teleosts. J. Fish Biol. 65(5): 1283-1297.

Lake, P.S. and V.J.Thorp. 1974. The gill lamellae of the shrimp *Paratya tasmaniensis* (Atyidae: Crustacea). normal ultrastructure and changes with low levels of cadmium. In: 8th Int. Congr. Electr. Microsc., Canberra, Australia 3: 448-449.

Lakshmi, P.S. and Y.P Rao. 2002. Evaluation of cadmium toxicity on survival, accumulation and depuration in an intertidal gastropod, *Turbo intercostalis*. Water Air Soil Pollut. 134(1-4): 229-238.

Lalande, M. and B. Pinel-Alloul. 1986. Acute toxicity of cadmium, copper, mercury and zinc to *Tropocyclops prasinus mexicanus* (Cyclopoida, Copepoda) from three Quebec lakes. Environ. Toxicol. Chem. 5: 95-102.

Lam, P.K.S. 1996a. Effects of cadmium on the consumption and absorption rates of a tropical freshwater snail, *Radix plicatulus*. Chemosphere 32(11): 2127-2132.

Lam, P.K.S. 1996b. Interpopulation differences in acute response of *Brotia hainanensis* (Gastropoda, Prosobranchia) to cadmium: genetic or environmental variance? Environ. Pollut. 94(1): 1-7.

Lam. P.K.S., K.N. Yu, K.P. Ng and M.W.K. Chong. 1997. Cadmium uptake and depuration in the soft tissues of *Brotia hainanensis* (Gastropoda: Prosobranchia: Thiaridae): A dynamic model. Chemosphere 35(11): 2449-2461.

Lamelas, C. and V.I. Slaveykova. 2007. Comparison of Cd(II), Cu(II), and Pb(II) biouptake by green algae in the presence of humic acid. Environ. Sci. Technol. 41(11): 4172-4178.

Lamelas, C., J.P. Pinheiro and V.I. Slaveykova. 2009. Effect of humic acid on Cd(II), Cu(II), and Pb(II) uptake by freshwater algae: Kinetic and cell wall speciation considerations. Environ. Sci. Technol. 43(3): 730-735.

Lanceleur, L., J. Schaefer, J.F. Chiffoleau, G. Blanc, D. Auger, S. Renault, M. Baudrimont, S. Audry and L. Lanceleur. 2011. Long-term records of cadmium and silver contamination in sediments and oysters from the Gironde fluvial-estuarine continuum - evidence of changing silver sources. Chemosphere 85(8): 1299-1305.

Landner, L. and A. Jernelov. 1969. Cadmium in aquatic systems. Metals and Ecology Symposium. Bulletin No. 5. Ecology Research Committee, Stockholm, Sweden. 47pp.

Lane, E.S., K. Jang, J.T. Cullen and M.T. Maldonado. 2008. The interaction between inorganic iron and cadmium uptake in the marine diatom *Thalassiosira Oceanica*. Limnol. Oceanogr. 53(5): 1784-1789.

Lane, T.W and F.M.M. Morel. 2000. A biological function for cadmium in marine diatoms. Proc. Natl. Acad. Sci. 97(9): 4627-4631.

Lang, C. and B. Lang-Dobler. 1979. The chemical environment of tubificid and lumbriculid worms according to the pollution level of the sediment. Hydrobiologia 65(3): 273-282.

Lang, W.H., D.C. Miller, P.J. Ritacco and M. Marcy. 1981. The effects of copper and cadmium on the behavior and development of barnacle larvae. *In*: F.J. Vernberg, A. Calabrese, F.P. Thurberg and W.B.Vernberg (*Eds.*), Biological Monitoring of Marine Pollutants, Academic Press, 165-203.

Lange, A., O. Ausseil and H. Segner. 2002. Alterations of tissue glutathione levels and metallothionein mrna in rainbow trout during single and combined exposure to cadmium and zinc. Comp. Biochem. Physiol. 131C(3): 231-243.

Langston, W.J. and M. Zhou. 1987. Cadmium accumulation, distribution and metabolism in the gastropod *Littorina littorea*: The role of metal-binding proteins. J. Mar. Biol. Assoc. 67: 585-601.

Lannig, G., A.S. Cherkasov and I.M. Sokolova. 2006a. Temperature-dependent effects of cadmium on mitochondrial and whole-organism bioenergetics of oysters (*Crassostrea virginica*). Mar. Environ. Res. 62(Suppl. 1): S79-S82.

Lannig, G., J.F. Flores and I.M Sokolova. 2006b. Temperature-dependent stress response in oysters, *Crassostrea virginica*: Pollution reduces temperature tolerance in oysters. Aquat. Toxicol. 79(3): 278-287.

Lannig, G., A.S. Cherkasov, H.O. Poertner, C. Bock and I.M. Sokolova. 2008. Cadmium-dependent oxygen limitation affects temperature tolerance in eastern oysters (*Crassostrea virginica* Gmelin). Am. J. Physiol. 294(4): R1338-R1346.

LaPoint, T.W., S.M. Melancon and M.K. Morris. 1984. Relationships among observed metal concentrations, criteria, and benthic community structural responses in 15 streams. J. Water Pollut. Control Fed. 56(9): 1030-1038.

Lapota, D., A.R. Osorio, C. Liao and B. Bjorndal. 2007. The use of bioluminescent dinoflagellates as an environmental risk assessment tool. Mar. Pollut. Bull. 54(12): 1857-1867.

Lares, M.L., M.A. Huerta-Diaz, S.G. Marinone and M. Valdez-Marquez. 2012. Mercury and cadmium concentrations in farmed bluefin tuna (*Thunnus orientalis*) and the suitability of using the caudal peduncle muscle tissue as a monitoring tool. J Food Prot. 75(4): 725-730.

Larsen, J. and B. Svensmark. 1991. Labile species of Pb, Zn and Cd determined by anodic stripping staircase voltammetry and their toxicity to *Tetrahymena*. Talanta. 38(9): 981-988.

Larsson, A. 1977. Some experimentally induced biochemical effects of cadmium on fish from the Baltic Sea. Ambio Spec. Rep. 5: 67-68.

Lasenby, D.C. and J. Van Duyn. 1992. Zinc and cadmium accumulation by the opossum shrimp *Mysis relicta*. Arch. Environ. Contam. Toxicol. 23: 179-183.

Lasheen, M.R., S.A. Shehata and G.H. Ali. 1990. Effect of cadmium, copper and chromium (VI) on the growth of Nile water algae. Water Air Soil Pollut. 50: 19-30.

Latif, A., M. Ali, R. Kaoser, R. Iqbal, K. Umer, M. Latif, S. Qadir and F. Iqbal. 2012. Effect of cadmium chloride and ascorbic acid exposure on the vital organs of freshwater cyprinid, *Labeo rohita*. African J. Biotechnol. 11(33): 8398-8403.

Latire, T., C. Le Pabic, E. Mottin, A. Mottier, K. Costil, N. Koueta, J.M. Lebel and A. Serpentini. 2012. Responses of primary cultured haemocytes from the marine gastropod *Haliotis tuberculata* under 10-day exposure to cadmium chloride. Aquat. Toxicol. 109(0): 213-221.

Laube, V.M., C.N. McKenzie and D.J. Kushner. 1980. Strategies of response to copper, cadmium, and lead by a blue-green and a green alga. Can. J. Microbiol. 26(11): 1300-1311.

Laurent, J., M. Casellas, M.N. Pons, C. Dagot and J. Laurent. 2010. Cadmium biosorption by ozonized activated sludge: the role of bacterial flocs surface properties and mixed liquor composition. J. Hazard. Mater. 183(1-3): 256-263.

Lavoie, M., C. Fortin and P.G.C. Campbell. 2012. Influence of essential elements on cadmium uptake and toxicity in a unicellular green alga: The protective effect of trace zinc and cobalt concentrations. Environ. Toxicol. Chem. 31(7): 1445-1452.

Lawrence, S.G. and M.H. Holoka. 1987. Effects of low concentrations of cadmium on the crustacean zooplankton community of an artificially acidified lake. Can. J. Fish. Aquat. Sci. 44: 163-172.

Lawrence, S.G. and M.H. Holoka. 1991. Response of crustacean zooplankton impounded *in situ* to cadmium at low environmental concentrations. Verh. Internat. Verein. Limnol. 24: 2254-2259.

Lawrence, S.G., M.H. Holoka, R.V. Hunt and R.H. Hesslein. 1996. Multi-year experimental additions of cadmium to a lake epilimnion and resulting water column cadmium concentrations. Can. J. Fish. Aquat. Sci. 53: 1876–1887.

LeBlanc, G.A. 1984. Interspecies relationships in acute toxicity of chemicals to aquatic organisms. Environ. Toxicol. Chem. 3: 47-60.

Leblebici, Z., A. Aksoy and F. Duman. 2010. Influence of nutrient addition on growth and accumulation of cadmium and copper in *Lemna gibba* . Chem. Spec. Bioavail. 22(3): 57-164.

Lee, B.G. and S.N. Luoma. 1998. Influence of microalgal biomass on absorption efficiency of Cd, Cr, and Zn by two bivalves from San Francisco Bay. Limnol. Oceanogr. 43(7): 1455-1466.

Lee, C.H., T.K. Ryu., M. Chang and J.W. Choi. 2004. Effect of silver, cadmium, chromium, copper, and zinc on the fertilization of the northern pacific asteroid, *Asterias amurensis*. Bull. Environ. Contam. Toxicol. 73(4): 613-619.

Lee, H.H. and C.H. Xu. 1984. Differential response of marine organisms to certain metal and agrichemical pollutants. Bull. Environ. Contam. Toxicol. 33: 460-467.

Lee, H.L., B. Lustigman, V. Schwinge, I.Y. Chiu and S. Hsu. 1992. Effects of mercury and cadmium on the growth of *Anacystis nidulans*. Bull. Environ. Contam. Toxicol. 49: 272-278.

Lee, J.S. and J.H. Lee. 2005. Influence of acid volatile sulfides and simultaneously extracted metals on the bioavailability and toxicity of a mixture of sediment-associated Cd, Ni, and Zn to polychaetes *Neanthes arenaceodentata*. Sci. Total Environ. 338(3): 229-241.

Lee, J.G., S.B. Roberts and F.M.M. Morel. 1995. Cadmium: A nutrient for the marine diatom *Thalassiosira weissflogii*. Limnol. Oceanogr. 40: 1056-1063.

Lee, J.S., B.G. Lee, H. Yoo, C.H. Koh and S.N. Luoma. 2001. Influence of reactive sulfide (AVS) and supplementary food on Ag, Cd and Zn bioaccumulation in the marine polychaete *Neanthes arenaceodentata*. Mar. Ecol. Prog. Ser. 216: 129-140.

Lee, J., K. Ji., J. Kim, C. Park, K.H. Lim, T.H. Yoon and K. Choi. 2010. Acute toxicity of two CdSe/ZnSe quantum dots with different surface coating in *Daphnia magna* under various light conditions. Environ. Toxicol. 25(6): 593-600.

Lee, K.W., S. Raisuddin, D.S. Hwang, H.G. Park and J.S. Lee. 2007. Acute toxicities of trace metals and common xenobiotics to the marine copepod *Tigriopus japonicus*: Evaluation of its use as a benchmark species for routine ecotoxicity tests in western Pacific coastal regions. Environ. Toxicol. 22(5): 532-538.

Lee, R.F. and T. Noone. 1995. Effect of reproductive toxicants on lipovitellin in female blue crabs, *Callinectes sapidus*. Mar. Environ. Res. 39(1-4): 151-154.

Lee, R. and Y. Oshima. 1998. Effects of selected pesticides, metals and organometallics on development of blue crab (*Callinectes sapidus*) embryos. Mar. Environ. Res. 46(1-5): 479-482.

Lee, R.F., K. O'Malley and Y. Oshima. 1996. Effects of toxicants on developing oocytes and embryos of the blue crab, *Callinectes sapidus*. Mar. Environ. Res. 42(1-4): 125-128.

Lee, S. III, E.J. Na, Y.O. Cho, B. Koopman and G. Bitton. 1997. Short-term toxicity test based on algal uptake by *Ceriodaphnia dubia*. Water Environ. Res. 69(7): 1207-1210.

Lee, S., J. An, Y.J. Kim and K. Nam. 2011. Binding strength-associated toxicity reduction by birnessite and hydroxyapatite in Pb and Cd contaminated sediments. J. Hazard. Mater. 186(2/3): 2117-2122.

Lee, S.E., D.H. Yoo, J. Son and K. Cho. 2006a. Proteomic evaluation of cadmium toxicity on the midge *Chironomus riparius* Meigen larvae. Proteomics 6(3): 945-957.

Lee, S.M., S.B. Lee, C.H. Park and J. Choi. 2006b. Expression of heat shock protein and hemoglobin genes in *Chironomus tentans* (Diptera, Chironomidae) larvae exposed to various environmental pollutants: A potential biomarker of freshwater monitoring. Chemosphere 65(6): 1074-1081.

Lee, S.W. 2009. Occurrence of heavy metals and antibiotic resistance in bacteria from internal organs of American bullfrog (*Rana catesbeiana*) raised in Malaysia. J. Venom. Anim. Tox. incl. Trop. Dis. 15(2).

Lee, W.Y. and W.X. Wang. 2001. Metal accumulation in the green macroalga *Ulva fasciata*: Effects of nitrate, ammonium and phosphate. Sci. Total Environ. 278(1-3): 11-22.

Lefcort, H., D.P. Abbott, D.A. Cleary, E. Howell, N.C. Keller and M.M. Smith. 2004. Aquatic snails from mining sites have evolved to detect and avoid heavy metals. Arch. Environ. Contam. Toxicol. 46(4): 478-484.

Lefèvre, I., G. Marchal, P. Meerts, E. Corréal and S. Lutts. 2009. Chloride salinity reduces cadmium accumulation by the Mediterranean halophyte species *Atriplex halimus* L. Environ. Exp. Bot. 65(1): 142-152.

Legeay, A., M. Achard-Joris, M. Baudrimont, J.C. Massabuau, and J.P. Bourdineaud. 2005. Impact of cadmium contamination and oxygenation levels on biochemical responses in the asiatic clam *Corbicula fluminea*. Aquat. Toxicol. 74(3): 242-253.

Lehtonen, K.K., S. Leinioe, R. Schneider and M. Leivuori. 2006. Biomarkers of pollution effects in the bivalves *Mytilus edulis* and *Macoma balthica* collected from the southern coast of Finland (Baltic Sea). Mar. Ecol. Prog. Ser. 322: 155-168.

Lei, M., B. Tie, P.N. Williams, Y. Zheng and Y. Huang, Y. 2011c. Arsenic, cadmium, and lead pollution and uptake by rice (*Oryza sativa* L.) grown in greenhouse. J. Soils Sediments 11(1): 115-123.

Lei, W., L. Wang and W. Lei. 2011a. Effect of cadmium on cytochrome C oxidase isozyme in the hepatopancreas, gill and heart of freshwater crab *Sinopotamon yangtsekiense*. Fresenius Environ. Bull. 20(10): 2580-2585.

Lei, W.W., L. Wang, D.M. Liu, T. Xu and J.X. Luo. 2011b. Histopathological and biochemical alternations of the heart induced by acute cadmium exposure in the freshwater crab *Sinopotamon yangtsekiense*. Chemosphere 84(5): 689-694.

Leidel, G. and E. McLaughlin. 1973. The effects of cadmium chloride on the embryonic development of the fresh-water snail, *Helisoma sp*. J. Ala. Acad. Sci. 44: 178.

Lekhi, P., D. Cassis, C.M. Pearce, N. Ebell, M.T. Maldonado and K.J. Orians. 2008. Role of dissolved and particulate cadmium in the accumulation of cadmium in cultured oysters (*Crassostrea Gigas*). Sci. Total Environ. 393(2-3): 309-325.

Lemke, A.E. 1965. Toxicity of copper, cadmium, and zinc to the bluegill (*Lepomis macrochirus*). Robert A. Taft Sanitary Engineering Center, U.S. Department of Health, Education and Welfare, Cincinnati, OH, 19 p.

Leonhard, S.L., S.G. Lawrence, M.K. Friesen and J.F. Flannagan. 1980. Evaluation of the acute toxicity of the heavy metal cadmium to nymphs of the burrowing mayfly, *Hexagenia rigida*. *In*: J.F. Flannagan and K.E. Marshall (*Eds*.), Advances in Ephemeroptera Biology. Plenum Publishing Corp., NY, p. 457.

Lera, S., S. Macchia, L. Dentone and D. Pellegrini. 2008. Variations in sensitivity of two populations of *Corophium orientale* (Crustacea: Amphipoda) towards cadmium and sodium laurylsulphate. Environ. Monit. Assess. 136(1-3): 121-127.

Les, A. and R.W. Walter. 1984. Toxicity and binding of copper, zinc and cadmium by the blue-green alga, *Chroococcus paris*. Water Air Soil Pollut. 23: 129-130.

Les, F.T. 2008. Cadmium uptake and depuration by the pleurocerid gastropod, *Leptoxis carinata* (Bruguiere), and its potential use as an indicator species. Published by Hood College, Frederick, MD, 92 p.

Lesage, E., D.P.L. Rousseau, E. Meers, A.M.K. Moortel, G. Laing, F.M.G. Tack, N. Pauw and M.G. Verloo. 2007a. Accumulation of metals in the sediment and reed biomass of a combined constructed wetland treating domestic wastewater. Water Air Soil Pollut. 183(1-4): 253-264.

Lesage, E., D.P.L. Rousseau, E. Meers, F.M.G. Tack and N. De Pauw. 2007b. Accumulation of metals in a horizontal subsurface flow constructed wetland treating domestic wastewater in Flanders, Belgium. Sci. Total Environ. 380(1-3): 102-115.

Leung, K.M.Y. and R.W. Furness. 1999. Induction of metallothionein in dogwhelk *Nucella lapillus* during and after exposure to cadmium. Ecotoxicol. Environ. Saf. 43(2): 156-164.

Leung, K.M.Y. and R.W. Furness. 2001a. Metallothionein induction and condition index of dogwhelks *Nucella lapillus* (L.) exposed to cadmium and hydrogen peroxide. Chemosphere 44(3): 321-325.

Leung, K.M.Y. and R.W. Furness. 2001b. Survival, growth, metallothionein and glycogen levels of *Nucella lapillus* (L.) exposed to sub-chronic cadmium stress: the influence of nutritional state and prey type. Mar. Environ. Res. 52(2): 173-194.

Leung, K.M.Y., J. Svavarsson, M. Crane and D. Morritt. 2002. Influence of static and fluctuating salinity on cadmium uptake and metallothionein expression by the dogwhelk *Nucella lapillus* (L.). J. Exp. Mar. Biol. Ecol. 274(2): 175-189.

Leung, K.M.Y., H. Ibrahim, R.E. Dewhurst, N.J. Morley, M. Crane and J.W. Lewis. 2003. Concentrations of metallothionein-like proteins and heavy metals in the freshwater snail *Lymnaea stagnalis* exposed to different levels of waterborne cadmium. Bull. Environ. Contam. Toxicol. 71(5): 1084-1090.

Leung, P.T.Y., Y. Wang, S.S.T. Mak, W.C. Ng and K.M.Y. Leung. 2011. Differential proteomic responses in hepatopancreas and adductor muscles of the green-lipped mussel *Perna viridis* to stresses induced by cadmium and hydrogen peroxide. Aquat. Toxicol. 105(1/2): 49-61.

Levit, S.M. 2010. A literature review of effects of cadmium on fish. Center for Science in Public Participation, Bozeman, MT.

Lewis, M.A. 1980. Selected heavy metals in sediments and biota from desert streams of the Gila River drainage (Arizona). In: J.G. Eaton, P.R. Parrish, and A.C. Hendricks (*Eds*.), Aquat. Toxicol., ASTM STP 707, Philadelphia, PA, 191-204.

Lewis, P.A. and W.B. Horning II. 1991. Differences in acute toxicity test results of three reference toxicants on *Daphnia* at two temperatures. Environ. Toxicol. Chem. 10: 1351-1357.

Lewis, P.A. and C.I. Weber. 1985. A study of the reliability of *Daphnia* acute toxicity tests. In: Aquatic Toxicology and Hazard Assessment: Seventh Symposium. ASTM STP 854, R.D. Cardwell, R. Purdy and R.C. Bahner (*Eds*.), American Society for Testing and Materials, Philadelphia, PA, pp. 73-86.

Li, E. 2001. Cadmium toxicity and random motility studies using marine dinoflagellates. Ph.D. Thesis, Univ. Rhode Island, RI, 88 p.

Li, F., W. Zhang and G. Liu. 2007. Bioaccumulation of heavy metals along food chain in the water of Zhalong wetland. J. Northeast Forest. Univ./Dongbei Linye Daxue Xuebao 35(1): 44-46.

Li, H., K. Mai, Q. Ai, C. Zhang, L. Zhang and K. Mai. 2009. Effects of dietary squid viscera meal on growth and cadmium accumulation in tissues of large yellow croaker, *Pseudosciaena crocea* R. Front. Agricult. China 3(1): 78-83.

Li, J.T., H.N. Duan, S.P. Li, J.L. Kuang, Y. Zeng and W.S. Shu. 2010b. Cadmium pollution triggers a positive biodiversity-productivity relationship: evidence from a laboratory microcosm experiment. J. Appl. Ecol. 47(4): 890-898.

Li, L., X. Liu, L. You, L. Zhang, J. Zhao and H. Wu. 2012a. Uptake pathways and subcellular fractionation of Cd in the polychaete *Nereis diversicolor*. Ecotoxicol. 21(1): 104-110.

Li, L., X. Huang, D. Borthakur and H. Ni. 2012c. Photosynthetic activity and antioxidative response of seagrass *Thalassia hemprichii* to trace metal stress. Acta Oceanol. Sin./Haiyang Xuebao 31(3): 98-108.

Li, M., J.C. Wu and L.Q. Li. 2008. Absorption and accumulation of heavy metals by plants in Poyang Lake wetland. J. Agro-Environ. Sci. 27(6): 2413-2418.

Li, M., C. Wan, X. Pan, Y. Zou, J. Chang and P. Xie. 2012b. Acute toxic effects of zinc, cadmium, and mercury on the growths of three unicellular green microalgae with relatively high initial densities. Fresenius Environ. Bull. 21(6): 1349-1356.

Li, M., C.Y. Wan, X.J. Pan, Y. Zou, S.Y. Chi and J.B. Chang. 2013. Comparative study of stress by four heavy metals on *Chlamydomonas reinhardtii* and the potential application in BBE algae toximeter. Fresenius Environ. Bull. 22(5a): 1494-1500.

Li, R., Y. Zhou, J. Ji and L. Wang. 2011a. Oxidative damages by cadmium and the protective effects of low-molecular-weight chitosan in the freshwater crab (*Sinopotamon yangtsekiense* Bott 1967). Aquacult. Res. 42(4): 506-515.

Li, R.J., Y.Y. Zhou, L. Wang and G.R. Ren. 2011b. Low-molecular-weight-chitosan ameliorates cadmium-induced toxicity in the freshwater crab, *Sinopotamon yangtsekiense*. Ecotoxicol. Environ. Saf. 74(5): 1164-1170.

Li, T. and Z.A. Xiong. 2004. A novel response of wild-type duckweed (*Lemna paucicostata* Hegelm.) to heavy metals. Environ. Toxicol. 19(2): 95-102.

Li, W.H., P.C.Y. Chan and K.M. Chan. 2004. Metal uptake in zebrafish embryo-larvae exposed to metal-contaminated sediments. Mar. Environ. Res. 58(2-5): 829-832.

Li, W.K.W. 1980. Cellular accumulation and distribution of cadmium in *Isochrysis galbana* during growth inhibition and recovery. J. Plankton Res. 2(4): 283-294.

Li, X., J. Li, Y. Wang, L. Fu, J. Zhu and Q. Duan. 2010a. Kinetic study of the bioaccumulation of heavy metals (Cu, Pb, and Cd) in Chinese domestic oyster *Ostrea plicatula*. J. Environ. Sci. 45A(7): 836-845.

Li, Y. and H. Lin. 2006. Acute toxicity of cadmium to *Argopecten irradiams*. Mar. Fish. Res. Vol. 27(6): 80-83.

Li, Y.U., Y. Zhiming, S. Xiuxian and M. Qinglin. 2006. Trace metal concentrations in suspended particles, sediments and clams (*Ruditapes philippinarum*) from Jiaozhou Bay of China. Environ. Monit. Assess. 121(1-3): 489-499.

Li, Z.H., P. Li, B. Dzyuba and T. Randak. 2010c. Influence of environmental related concentrations of heavy metals on motility parameters and antioxidant responses in sturgeon sperm. Chem Biol Interact. 188(3): 473-477.

Li, Z.H., P. Li, M. Rodina and T. Randak. 2010d. Evaluating the function of calcium antagonist on the Cd-induced stress in sperm of Russian sturgeon, *Acipenser gueldenstaedtii*. Aquat. Toxicol. 100(4): 373-375.

Li, Z.H., P. Li and T. Randak. 2011c. Protective roles of calcium channel blocker against cadmium-induced physiological stress in freshwater teleost *Oncorhynchus mykiss*. Water Air Soil Pollut. 220(1-4): 293-299.

Liao, C.M., Y.R. Ju, W.Y. Chen and B.C. Chen. 2011b. Assessing the impact of waterborne and dietborne cadmium toxicity on susceptibility risk for rainbow trout. Sci. Total Environ. 409(3): 503-513.

Liao, C.M., Y.R. Ju and W.Y. Chen. 2011a. Subcellular partitioning links BLM-Based toxicokinetics for assessing cadmium toxicity to rainbow trout. Environ. Toxicol. 26(6): 600-609.

Liao, I.C. and C.S. Hsieh. 1990. Toxicity of three heavy metals to *Macrobrachium rosenbergii*. In: Proc. of the 2nd Asian Fisheries Forum, April 17 - 22, 1989, Tokyo, Japan, Asian Fish. Soc., Manila, Philippines: 923-926.

Lieb, D.A. and R.F. Carline. 2000. Effects of urban runoff from a detention pond on water quality, temperature and caged *Gammarus minus* (Say) (Amphipoda) in a headwater stream. Hydrobiologia 441(1-3): 107-116.

Lin, H.C. and W.A. Dunson. 1993. The effect of salinity on the acute toxicity of cadmium to the tropical, estuarine, hermaphroditic fish, *Rivulus marmoratus*: A comparison of Cd, Cu, and Zn tolerance with *Fundulus heteroclitus*. Arch. Environ. Contam. Toxicol. 25: 41-47.

Lin, J.H., W.C. Kao, K.P. Tsai and C.Y. Chen. 2005. A novel algal toxicity testing technique for assessing the toxicity of both metallic and organic toxicants. Water Res. 39(9): 1869-1877.

Lin, K.C., Y.L. Lee and C.Y. Chen. 2007. Metal toxicity to *Chlorella pyrenoidosa* assessed by a short-term continuous test. J. Hazard. Mater. 142 (1/2): 236-241.

Lin, L., W. Zhou, H. Dai, F. Cao, G. Zhang and F. Wu. 2012. Selenium reduces cadmium uptake and mitigates cadmium toxicity in rice. J. Hazard. Mater. 235/236: 343-351.

Lin, Y.S., S.C. Tsai, H.C. Lin, C.D. Hsiao and S.M. Wu. 2011. Changes of glycogen metabolism in the gills and hepatic tissue of tilapia (*Oreochromis mossambicus*) during short-term Cd exposure. Comp. Biochem. Physiol. 154C(4): 296-304.

Lira, V.F., G.A.P. Santos, S. Derycke, M.E.L. Larrazabal, V.G. Fonseca-Genevois and T. Moens. 2011. Effects of barium and cadmium on the population development of the marine nematode *Rhabditis* (*Pellioditis*) *marina*. Mar. Environ. Res. 72(4): 151-159.

Lithner, G., K. Holm and H. Borg. 1995. Bioconcentration factors for metals in humic waters at different pH in the Ronnskar area (N. Sweden). Water Air Soil Pollut. 85: 785-790.

Liu, C.T., M.Y. Chou, C.H. Lin and S.M. Wu. 2012d. Effects of ambient cadmium with calcium on mRNA expressions of calcium uptake related transporters in zebrafish (*Danio rerio*) larvae. Fish Physiol. Biochem. 38(4): 977-988.

Liu, D., B. Yan, J. Yang, W. Lei and L. Wang. 2011a. Mitochondrial pathway of apoptosis in the hepatopancreas of the freshwater crab *Sinopotamon yangtsekiense* exposed to cadmium. Aquat. Toxicol. 105(3/4): 394-402.

Liu, D., J. Yang and L. Wang. 2013. Cadmium induces ultrastructural changes in the hepatopancreas of the freshwater crab *Sinopotamon henanense*. Micron 47: 24-32.

Liu, F. and W.X. Wang. 2011b. Differential roles of metallothionein-like proteins in cadmium uptake and elimination by the scallop *Chlamys nobilis*. Environ. Toxicol. Chem. 30(3): 738-746.

Liu, F. and W.X. Wang. 2011a. Metallothionein-like proteins turnover, Cd and Zn biokinetics in the dietary Cd-exposed scallop *Chlamys nobilis*. Aquat. Toxicol. 105(3/4): 361-368.

Liu, F., H.G. Ni, F. Chen, Z.X. Luo, H. Shen, L. Liu and P. Wu. 2012a. Metal accumulation in the tissues of grass carps (*Ctenopharyngodon idellus*) from fresh water around a copper mine in Southeast China. Environ Monit Assess 184(7): 4289-4299.

Liu, F., D.Z. Wang and W.X. Wang. 2012b. Cadmium-induced changes in trace element bioaccumulation and proteomics perspective in four marine bivalves. Environ. Toxicol. Chem. 31(6): 1292-1300.

Liu, G., X. Chai, Y. Shao, L. Hu, Q. Xie and H. Wu. 2011b. Toxicity of copper, lead, and cadmium on the motility of two marine microalgae *Isochrysis galbana* and *Tetraselmis chui*. J. Environ. Sci. 23(2): 330-335.

Liu, H., H. Chen, J. Jing and X. Ma. 2012c. Cloning and characterization of the HSP90 Beta gene from *Tanichthys albonubes* Lin (Cyprinidae): Effect of copper and cadmium exposure. Fish Physiol. Biochem. 38(3): 745-756.

Liu, W. and P.Y. Deng. 2007. Accumulation of cadmium, copper, lead and zinc in the Pacific oyster, *Crassostrea gigas*, collected from the Pearl River Estuary, southern China. Bull. Environ. Contam. Toxicol. 78: 535-538.

Liu, W., J. Chen, X. Lin, Y. Fan and S. Tao. 2007. Residual concentrations of micropollutants in benthic mussels in the coastal areas of Bohai Sea, north China. Environ. Pollut. 146(2): 470-477.

Liu, W.X., J. Hu, J.L. Chen, Y.S. Fan, B. Xing and S. Tao. 2008. Distribution of persistent toxic substances in benthic bivalves from the inshore areas of the Yellow Sea. Environ. Toxicol. Chem. 27(1): 57-66.

Liu, X.J., Z. Luo, C.H. Li, B.X. Xiong, Y.H. Zhao and X.D. Li. 2011c. Antioxidant responses, hepatic intermediary metabolism, histology and ultrastructure in *Synechogobius hasta* exposed to waterborne cadmium. Ecotoxicol. Environ. Saf. 74(5): 1156-1163.

Liu, X.L., C.Y. Yang, L.B. Zhang, L.Z. Li, S.J. Liu, J.B. Yu, L.P. You, D. Zhou, C.H. Xia, J.M. Zhao and H.F. Wu. 2011d. Metabolic profiling of cadmium-induced effects in one pioneer intertidal halophyte *Suaeda salsa* by NMR-based metabolomics. Ecotoxicol. 20(6): 1422-1431.

Liu, Y.H., R.B. Yang, J.X. Qiu and Z.Y. Guo. 2005. Complex toxicity of triadimefon and Cd towards aquatic organisms. J. Agro-Environ. Sci. 24(6): 1075-1078.

Lizardo-Daudt, H.M. and C. Kennedy. 2008. Effects of cadmium chloride on the development of rainbow trout *Oncorhynchus mykiss* early life stages. J. Fish Biol. 73(3): 702-718.

Loayza-Muro, R. and R. Elias-Letts. 2007. Responses of the mussel *Anodontites trapesialis* (Unionidae) to environmental stressors: Effect of pH, temperature and metals on filtration rate. Environ. Pollut. 149(2): 209-215.

Lobato, R.O., S.M. Nunes, W. Wasielesky, D. Fattorini, F. Regoli, J.M. Monserrat and J. Ventura-Lima. 2013. The role of lipoic acid in the protection against of metallic pollutant effects in the shrimp *Litopenaeus vannamei* (Crustacea, Decapoda). Comp. Biochem. Physiol. Part A Molec. Integ. Physiol. 165(4): 491-497.

Lochner, C. and Water Quality Monitoring and Surveillance, Environment Canada. 2008. Environmental levels of cadmium.

Loehle, C. and M. Paller. 1991. Heavy metals in fish from streams near F-area and H-area seepage basins. Govt. Reports Announce. Index, Issue 11.

Lokeshwari, H. and G.T. Chandrappa. 2006. Heavy metals content in water, water hyacinth and sediments of Lalbagh Tank, Bangalore (India). J. Environ. Sci. Eng. 48(3): 183-188.

Lomagin, A.G. and L.V. Ul'yanova. 1993. A new bioassay on water pollution using duckweed *Lemna minor* L. Sov. Plant Physiol./Fiziol. Rast. 49(2): 283-284.

Lombardi, P.E., S.I. Peri and N.R. Verrengia Guerrero. 2010. Trace metal levels in *Prochilodus lineatus* collected from the La Plata River, Argentina. Environ. Monit. Assess. 160(1-4): 47-59.

Long, A. and W.X. Wang. 2005. Metallothionein induction and bioaccumulation kinetics of Cd and Ag in the marine fish *Terapon jarbua* challenged with dietary or waterborne Ag and Cu. Mar. Ecol. Prog. Ser. 291: 215-226.

Long, A., C. Li, S. Chen, W. Yan, A. Dang, Y. Cheng and D. Lu. 2010. Short-term metal accumulation and MTLP induction in the digestive glands of *Perna virdis* exposed to Zn and Cd. J. Environ. Sci. 22(7): 975-981.

Lopez, M.S. and C. Thompson. 2009. An assessment of heavy metal pollution in egg yolks of Olive Ridley turtles of the tropical eastern Pacific. M.S. Thesis, Tarleton State University, Stephenville, TX.

Lopez Greco, L.S., M.V. Sanchez, G.L. Nicoloso, D.A. Medesani and E.M. Rodriguez. 2001. Toxicity of cadmium and copper on larval and juvenile stages of the estuarine crab *Chasmagnathus granulata* (Brachyura, Grapsidae). Arch. Environ. Contam. Toxicol. 41(3): 333-338.

Lorenzon, S., M. Francese, V.J. Smith and E.A. Ferrero. 2001. Heavy metals affect the circulating haemocyte number in the shrimp *Palaemon elegans*. Fish Shellfish Immunol. 11(6): 459-472.

Lorz, H.W., R.H. Williams and C.A. Fustish. 1978. Effects of several metals on smolting of coho salmon. EPA-600/3-78-090. National Technical Information Service, Springfield, Virginia.

Loumbourdis, N.S. 2005. Hepatotoxic and nephrotoxic effects of cadmium in the frog *Rana ridibunda*. Arch. Toxicol. 79(8): 434-440.

Loumbourdis, N.S., P. Kyriakopoulou-Sklavounou and G. Zachariadis. 1999. Effects of cadmium exposure on bioaccumulation and larval growth in the frog *Rana ridibunda*. Environ. Pollut. 104: 429-433.

Loumbourdis, N.S., I. Kostaropoulos, B. Theodoropoulou and D. Kalmanti. 2007. Heavy metal accumulation and metallothionein concentration in the frog *Rana ridibunda* after exposure to chromium or a mixture of chromium and cadmium. Environ. Pollut. 145(3): 787-792.

Lourdes, M. 1994. Survival and heavy metal accumulation of two *Oreochromis niloticus* (L.) strains exposed to mixtures of zinc, cadmium and mercury. Sci. Total Environ. 148: 31-38.

Lourdes, M. and E.V. Aralar. 1993. Effects of long-term exposure to a mixture of cadmium, zinc, and inorganic mercury on two strains of tilapia *Oreochromis niloticus* (L.). Bull. Environ. Contam. Toxicol. 50: 891-897.

Loureiro, C., B.B. Castro, J.L. Pereira and F. Goncalves. 2011. Performance of standard media in toxicological assessments with *Daphnia magna*: Chelators and ionic composition versus metal toxicity. Ecotoxicol.20(1): 139-148.

Loureiro, S., M.J. Amorim, B. Campos, S.M. Rodrigues and A.M. Soares. 2009. Assessing joint toxicity of chemicals in *Enchytraeus albidus* (Enchytraeidae) and *Porcellionides pruinosus* (Isopoda) using avoidance behaviour as an endpoint. Environ. Pollut. 157(2): 625-636.

Lovett, R.J., W.G. Gutenmann, I.S. Pakkala, W.D. Youngs, D.J. Lisk and G.E.A. Burdick. 1972. Survey of the total cadmium content of 406 fish from 49 New York State fresh waters. J. Fish. Res. Board Can. 29(9): 1283-1290.

Low, J.S.C. 2009. Sub-lethal effects of cadmium on auditory structure and function in the fathead (*Pimephales promelas*) and bluntnose (*Pimephales notatus*) minnows. M.S. Thesis, University of Windsor, Canada.

Lozano, G., A. Hardisson, A.J. Gutierez and M.A. Lafuente. 2003. Lead and cadmium levels in coastal benthic algae (seaweeds) of Tenerife, Canary Islands. Environ. Intern. 28(7): 627-631.

Lozano, G., A. Brito, A. Hardisson, A. Gutierrez, D. Gonzalez-Weller and I.J. Lozano. 2009. Content of lead and cadmium in barred hogfish, *Bodianus scrofa*, island grouper, *Mycteroperca fusca*, and Portuguese dogfish, *Centroscymnus coelolepis*, from Canary Islands, Spain. Bull. Environ. Contam. Toxicol. 83(4): 591-594.

Lu, B., C. Ke and W.X. Wang. 2012a. Importance of waterborne cadmium and zinc accumulation in the suspension-feeding amphioxus *Branchiostoma belcheri*. Aquat. Biol. 16(2): 137-147.

Lu, H.X. and Y.J. Xu. 2011. Effects of cadmium on antioxidant enzyme activity and DNA damage in *Sinonovacula constricta*. Mari. Environ. Sci. 30(1): 96-101.

Lu, L. and R.S.S. Wu. 2003. Recolonization and succession of subtidal macrobenthic infauna in sediments contaminated with cadmium. Environ. Pollut. 121(1): 27-38.

Lu, X.J., J. Chen, Z.A. Huang, L. Zhuang, L.Z. Peng and Y.H. Shi. 2012c. Influence of acute cadmium exposure on the liver proteome of a teleost fish, ayu (*Plecoglossus altivelis*). Mol. Biol. Rep. 39(3): 2851-2859.

Lu, X.F., F.Y. Liu, X.P. Zhou, Q.F. Zhou and Y.L. Deng. 2012b. Effects of cadmium, 17 beta-estradiol and their interaction in the male Chinese loach (*Misgurnus anguillicaudatus*). Chinese Sci. Bull. 57(8): 858-863.

Lucas Jr., H.F., D.N. Edgington and P.J. Colby. 1970. Concentrations of trace elements in Great Lakes Fishes. J. Fish. Res. Board Can. 27: 677-684.

Lucia, M., J.M. Andre, P. Gonzalez, M. Baudrimont, M.D. Bernadet, K. Gontier, R. Maury-Brachet, G. Guy and S. Davail. 2010. Effect of dietary cadmium on lipid metabolism and storage of aquatic bird *Cairina moschata*. Ecotoxicol. 19(1): 163-170.

Lucker, T., D. Busch and W. Wosniok. 1997. Experiments to determine the impact of salinity on the heavy metal accumulation of *Dreissena polymorpha* (Pallas 1771). Limnologica 27: 91-101.

Lue-Kim, H., P.C. Wozniak and R.A. Fletcher. 1980. Cadmium toxicity on synchronous populations of *Chlorella ellipsoidea*. Can. J. Biol. 58(16): 1780-1788.

Lugowska, K. 2007. The effect of cadmium and cadmium/copper mixture during the embryonic development on deformed common carp *Cyprinus carpio* larvae. Electron. J. Pol. Agric. Univ. 10(4).

Luis, A.T., P. Teixeira, S.F.P. Almeida, L. Ector, J.X. Matos and E.A.F. daSilva. 2009. Impact of acid mine drainage (AMD) on water quality, stream sediments and periphytic diatom communities in the surrounding streams of Aljustrel Mining Area (Portugal). Water Air Soil Pollut. 200(1-4): 147-167.

Lukashev, D.V. 2008. Peculiarities of seasonal dynamics of manganese, cobalt and chromium accumulation by the mollusks *Dreissena bugensis* (Andr.) nearby city of Kyiv. Hydrobiol. J./Gidrobiol. Zh. 44(5): 63-72.

Lussier, S.M., J.H. Gentile and J. Walker. 1985. Acute and chronic effects of heavy metals and cyanide on *Mysidopsis bahia* (Crustacea: Mysidacea). Aquat. Toxicol. 7(1-2): 25-35.

Lussier, S.M., A. Kuhn, M. Chammas and J. Sewall. 1988. A Rapid-chronic test method to determine sublethal effects on two species of saltwater mysids. Aquat. Toxicol. 11(3-4): 409-410.

Lussier, S.M., W.S. Boothman, S. Poucher, D. Champlin and A. Helmstetter. 1995. Derivation of conversion factors for dissolved saltwater aquatic life criteria for metals. Draft Report to the Office of Water. U.S. EPA. ERL, Narragansett, RI, 55 pp.

Lussier, S.M., W.S. Boothman, S. Poucher, D. Champlin and A. Helmstetten. 1999. Comparison of dissolved and total metals concentrations from acute tests with saltwater organisms. Environ. Toxicol. Chem. 18(5): 889-898

Lytle, T.F. and J.S. Lytle. 1982. Heavy metals in oysters and clams of St. Louis Bay, Mississippi. Bull. Environ. Contam. Toxicol. 29(1): 50-57.

Lyubenova, L., C. Götz, A. Golan-Goldhirsh and P. Schröder. 2007. Direct effect of Cd on glutathione s-transferase and glutathione reductase from *Calystegia sepium*. Int. J. Phytoremed. 9(6): 465-473.

Ma, D., Y. Hou, L. Du, N. Li, R. Xuan, F. Wang, W. Jing and L. Wang. 2013. Oxidative damages and ultrastructural changes in the sperm of freshwater crab *Sinopotamon henanense* exposed to cadmium. Ecotoxicol. Environ. Saf. 98: 244-249.

Ma, M., Z. Tong, Z. Wang and W. Zhu. 1999. Acute toxicity bioassay using the freshwater luminescent bacterium *Vibrio-qinghaiensis sp.* Nov.-Q67. Bull. Environ. Contam. Toxicol. 62: 247-253.

Ma, W., L. Wang, Y. He and Y. Yan. 2008. Tissue-specific cadmium and metallothionein levels in freshwater crab sinopotamon henanense during acute exposure to waterborne cadmium. Environ. Toxicol. 23(3): 393-400.

Maanan, M. 2007. Biomonitoring of heavy metals using *Mytilus galloprovincialis* in Safi coastal waters, Morocco. Environ. Toxicol. 22(5): 525-531.

Maanan, M. 2008. Heavy metal concentrations in marine molluscs from the Moroccan coastal region. Environ. Pollut. 153(1): 176-183.

Maas, R.P. 1978. A field study of the relationship between heavy metal concentrations in stream water and selected benthic macroinvertebrate species. PB 297284. National Technical Information Service, Springfield, VA.

MacDonald, C.R. and J.B. Sprague. 1998. Cadmium in marine invertebrates and Arctic cod in the Canadian Arctic. Distibution and ecological implications. Mar. Ecol. Prog. Ser. 47: 17-30.

MacDonald, J.M., J.D. Shields and R.K. Zimmer-Faust. 1988. Acute toxicities of eleven metals to early life-history stages of the yellow crab *Cancer anthonyi*. Mar. Biol. 98: 201-207.

MacDonald, P. 2010. Assessing the toxicity of aquatic sediments using Japanese medaka (*Oryzias latipes*) embryolarval bioassays. M.S. Thesis, University of Prince Edward Island, Canada.

Maceda-Veiga, A., M. Monroy and A. de Sostoa. 2012. Metal bioaccumulation in the Mediterranean barbel (*Barbus meridionalis*) in a Mediterranean river receiving effluents from urban and industrial wastewater treatment plants. Ecotoxicol. Environ. Saf. 76(2): 93-101.

Macek, K.J. and B.H. Sleight III. 1977. Utility of toxicity tests with embryos and fry of fish in evaluating hazards associated with the chronic toxicity of chemicals to fishes. In: F.L. Mayer and J.L. Hamelink (*Eds*.), Aquat. Toxicol. Hazard Eval., ASTM STP 634, Philadelphia, PA, 137-146.

MacFarlane, R.D., G.L. Bullock and J.J.A. McLaughlin. 1986. Effects of five metals on susceptibility of striped bass to *Flexibacter columnaris*. Trans. Am. Fish. Soc. 115(2): 227-231.

Macfie, S.M., Y. Tarmohamed and P.M. Welbourn. 1994. Effects of cadmium, cobalt, copper, and nickel on growth of the green alga *Chlamydomonas reinhardtii*: The influences of the cell wall and pH. Arch. Environ. Contam. Toxicol. 27: 454-458.

Machreki-Ajmi, M. and A. Hamza-Chaffai. 2006. Accumulation of cadmium and lead in *Cerastoderma glaucum* originating from the Gulf of Gabegrave; S., Tunisia. Bull. Environ. Contam. Toxicol. 76(3): 529-537.

Machreki-Ajmi, M. and A. Hamza-Chaffai. 2008. Assessment of sediment/water contamination by in vivo transplantation of the cockles *Cerastoderma glaucum* from a non-contaminated to a contaminated area by cadmium. Ecotoxicol. 17(8): 802-810.

MacInnes, J.R. and F.P. Thurberg. 1973. Effects of metals on the behaviour and oxygen consumption of the mud snail. Mar. Pollut. Bull. 4(12): 185-186.

MacInnes, J.R., F.P. Thurberg, R.A. Greig and E. Gould. 1977. Long-term cadmium stress in the cunner *Tautogolabrus adspersus*. Fish. Bull. 75(1): 199-203.

Macka, W., H. Wihlidal, G. Stehlik, J. Washuttl and E. Banchar. 1979. Uptake of 203Hg++ and 115m Cd++ *by Chlamydomonas reinhardi* under various conditions. Chemosphere 10: 787-796.

Macken, A., M. Giltrap, K. Ryall, B. Foley, E. McGovern, B. McHugh and M. Davoren. 2009. A test battery approach to the ecotoxicological evaluation of cadmium and copper employing a battery of marine bioassays. Ecotoxicol. 18(4): 470-480.

Mackey, E.A., P.R. Becker, R. Demiralp, R.R. Greenberg, B.J. Koster and S.A. Wise. 1996. Bioaccumulation of vanadium and other trace metals in livers of alaskan cetceans and pinnipeds. Arch. Environ. Contam. Toxicol. 30(4): 503-512.

Mackie, G.L. 1989. Tolerances of five benthic invertebrates to hydrogen ions and metals (Cd, Pb, Al). Arch. Environ. Contam. Toxicol. 18: 215-223.

Madhusudan, S., F. Liyaquat and C. Nadim. 2003. Bioaccumulation of zinc and cadmium in freshwater fishes. Indian J. Fish. 50(1): 53-65.

Madkour, H.A. and M.Y. Ali. 2009. Heavy metals in the benthic foraminifera from the coastal lagoons, Red Sea, Egypt: Indicators of anthropogenic impact on environment (case study). Environ. Geol. 58(3): 543-553.

Madoni, P. and M.G. Romeo. 2006. Acute toxicity of heavy metals towards freshwater ciliated protists. Environ. Pollut. 141(1): 1-7.

Madoni, P., D. Davoli and G. Gorbi. 1994. Acute toxicity of lead, chromium, and other heavy metals to ciliates from activated sludge plants. Bull. Environ. Contam. Toxicol. 53: 420-425.

Maeda, S., M. Mizoguchi, A. Ohki and J. Inanaga. 1990. A bioaccumulation of zinc and cadmium in freshwater alga, *Chlorella vulgaris*. Part II. Association mode of the metals and cell tissue. Chemosphere 21(8): 965-973.

Maes, J., C. Belpaire and G. Goemans. 2008. Spatial variations and temporal trends between 1994 and 2005 in polychlorinated biphenyls, organochlorine pesticides and heavy metals in European eel (*Anguilla anguilla* L.) in Flanders, Belgium. Environ. Pollut. 153(1): 223-237.

Maestre, Z., M. Martinez-Madrid and P. Rodriguez. 2009. Monitoring the sensitivity of the oligochaete *Tubifex tubifex* in laboratory cultures using three toxicants. Ecotoxicol. Environ. Saf. 72: 2083-2089.

Maffucci, F., F. Caurant, P. Bustamante and F. Bentivegna. 2005. Trace element (Cd, Cu, Hg, Se, Zn) accumulation and tissue distribution in loggerhead turtles (*Caretta caretta*) from the western Mediterranean Sea (southern Italy). Chemosphere 58(5): 535-542.

Mahmoud, N., M. Dellali, P. Aissa and E. Mahmoudi. 2012. Acute toxicities of cadmium and permethrin on the pre-spawning and post-spawning phases of *Hexaplex trunculus* from Bizerta Lagoon, Tunisia. Environ. Monit. Assess. 184(10): 5851-5861.

Mahon, S. and K.R. Carman. 2008. The influence of salinity on the uptake, distribution, and excretion of metals by the smooth cordgrass, *Spartina alterniflora* (Loisel.), grown in sediment contaminated by multiple metals. Estuaries Coasts 31(6): 1089-1097.

Mai, H., J. Cachot, J. Brune, O. Geffard, A. Belles, H. Budzinski and B. Morin. 2012. Embryotoxic and genotoxic effects of heavy metals and pesticides on early life stages of Pacific oyster (*Crassostrea gigas*). Mar. Pollut. Bull. 64(12): 2663-2670.

Maine, M.A., M.V. Duarte and N.L. Sune. 2001. Cadmium uptake by floating macrophytes. Water Res. 35(11): 2629-2634.

Majewski, H.S. and M.A. Giles. 1984. Cardio vascular-respiratory responses of rainbow trout (*Salmo gairdneri*) during chronic exposure to sublethal concentrations of cadmium. Water Res. 15: 1211.

Malea, P. 1994. Uptake of cadmium and the effect on viability of leaf cells in the seagrass *Halophila stipulacea* (Forsk.) Aschers. Bot. Mar. 37: 67-73.

Malea, P., S. Haritonidis and T. Kevrekidis. 1995. Metal content of some green and brown seaweeds from Antikyra Gulf (Greece). Hydrobiol. 310(1): 19-31.

Malea, P., T. Boubonari and T. Kevrekidis. 2008. Iron, zinc, copper, lead and cadmium contents in *Ruppia maritima* from a Mediterranean coastal lagoon: Monthly variation and distribution in different plant fractions. Bot. Mar. 51(4): 320-330.

Malea, P., I.D.S. Adamakis and T. Kevrekidis. 2013. Kinetics of cadmium accumulation and its effects on microtubule integrity and cell viability in the seagrass *Cymodocea nodosa*. Aquat. Toxicol. 144-145: 257-264.

Malec, P., M.G. Maleva, M.N.V. Prasad and K. Strzalka. 2010. Responses of *Lemna trisulca* L. (duckweed) exposed to low doses of cadmium: Thiols, metal binding complexes, and photosynthetic pigments as sensitive biomarkers of ecotoxicity. Protoplasma 240(1-4): 69-74.

Malekpouri, P. and A. A. Moshtaghie. 2011. Novel observation in cadmium-zinc interaction on parameters related to bone metabolism in common carp (*Cyprinus carpio* L.). Clin. Biochem. 44(13): S107-S107.

Malekpouri, P., A.A. Moshtaghie, M. Kazemian and M. Soltani. 2011. Protective effect of zinc on related parameters to bone metabolism in common carp fish (*Cyprinus carpio* L.) intoxified with cadmium. Fish Physiol. Biochem. 37(1): 187-196.

Maleva, M.G., G.F. Nekrasova and V. S. Bezel. 2004. The response of hydrophytes to environmental pollution with heavy metals. Russ. J. Ecol. 35(4): 230-235.

Maleva, M.G., G.F. Nekrasova, G.G. Borisova, N.V. Chukina and O.S. Ushakova. 2012. Effect of heavy metals on photosynthetic apparatus and antioxidant status of *Elodea*. Russ. J. Plant Physiol. 59(2): 190-197.

Malley, D.F. 1996. Cadmium whole-lake experiment at the Experimental Lakes Area: An anachoronism? Can. J. Fish. Aquat. Sci. 53(8): 1862-1870.

Malley, D.F. and P.S.S. Chang. 1991. Early observations on the zooplankton community of a precambrian shield lake receiving experimental additions of cadmium. Verh.-Int. Ver. Theor. Angew. Limnol. 24: 2248-2253.

Malley, D.F., P.S.S. Chang and R.H. Hesslein. 1989. Whole lake addition of cadmium-109: radiotracer accumulation in the mussel population in the first season. Sci. Total Environ. 87/88: 397-417.

Mallick, N. and F.H. Mohn. 2003. Use of chlorophyll fluorescence in metal-stress research: A case study with the green microalga scenedesmus. Ecotoxicol. Environ. Saf. 55(1): 64-69.

Malone-Oliver, A., S. O'Shea and K.S. Warren. 2011. Metallothionein and cadmium toxicity in developing zebrafish. Dev. Biol. 356(1): 268.

Maloney, J. 1996. Influence of organic enrichment on the partitioning and bioavailability of cadmium in a microcosm study. Mar. Ecol. Prog. Ser. 144: 147-161.

Mandal, S.K., H.V. Joshi, D.C. Bhatt, B. Jha and T. Ishimaru. 2006. Experiences with some toxic and relatively accessible heavy metals on the survival and biomass production of *Amphora costata* W. Smith. Algae 21(4): 471-477.

Manga, N. 1980. Trace metals in the common mussel *Mytilus edulis* from Belfast Lough Northern Ireland, UK. Ir. Nat. J. 20(4): 160-163.

Mann, H. and W.S. Fyfe. 1985. Algal uptake of U and some other metals: Implications for global geochemical cycling. Precambrian Res. 30: 337-349.

Mann, H., W.S. Fyfe and R. Kerrich. 1988. The chemical content of algae and waters: Bioconcentration. Toxic. Assess. 3: 1-16.

Mano, H., Y. Ogamino, M. Sakamoto and Y. Tanaka. 2011. Acute toxic impacts of three heavy metals (copper, zinc, and cadmium) on *Diaphanosoma brachyurum* (Cladocera: Sididae). Limnol. 12(2): 193-196.

Mansour, G.M.M. 1993. Effects on fish of cadmium concentrations in water. Oceanologia. 34: 91.

Manyin, T. and C.L. Rowe. 2009. Bioenergetic effects of aqueous copper and cadmium on the grass shrimp, *Palaemonetes pugio*. Comp. Biochem. Physiol.150C(1): 65-71.

Manz, W., M. Wagner and D.H. Schleifer. 1994. *In situ* characterization of the microbial consortia active in two wastewater treatment plants. Water Res. 28(8): 1715-1732.

Manzl, C., G. Krumschnabel, P.J. Schwarzbaum and R. Dallinger. 2004. Acute toxicity of cadmium and copper in hepatopancreas cells from the roman snail (*Helix pomatia*). Comp. Biochem. Physiol. Part 138C(1): 45-52.

Manzo, S., S. Buono and C. Cremisini. 2010. Cadmium, lead and their mixtures with copper: *Paracentrotus lividus* embryotoxicity assessment, prediction, and offspring quality evaluation. Ecotoxicol. 19(7): 1209-1223.

Mao, H., F.Q. Tan, D.H. Wang, J.Q. Zhu, H. Zhou and W.X. Yang. 2012. Expression and function analysis of metallothionein in the testis of stone crab *Charybdis japonica* exposed to cadmium. Aquat. Toxicol. 124/125: 11-21.

Maranhao, P., J.C. Marques and V.M.C. Madeira. 1999. Zinc and cadmium concentrations in soft tissues of the red swamp crayfish *Procambarus clarkii* (Girard, 1852) after exposure to zinc and cadmium. Environ. Toxicol. Chem. 18(8): 1769-1771.

Marcano, L.B., I.M. Carruyo, X.M. Montiel, C.B. Morales and P.M. De Soto. 2009. Effect of cadmium on cellular viability in two species of microalgae (*Scenedesmus sp*. and *Dunaliella viridis*). Biol. Trace Elem. Res. 130(1): 86-93.

Marcussen, H., P.E. Holm, T.H. Le and A. Dalsgaard. 2007. Food safety aspects of toxic element accumulation in fish from wastewater-fed ponds in Hanoi, Vietnam. Trop. Med. Int. Health 12(Suppl. 2): 34-39.

Marie, V., M. Baudrimont and A. Boudou. 2006a. Cadmium and zinc bioaccumulation and metallothionein response in two freshwater bivalves (*Corbicula fluminea* and *Dreissena polymorpha*) transplanted along a polymetallic gradient. Chemosphere 65(4): 609-617.

Marie, V., P. Gonzalez, M. Baudrimont, J.P. Bourdineaud and A. Boudou. 2006b. Metallothionein response to cadmium and zinc exposures compared in two freshwater bivalves, *Dreissena polymorpha* and *Corbicula fluminea*. Biometals 19(4): 399-407.

Marigomez, I., U. Izagirre and X. Lekube. 2005. Lysosomal enlargement in digestive cells of mussels exposed to cadmium, benzo(a)pyrene and their combination. Comp. Biochem. Physiol. 141C(2): 188-193.

Marion, M. and F. Denizeau. 1983. Rainbow trout and human cells in culture for the evaluation of the toxicity of aquatic pollutants: A study with cadmium. Aquat. Toxicol. 3: 329-343.

Mark, U. and J. Solbe. 1998. Analysis of the ecetoc aquatic toxicity (EAT) database V: The relevance of *Daphnia magna* as a representative test species. Chemosphere 36(1): 155-166.

Markham, J.W., B.P. Kremer and K.R. Sperling. 1980. Effects of cadmium on *Laminaria saccharina* in culture. Mar. Ecol. Prog. Ser. 3: 31-39.

Markich, S.J. and R.A. Jeffree. 1994. Absorption of divalent trace metals as analogues of calcium by Australian freshwater bivalves: An explanation of how water hardness reduces metal toxicity. Aquat. Toxicol. 29: 257-290.

Markich, S.J., P.L. Brown, R.A. Jeffree and R.P. Lim. 2003. The effects of pH and dissolved organic carbon on the toxicity of cadmium and copper to a freshwater bivalve: Further support for the extended free ion activity model. Arch. Environ. Contam. Toxicol. 45(4): 479-491.

Marr, J.C.A., H.L. Bergman, J. Lipton and C. Hogstrand. 1995a. Differences in relative sensitivity of naive and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana. Can. J. Aquat. Sci. 52: 2016-2030.

Marr, J.C.A., H.L. Bergman, M. Parker, J. Lipton, D. Cacela, W. Erickson and G.R Phillips. 1995b. Relative sensitivity of brown and rainbow trout to pulsed exposures of an acutely lethal mixture of metals typical of the Clark Fork River, Montana. Can. J. Aquat. Sci. 52: 2005-2015.

Marshall, J.S. 1978a. Population dynamics of *Daphnia galeata mendotae* as modified by chronic cadmium stress. J. Fish. Res. Board Can. 35: 461.

Marshall, J.S. 1978b. Field verification of cadmium toxicity to laboratory *Daphnia* populations. Bull. Environ. Contam. Toxicol. 20: 387.

Marshall, J.S., J.I. Parker, D.L. Mellinger and S.G. Lawrence. 1981. An *in situ* study of cadmium and mercury stress in the plankton community of lake 382, Experimental Lakes Area, northwestern Ontario. Can. J. Fish. Aquat. Sci. 38(10): 1209-1214.

Marshall, J.S., J.I. Parker, D.L. Mellinger and C. Lei. 1983. Bioaccumulation and effects of cadmium and zinc in a Lake Michigan plankton community. Can. J. Fish. Aquat. Sci. 40(9): 1469-1479.

Martignago, R., F. Trinchella, R. Scudiero and P. Cretì. 2009. Cadmium, lead and metallothionein contents in tissues of the sea bream *Sparus aurata* from three different fish farming systems. Compart. Biochem. Physiol. Part A Molecul. Integrat. Physiol. 154(Suppl. 1): S21.

Martin, C.A., D.J. Cain, S.N. Luoma and D.B. Buchwalter. 2007. Cadmium ecophysiology in seven stonefly (Plecoptera) species: Delineating sources and susceptibility. Environ. Sci. Technol. 41: 7171-7177.

Martin, M., K. Osborn, P. Billig and N. Glickstein. 1981. Toxicities of ten metals to *Crassostrea gigas* and *Mytilus edulis* embryos and *Cancer magister* larvae. Mar. Pollut. Bull. 12: 305.

Martin, T.R. and D.M. Holdich. 1986. The acute lethal toxicity of heavy metals to peracarid crustaceans (with particular reference to fresh-water asellids and gammarids). Water Res. 20(9): 1137-1147.

Martin-Diaz, M.L, J. Blasco, M.G. De Canales, D. Sales and T.A. DelValls. 2005a. Bioaccumulation and toxicity of dissolved heavy metals from the Guadalquivir Estuary after the Aznalcollar mining spill using *Ruditapes philippinarum*. Arch. Environ. Contam. Toxicol. 48(2): 233-241.

Martin-Diaz, M.L., S.R. Tuberty, C.L. McKenney Jr., D. Sales and T.A. Del Valls. 2005b. Effects of cadmium and zinc on *Procambarus clarkii*: Simulation of the Aznalcollar mining Spill. Cienc. Mar. 31(1B): 197-202.

Martin-Gonzalez, A., S. Borniquel, S. Diaz, R. Ortega and J.C. Gutierrez. 2005. Ultrastructural alterations in ciliated protozoa under heavy metal exposure. Cell Biol. Intern. 29: 119-126.

Martinez, E.A., B.C. Moore, J. Schaumloffel and N. Dasgupta. 2003. Morphological abnormalities in *Chironomus tentans* exposed to cadmium- and copper-spiked sediments. Ecotoxicol. Environ. Saf. 55(2): 204-212.

Martinez, M., J. Del Ramo, A. Torreblanca, A. Pastor and J. Diaz-Mayans. 1996. Cadmium toxicity, accumulation and metallothionein induction in *Echinogammarus echinosetosus*. J. Environ. Sci. Health. A31(7): 1605-1617.

Martinez-Guitarte, J.L., R. Planello and G. Morcillo. 2012. Overexpression of long non-coding RNAs following exposure to xenobiotics in the aquatic midge *Chironomus riparius*. Aquat. Toxicol. 110: 84-90.

Martín-González, A., S. Borniquel, S. Díaz, R. Ortega and J.C. Gutiérrez. 2005. Ultrastructural alterations in ciliated protozoa under heavy metal exposure. Cell Biol. Int. 29(2): 119-126.

Masoudzadeh, N., F. Zakeri, T.B. Lotfabad, H. Sharafi, F. Masoomi, H.S. Zahiri, G. Ahmadian, K.A. Noghabi. 2011. Biosorption of cadmium by *Brevundimonas sp.* ZF12 strain, a novel biosorbent isolated from hot-spring waters in high background radiation areas. J. Hazard. Mater. 197: 190-198.

Masson, S., Y. Couillard, P.G.C. Campbell, C. Olsen, B. Pinel-Allou and O. Perceval. 2010. Responses of two sentinel species (*Hexagenia limbata*--mayfly; *Pyganodon grandis*--bivalve) along spatial cadmium gradients in lakes and rivers in Northwestern Quebec. J. Environ. Monit. 12(1): 143-158.

Masters, J.A., M.A. Lewis and D.H. Davidson. 1991. Validation of a four-day *Ceriodaphnia* toxicity test and statistical considerations in data analysis. Environ. Toxicol. Chem. 10: 47-55.

Mastrangelo, M., M.D. Afonso and L. Ferrari. 2011. Cadmium toxicity in tadpoles of *Rhinella arenarum* in relation to calcium and humic acids. Ecotoxicol. 20(6): 1225-1232.

Mateo, P., F. Fernandez-Pinas and I. Bonilla. 1994. O_2-induced inactivation of nitrogenase as a mechanism for the toxic action of Cd^{2+} on *Nostoc* UAM 208. New Phytologist. 126(2): 267-272.

Mathad, P., S.B. Angadi and R.D. Mathad. 2004. Short and long term effects of exposure of microalgae to heavy metal stress. Asian J. Microbiol. Biotechnol. Environ. Sci. 6(1): 99-106.

Mathew, P. and N.R. Menon. 1992. Toxic responses of bivalves to metal mixtures. Bull. Environ. Contam. Toxicol. 48: 185-193.

Mathew, P. and N.R. Menon. 2004. Filtration rates and heavy metal toxicity in *Donax incarnatus*. J. Mar. Biol. Assoc. India. 46(1): 56-63.

Mathew, P. and N.R. Menon. 2005. Histological aberrations accompanying chronic metal toxicity in the mussel *Perna indica*. J. Mar. Bio. Assoc. India. 47(2): 144-149.

Mathews, T., N.S. Fisher and F. Briand. 2007. Metal concentrations in Mediterranean fish tissues: Exploring biomagnification patterns. Monaco (38): 290.

Mathews, T., N.S. Fisher, R.A. Jeffree and J.L. Teyssie. 2008. Assimilation and retention of metals in teleost and elasmobranch fishes following dietary exposure. Mar. Ecol. Prog. Ser. 360: 1-12.

Mathis, B.J. and T.F. Cummings. 1973. Selected metals in sediments, water, and biota in the illinois river. J. Water Pollut. Control Fed. 45(7): 1573-1583.

Matozzo, V., L. Ballarin, D.M. Pampanin and M.G. Marin. 2001. Effects of copper and cadmium exposure on functional responses of hemocytes in the clam, *Tapes philippinarum*. Arch. Environ. Contam. Toxicol. 41(2): 163-170.

Matsuo, A.Y. and A.L. Val. 2007. Dietary tissue cadmium accumulation in an Amazonian teleost (Tambaqui, *Colossoma macropomum* Cuvier, 1818). Braz. J. Biol. 67(4): 657-661.

Matz, C.J. and P.H. Krone. 2007. Cell death, stress-responsive transgene activation, and deficits in the olfactory system of larval zebrafish following cadmium exposure. Environ. Sci. Technol. 41(14): 5143-5148.

Matz, C.J., R.G. Treble and P.H. Krone. 2007. Accumulation and elimination of cadmium in larval stage zebrafish following acute exposure. Ecotoxicol. Environ. Saf. 66(1): 44-48.

Maunder, R.J., J. Buckley, A.L. Val and K.A. Sloman. 2011. Accumulation of dietary and aqueous cadmium into the epidermal mucus of the discus fish *Symphysodon sp.* Aquat. Toxicol. 103(3/4): 205-212.

Maunder, R.J., K.A. Sloman, A.L. Val, J. Pearce and J. Buckley. 2009. Uptake, tissue distribution and excretion of dietary cadmium and copper in discus fish *Symphysodon spp*. Comp. Biochem. Physiol.Part A Molec. Integrat. Physiol. 153(2, Suppl. 1): S93.

Mavrin, A.S., G.A.Vinogradov, T.B. Lapirova, I. Ermov and T.F. Mikryakova. 1991. Effect of calcium, magnesium and heavy metals on young bream, *Abramis brama* L. experimental results. Biol. Vnutr. Vod Inf. Byull. 91: 45-50.

Mayer Jr., F.L. 1987. Acute toxicity handbook of chemicals to estuarine organisms. EPA 600/8-87-017, U.S. EPA, Gulf Breeze, FL, 274 p.

Mayrand, E.and J.D. Dutil. 2008. Physiological responses of rock crab *Cancer irroratus* exposed to waterborne pollutants. J. Crust. Biol. 28(3): 510-518.

Mazen, A.M.A. and O.M.O. El Maghraby. 1997. Accumulation of cadmium, lead and strontium, and a role of calcium oxalate in water hyacinth tolerance. Biol. Plant. 40(3): 411-417.

Mazet, A., G. Keck and P. Berny. 2005. Concentrations of PCBs, organochlorine pesticides and heavy metals (lead, cadmium, and copper) in fish from the Drome river: Potential effects on otters (*Lutra lutra*). Chemosphere 61(6): 810-816.

McCahon, C.P. and D. Pascoe. 1988a. Cadmium toxicity to the freshwater amphipod *Gammarus pulex* (L.) during the molt cycle. Fresh. Biol. 19: 197-203.

McCahon, C.P. and D. Pascoe. 1988b. Increased sensitivity to cadmium of the freshwater amphipod *Gammarus pulex* (L.) during the reproductive period. Aquat. Toxicol. 13: 183-194.

McCahon, C.P. and D. Pascoe. 1988c. Use of *Gammarus pulex* (L.) in safety evaluation tests: Culture and selection of a sensitive life stage. Ecotoxicol. Environ. Saf. 15: 245-252.

McCahon, C.P. and D. Pascoe. 1991. Brief-exposure of first and fourth instar *Chironomus riparius* larvae to equivalent assumed doses of cadmium: Effects on adult emergence. Water Air Soil Pollut. 60: 395-403.

McCahon, C.P., A.F. Brown and D. Pascoe. 1988. The effect of the acanthocephalan *Pomphorhynchus laevis* (Muller 1776) on the acute toxicity of cadmium to its intermediate host, the amphipod *Gammarus pulex* (L.). Arch. Environ. Contam. Toxicol 17: 239-243.

McCahon, C.P., A.J. Whiles and D. Pascoe. 1989. The toxicity of cadmium to different larval instars of the trichopteran larvae *Agapetus fuscipes* Curtis and the importance of life cycle information to the design of toxicity tests. Hydrobiol. 185: 153-162.

McCarty, L.S. and A.H. Houston. 1976. Effects of exposure to sublethal levels of cadmium upon water-electrolyte status in the goldfish (*Carassius auratus*). J. Fish. Biol. 9: 11.

McCarty, L.S., J.A.C. Henry and A.H. Houston. 1978. Toxicity of cadmium to goldfish, *Carassius auratus*, in hard and soft water. J. Fish. Res. Board Can. 35(1): 35-42.

McClain, J.S., J.T. Oris, G.A. Burton Jr. and D. Lattier. 2003. Laboratory and field validation of multiple molecular biomarkers of contaminant exposure in rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 22(2): 361-370.

McClosky, J.T. and M.C. Newman. 1995. Sediment preference in the asiatic clam (*Corbicula fluminea*) and viviparid Snail (*Campeloma decisum*) as a response to low-level metal and metalloid contamination. Arch. Environ. Contam. Toxicol. 28(2): 195-202.

McClurg, T.P. 1984. Effects of fluoride, cadmium and mercury on the estuarine prawn *Penaeus indicus*. Water SA 10: 40.

McDonald, B.G., C.A. McPherson, R. DeWynter, P. Kickham and C. Brown. 2010. Incorporation of 28-d *Leptocheirus plumulosus* toxicity data in a sediment weight-of-evidence framework. Ecotoxicol. Environ. Saf. 73(1): 51-55.

McFarlane, G.A. and W.G. Franzin. 1977. Effects of elevated heavy metals on a natural population of white suckers, *Catostomus commersoni*, in Hamell Lake, Saskatchewan: near a base metal smelter at Flin Flon, Manitoba. Dep. of Fish. and the Environ., Freshw. Inst., Winnipeg, Manitoba, Canada, 20 p.

McFarlane, G.A. and W.G. Franzin. 1978. Elevated heavy metals: a stress on a population of white suckers, *Catostomus commersoni*, in Hamell Lake, Saskatchewan. J. Fish. Res. Board Can. 35: 963-970.

McGee, B.L., D.A. Wright and D.J. Fisher. 1998. Biotic factors modifying acute toxicity of aqueous cadmium to estuarine amphipod *Leptocheirus plumulosus*. Arch. Environ. Contam. Toxicol. 34: 34-40.

McGeer, J.C., R.C. Playle, C.M. Wood and F. Galvez. 2000. A physiologically based biotic ligand model for predicting the acute toxicity of waterborne silver to rainbow trout in freshwaters. Environ. Sci. Technol. 34: 4199-4207.

McGeer, J.C., K.V. Brix, J.M. Skeaff, D.K. DeForest, S.I. Brigham, W.J. Adams and A.S. Green. 2003. The inverse relationship between bioconcentration factor and exposure concentration for metals: Implications for hazard assessment of metals in the aquatic environment. Environ. Toxicol. Chem. 22(5): 1017-1037.

McGeer, J.C., S. Nadella, D.H. Alsop, L. Hollis, L.N. Taylor, D.G. McDonald and C.M. Wood. 2007. Influence of acclimation and cross-acclimation of metals on acute Cd toxicity and Cd uptake and distribution in rainbow trout (*Oncorhynchus mykiss*). Aquat. Toxicol. 84(2): 190-197.

McGeer, J.C., S. Niyogi and D. Smith. 2011. Cadmium. Fish Physiol. 31: 125-184.

McGeer, J.C., S. Niyogi and D.S. Smith. 2012. Cadmium. In: C.M. Wood, A.P. Farrell and C.J. Brauner (*Eds*.), Homeostasis and Toxicology of Non-Essential Metals. Fish Physiol. 31 (Part B): 125–184.

McHardy, B.M. and J.J. George. 1985. The uptake of selected heavy metals by the green alga *Cladophora glomerata*. In: J.Salanki (*Ed*.), Symp. Biol. Hung., 29: 3-19.

Mckee, M.J., G.B. Kromrey, T.W. May and C.E. Orazio. 2008. Contaminant levels in rainbow trout, *Oncorhynchus mykiss*, and their diets from Missouri coldwater hatcheries. Bull. Environ. Contam. Toxicol. 80(5): 450-454.

McKim, J.M. 1977. Evaluation of tests with early life stages of fish for predicting long-term toxicity. J. Fish. Res. Board Can. 34(8): 1148-1154.

McLean, J.E. and B.E. Bledsoe. 1992. Ground water issue: Behavior of metals in soils. U.S. EPA, Office of Research and Development, Office of Solid Waste and Emergency Response. EPA/540/S-92/018, 25pp.

McLean, M.W. and F.B. Williamson. 1977. Cadmium accumulation by marine red alga *Porphyra umbilicalis*. Physiol. Plant. 41: 268-272.

McLeese, D.W. 1981. Cadmium and marine invertebrates. Water Sci. Technol. 13: 1085-1086.

McLeese, D.W. and S. Ray. 1984. Uptake and excretion of cadmium, CdEDTA, and zinc by *Macoma balthica*. Bull. Environ. Contam. Toxicol. 32: 85.

McLeese, D.W. and S. Ray. 1986. Toxicity of $CdCl_2$, CdEDTA, $CuCl_2$, and CuEDTA to marine invertebrates. Bull. Environ. Contam. Toxicol. 36: 749-755.

McLeese, D.W., S. Ray and L.E. Burridge. 1981. Lack of excretion of cadmium from lobsters. Chemosphere 10: 775-778.

McNicol, R.E. 1997. The influence of environmental factors on the preference-avoidance responses of lake whitefish (*Coregonus clupeaformis*) to cadmium. Winnipeg, Manitoba, University of Manitoba, Ph.D. Thesis, 146 p.

McNicol, R.E. and E. Scherer. 1993. Influence of cadmium pre-exposure on the preference-avoidance responses of lake whitefish (*Coregonus clupeaformis*) to cadmium. Arch. Environ. Contam. Toxicol. 25: 36-40.

McNulty, E.W., F.J. Dwyer, M.R. Ellersieck, E.I. Greer, C.G. Ingersoll and C.F. Rabeni. 1999. Evaluation of ability of reference toxicity tests to identify stress in laboratory populations of the amphipod *Hyalella azteca*. Environ. Toxicol. Chem. 18(3): 544-548.

McPherson, R. and K. Brown. 2001. The bioaccumulation of cadmium by the blue swimmer crab *Portunus pelagicus* L. Sci. Total Environ. 279(1-3): 223-230.

McWilliam, R.A. and D.J. Baird. 2002. Postexposure feeding depression: A new toxicity endpoint for use in laboratory studies with *Daphnia magna*. Environ. Toxicol. Chem. 21(6): 1198-1205.

Meador, J.P. 1993. The effect of laboratory holding on the toxicity response of marine infaunal amphipods to cadmium and tributyltin. J. Exp. Mar. Biol. Ecol. 174: 227-242.

Meador, J.P., D.W. Ernest and A.N. Kagley. 2005. A comparison of the non-essential elements cadmium, mercury, and lead found in fish and sediment from Alaska and California. Sci. Total Environ. 339(1-3): 189-205.

Mebane, C.A. 2003. Development of site-specific water quality criteria for the segment of the South Fork Coeur d'Alene River from Daisy Gulch to Wallace, Idaho: Comparisons of cadmium criteria to the results toxicity testing with species resident to the South Fork Couer D'Alene River. Idaho Dep. of Environ. Qual., Boise, ID, 44 p.

Mebane, C.A. 2006. Cadmium risks to freshwater life: Derivation and validation of low-effect criteria values using laboratory and field studies. U.S. Geological Survey Scientific Investigation Report 2006-5245 (2010 rev.). Available online at: http://pubs.usgs.gov/sir/2006/5245/.

Mebane, C.A. 2010. Relevance of risk predictions derived from a chronic species sensitivity distribution with cadmium to aquatic populations and ecosystems. Risk Anal. 30(2): 203-223.

Mebane, C.A., D.P. Hennessy and F.S. Dillon. 2007. Developing acute-to-chronic toxicity ratios for lead, cadmium, and zinc using rainbow trout, a mayfly, and a midge. Water Air Soil Pollut. DOI 10.10007/s11270-007-9524-8.

Mebane, C.A., D.P. Hennessy and F.S. Dillon. 2008. Developing acute-to-chronic toxicity ratios for lead, cadmium, and zinc using rainbow trout, a mayfly, and a midge. Water Air Soil Pollut. 188(1-4): 41-66.

Mebane, C.A., D.P. Hennessy and F.S. Dillon. 2010. Incubating rainbow trout in soft water increased their later sensitivity to cadmium and zinc. Water Air Soil Pollut. 205(1-4): 245-250.

Mebane, C.A., F.S. Dillon and D.P. Hennessy. 2012. Acute toxicity of cadmium, lead, zinc, and their mixtures to stream-resident fish and invertebrates. Environ. Toxicol. Chem. 31(6): 1334-1348.

Mebane, C.A., T.S. Schmidt and L.S. Balistrieri. 2014. The cadmium paradox: Lethal to aquatic insects at low concentrations but moderated by zinc in ambient freshwater settings? [poster]. *in* Abstracts, Society of Environmental Toxicology and Chemistry North America, 33rd Annual Meeting, Vancouver, BC, Canada. http://vancouver.setac.org/.

Medina, M.F., A. Cosci, S. Cisint, C.A. Crespo, I. Ramos, A.L. Iruzubieta Villagra and S.N. Fernandez. 2012. Histopathological and biological studies of the effect of cadmium on *Rhinella arenarum* gonads. Tissue Cell 44(6): 418-426.

Megateli, S., S. Semsari and M. Couderchet. 2009. Toxicity and removal of heavy metals (cadmium, copper, and zinc) by *Lemna gibba*. Ecotoxicol. Environ. Saf. 72(6): 1774-1780.

Meinelt, T., R.C. Playle, M. Pietrock, B.K. Burnison, A. Wienke and C.E.W. Steinberg. 2001. Interaction of cadmium toxicity in embryos and larvae of zebrafish (*Danio rerio*) with calcium and humic substances. Aquat. Toxicol. 54(3/4): 205-215.

Mekkawy, I.A., U.M. Mahmoud, E.T. Wassif and M. Naguib. 2011. Effects of cadmium on some haematological and biochemical characteristics of *Oreochromis niloticus* (Linnaeus, 1758) dietary supplemented with tomato paste and vitamin E. Fish Physiol. Biochem. 37(1): 71-84.

Melgar, M.J., M. Perez, M.A. Garcia, J. Alonso and B. Miguez. 1997. Accumulation profiles in rainbow trout (*Oncorhynchus mykiss*) after short-term exposure to cadmium. J. Environ. Sci. Health. A32(3): 621-631.

Mellinger, P.J. 1972. The comparative metabolism of cadmium, mercury and zinc as environmental contaminants in the freshwater mussel, *Margaritifera margaritifera*. Ph.D. Thesis, Oregon State University, Corvallis, OR.

Menchaca, I., M.J. Belzunce, J. Franco, J.M. Garmendia, N. Montero and M. Revilla. 2010. Sensitivity comparison of laboratory-cultured and field-collected amphipod *Corophium multisetosum* in toxicity tests. Bull. Environ. Contam. Toxicol. 84(4): 390-394.

Mendez, N. and D.J. Baird. 2002. Effects of cadmium on sediment processing on members of the *Capitella* species-complex. Environ. Pollut. 120(2): 299-305.

Mendez, N. and C. Green-Ruiz. 2006. Cadmium and copper effects on larval development and mortality of the polychaete *Capitella sp.* Y from Estero del Yugo, Mazatlan, Mexico. Water Air Soil Pollut. 171: 291-299.

Mendez, N., and C. Green-Ruiz. 2005. Preliminary observations of cadmium and copper effects on juveniles of the polychaete *Capitella sp.* (Annelida: Polychaeta) from Estero del Yugo, Mazatlan, Mexico. Rev. Chilena Hist. Nat. 78(4): 701-710.

Mendoza-Cozatl, D., S. Devars, H. Loza-Tavera and R. Moreno-Sanchez. 2002. Cadmium accumulation in the chloroplast of *Euglena gracilis*. Physiol. Plant. 115(2): 276-283.

Merck. 1989. The Merck index: An encyclopedia of chemicals, drugs, and biologicals. Merck and Co. Inc., Rahway, NJ.

Merivirta, L.O., J. Nordlund and H.J. Korkeala. 2001. Cadmium, mercury and lead content of river lamprey caught in Finnish rivers. Arch. Lebensmittel. 52(3): 69-71.

Mersch, J., E. Morhain and C. Mouvet. 1993. Laboratory accumulation and depuration of copper and cadmium in the freshwater mussel *Dreissena polymorpha* and the aquatic moss *Rhynchostegium riparioides*. Chemosphere 27(8): 1475-1485.

Mersch, J., P. Wagner and J.C. Pihan. 1996. Copper in indigenous and transplanted zebra mussels in relation to changing water concentrations and body weight. Environ. Toxicol. Chem. 15(6): 886-893.

Messaoudi, I., S. Barhoumi, K. Saied and A. Kerken. 2009. Study on the sensitivity to cadmium of marine fish *Salaria basilisca* (Pisces: Blennidae). J. Environ. Sci. 21(11): 1620-1624.

Messiaen, M., K.A. De Schamphelaere, B.T. Muyssen and C.R. Janssen. 2010. The micro-evolutionary potential of *Daphnia magna* population exposed to temperature and cadmium stress. Ecotoxicol. Environ. Saf. 73(6): 1114-1122.

Messiaen, M., C.R. Janssen, O. Thas and K.A.C. De Schamphelaere. 2012. The potential for adaptation in a natural *Daphnia magna* population: Broad and narrow-sense heritability of net reproductive rate under Cd stress at two temperatures. Ecotoxicol. 21(7): 1899-1910.

Metayer, C., et al. 1982. Accumulation of some trace metals (cadmium, lead, copper and zinc) in sole (*Solea solea*) and flounder (*Platichthus flesus*): Changes as a function of age and organotropism. Rev. Int. Oceanogr. Med. 66-67: 33.

Metayer, C., J.C. Amiard, C. Amiard-Triquet and P. Elie. 1984. Evolution of the bioaccumulation of some trace elements in elvers and eels *Anguilla anguilla* of 3 estuaries of the Atlantic Ocean. Rev. Fr. Sci. Eau. 3(3): 249-258.

Metcalfe-Smith, J.L. 1994. Influence of species and sex on metal residues in freshwater mussels (family Unionidae) from the St. Lawrence River, with implications for biomonitoring programs. Environ. Toxicol. Chem. 13(9): 1433-1443.

Metcalfe-Smith, J.L., R.H. Green and L.C. Grapentine. 1996. Influence of biological factors on concentrations of metals in the tissues of freshwater mussels (*Elliptio complanata* and *Lampsilis radiata* Radiata) from the St. Lawrence River. Can. J. Fish. Aquat. Sci. 53(1): 205-219.

Meteyer, M.J., D.A. Wright and F.D. Martin. 1988. Effect of cadmium on early developmental stages of the sheepshead minnow (*Cyprinodon variegatus*). Environ. Toxicol. Chem. 7: 321-328.

Metian, M., M. Warnau, F. Oberhansli, J.L. Teyssie and P. Bustamante. 2007. Interspecific comparison of Cd bioaccumulation in European pectinidae (*Chlamys varia* and *Pecten maximus*). J. Exp. Mar. Biol. Ecol. 353(1): 58-67.

Metian, M., P. Bustamante, L. Hedouin and M. Warnau. 2008. Accumulation of nine metals and one metalloid in the tropical scallop *Comptopallium radula* from coral reefs in New Caledonia. Environ. Pollut. 152(3): 543-552.

Meyer, J.S. 1999. A mechanistic explanation for the ln(LC50) vs 1n(hardness) adjustment equation for metals. Environ. Sci. Technol. 33: 908-912.

Meyer, J.S., C.G. Ingersoll and L.L. McDonald. 1987. Sensitivity analysis of population growth rates estimated from cladoceran chronic toxicity tests. Environ. Toxicol. Chem. 6(2): 115-126.

Meyer, J.S., R.C. Santore, J.P. Bobbitt, L.D. Debrey, C.J. Boese, P.R. Paquin, H.E. Allen, H.L. Bergman and D.M. DiToro. 1999. Binding of nickel and copper to fish gills predicts toxicity when water hardness varies, but free-ion activity does not. Environ. Sci. Technol. 33: 913-916.

Meyer, J.S., S.J. Clearwater, T.A. Doser, M.J. Rogaczewski and J.A. Hansen. 2007. Effects of water chemistry on bioavailability and toxicity of waterborne cadmium, copper, nickel, lead, and zinc on freshwater organisms. SETAC Press, Pensacola, FL, 352 p.

Mhadhbi, L., M. Boumaiza and R. Beiras. 2010. A standard ecotoxicological bioassay using early life stages of the marine fish *Psetta maxima*. Aquat. Living Resour. 23(2): 209-216.

Miao, A.J. and W.X. Wang. 2006. Cadmium toxicity to two marine phytoplankton under different nutrient conditions. Aquat. Toxicol. 78(2): 114-126.

Miao, A.J., W.X. Wang and P. Juneau. 2005. Comparison of Cd, Cu, and Zn toxic effects on four marine phytoplankton by pulse-amplitude-modulated fluorometry. Environ. Toxicol. Chem. 24(10): 2603-2611.

Michibata, H., S. Sahara and M.K. Kojima. 1986. Effects of calcium and magnesium ions on the toxicity of cadmium to the egg of the teleost, *Oryzias latipes*. Environ. Res. 40: 110-114.

Michibata, H., Y. Nojima and M.K. Kojima. 1987. Stage sensitivity of eggs of the teleost *Oryzias latipes* to cadmium exposure. Environ. Res. 42: 321-327.

Middaugh, D.P. and J.M. Dean. 1977. Comparative sensitivity of eggs, larvae and adults of the estuarine teleosts, *Fundulus heteroclitus* and *Menidia menidia* to cadmium. Bull. Environ. Contam. Toxicol. 17: 645.

Middaugh, D.P. and G. Floyd. 1978. The effect of prehatch and posthatch exposure to cadmium on salinity tolerance of larval grass shrimp, *Palaemonetes pugio*. Estuaries 1: 123.

Middaugh, D.P., W.R. Davis and R.L. Yoakum. 1975. The response of larval fish *Leiostomus xanthurus* to environmental stress following sublethal cadmium exposure. Contrib. Mar. Sci. 19.

Migliarini, B., A.M. Campisi, F. Maradonna, C. Truzzi, A. Annibaldi, G. Scarponi and O. Carnevali. 2005. Effects of cadmium exposure on testis apoptosis in the marine teleost *Gobius niger*. Gen. Comp. Endocrinol. 142(1/2): 241-247.

Migliore, J. and M. De Nicola Giudici. 1988. Effect of heavy metals (Hg, Cd, Cu and Fe) on two species of crustacean isopods, *Asellus aquaticus* (L.) and *Proasellus coxalis* Dollf. Verh. Int. Ver. Theor. Angew. Limnol. 23: 1655-1659.

Milani, D., T.B. Reynoldson, U. Borgmann and J. Kolasa. 2003. The relative sensitivity of four benthic invertebrates to metals in spiked-sediment exposures and application to contaminated field sediment. Environ. Toxicol. Chem. 22(4): 845-854.

Mills, E.L., E.F. Roseman, M. Rutzke, W.H. Gutenmann and D.J. Lisk. 1993. Contaminant and nutrient element levels in soft tissues of zebra and quagga mussels from waters of southern Lake Ontario. Chemosphere 27(8): 1465-1473.

Millward, R.N., K.R. Carman, J.W. Fleeger, R.P. Gambrell and R. Portier. 2004. Mixtures of metals and hydrocarbons elicit complex responses by a benthic invertebrate community. J. Exp. Mar. Biol. Ecol. 310(1): 115-130.

Milne, J. 2010. The dynamics of chronically bioaccumulated Cd in rainbow trout (*Oncorhynchus mykiss*) during both moderately hard and soft waterborne exposures. M.S. Thesis, Wilfrid Laurier University, Canada.

Ministry of Technology. 1967. Water Pollut. Res. 1966. London. p. 50

Minnesota Department of Health (MNDH). 2014. Heavy metals in fertilizers. Available at: http://www.health.state.mn.us/divs/eh/risk/studies/metals.html

Mirenda, R.J. 1986. Toxicity and accumulation of cadmium in the crayfish, *Orconectes virilis* (Hagen). Arch. Environ. Contam. Toxicol. 15: 401-407.

Mirkes, D.Z., W.B. Vernberg and P.J. DeCoursey. 1978. Effects of cadmium and mercury on the behavioral responses and development of *Eurypanopeus depressus* larvae. Mar. Biol. 47: 143-147.

Mironova, A.P. and V.B. Andronikov. 1992. The effect of salts of heavy metals on embryos of the grass frog. Tsitologiya 34(8): 96-101.

Mishra, V.K. and B.D. Tripathi. 2008. Concurrent removal and accumulation of heavy metals by the three aquatic macrophytes. Bioresour. Technol. 99(15): 7091-7097.

Mishra, V., V. Pathak, B. Tripathi and V. Mishra. 2009. Accumulation of cadmium and copper from aqueous solutions using indian lotus (*Nelumbo nucifera*). Ambio 38(2): 110-112.

Misitano, D.A. and M.H. Schiewe. 1990. Effect of chemically contaminated marine sediment on naupliar production of the marine harpacticoid copepod, *Tigriopus californicus*. Bull. Environ. Contam. Toxicol. 44(4): 636-642.

Mitchell, D.G., J.D. Morgan, G.A. Vigers and P.M. Chapman. 1985. Acute toxicity of mine tailings to four marine species. Mar. Pollut. Bull. 16(11): 450-455.

Mitchelmore, C.L., E.A. Verde, A.H. Ringwood and V.M. Weis. 2003. Differential accumulation of heavy metals in the sea anemone *Anthopleura elegantissima* as a function of symbiotic state. Aquat. Toxicol. 64(3): 317-329.

Mitchelmore, C.L., E.A. Verde and V.M. Weis. 2007. Uptake and partitioning of copper and cadmium in the coral *Pocillopora damicornis*. Aquat.Toxicol. 85(1): 48-56.

Miyoshi, N., T. Kawano, M. Tanaka, T. Kadono, T. Kosaka, M. Kunimoto, T. Takahashi and H. Hosoya. 2003. Use of paramecium species in bioassays for environmental risk management: Determination of IC50 values for water pollutants. J. Health Sci. 49(6): 429-435.

Mizutani, A., E. Ifune, A. Zanella and C. Eriksen. 1991. Uptake of lead, cadmium and zinc by the fairy shrimp, *Branchinecta longiantenna* (Crustacea: Anostraca). Hydrobiol. 212: 145-149.

Mohammed, A. 2007. Comparative sensitivities of the tropical cladoceran, *Ceriodaphnia rigaudii* and the temperate species *Daphnia magna* to seven toxicants. Toxicol. Environ. Chem. 89(2): 347-352.

Mohammed, A. and J.B.R. Agard. 2006. Comparative sensitivity of three tropical cladoceran species (*Diaphanosoma brachyurum*, *Ceriodaphnia rigaudii* and *Moinodaphnia macleayi*) to six chemicals. J. Environ. Sci. Health 41A(12): 2713-2720.

Mohammed, M.H. and B. Markert. 2006. Toxicity of heavy metals on *Scenedesmus quadricauda* (Turp.) de Brebisson in batch cultures. Environ. Sci. Pollut. Res. 13(2): 98-104.

Mohan, C.V., T.R.C. Gupta, H.P.C. Shetty and N.R. Menon. 1986. Combined toxicity of mercury and cadmium to the tropical green mussel *Perna viridis*. Dis. Aquat. Org. 2(1): 65-72.

Mohlenberg, F. and A. Jensen. 1980. The ecotoxicology of cadmium in fresh and sea water and water pollution with cadmium in Denmark. The National Agency of Environmental Protection, Denmark. 48 pp.

Moller, V., V.E. Forbes and M.H. Depledge. 1994. Influence of acclimation and exposure temperature on the acute toxicity of cadmium to the freshwater snail *Potamopyrgus antipodarum* (Hydrobiidae). Environ. Toxicol. Chem. 13(9): 1519-1524.

Monahan, T.J. 1976. Effects of cadmium on the growth and morphology of *Scenedesmus obtusuisculus*. J. Phycol. 12(Suppl.): 98.

Mondal, S. 1997. Pesticides and heavy metals influence steroidogenic activity in fish gonad and interrenal. Ph.D. Thesis, Visva Bharati University, Santiniketan, India.

Mondon, J.A., S. Duda and B.F. Nowak. 2001. Histological, growth and 7-ethoxyresorufin o-deethylase (EROD) activity responses of greenback flounder *Rhombosolea tapirina* to contaminated marine sediment and diet. Aquat. Toxicol. 54(3/4): 231-247.

Monteiro-Neto, C., R.V. Itavo and L.E.U. Moraes. 2003. Concentrations of heavy metals in *Sotalia fluviatilis* (Cetacea: Delphinidae) off the coast of Ceara, northeast Brazil. Environ. Pollut. 123(2): 319-324.

Moolman, L., J.H.J. Van Vuren and V. Wepener. 2007. Comparative studies on the uptake and effects of cadmium and zinc on the cellular energy allocation of two freshwater gastropods. Ecotoxicol. Environ. Saf. 68(3): 443-450.

Moore, M.N. and A.R.D. Stebbing. 1976. The quantitative cytochemical effects of three metal ions on a lysosomal hydrolase of a hydroid. J. Mar. Biol. Assoc. U.K. 56: 995.

Moraitou-Apostolopoulou, M. and G. Verriopoulos. 1982. Individual and combined toxicity of three heavy metals copper cadmium and chromium for the marine copepod *Tisbe holothuriae*. Hydrobiologia. 87(1): 83-88.

Moraitou-Apostolopoulou, M., G. Verriopoulos and P. Lentzou. 1979. Effects of sublethal concentrations of cadmium pollution for two populations of *Acartis clausi* (Copepoda) living at two differently polluted areas. Bull. Environ. Contam. Toxicol. 23: 642-649.

Morales-Hernandez, F., M.F. Soto Jimenez and F. Paez Osuna. 2004. Heavy metals in sediments and lobster (*Panulirus gracilis*) from the discharge area of the submarine sewage outfall in Mazatlan Bay (SE Gulf of California). Arch. Environ. Contam. Toxicol. 46(4): 485-491.

Morel, F.M.M. and J.G. Hering. 1993. Principals and applications of aquatic chemistry. J. Wiley, NY, 588 pp.

Moreno, P.A.R., D.A. Medesani and E.M. Rodriguez. 2003. Inhibition of molting by cadmium in the crab *Chasmagnathus granulata* (Decapoda Brachyura). Aquat. Toxicol. 64(2): 155-164.

Morgan, W.S.G. 1979. Fish locomotor behavior patterns as a monitoring tool. J. Water Pollut. Control Fed. 51: 580.

Mori, K.1979. Effects of Hg and Cd upon the eggs and fry of goldfish, *Carassius auratus* (Linnaeus). Bull. Fac. Agric. Meiji Univ. 6: 173-180.

Mori, M. and M. Wakabayashi. 1996. Cells in culture for the evaluation of the toxicity of chemicals. 1. Cytotoxicity of cadmium and copper to CHSE-214 cells derived from chinook salmon. Tokyo-to Kankyo Kagaku Kenkyusho Nenpo: 72-79.

Mori, M. and M. Wakabayashi. 1997. Cells in culture for the evaluation of the toxicity of chemicals. 2. Cytotoxicity of metals toward cultured fish cells and effect of exposure temperature on cytotoxicity. Tokyo-to Kankyo Kagaku Kenkyusho Nenpo: 134-142.

Morillo-Velarde, P.S., J. Lloret, A. Marin and F.J. Sanchez-Vazquez. 2011. Effects of cadmium on locomotor activity rhythms of the amphipod *Gammarus aequicauda*. Arch. Environ. Contam. Toxicol. 60(3): 444-451.

Morin, B., J. Filatreau, L. Vicquelin, I. Barjhoux, S. Guinel, J. Leray-Forget and J. Cachot. 2011. Detection of DNA damage in yolk-sac larvae of the Japanese medaka, *Oryzias latipes*, by the comet assay. Anal. Bioanal. Chem. 399(6): 2235-2242.

Morley, N.J., M. Crane and J.W. Lewis. 2002. Toxicity of cadmium and zinc mixtures to *Diplostomum spathaceum* (Trematoda: Diplostomidae) cercarial survival. Arch. Environ. Contam. Toxicol. 43(1): 28-33.

Morley, N.J., M. Crane and J.W. Lewis. 2005. Toxicity of cadmium and zinc mixtures to cercarial tail loss in *Diplostomum spathaceum* (Trematoda: Diplostomidae). Ecotoxicol. Environ. Saf. 60(1): 53-60.

Mormede, S. and I.M. Davies. 2001. Heavy metal concentrations in commercial deep-sea fish from the Rockall Trough. Cont. Shelf Res. 21(8-10): 899-916.

Morris, D.D. 1973. Toxicity of cyanide, chromium, cadmium, copper, lead, nickel, and zinc. Summary Report. Unpublished report, 46 p.

Morrison, P.F., J.F. Leatherland and R.A. Sonstegard. 1985. Proximate composition and organochlorine and heavy metal contamination of eggs from Lake Ontario, Lake Erie and Lake Michigan coho salmon (*Oncorhynchus kisutch* Walbaum) in relation to egg survival. Aquat. Toxicol. 6: 73-86.

Morrow, H. 2001. Cadmium and cadmium alloys. In: Kirk-Othmer encyclopedia of chemical technology. John Wiley & Sons, Inc., pp. 471-507.

Mostafa, L.Y. and Z. Khalil. 1986. Uptake, release and incorporation of radio active cadmium and mercury by the fresh water alga *Phormidium fragile*. Isot. Rad. Res. 18(1): 57-62.

Motohashi, K. and T. Tsuchida. 1974. Uptake of cadmium by pure cultured diatom, *Skeletonema costatum*. Bull. Plankton. Soc. Japan 21(1): 55-59.

Mouchet, F., L. Gauthier, M. Baudrimont, P. Gonzalez, C. Mailhes, V. Ferrier and A. Devaux. 2007. Comparative evaluation of the toxicity and genotoxicity of cadmium in amphibian larvae (*Xenopus laevis* and *Pleurodeles waltl*) using the comet assay and the micronucleus test. Environ. Toxicol. 22(4): 422-435.

Mouneyrac, C., C. Amiard-Triquet, J.C. Amiard and P.S. Rainbow. 2001. Comparison of metallothionein concentrations and tissue distribution of trace metals in crabs (*Pachygrapsus marmoratus*) from a metal-rich estuary, in and out of the reproductive season. Comp. Biochem. Physiol. C. 129(3): 193-209.

Mount, D.I. and T.J. Norberg. 1984. A seven-day life-cycle cladoceran toxicity test. Environ. Toxicol. Chem. 3: 425.

Mount, D.R., A.K. Barth, T.D. Garrison, D.A. Barten and J.R. Hockett. 1994. Dietary and waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium, lead and zinc using a live diet. Environ. Toxicol. Chem. 13(12): 2031-2041.

Moureaux, C., J. Simon, G. Mannaerts, A.I. Catarino, P. Pernet and P. Dubois. 2011. Effects of field contamination by metals (Cd, Cu, Pb, Zn) on biometry and mechanics of echinoderm ossicles. Aquat Toxicol 105(3-4): 698-707.

Moyer, A.T. 2012. The effects of cadmium exposure on the activity of *Rana sphenocephala* tadpoles from two Oklahoma populations. M.S. Thesis, Oklahoma State University, Stillwater, OK.

Moza, U., S.S. De Solva and B.M. Mitchell. 1995. Effect of sub-lethal concentrations of cadmium on food intake, growth and digestibility in the gold fish, *Carassius auratus* L. J. Environ. Biol. 16(3): 253-264.

Mubiana, V.K. and R. Blust. 2007. Effects of temperature on scope for growth and accumulation of Cd, Co, Cu and Pb by the marine bivalve *Mytilus edulis*. Mar. Environ. Res. 63(3): 219-235.

Mueller, G. and F. Prosi. 1978. Distribution of zinc, copper, and cadmium in various organs of roaches (*Rutilus rutilus* L.) from the Neckar and Elsenz Rivers. Z. Naturforsch Sect. C Biosci. 33(1-2): 7-14.

Muino, C.V., L. Ferrari and A. Salibian. 1990. Protective action of ions against cadmium toxicity to young *Bufo arenarum* tadpoles. Bull. Environ. Contam. Toxicol. 45: 313-319.

Mullaugh, K.M. and G.W. Luther III. 2009. Formation and persistence of cadmium sulfide nanoparticle in aqueous solution. Ph.D. Thesis, University of Delaware, Newark, DE.

Muller, K.W. and H.D. Payer. 1979. The influence of pH on the cadmium-repressed growth of the alga *Coelostrum proboscideum*. Physiol. Plant. 45: 415.

Muller, K.W. and H.D. Payer. 1980. The influence of zinc and light conditions on the cadmium-repressed growth of the green alga *Coelostrum proboscideum*. Physiol. Plant. 50: 265.

Munawar, M. and M. Legner. 1993. Detection of metal toxicity using natural phytoplankton as test organisms in the Great Lakes. Water Pollut. Res. J. Can. 28(1): 155-176.

Muncke, J.I. 2006. Molecular scale ecotoxicological testing in developing zebrafish (*Danio rerio*). Ph.D. Thesis, Eidgenoessische Technische Hochschule Zuerich, Switzerland.

Munger, C. and L. Hare. 1997. Relative importance of water and food as cadmium sources to an aquatic insect (*Chaoborus punctipennis*): Implications for predicting Cd bioaccumulation in nature. Environ. Sci. Technol. 31: 891-895.

Munger, C., L. Hare, A. Craig and P.M. Charest. 1999. Influence of exposure time on the distribution of cadmium within the cladoceran *Ceriodaphnia dubia*. Aquat. Toxicol. 44(3): 195-200.

Muramoto, S. 1980. Decrease in cadmium concentration in a Cd-contaminated fish by short-term exposure to EDTA. Bull. Environ. Contam. Toxicol. 25: 828.

Musko, I.B., W. Meinel, R. Krause and M. Barlas. 1990. The impact of Cd and different pH on the amphipod *Gammarus fossarum* Koch (Crustacea: amphipoda). Comp. Biochem. Physiol. 96C(1): 11-16.

Musthafa, M.S., S. Shajithanoop, A. Paneerselvam and A.S. Bukhari. 2009. Bioaccumulation of cadmium in selected tissues of *Oreochromis mossambicus* exposed to sublethal concentrations of cadmium chloride. Asian J. Exp. Sci. 23(3): 511-518.

Muyssen, B.T.A. and C.R. Janssen. 2004. Multi-generation cadmium acclimation and tolerance in *Daphnia magna* Straus. Environ. Pollut. 130(3): 309-316.

Muyssen, B.T., M. Messiaen and C.R. Janssen. 2010. Combined cadmium and temperature acclimation in *Daphnia magna*: Physiological and sub-cellular effects. Ecotoxicol. Environ. Saf. 73(5): 735-742.

Mwangi, S.M. and M.A. Alikhan. 1993. Cadmium and nickel uptake by tissues of *Cambarus bartoni* (Astacidae, Decapoda, Crustacea): Effects on copper and zinc stores. Water Res. 27(5): 921-927.

Mwashote, B.M. 2003. Levels of cadmium and lead in water, sediments and selected fish species in Mombasa, Kenya. West. Indian Ocean J. Mar. Sci. 2(1): 25-34.

Mysing-Gubala, M. and M.A. Poirrier. 1979. The effects of cadmium and mercury upon survival, gemmulation and gemmosclere morphology in the freshwater sponge, *Ephydatia fluviatilis*. ASB Bull. 82

Nacci, D., E. Jackim and R. Walsh. 1986. Comparative evaluation of three rapid marine toxicity tests: Sea urchin early embryo growth test, sea urchin sperm cell toxicity test and Microtox. Environ. Toxicol. Chem. 5: 521-525.

Nacorda, J.O., M.R. Martinez-Goss, N.K. Torreta and F.E. Merca. 2007. Metal resistance and removal by two strains of the green alga, *Chlorella vulgaris* Beijerinck, isolated from Laguna de Bay, Philippines. J. Appl. Phycol. 19: 701-710.

Nadella, S.R., J.L. Fitzpatrick, N. Franklin., C. Bucking, S. Smith and C.M. Wood. 2009. Toxicity of dissolved Cu, Zn, Ni and Cd to developing embryos of the blue mussel (*Mytilus trossolus*) and the protective effect of dissolved organic carbon. Comp. Biochem. Physiol. 149C(3): 340-348.

Nagel, K. and J. Voigt. 1995. Impaired photosynthesis in a cadmium-tolerant *Chlamydomonas* mutant strain. Microbiol. Res. 150: 105-110.

Nair, P.M.G. and J. Choi. 2011. Identification, characterization and expression profiles of *Chironomus riparius* glutathione S-transferase (GST) genes in response to cadmium and silver nanoparticles exposure. Aquat. Toxicol. 101(3/4): 550-560.

Nair, P.M. and J. Choi. 2012. Effects of cadmium chloride and nonylphenol on the expression of star-related lipid transfer domain containing protein (Start1) gene in aquatic midge, *Chironomus riparius*. Comp. Biochem. Physiol. 155C(2): 369-374.

Nair, P.M.G., S.Y. Park and J. Choi. 2011. Expression of catalase and glutathione S-transferase genes in *Chironomus riparius* on exposure to cadmium and nonylphenol. Comp. Biochem. Physiol.154C(4): 399-408.

Najeeb, U., G. Jilani, S. Ali, M. Sarwar, L. Xu and W. Zhou. 2011. Insights into cadmium induced physiological and ultra-structural disorders in *Juncus effusus* L. and its remediation through exogenous citric acid. J. Hazard. Mater. 186(1): 565-574.

Nakagawa, H. and S. Ishio. 1988. Aspects of accumulation of cadmium ion in the egg of medaka *Oryzias latipes*. Bull. Japan. Soc. Sci. Fish. 54(12): 2159-2164.

Nakagawa, H. and S. Ishio. 1989. Effects of water hardness on the toxicity and accumulation of cadmium in eggs and larvae of medaka *Oryzias latipes*. Bull. Japan. Soc. Sci. Fish. 55(2): 327-331.

Nakamoto, R.J. and T.J. Hassler. 1992. Selenium and other trace elements in bluegills from agricultural return flows in the San Joaquin Valley, California. Arch. Environ. Contam. Toxicol. 22(1): 88-98.

Nakamura, M. 1974. Experimental studies on the accumulation of cadmium in the fish body. Japan. J. Public Health 21(16): 321-327.

Nakano, Y. 1980. Chloroplast replication in *Euglena gracilis* grown in cadmium ion containing media. Agric. Biol. Chem. 44: 2733.

Nakano, Y., K. Abe and S. Toda. 1980. Morphological observation on *Euglena gracilis* grown in zinc-sufficient media containing cadmium ions. Agric. Biol. Chem. 44(10): 2305-2316.

Nakhle, K., D. Cossa, D. Claisse, B. Beliaeff and S. Simon. 2007. Cadmium and mercury in Seine Estuary flounders and mussels: The results of two decades of monitoring. ICES J. Mar. Sci. 64(5): 929-938.

Nalecz-Jawecki, G. and J. Sawicki. 1998. Toxicity of inorganic compounds in the spirotox test: A miniaturized version of the *Spirostomum ambiguum* test. Arch. Environ. Contam. Toxicol. 34: 1-5.

Nalecz-Jawecki, G. and J. Sawicki. 2005. Influence of water hardness on the toxicity of selected pharmaceuticals and metals to the protozoa *Spirostomum ambiguum* and *Tetrahymena termophila*. Fresenius Environ. Bull. 14(10): 873-877.

Nalecz-Jawecki, G., K. Demkowicz-Dobrzanski and J. Sawicki. 1993. Protozoan *Spirostomum ambiguum* as a highly sensitive bioindicator for rapid and easy determination of water quality. Sci. Total Environ. Supplemental Part 2: 1227-1234.

Nalewajko, C. 1995. Effects of cadmium and metal-contaminated sediments on photosynthesis heterotrophy, and phosphate uptake in Mackenzie River delta phytoplankton. Chemosphere 30(7): 1401-1414.

Nandini, S., D.D.J. Chaparro-Herrera, S.L. Cárdenas-Arriola and S.S.S. Sarma. 2007. Population growth of *Brachionus macracanthus* (Rotifera) in relation to cadmium toxicity: Influence of algal (*Chlorella vulgaris*) density. J. Environ. Sci. Health 42A(10): 1467-1472.

Naqvi, S.M. and R.D. Howell. 1993. Toxicity of cadmium and lead to juvenile red swamp crayfish, *Procambarus clarkii*, and effects on fecundity of adults. Bull. Environ. Contam. Toxicol. 51: 303-308.

Narayanan, K.R., P.S. Lyla and S.A. Khan. 1999. Pattern of depuration of accumulated heavy metals in the mud crab, *Scylla serrata* (Forskal). J. Environ. Biol. 20(3): 213-216..

Narvaez, N., C. Lodeiros, O. Nusetti, M. Lemus and A.N. Maeda-Martinez. 2005. Uptake, depuration and effect of cadmium on the green mussel *Perna viridis* (L. 1758) (Mollusca: Bivalvia). Cienc. Mar. 31(1A): 91-102.

Nassiri, Y., J. Wery, J.L. Mansot and T. Ginsburger-Vogel. 1997. Cadmium bioaccumulation in *Tetraselmis suecica* and electron energy loss spectroscopy (EELS) study. Arch. Environ. Contam. Toxicol. 33: 156-161.

Nasu, Y., M. Kugimoto, O. Tanaka and A. Takimoto. 1983. Comparative studies on the absorption of cadmium and copper in *Lemna paucicostata*. Environ. Pollut. (Series A) 32(3): 201-209.

Nasu, Y., K. Hirabayashi and M. Kugimoto. 1988. The toxicity of some water pollutants for Lemnaceae (duckweed) plant. Proc. ICMR Semin. 8: 485-491.

National Research Council (NRC). 2005. Mineral tolerance in animals. Second Revised Edition. Committee on Minerals and Toxic Substances in Diets and Water for Animals, National Academies Press. 496 pages.

National Research Council (NRC). 2008. Urban stormwater management in the United States. The National Academies Press. Washington, D.C.

Naumann, B., M. Eberius and K.J. Appenroth. 2007. Growth rate based dose-response relationships and EC-values of ten heavy metals using the duckweed growth inhibition test (ISO 20079) with *Lemna minor* L. Clone St. J. Plant Physiol. 164(12): 1656-1664.

Nawaz, M., C. Manzl and G. Krumschnabel. 2005. In vitro toxicity of copper, cadmium, and chromium to isolated hepatocytes from carp, *Cyprinus carpio* L. Bull. Environ. Contam. Toxicol. 75(4): 652-661.

Nawaz, S., S.A. Nagra, Y. Saleem and A. Priyadarshi. 2010. Determination of heavy metals in fresh water fish species of the River Ravi, Pakistan compared to farmed fish varieties. Environ. Monit. Assess. 167(1-4): 461-71.

Naylor, C., E.J. Cox, M.C. Bradley and P. Calow. 1992. Effect of differing maternal food ration on susceptibility of *Daphnia magna* Straus neonates to toxic substances. Aquat. Toxicol. 24: 75-82.

Nebeker, A.V., G.S. Schuytema and S.L. Ott. 1994. Effects of cadmium on limb regeneration in the northwestern salamander *Ambystoma gracile*. Arch. Environ. Contam. Toxicol. 27: 318-322.

Nebeker, A.V., G.S. Schuytema and S.L. Ott. 1995. Effects of cadmium on growth and bioaccumulation in the northwestern salamander *Ambystoma gracile*. Arch. Environ. Contam. Toxicol. 29: 492-499.

Nebeker, A.V., M.A. Cairns, S.T. Onjukka and R.H. Titus. 1986a. Effect of age on sensitivity of *Daphnia magna* to cadmium, copper and cyanazine. Environ. Toxicol. Chem. 5: 527-530.

Nebeker, A.V., S.T. Onjukka, M.A. Cairns and D.F. Krawczyk. 1986b. Survival of *Daphnia magna* and *Hyalella azteca* in cadmium-spiked water and sediment. Environ. Toxicol. Chem. 5: 933-938.

Neff, J.M. 2002. Bioaccumulation in marine organisms: Effect of contaminants from oil well produced water. Elsevier. New York, NY.

Negilski, D.S. 1976. Acute toxicity of zinc, cadmium and chromium to the marine fishes, yellow-eye mullet (*Aldrichetta forsteri* C. and V.) and smallmouth hardy head (*Atherinasoma microstoma* Whitley). Aust. J. Mar. Freshwater Res. 27: 137.

Negri, A., K. Burns, S. Boyle, D. Brinkman and N. Webster. 2006. Contamination in sediments, bivalves and sponges of McMurdo Sound, Antarctica. Environ. Pollut. 143: 456-467.

Nelson, D.A., A. Calabrese, B.A. Nelson, J.R. MacInnes and D.R. Wenzloff. 1976. Biological effects of heavy metals on juvenile bay scallops, *Argopecten irradians*, in short-term exposures. Bull. Environ. Contam. Toxicol. 16(3): 275-282.

Nelson, D.A., J.E. Miller and A. Calabrese. 1988. Effect of heavy metals on bay scallops, surf clams, and blue mussels in acute and long-term exposures. Arch. Environ. Contam. Toxicol. 17: 595-600.

Nelson, S.M. 1994. Observed field tolerance of caddisfly larvae (*Hesperophylax sp.*) to fish metal concentrations and low pH. J. Freshwater Ecol. 9(2): 169-170.

Nelson, S.M. and R.A. Roline. 1998. Evaluation of the sensitivity of rapid toxicity tests relative to daphnid acute lethality tests. Bull. Environ. Contam. Toxicol. 60: 292-299.

Nendza, M., T. Herbst, C. Kussatz and A. Gies. 1997. Potential for secondary poisoning and biomagnification in marine organisms. Chemosphere 35(9): 1875-1885.

Nessim, R.B., A.R. Bassiouny, H.R. Zaki, M.N. Moawad and K.M. Kandeel. 2011. Biosorption of lead and cadmium using marine algae. Chem. Ecol. 27(6): 579-594.

Nesto, N., S. Romano, V. Moschino, M. Mauri and L. Da Ros. 2007. Bioaccumulation and biomarker responses of trace metals and micro-organic pollutants in mussels and fish from the Lagoon of Venice, Italy. Mar. Pollut. Bull. 55: 469-484.

Neter, J. and W. Wasserman. 1974. Applied linear statistical models. Irwin, Inc., Homewood, IL.

Neuberger-Cywiak, L., Y. Achituv and E.M. Garcia. 2003. Effects of zinc and cadmium on the burrowing behavior, LC50, and LT50 on *Donax trunculus* Linnaeus (Bivalvia-Donacidae). Bull. Environ. Contam. Toxicol. 70(4): 713-722.

Neuberger-Cywiak, L., Y. Achituv and E.M. Garcia. 2005. Sublethal effects of Zn++ and Cd++ on respiration rate, ammonia excretion, and O:N ratio of *Donax trunculus* (Bivalvia; Donacidae). Bull. Environ. Contam. Toxicol. 75(3): 505-514.

Neuberger-Cywiak, L., Y. Achituv and E.M. Garcia. 2007. Effects of sublethal Zn++ and Cd++ concentrations on filtration rate, absorption efficiency and scope for growth in *Donax trunculus* (Bivalvia; Donacidae). Bull. Environ. Contam. Toxicol. 79(6): 622-627.

Neumann, M. and S. Leimkuhler. 2008. Heavy metal ions inhibit molybdoenzyme activity by binding to the dithiolene moiety of molybdopterin in *Escherichia coli*. FEBS J. 275(22): 5678-5689.

New Hampshire Department of Environmental Services (NHDES). 2008. Hardness in drinking water. Environmental Fact Sheet WD-DWGB-3-6, New Hampshire Department of Environmental Services, Concord, NH.

Ney, J.J. and M.G. Martin. 1985. Influence of prefreezing on heavy metal concentrations in bluegill sunfish. Water Res. 19(7): 905-907.

Ney, J.J., M.G. Martin and J.M. Mudre. 1982. Patterns of bioaccumulation of heavy metals in stream fishes. Va. J. Sci. 33(3): 116.

Ng, T.Y.T. and W.X. Wang. 2004. Detoxification and effects of Ag, Cd, and Zn pre-exposure on metal uptake kinetics in the clam *Ruditapes philippinarum*. Mar. Ecol. Prog. Ser. 268: 161-172.

Ng T.Y.T. and W.X. Wang. 2005. Modeling of cadmium bioaccumulation in two populations of the green mussel *Perna viridis*. Environ. Toxicol. Chem. 24(9): 2299-2305.

Ng, T.Y.T. and W.X. Wang. 2007. Interactions of silver, cadmium, and copper accumulation in green mussels (*Perna viridis*). Environ. Toxicol. Chem. 26(8): 1764-1769.

Ng, T.Y.T. and C.M. Wood. 2008. Trophic transfer and dietary toxicity of Cd from the oligochaete to the rainbow trout. Aquat. Toxicol. 87(1): 47-59.

Ng, T.Y., J.S. Klinck and C.M. Wood. 2009. Does dietary Ca protect against toxicity of a low dietborne Cd exposure to the rainbow trout? Aquat. Toxicol. 91(1): 75-86.

Ng, T.Y.T, C.Y. Chuang, I. Stupakoff, A.E. Christy, D.P. Cheney and W.X. Wang. 2010. Cadmium accumulation and loss in the pacific oyster *Crassostrea gigas* along the west coast of the USA. Mar. Ecol. Prog. Ser. 401: 147-160.

Ngo, H.T.T., S. Gerstmann and H. Frank. 2009. Toxicity of cadmium to the green alga *Parachlorella kessleri*: Producing Cd-loaded algae for feeding experiments. Toxicol. Environ. Chem. 91(2): 279-288.

Nguyen, L.T.H. and C.R. Janssen. 2001. Comparative sensitivity of embryo-larval toxicity assays with African catfish (*Clarias gariepinus*) and zebra fish (*Danio rerio*). Environ. Toxicol. 16(6): 566-571.

Nguyen, L.T.H. and C.R. Janssen. 2002. Embryo-larval toxicity tests with the African catfish (*Clarias gariepinus*): Comparative sensitivity of endpoints. Arch. Environ. Contam. Toxicol. 42(2): 256-262.

Ni, I.H., S.M. Chan and W.X. Wang. 2005. Influences of salinity on the biokinetics of Cd, Se, and Zn in the intertidal mudskipper *Periophthalmus cantonensis*. Chemosphere 61(11): 1607-1617.

Niederlehner, B. 1984. A comparison of techniques for estimating the hazard of chemicals in the aquatic environment. M.S. thesis. Virginia Polytechnic Institute and State University.

Niederlehner, B.R., A.L. Buikema Jr., C.A. Pittinger and J. Cairns Jr. 1984. Effects of cadmium on the population growth of a benthic invertebrate *Aeolosoma headleyi* (Oligochaeta)/ Environ. Toxicol. Chem. 3: 255-262.

Niederlehner, B.R., J.R. Pratt, A.L. Buikema Jr. and J. Cairns Jr. 1985. Laboratory test evaluating the effects of cadmium on freshwater protozoan communities. Environ. Toxicol. Chem. 4(2): 155-165.

Nilsson, R. 1970. Aspects on the toxicity of cadmium and its compounds: A review. Ecol. Res. Comm. Bull. 7, Swed. Natur. Sci. Res. Council. Stockholm. 49 pp.

Nimick, D.A., D.D. Harper, A.M. Farag, T.E. Cleasby, E. MacConnell and D. Skaar. 2007. Influence of in-stream diet concentration cycles of dissolved trace metals on acute toxicity to one-year-old cutthroat trout (*Oncorhynchus clarki* Lewisi). Environ. Toxicol. Chem. 26(12): 2667-2678.

Nimmo, D.R. 1978. Cadmium. Feb.14th Letter to C.Stephan, U.S.EPA, Duluth, MN, from D.R.Nimmo, U.S. EPA, Gulf Breeze, FL, 2 p.

Nimmo, D.R., L.H. Bahner. R.A. Rigby, J.M Sheppard and A.J. Wilson Jr. 1977a. *Mysidopsis bahia*: An estuarine species suitable for life-cycle toxicity tests to determine the effects of a pollutant. In: F.L. Mayer and J.L. Hamelink (*Eds*.), Aquatic Toxicology and Hazard Evaluation. ASTM STP 634. American Society for Testing and Materials, Philadelphia, PA. p. 109.

Nimmo, D.R., D. Lightner and L. Bahner. 1977b. Effects of cadmium on the shrimps *Penaeus duorarum*, *Palaemonetes pugio*, and *Palaemonetes vulgaris*. *In:* F.J. Vernberg, et al. (eds.), Physiological Responses of Marine Biota to Pollutants. Academic Press, New York. p. 131.

Nimmo, D.R., M.H. Dodson, P.H. Davies, J.C. Greene and M.A. Kerr. 1990. Three studies using *Ceriodaphnia* to detect nonpoint sources of metals from mine drainage. Res. J. Water Pollut. Control Fed. 62: 7-15.

Nimmo, D.W.R., S.J. Herrmann, J.A. Romine, K.W. Meyer, R.W. Johnson, P.H. Davies, D.L. Hansen and S.F. Brinkman. 2006. Cadmium and zinc accumulation in aquatic bryophytes immersed in the Arkansas River, Colorado: Comparison of fall versus spring. J. Freshwat. Ecol. 21(2): 331-339.

Nir, R., A. Gasith and A.S. Perry. 1990. Cadmium uptake and toxicity to water hyacinth: Effect of repeated exposures under controlled conditions. Bull. Environ. Contam. Toxicol. 44: 149-157.

Nishikawa, K. and N. Tominaga. 2001. Isolation, growth, ultrastructure, and metal tolerance of the green alga, *Chlamydomonas acidophila* (Chlorophyta). Biosci. Biotechnol. Biochem. 65(12): 2650-2656.

Niyogi, S. and C.M. Wood. 2003. Effects of chronic waterborne and dietary metal exposures on gill metal-binding: Implications for the biotic ligand model. Hum. Ecol. Risk Assess. 9(4): 813-846.

Niyogi, S., C.M. Wood and S. Niyogi. 2004a. Kinetic analyses of waterborne Ca and Cd transport and their interactions in the gills of rainbow trout (*Oncorhynchus mykiss*) and yellow perch (*Perca flavescens*), two species differing greatly in acute waterborne Cd sensitivity. J. Comp. Physiol. B 174(3): 243-253.

Niyogi, S., P. Couture, G. Pyle, D.G. McDonald and C.M. Wood. 2004b. Acute cadmium biotic ligand model characteristics of laboratory-reared and wild yellow perch (*Perca flavescens*) relative to rainbow trout (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 61(6): 942-953.

Niyogi, S., R. Kent and C.M. Wood. 2008. Effects of water chemistry variables on gill binding and acute toxicity of cadmium in rainbow trout (*Oncorhynchus mykiss*): A biotic ligand model (BLM) approach. Comp. Biochem. Physiol. C 148: 305-314.

Noel-Lambot, F., C. Gerday and A. Disteche. 1978. Distribution of Cd, Zn and Cu in liver and gills of the eel *Anguilla anguilla* with special reference to metallothioneins. Comp. Biochem. Physiol. 61C(1): 177-187.

Noel-Lambot, F., J.M. Bouquegneau, F. Frankenne and A. Disteche. 1980. Cadmium, zinc, and copper accumulation in limpets (*Patella vulgata*) from the British channel and special reference to metallothioneins. Mar. Ecol. Prog. Ser. 2: 81-89.

Nolan, C.V. and E.J. Duke. 1983. Cadmium accumulation and toxicity in *Mytilus edulis*: Involvement of metallothioneins and heavy molecular weight protein. Aquat. Toxicol. 4: 153.

Noraho, N. and J.P. Gaur. 1995. Effect of cations, including heavy metals, on cadmium uptake by *Lemna polyrhiza* L. BioMetals. 8: 95-98.

Norberg-King, T. and D. Mount. 1986. Validity of effluent and ambient toxicity tests for predicting biological impact, Skeleton Creek, Enid, Oklahoma. Environmental Research Laboratory, Office of Research and Development, U.S. EPA. Duluth, MN. EPA/600/8-86/002.

Norberg-King, T.J., P.K. Sibley, G.A. Burton, C.G. Ingersoll, N.E. Kemble, S. Ireland, D.R. Mount and C.D. Rowland. 2006. Interlaboratory evaluation of *Hyalella azteca* and *Chironomus tentans* short-term and long-term sediment toxicity tests. Environ. Toxicol. Chem. 25(10): 2662-2674.

Nordberg, G.F. 2009. Historical perspectives on cadmium toxicology. Toxicol. Appl. Pharmacol. 238(3): 192-200.

Nordberg, G.F., K. Nogawa, M. Nordberg and L.T. Friberg. 2007. Cadmium: Handbook on the toxicology of metals (third edition). G.F. Nordberg, B.A. Fowler, M. Nordberg and L.T. Friberg (*Eds.*). Burlington, Academic Press.

Norey, C.G., M.W. Brown, A. Cryer and J. Kay. 1990a. A comparison of the accumulation, tissue distribution and secretion of cadmium in different species of freshwater fish. Comp. Biochem. Physiol. 96C(1): 181-184.

Norey, C.G., A. Cryer and J. Kay. 1990b. Cadmium uptake and sequestration in the pike (*Esox lucius*). Comp. Biochem. Physiol. 95C(2): 217-221.

Norey, C.G., A. Cryer and J. Kay. 1990c. Induction of metallothionein gene expression by cadium and the retention of the toxic metal in the tissues or rainbow trout (*Salmo gairdneri*). Comp. Biochem. Physiol. 97C(2): 215-220.

Norris, R.H. and P.S. Lake. 1984. Trace metal concentrations in fish from the South Esk River, northeastern Tasmania, Australia. Bull. Environ. Contam. Toxicol. 33(3): 348-354.

Norum, U., V.W.M. Lai and W.R. Cullen. 2005. Trace element distribution during the reproductive cycle of female and male spiny and Pacific scallops, with implications for biomonitoring. Mar. Pollut. Bull. 50(2): 175-184.

Norwood, W.P., U. Borgmann and D.G. Dixon. 2007. Interactive effects of metals in mixtures on bioaccumulation in the amphipod *Hyalella azteca*. Aquat. Toxicol. 84(2): 255-267.

Notch, E.G., D.M. Miniutti, J.P. Berry and G.D. Mayer. 2011. Cyanobacterial LPS potentiates cadmium toxicity in zebrafish (*Danio rerio*) embryos. Environ. Toxicol. 26(5): 498-505.

Notenboom, J., K. Cruys, J. Hoekstra and P. Van Beelen. 1992. Effect of ambient oxygen concentration upon the acute toxicity of chlorophenols and heavy metals to the groundwater copepod *Parastenocaris germanica* (crustacea). Ecotoxicol. Environ. Saf. 24: 131-143.

Nott, J.A. and A. Nicolaidou. 1994. Variable transfer of detoxified metals from snails to hermit crabs in marine food chains. Mar. Biol. 120: 369-377.

Novais, S.C., S.I.L. Gomes, C. Gravato, L. Guilhermino, W. De Coen, A. Soares and M.J.B. Amorim. 2011. Reproduction and biochemical responses in *Enchytraeus albidus* (Oligochaeta) to zinc or cadmium exposures. Environ. Pollut. 159(7): 1836-1843.

Novais, S.C., A.M.V.M. Soares, W. De Coen and M.J.B. Amorim. 2013. Exposure of *Enchytraeus albidus* to Cd and Zn - Changes in cellular energy allocation (CEA) and linkage to transcriptional, enzymatic and reproductive effects. Chemosphere 90(3): 1305-1309.

Novakova, J., D. Danova, K. Striskova, R. Hromada, H. Mickova and M. Rabiskova. 2007. Zinc and cadmium toxicity using a biotest with *Artemia franciscana*. Acta Vet. (Brno). 76(4): 635-642.

Novelli, A.A., C. Losso, P.F.Ghetti, and A.V. Ghirardini. 2003. Toxicity of heavy metals using sperm cell and embryo toxicity bioassays with *Paracentrotus lividus* (Echinodermata: Echinoidea): Comparisons with exposure concentrations in the Lagoon of Venice, Italy. Environ. Toxicol. Chem. 22(6): 1295-1301.

Nowak, C., D. Jost, C. Vogt., M. Oetken, K. Schwenk and J. Oehlmann. 2007. Consequences of inbreeding and reduced genetic variation on tolerance to cadmium stress in the midge *Chironomus riparius*. Aquat. Toxicol. 85(4): 278-284.

Nowak, C., A. Czeikowitz, C. Vogt, M. Oetken, B. Streit and K. Schwenk. 2008. Variation in sensitivity to cadmium among genetically characterized laboratory strains of the midge *Chironomus riparius*. Chemosphere 71(10): 1950-1956.

Nowierski, M., D.G. Dixon and U. Borgmann. 2005. Effects of water chemistry on the bioavailability of metals in sediment to *Hyalella azteca*: Implications for sediment quality guidelines. Arch. Environ. Contam. Toxicol. 49(3): 322-332.

Nowierski, M., D.G. Dixon and U.W.E. Borgmann. 2006. Lac Dufault sediment core trace metal distribution, bioavailability and toxicity to *Hyalella azteca*. Environ. Pollut. 139(3): 532-540.

NRCC (National Research Council of Canada). 1979. Effects of cadmium in the Canadian environment. National Research Council of Canada.

Nriagu, J.O. 1980. Production, uses, and properties of cadmium. In: Cadmium in the environment. Part 1. Ecological cycling. Nriagu, J.O. (*Ed.*) Toronto, John Wiley and Sons, pp. 35-70.

Nriagu, J.O. and J.M. Pacyna. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333: 134-139.

Nugegoda, D. and P.S. Rainbow. 1995. The uptake of dissolved zinc and cadmium by the decapod crustacean *Palaemon elegans*. Mar. Pollut. Bull. 31(4-12): 460-463.

Nunes, BS., C. Caldeira, J. Pereira, A.T. Correia and F. Gonăcalves. 2011. Acute and chronic effects of copper and cadmium on oxidative stress biomarkers in *Gambusia holbrooki.* Toxicol. Lett. 205, Suppl. (0): S66.

Nunez-Nogueira, G. and P.S. Rainbow. 2005. Cadmium uptake and accumulation by the decapod crustacean *Penaeus indicus*. Mar. Environ. Res. 60(3): 339-354.

Nusetti, O., M. Tovar and E. Zapata-Vivenes. 2010. Pyruvate kinase, phosphoenolpyruvate carboxykinase, cytochrome c oxidase and catalase activities in cadmium exposed *Perna viridis* subjected to anoxic and aerobic conditions. J. Shellfish Res. 29(1): 203-208.

Nyholm, N. and T. Kallqvist. 1989. Methods for growth inhibition toxicity tests with freshwater algae. Environ. Toxicol. Chem. 8: 689-703.

Nyman, M., J. Koistinen, M.L. Fant, T. Vartiainen and E. Helle. 2002. Current levels of DDT, PCB and trace elements in the Baltic ringed seals (*Phoca hispida baltica*) and grey seals (*Halichoerus grypus*). Environ. Pollut. 119(3): 399-412.

Nyquist, J. and M. Greger. 2009. Response of two wetland plant species to Cd exposure at low and neutral pH. Environ. Exp. Bot. 65(2/3): 417-424.

Oakley, S.M., K.J. Williamson and P.O. Nelson. 1983. Accumulation of cadmium by *Abarenicola pacifica*. Sci. Total Environ. 28(1-3): 105-118.

Obande, R.A., L.O. Chukwu, P.E. Anyanwu, B.W. Ayonoadu, E.S. Erondu, S.N. Deekae, Fisheries Society of Nigeria and E.J. Ansa (*Eds*.). 2006. Trace metal analysis of the prawn (*Atya gabonesis*), water and bottom sediments of Lower River Benue. Fisheries Society of Nigeria Lagos.

Occhiogrosso, T.J., W.T. Waller and G.J. Lauer. 1979. Effects of heavy metals on benthic macroinvertebrate densities in foundry cove on the Hudson River. Bull. Environ. Contam. Toxicol. 22: 230-237.

O'Connor, T.P. 1996. Trends in chemical concentrations in mussels and oysters collected along the US Coast from 1986 to 1993. Mar. Environ. Res. 41(2): 183-200.

O'Connor, T.P. and G.G. Lauenstein. 2006. Trends in chemical concentrations in mussels and oysters collected along the US Coast: Update to 2003. Mar. Environ. Res. 62(4): 261-285.

Odin, M., F. Ribeyre and A. Boudou. 1996. Temperature and pH effects on cadmium and methylmercury bioaccumulation by nymphs of the burrowing mayfly *Hexagenia rigida*, from water column or sediment source. Arch. Environ. Contam. Toxicol. 31: 339-349.

Odin, M., F. Ribeyre and A. Boudou. 1997. Depuration processes after exposure of burrowing mayfly nymphs (*Hexagenia rigida*) to methylmercury and cadmium from water column or sediment: Effects of temperature and pH. Aquat. Toxicol. 37: 125-137.

OECD (Organisation for Economic Co-operation and Development). 1994. Risk Reduction Monograph No. 5: Cadmium. OECD Environment Monograph Series No. 104. OECD Environment Directorate, Paris, France.

OECD (Organisation for Economic Co-operation and Development). 1995. Risk reduction monograph No. 5: Cadmium background and national experience with reducing risk. OECD Environment Monograph Series No. 104. OECD Environment Directorate, Paris, France.

Offermann, K., A. Matthai and W. Alf. 2009. Assessing the importance of dietborne cadmium and particle characteristics on bioavailability and bioaccumulation in the nematode *Caenorhabditis elegans*. Environ. Toxicol. Chem. 28(6): 1149-1158.

Oguma, A.Y. and P.L. Klerks. 2013. The role of native salinity regime on grass shrimp (*Palaemonetes pugio*) sensitivity to cadmium. Ecotoxicol. 22(2): 279-286.

Ogwok, P., J.H. Muyonga and M.L. Sserunjogi. 2009. Pesticide residues and heavy metals in Lake Victoria Nile perch, *Lates niloticus*, belly flap oil. Bull. Environ. Contam. Toxicol. 82(5): 529-533.

O’Hara, J. 1973a. The influence of temperature and salinity on the toxicity of cadmium to the fiddler crab, *Uca pugilator*. Fish. Bull. 71: 149.

O'Hara, J. 1973b. Cadmium uptake by fiddler crabs exposed to temperature and salinity stress. J. Fish. Res. Board Can. 30: 846.

Oikari, A., J. Kukkonen and V. Virtanen. 1992. Acute toxicity of chemicals to *Daphnia magna* in humic water. Sci. Total Environ. 117/118: 367-377.

Ojaveer, E., J. Annist, H. Jankowski, T. Palm and T. Raid. 1980. On the effect of copper, cadmium and zinc on the embryonic development of Baltic spring spawning herring. Finnish Mar. Res. 247: 35-140.

Okamoto, O.K., C.S. Asano, E. Aidar and P. Colepicolo. 1996. Effects of cadmium on growth and superoxide dismutase activity of the marine microalga *Tetraselmis gracilis* (Prasinophyceae) J. Physiol. 32: 74-79.

Okocha, R.C. and O.B. Adedeji. 2011. Overview of cadmium toxicity in fish. J. Appl. Sci. Res. 7(7): 1195-1207.

Olesen, T.M.E. and J.M. Weeks. 1994. Accumulation of Cd by the marine sponge *Halichondria panicea* Pallas: Effects upon filtration rate and its relevance for biomonitoring. Bull. Environ. Contam. Toxicol. 52: 722-728.

Olgunoglu, M.P. and S. Polat. 2008. Trace metals in marine macroalgae samples from the Iskenderun Bay, Turkey. Fresenius Environ. Bull. 17(5): 589-595.

Oliveira, M., I. Ahmad, V.L. Maria, A. Serafim, M.J. Bebianno, M. Pacheco and M.A. Santos. 2010. Hepatic metallothionein concentrations in the golden grey mullet (*Liza aurata*) relationship with environmental metal concentrations in a metal-contaminated coastal system in Portugal. Mar. Environ. Res. 69(4): 227-233.

Oliver, J.I., L.A. Flores and A.G. Roman. 1999. Five ecotoxicological assays for evaluation of heavy metals in freshwater. Bol. Soc. Quim. Peru 65: 30-45.

Ololade, I.A., L. Lajide, V.O. Olumekun, O.O. Ololade and B.C. Ejelonu. 2011. Influence of diffuse and chronic metal pollution in water and sediments on edible seafoods within Ondo oil-polluted coastal region, Nigeria. J. Environ. Sci. Health 46A(8): 898-908.

Olson, D.L. and G.M. Christensen. 1980. Effects of water pollutants and other chemicals on fish acetylcholinesterase (*in vitro*). Environ. Res. 21: 327-335.

Olsvik, P.A., P. Gundersen, R.A. Andersen and K.E. Zachariassen. 2001. Metal accumulation and metallothionein in brown trout, *Salmo trutta*, from two Norwegian rivers differently contaminated with Cd, Cu and Zn. Comp. Biochem. Physiol. C. 128(2): 189-201.

Olsvik, P.A., L.S. Heier, B.O. Rosseland, H.C. Teien and B. Salbu. 2010. Effects of combined gamma-irradiation and metal (Al+Cd) exposures in Atlantic salmon (*Salmo salar* L.). J. Environ. Radioactiv. 101(3): 230-236.

Olusegun, A.O., T.O. Olukemi and M.B. Olukemi. 2009. Heavy metal distribution in crab (*Callinectes amnicola*) living on the shores of Ojo Rivers, Lagos, Nigeria. Environmentalist 29(1): 33-36.

Omoregie, E., M.O. Okoronkwo, A.C. Eziashi and A.I. Zoakah. 2002. Metal concentrations in water column, benthic macroinvertebrates and tilapia from Delimi River, Nigeria. J. Aquat. Sci. 17(1): 55-59.

O'Neill, J.G. 1981. Effects of intraperitoneal lead and cadmium on the humoral immune response of *Salmo trutta*. Bull. Environ. Contam. Toxicol. 27: 42.

Oner, M., G. Atli and M. Canli. 2008. Changes in serum biochemical parameters of freshwater fish *Oreochromis niloticus* following prolonged metal (Ag, Cd, Cr, Cu, Zn) exposures. Environ. Toxicol. Chem. 27(2): 360-366.

Ong, E.S. and Z.B. Din. 2001. Cadmium, copper, and zinc toxicity to the clam, *Donax faba* C., and the blood cockle, *Anadara granosa* L. Bull. Environ. Contam. Toxicol. 66(1): 86-93.

Ongeri, D.M.K., J.O. Lalah, S.O. Wandiga, K.W. Schramm and B. Michalke. 2012. Seasonal variability in cadmium, lead, copper, zinc and iron concentrations in the three major fish species, *Oreochromis niloticus*, *Lates niloticus* and *Rastrineobola argentea* in Winam Gulf, Lake Victoria: Impact of wash-off into the lake. Bull. Environ. Contam. Toxicol. 88(2): 166-171.

Onuoha, G.C., F.O. Nwadukwe and E.S. Erondu. 1996. Comparative toxicity of cadmium to crustacean zooplankton (copepods and ostracods). Environ. Ecol. 14(3): 557-562.

Opuene, K. and I.E. Agbozu. 2008. Relationships between heavy metals in shrimp (*Macrobrachium felicinum*) and metal levels in the water column and sediments of Taylor Creek. Int. J. Environ. Res. 2(4): 343-348.

Orchard, S.J., D.A. Holdway, C. Barata and R.A. Van Dam. 2002. A rapid response toxicity test based on the feeding rate of the tropical cladoceran *Moinodaphnia macleayi*. Ecotoxicol. Environ. Saf. 53(1): 12-19.

Oronsaye, J.A.O. 1989. Histological changes in the kidneys and gills of the stickleback, *Gasterosteus aculeatus* L, exposed to dissolved cadmium in hard water. Ecotox. Environ. Safety. 17: 279-290.

Oronsaye, J.A.O. 2001. Ultrastructural changes in the kidneys of the stickleback, *Gasterosteus aculeatus* (L.) exposed to dissolved cadmium. J. Aquat. Sci. 16: 53-56.

Oronsaye, J.A.O., N.F. Okolo and E.E. Obano. 2003. The toxicity of zinc and cadmium to *Clarias submaginatus*. J. Aquat. Sci. 18(1): 65-69.

Orun, I. and Z.S. Tolas. 2008. Antioxidative role of sodium selenite against the toxic effect of heavy metals (Cd+2, Cr+3) on some biochemical and hematological parameters in the blood of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792). Fresenius Environ. Bull. 17(9): 1242-1246.

Osuna-Martinez, C.C., F. Paez-Osuna and R. Alonso-Rodrigueza. 2011. Cadmium, copper, lead and zinc in cultured oysters under two contrasting climatic conditions in coastal lagoons from SE Gulf of California, Mexico. Bull. Environ. Contam. Toxicol. 87(3): 272-275.

Othman, M.S., W. Khonsue, J. Kitana, K. Thirakhupt, M.G. Robson and N. Kitana. 2009. Cadmium accumulation in two populations of rice frogs (*Fejervarya limnocharis*) naturally exposed to different environmental cadmium levels. Bull. Environ. Contam. Toxicol. 83(5): 703-707.

Otitoloju, A.A. and K.N. Don-Pedro. 2004. Integrated laboratory and field assessments of heavy metals accumulation in edible periwinkle, *Tympanotonus fuscatus var radula* (L.). Ecotoxicol. Environ. Saf. 57(3): 354-362.

Otitoloju, A.A. and K.N. Don-Pedro. 2006. Determination of types of interactions exhibited by binary mixtures of heavy metals tested against the hermit crab, *Clibanarius africanus*. Toxicol. Environ. Chem. 88(2): 331-343.

Outridge, P.M. 1992. Comparing Cd toxicity tests with plants in monocultures and species mixtures. Bull. Environ. Contam. Toxicol. 48: 344-351.

Outridge, P.M., K.A. Hobson and J.M. Savelle. 2005. Changes in mercury and cadmium concentrations and the feeding behaviour of beluga (*Delphinapterus leucas*) near Somerset Island, Canada, during the 20th century. Sci. Total Environ. 350(1-3): 106-118.

Packer, D.M., M.P. Ireland and R.J. Wootton. 1980. Cadmium copper lead zinc and manganese in the polychaete *Arenicola marina* from sediments around the coast of Wales UK. Environ. Pollut. Ser. A Ecol. Biol. 22(4): 309-322.

Paczkowska, M., M. Kozlowska and P. Golinski. 2007. Oxidative stress enzyme activity in *Lemna minor* L. exposed to cadmium and lead. Acta Biol. Cracov. 49(2): 33-37.

Pagenkopf, G.K. 1983. Gill surface interaction model for trace-metal toxicity to fishes: Role of complexation, pH and water hardness. Environ. Sci. Technol. 17: 342-347.

Pais, N.M. 2012. Studies on waterborne cadmium exposure to *Lymnaea stagnalis* in varying water qualities and the development of a novel tissue residue approach. M.S. Thesis, Wilfrid Laurier University, Canada.

Pajevic, S., M. Vuckovic, Z. Stankovic, B. Krstic, Z. Kevresan and S. Radulovic. 2002. The content of some macronutrients and heavy metals in aquatic macrophytes of three ecosystems connected to the Danube in Yugoslavia. Arch. Hydrobiol. Suppl. Large Rivers. 141(1-2): 73-83.

Pajevic, S., M. Borisev, S. Roncevic, D. Vukov and R. Igic. 2008. Heavy metal accumulation of Danube River aquatic plants -- indication of chemical contamination. Cent. Eur. J. Biol. 3(3): 285-294.

Palackova, J., D. Pravda, K. Fasaic and O. Celechovska. 1994. Sublethal effects of cadmium on carp (*Cyprinus carpio*) fingerlings. In: R. Muller and R. Lloyd (*Eds*.), Sublethal and chronic effects of pollutants on freshwater fish, chapter 5, Fishing News Books, London, pp. 53-61.

Palawski, D., J.B. Hunn and F.J. Dwyer. 1985. Sensitivity of young striped bass to organic and inorganic contaminants in fresh and saline water. Trans. Am. Fish. Soc. 114: 748-753.

Palm, H. and C. Wikberger. 1995. Tungmetallanalyser av mossor och baeckvattenvaexter i norra Estland. (Heavy metals in mosses and aquatic plants in northern Estonia). Govt. Report. Announ. Index. Issue 08.

Palumbo, A.J., P.L. TenBrook, T.L. Fojut, I.R. Faria and R.S. Tjeerdema. 2012. Aquatic life water quality criteria derived via the UC Davis method: I. Organophosphate insecticides. In *Reviews of Environmental Contamination and Toxicology 216*. Aquatic Life Water Quality Criteria for Selected Pesticides. R.S. Tjeerdema (*Ed.*)., Springer Science+Business Media, LLC pp. 1-49.

Pan, J.F. and W.X. Wang. 2004. Influences of dissolved and colloidal organic carbon on the uptake of Ag, Cd, and Cr by the marine mussel *Perna viridis*. Environ. Pollut. 129(3): 467-477.

Pan, J., J.A. Plant, N. Voulvoulis, C.J. Oates and C. Ihlenfeld. 2010. Cadmium levels in Europe: Implications for human health. Environ. Geochem. Health. 32: 1-12.

Pan, K. 2009. Application of biokinetic model in studying the bioaccumulation of cadmium, zinc, and copper in the scallop *Chlamys nobilis*. Ph.D. Thesis, Hong Kong University of Science and Technology, Hong Kong.

Pan, K. and W.X. Wang. 2008. The subcellular fate of cadmium and zinc in the scallop *Chlamys nobilis* during waterborne and dietary metal exposure. Aquat. Toxicol. 90(4): 253-260.

Pan, L. and H. Zhang. 2006. Metallothionein, antioxidant enzymes and DNA strand breaks as biomarkers of Cd exposure in a marine crab, *Charybdis japonica*. Comp. Biochem. Physiol. 144C(1): 67-75.

Pan, L., N. Liu, H. Zhang, J. Wang and J. Miao. 2011. Effects of heavy metal ions (Cu^{2+}, Pb^{2+} and Cd^{2+}) on DNA damage of the gills, hemocytes and hepatopancreas of marine crab, *Charybdis japonica*. J. Ocean Univ. China 10(2): 177-184.

Panagapko, D. 2007. Mineral and metal commodity reviews: Cadmium. Natural Resources Canada. Available at: http://www.nrcan.gc.ca/smm-mms/busi-indu/cmy-amc/content/2007/15.pdf

Pandeswara, S.L. and P.R. Yallapragada. 2000. Tolerance, accumulation and depuration in an intertidal gastropod, *Turbo intercostalis*, exposed to cadmium. Mar. Environ. Res. 50(1-5): 103-106.

Pandey, S., S. Parvez, R.A. Ansari, M. Ali, M. Kaur, F. Hayat, F. Ahmad and S. Raisuddin. 2008. Effects of exposure to multiple trace metals on biochemical, histological and ultrastructural features of gills of a freshwater fish, *Channa punctata* Bloch. Chem. Biol. Interact. 174(3): 183-192.

Pantani, C., G. Pannunzio, M. De Cristofaro, A.A. Novelli and M. Salvatori. 1997. Comparative acute toxicity of some pesticides, metals, and surfactants to *Gammarus italicus* Goedm. and *Echinogammarus tibaldii* Pink. and stock (Crustacea: Amphipoda). Bull. Environ. Contam. Toxicol. 59(6): 963-967.

Papa, M., P. Casoria and M. Guida. 2008. Determination of heavy metal in seawater and macroalgae of shorelines of Naples and Ischia Island, Italy. Chem. Ecol. 24(S1): 27-37.

Papathanassiou, E. 1983. Effects of cadmium and mercury ions on respiration and survival of the common prawn *Palaemon serratus* (Pennant). Rev. Int. Oceanogr. Med. 72: 21-35.

Papathanassiou, E. 1986. Cadmium accumulation and ultrastructural alterations in oogenesis of the prawn *Palaemon serratus* (Pennant). Bull. Environ. Contam. Toxicol. 36: 192-198.

Papoutsoglou, S.E. and P.D. Abel. 1988. Sublethal toxicity and accumulation of cadmium in *Tilapia aurea*. Bull. Environ. Contam. Toxicol. 41: 404-411.

Papoutsoglou, S.E. and D. Abel. 1993. Studies on the lethal and sublethal effects of cadmium on some commercially cultured species of the Mediterranean. In: Final Reports on Projects (activity G), UNEP Mediterranean Action Plan, Athens, Greece. MAP Tech. Rep. Ser. No. 48, pp. 33-43.

Paquin, P., D. DiToro, R.C. Santore, B. Trivedi and B. Wu. 1999. A biotic ligand model of the acute toxicity of metals III: Application to fish and daphnia exposure to silver. U.S. Government Printing Office: Washington, D.C. EPA-E-99-001.

Pardue, W.J. and T.S. Wood. 1980. Baseline toxicity data for freshwater bryoza exposed to copper, cadmium, chromium, and zinc. J. Tennessee Acad. Sci. 55: 27.

Park, E.H., H.H. Chang, W.N. Joo, H.S. Chung and H.S. Kwak. 1994. Assessment of the estuarine hermaphroditic fish *Rivulus marmoratus* as a useful euryhaline species for acute toxicity tests as shown using cadmium. Can. J. Fish. Aquat. Sci. 51: 280-285.

Park, J.S. and H.G. Kim. 1978. Bioassays on marine organisms: Acute toxicity test of mercury, cadmium and copper to arkshell, *Anadara broughtonii*, from Jin-Dong Bay, and to oyster, *Crassostrea gigas*, from Kwang-Do Bay, south coast of Korea. J. Oceanol. Soc. Korea 13(1): 35-43.

Park, J.S. and H.G. Kim. 1979. Bioassays on marine organisms. II. Acute toxicity test of mercury, copper and cadmium to clam, *Meretrix lusoria*. Bull. Korean Fish. Soc.(Han'Guk Susan Halchoiji) 12(2): 113-117.

Park, J. and Presley, B.J. 1997. Trace metal contamination of sediments and organisms from the Swan Lake Area of Galveston Bay. Environ. Pollut. 98(2): 209-221.

Parker, J.G. 1984. The effects of selected chemicals and water quality on the marine polychaete *Ophryotrocha diadema*. Water Res. 18: 865.

Part, P. and O. Svanberg, O. 1981. Uptake of cadmium in perfused rainbow trout (*Salmo gairdneri*) gills. Can. J. Fish. Aquat. Sci. 38: 917-924.

Parveen, N. and G.G. Shadab. 2012. Cytogenetic evaluation of cadmium chloride on *Channa punctatus*. J. Environ. Biol. 33(3): 663-666.

Parvin, E., M.K. Ahmed, M.M. Islam, M.S. Akter and M.A. Kabir. 2011. Preliminary acute toxicity bioassays of lead and cadmium on fresh water climbing perch, *Anabas testudineus* (Bloch). Terrest. Aquat. Environ. Toxicol. 5(1): 55-58.

Pascal, P.Y., J.W. Fleeger, F. Galvez and K.R. Carman. 2010. The toxicological interaction between ocean acidity and metals in coastal meiobenthic copepods. Mar. Pollut. Bull. 60(12): 2201-2208.

Pascoe, D. and K. Carroll. 2004. Comparison of cadmium toxicity to *Asellus aquaticus* (L.) populations following 17 years isolation in pond and laboratory cultures. Bull. Environ. Contam. Toxicol. 73(1): 167-173.

Pascoe, D. and P. Cram. 1977. The effect of parasitism on the toxicity of cadmium to the three-spined stickleback, *Gasterosteus aculeatus* L. J. Fish. Biol. 10: 467.

Pascoe, D. and D.L. Mattey. 1977. Studies on the toxicity of cadmium to the three-spined stickleback *Gasterosteus aculeatus* L. J. Fish. Biol. 11: 207.

Pascoe, D. and N.A.M. Shazili. 1986. Episodic pollution - a comparison of brief and continuous exposure of rainbow trout to cadmium. Ecotoxicol. Environ. Safety. 12: 189-198.

Pascoe, D., S.A. Evans and J. Woodworth. 1986. Heavy metal toxicity to fish and the influence of water hardness. Arch. Environ. Contam. Toxicol. 15: 481-487.

Pascoe, D., K.A. Williams and D.W.J. Green. 1989. Chronic toxicity of cadmium to *Chironomus riparius* Meigen - effects upon larval development and adult emergence. Hydrobiol. 175: 109-115.

Pascoe, D., A.F. Brown, B.M.J. Evans and C. McKavanagh. 1990. Effects and fate of cadmium during toxicity tests with *Chironomus riparius* - the influence of food and artificial sediment. Arch. Environ. Contam. Toxicol. 19: 872-877.

Pastorinho, M.R., T.C. Telfer and A.M. Soares. 2009. Amphipod susceptibility to metals: Cautionary tales. Chemosphere 75(11): 1423-1428.

Patel, B., M.C. Balani and S. Patel. 1985. Sponge 'sentinel' of heavy metals. Sci. Total Environ. 41: 143-152.

Patthebahadur, M.M. and U.E. Bais. 2008. Studies on some physiological aspects in fresh water fish *Ophiocephalus striatus* (Channa) in relation to heavy metal cadmium (Cd) toxicity. Oriental J. Chem. 24(3): 1099-1102.

Pauli, W. and S. Berger. 1997. Toxicological comparisons of *Tetrahymena* species, end points and growth media: Supplementary investigations to the pilot ring test. Chemosphere 35(5): 1043-1052.

Paul-Pont, I.K.A., P. Gonzalez, M. Baudrimont, H. Nili and X. De Montaudouin. 2010a. Short-term metallothionein inductions in the edible cockle *Cerastoderma edule* after cadmium or mercury exposure: Discrepancy between MRNA and protein responses. Aquat. Toxicol. 97(3): 260-267.

Paul-Pont, I.K.A., X. Montaudouin, P. Gonzalez, P. Soudant and M. Baudrimont. 2010b. How life history contributes to stress response in the manila clam *Ruditapes philippinarum*. Environ. Sci. Pollut. Res. Int. 17(4): 987-998.

Paul-Pont, I., P. Gonzalez, N. Montero, X. De Montaudouin and M. Baudrimont. 2012. Cloning, characterization and gene expression of a metallothionein isoform in the edible cockle *Cerastoderma edule* after cadmium or mercury exposure. Ecotoxicol. Environ. Saf. 75(1): 119-126.

Pavicic, J. 1977. Combined cadmium-zinc toxicity on embryonic development of *Mytilus galloprovincialis* LMK. (Mollusca, Mytilidae). In: Protection of the Mediterranean Coast, Part I. 3rd Study Session on Mar.Pollut., Comm. Int. pour lExplor. Sci. de la Mer Mediterranee, Monaco, 79-80.

Pavicic, J. and T. Jarvenpaa. 1974. Cadmium toxicity in adults and early larval stages of the mussel *Mytilus galloprovincialis* Lam. In: Proc. Comparative Studies of Food and Environmental Contamination, Int. Atomic Energy Agency, Vienna, Austria, 179-188.

Pavicic, J., M. Skreblin, I. Kregar, M. Tusek-Znidaric and P. Stegnar. 1994. Embryo-larval tolerance of *Mytilus galloprovincialis*, exposed to the elevated sea water metal concentrations - I. Toxic effects of Cd, Zn and Hg in relation to the metallothionein level. Comp. Biochem. Physiol. 107C(2): 249-257.

Pawlik, B. and T. Skowronski. 1994. Transport and toxicity of cadmium: Its regulation in the cyanobacterium *Synechocystis aquatilis*. Environ. Exp. Bot. 34(2): 225-233.

Pawlik, B., T. Skowronski, Z. Ramazanow, P. Gardestrom and G. Samuelsson. 1993. pH-dependent cadmium transport inhibits photosynthesis in the cyanobacterium *Synechocystis aquatilis*. Environ. Exp. Bot. 33(2): 331-337.

Pechenik, J.A., T. Gleason, D. Daniels and D. Champlin. 2001. Influence of larval exposure to salinity and cadmium stress on juvenile performance of two marine invertebrates (*Capitella sp*. I and *Crepidula fornicata*). J. Exp. Mar. Biol. Ecol. 264(1): 101-114.

Pecon, J. and E.N. Powell. 1981. Effect of the amino acid histidine on the uptake of cadmium from the digestive system of the blue crab, *Callinectes sapidus*. Bull. Environ. Contam. Toxicol. 27: 34.

Pedersen, F. and G.I. Petersen. 1996. Variability of species sensitivity to complex mixtures. Water Sci. Tech. 33(6): 109-119.

Pedro, C.A., M.S.S. Santos, S.M.F. Ferreira and S.C. Goncalves. 2013. The influence of cadmium contamination and salinity on the survival, growth and phytoremediation capacity of the saltmarsh plant *Salicornia ramosissima*. Mar. Environ. Res. 92: 197-205.

Peles, J.D., D.H. Pistole and M. Moffe. 2012. Influence of cadmium concentration and length of exposure on metabolic rate and gill Na+/K+ ATPase activity of golden shiners (*Notemigonus crysoleucas*). Comp. Biochem. Physiol. 156C(1): 24-28.

Pelgrom, S.M.G.J., L.P.M. Lamers, J.A.M. Garritsen, B.M. Pels, R.A.C. Lock, P.H.M. Balm and S.E.W. Bonga. 1994. Interactions between copper and cadmium during single and combined exposure in juvenile tilapia *Oreochromis mossambicus*: Influence of feeding condition on whole body metal accumulation and the effect of the metals on tissue water and ion content. Aquat. Toxicol. 30: 117-135.

Pelgrom, S.M.G.J., R.A.C. Lock, P.H.M. Balm and S.E.W. Bonga. 1997. Calcium fluxes in juvenile tilapia, *Oreochromis mossambicus*, exposed to sublethal waterborne Cd, Cu or mixtures of these metals. Environ. Toxicol Chem. 16(4): 770-774.

Pellegrini, M., A. Laugier, M. Sergent, R. Phan-Tan-Luu, R. Valls and L. Pellegrini. 1993. Interactions between the toxicity of the heavy metals cadmium, copper, zinc in combinations and the detoxifying role of calcium in the brown alga *Cystoseira barbata*. J. Appl. Phycol. 5: 351-361.

Pellet, B., O. Geffard, C. Lacour, T. Kermoal, C. Gourlay-Francé, M.H. Tusseau-Vuillemin. 2009. A model predicting waterborne cadmium bioaccumulation in *Gammarus pulex*: The effects of dissolved organic ligands, calcium, and temperature. Environ. Toxicol. Chem. 28(11): 2434-2442.

Peltier, G.L., M.S. Wright, W.A. Hopkins and J.L. Meyer. 2009. Accumulation of trace elements and growth responses in *Corbicula fluminea* downstream of a coal-fired power plant. Ecotoxicol. Environ. Saf. 72(5): 1384-1391.

Pempkowiak, J., K. Pazdro, J. Kopecka, E. Perez and M. Sole. 2006a. Toxicants accumulation rates and effects in *Mytilus trossulus* and *Nereis diversicolor* exposed separately or together to cadmium and PAHs. J. Environ. Sci. Health 41A(11): 2571-2586.

Pempkowiak, J., J. Walkusz-Miotk, J. Beldowski and W. Walkusz. 2006b. Heavy metals in zooplankton from the southern Baltic. Chemosphere 62(10): 1697-1708.

Peneda-Saraiva, M.C. 1976. Use of a nanoplankton alga as test organism in marine molysmology: Some responses of *Dunaliella bioculata* to gamma irradiation and to contamination and cadmium. Rev. Int. Oceanogr. Med. 43: 111-115.

Peng, K., C. Luo, L. Lou, X. Li and Z. Shen. 2008. Bioaccumulation of heavy metals by the aquatic plants *Potamogeton pectinatus* L. and *Potamogeton malaianus* Miq. and their potential use for contamination indicators and in wastewater treatment. Sci. Total Environ. 392(1): 22-29.

Peng, S.H., J.S. Hwang, T.H. Fang and T.P. Wei. 2006. Trace metals in *Iaustinogebia edulis* (Ngoc-Ho & Chan, 1992) (Decapoda, Thalassinidea, Upogebiidae) and its habitat sediment from the central western Taiwan coast. Crustaceana 79(3): 263-273.

Pennington, C.H., J.A. Baker and M.E. Potter. 1982. Contaminant levels in fishes from Brown's Lake, Mississippi. J. Mississippi Acad. Sci. 27: 139-147.

Penttinen, S., J. Kukkonen and A. Oikari. 1995. The kinetics of cadmium in *Daphnia magna* as affected by humic substances and water hardness. Ecotoxicol. Environ. Safety. 30: 72-76.

Penttinen, S., A. Kostamo and J.V.K. Kukkonen. 1998. Combined effects of dissolved organic material and water hardness on toxicity of cadmium to *Daphnia magna*. Environ. Toxicol. Chem. 17(12): 2498-2503.

Penttinen, S., V. Malk, A. Vaisanen and O.P. Penttinen. 2011. Using the critical body residue approach to determine the acute toxicity of cadmium at varying levels of water hardness and dissolved organic carbon concentrations. Ecotoxicol. Environ. Saf. 74(5): 1151-1155.

Perceval, O., Y. Couillard, B. Pinel-Alloul, E. Bonneris and P.G.C. Campbell. 2006. Long-term trends in accumulated metals (Cd, Cu and Zn) and metallothionein in bivalves from lakes within a smelter-impacted region. Sci. Total Environ. 369(1-3): 403-418.

Percy, K.E. 1983. Heavy metal and sulphur concentrations in *Sphagnum magellanicum* Brid. in the maritime provinces, Canada. Water Air Soil Pollut. 19: 341-349.

Pereira, J.J., R. Mercaldo-Allen, C. Kuropat, D. Luedke and G. Sennefelder. 1993. Effect of cadmium accumulation on serum vitellogenin levels and hepatosomatic and gonadosomatic indices of winter flounder (*Pleuronectes americanus*). Arch. Environ. Contam. Toxicol. 24: 427-431.

Pereira, M.J., P. Resende, U.M. Azeiteiro, J. Oliveira and D.R. De Figueiredo. 2005. Differences in the effects of metals on growth of two freshwater green algae (*Pseudokirchneriella subcapitata* (Korshikov) Hindak and *Gonium pectorale* Muller). Bull. Environ. Contam. Toxicol. 75(3): 515-522.

Perez, S. and R. Beiras. 2010. The mysid *Siriella armata* as a model organism in marine ecotoxicology: Comparative acute toxicity sensitivity with *Daphnia magna*. Ecotoxicol. 19(1): 196-206.

Perez-Coll, C.S. and J. Herkovits. 1996. Stage-dependent uptake of cadmium by *Bufo arenarum* embryos. Bull. Environ. Contam. Toxicol. 56: 663-669.

Perez-Coll, C.S., J. Herkovits and A. Salibian. 1986. Teratogenic effects of cadmium on *Bufo arenarum* during gastrulation. Experientia 42(10): 1174-1176.

Perez-Legaspi, I.A. and R. Rico-Martinez. 2001. Acute toxicity tests on three species of the genus *Lecane* (Rotifera: Monogononta). Hydrobiol. 446/447: 375-381.

Perez-Legaspi, I.A. and R. Rico-Martinez. 2003. Phospholipase A2 activity in three species of littoral freshwater rotifers exposed to several toxicants. Environ. Toxicol. Chem. 22(10): 2349-2353.

Perez-Legaspi, I.A., R. Rico-Martinez and A. Pineda-Rosas. 2002. Toxicity testing using esterase inhibition as a biomarker in three species of the genus *Lecane* (Rotifera). Environ. Toxicol. Chem. 21(4): 776-782.

Perkins, E.J., J. Furey and E. Davis, E. 2004. The potential of screening for agents of toxicity using gene expression fingerprinting in *Chironomus tentans*. Aquat. Ecosyst. Health Manag. 7(3): 399-405.

Pernice, M., J. Boucher, R. Boucher-Rodoni, P. Joannot and P. Bustamante. 2009. Comparative bioaccumulation of trace elements between *Nautilus pompilius* and *Nautilus macromphalus* (Cephalopoda: Nautiloidea) from Vanuatu and New Caledonia. Ecotoxicol. Environ. Saf. 72: 365-371.

Perrein-Ettajani, H., J.C. Amiard, J. Haure and C. Renaud. 1999. Effects of metals (Ag, Cd, Cu) on growth and biochemical composition of two microalgae, *Skeletonema costatum* and *Tetraselmis suecica*. Can. J. Fish. Aquat. Sci. 56(10): 1757-1765.

Pery, A.R.R., A. Geffard, A. Conrad, R. Mons and J. Garric. 2008. Assessing the risk of metal mixtures in contaminated sediments on *Chironomus riparius* based on cytosolic accumulation. Ecotoxicol. Environ. Saf. 71(3): 869-873.

Pesch, G.G. and N.E. Stewart. 1980. Cadmium toxicity to three species of estuarine invertebrates. Mar. Environ. Res. 3: 145.

Pesonen, M. and T.B. Andersson. 1997. Fish primary hepatocyte culture; and important model for xenobiotic metabolism and toxicity studies. Aquat. Toxicol. 37: 253-267.

Pestana, J.L.T., A. Re, A.J.A. Nogueira and A.M.V.M. Soares. 2007. Effects of cadmium and zinc on the feeding behaviour of two freshwater crustaceans: *Atyaephyra desmarestii* (Decapoda) and *Echinogammarus meridionalis* (Amphipoda). Chemosphere 68(8): 1556-1562.

Pesticide Action Network (PAN). 2014. PAN Pesticides Database - Chemical Toxicity Studies on Aquatic Organisms. Toxicity Studies for Cadmium on All Organism Groups. Available at: http://www.pesticideinfo.org/List_AquireAll.jsp?Rec_Id=PC33703

Peterson, H.G. 1991. Toxicity testing using a chemostat-grown green alga, *Selenastrum capricornutum*. In: J.W. Garoch, W.K. Lower, W. Wang and M.A. Lewis (*Eds*.), Plants for toxic assessment, 2nd Volume, ASTM STP 1115, Philadelphia, PA, pp. 107-117.

Peterson, H.G., F.P. Healey and R. Wagemann. 1984. Metal toxicity to algae: A highly pH dependent phenomenon. Can. J. Fish. Aquat. Sci. 41: 974-979.

Peterson, R.H., J.L. Metcalfe and S. Ray. 1983. Effects of cadmium on yolk utilization, growth, and survival of Atlantic salmon alevins on newly feeding fry. Arch. Environ. Contam. Toxicol. 12: 37-44.

Peterson, R.H., J.L. Metcalfe and S. Ray. 1985. Uptake of cadmium by eggs and alevins of Atlantic salmon (*Salmo salar*) as influenced by acidic conditions. Bull. Environ. Contam. Toxicol. 34: 359-368.

Phelps, H.L. 1979. Cadmium sorption in estuarine mud-type sediment and the accumulation of cadmium in the soft-shell clam, *Mya arenaria*. Estuaries 2: 40.

Phetsombat, S., M. Kruatrachue, P. Pokethitiyook and S. Upatham. 2006. Toxicity and bioaccumulation of cadmium and lead in *Salvinia cucullata*. J. Environ. Biol. 27(4): 645-652.

Phillips, B.M., P.A. Nicely, J.W. Hunt, B.S. Anderson, R.S. Tjeerdema, S.E. Palmer, F.H. Palmer and H.M. Puckett. 2003. Toxicity of cadmium-copper-nickel-zinc mixtures to larval purple sea urchins (*Strongylocentrotus purpuratus*). Bull. Environ. Contam. Toxicol. 70(3): 592-599.

Phillips, D.J.H. 1976. The common mussel *Mytilus edulis* as an indicator of pollution by zinc, cadmium, lead and copper. I. Effects of environmental variables on uptake of metals. Mar. Biol. 38: 59.

Phillips, D.J.H. 1977. The common mussel *Mytilus edulis* as an indicator of trace metals in Scandinavian waters. I. Zinc and cadmium. Mar. Biol. 43: 283-291.

Phillips, D.J.H. 1979. Trace metals in the common mussel, *Mytilus edulis* (L.), and in the alga *Fucus vesiculosus* (L.) from the region of the Sound (Oresund). Environ. Pollut. 18: 31-43.

Phillips, D.J.H. 1980. Toxicity and accumulation of cadmium in marine and estuarine biota. Part 1. Ecological cycling. In: J.O. Nriagu (*Ed.*), Cadmium in the Environment, Part I, Wiley-Interscience, NY, 425-569.

Phillips, G.R. and R.C. Russo. 1978. Metal bioaccumulation in fishes and aquatic invertebrates: A literature review. EPA-600/3-78-103. National Technical Information Service, Springfield, Virginia.

Philp, R.B. 2001. Effects of experimental manipulation of pH and salinity on Cd2+ uptake by the sponge *Microciona prolifera* and on sponge cell aggregation induced by Ca2+ and Cd2+. Arch. Environ. Contam. Toxicol. 41(3): 282-288.

Phipps, G.L. and G.W. Holcombe. 1985. A method for aquatic multiple species toxicant testing: Acute toxicity of 10 chemicals to 5 vertebrates and 2 invertebrates. Environ. Pollut. (Series A). 38: 141-157.

Phipps, G.L., M.J. Harden, E.N. Leonard, T.H. Roush, D.L. Spehar, C.E. Stephan, Q.H. Pickering and A.L. Buikema Jr. 1984. Effects of pollution on freshwater organisms. J. Water Pollut. Control Fed. 56(6): 725-758.

Phipps, G.L., V.R. Mattson and G.T. Ankley. 1995. Relative sensitivity of three freshwater benthic macroinvertebrates to ten contaminants. Arch. Environ. Contam. Toxicol. 28: 281-286.

Piazza, V., A. Ferioli, E. Giacco, N. Melchiorre, A. Valenti, F. Del Prete, F. Biandolino, L. Dentone, P. Frisenda and M.A. Faimali. 2012. A standardization of *Amphibalanus* (*Balanus*) *amphitrite* (Crustacea, Cirripedia) larval bioassay for ecotoxicological studies. Ecotoxicol. Environ. Saf. 79: 134-138.

Pickering, Q.H. and M.H. Gast. 1972. Acute and chronic toxicity of cadmium to fathead minnow (*Pimephales promelas*). J. Fish. Res. Board Can. 29(8): 1099-1106.

Pickering, Q.H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warmwater fishes. Air Water Pollut. Int. J. 10: 453.

Pierron, F., M. Baudrimont, A. Bossy, J.P. Bourdineaud, D. Brethes, P. Elie and J.C. Massabuau. 2007a. Impairment of lipid storage by cadmium in the European eel (*Anguilla anguilla*). Aquat. Toxicol. 81(3): 304-311.

Pierron, F., M. Baudrimont, A. Boudou and J.C. Massabuau. 2007b. Effects of salinity and hypoxia on cadmium bioaccumulation in the shrimp *Palaemon longirostris*. Environ. Toxicol. Chem. 26 (5): 1010-1017.

Pierron, F., V. Bourret, J. St-Cyr, P.G.C.Campbell, L. Bernatchez and P. Couture. 2009a. Transcriptional responses to environmental metal exposure in wild yellow perch (*Perca flavescens*) collected in lakes with differing environmental metal concentrations (Cd, Cu, Ni). Ecotoxicol. 18(5): 620-631.

Pierron, F., M. Baudrimont, S. Dufour, P. Elie, A. Bossy, M. Lucia and J.C. Massabuau. 2009b. Ovarian gene transcription and effect of cadmium pre-exposure during artificial sexual maturation of the European eel (*Anguilla anguilla*). Biometals 22(6): 985-994.

Pierron, F., E. Normandeau, M.A. Defo, P.G. Campbell, L. Bernatchez and P. Couture. 2011. Effects of chronic metal exposure on wild fish populations revealed by high-throughput cDNA sequencing. Ecotoxicol. 20(6): 1388-1399.

Pinkina, T.V. 2006. Effect of the ionic form of cadmium on reproduction and development of *Lymnaea stagnalis* L. Hydrobiol. J. 42(1): 68-74.

Pinto, A.P., A.M. Mota, A. De Varennes and F.C. Pinto. 2004. Influence of organic matter on the uptake of cadmium, zinc, copper and iron by sorghum plants. Sci. Total Environ. 326(1-3): 239-247.

Piotrowska, A., A. Bajguz, B. Godlewska-Zylkiewicz and E. Zambrzycka. 2010. Changes in growth, biochemical components, and antioxidant activity in aquatic plant *Wolffia arrhiza* (Lemnaceae) exposed to cadmium and lead. Arch. Environ. Contam. Toxicol. 58(3): 594-604.

Pip, E. and C. Mesa. 2002. Cadmium, copper, and lead in two species of *Artemisia* (compositae) in southern Manitoba, Canada. Bull. Environ. Contam. Toxicol. 69(5): 644-648.

Pistole, D.H., J.D. Peles and K. Taylor. 2008. Influence of metal concentrations, percent salinity, and length of exposure on the metabolic rate of fathead minnows (*Pimephales promelas*). Comp. Biochem. Physiol. 148C(1): 48-52.

Pitt, R., A. Maestre and R. Morquecho. 2004. The national stormwater quality database (NSQD) version 1.1 report. University of Alabama, Department of Civil and Environmental Engineering, Tuscaloosa, AL.

Piyatiratitivorakul, P. and P. Boonchamoi. 2008. Comparative toxicity of mercury and cadmium to the juvenile freshwater snail, *Filopaludina martensi martensi*. Sci. Asia 34(4): 367-370.

Piyatiratitivorakul, P., S. Ruangareerat and B. Vajarasathira, B. 2006. Comparative toxicity of heavy metal compounds to the juvenile golden apple snail, *Pomacea sp*. Fresenius Environ. Bull. 15(5): 379-384.

Planello, R., J.L. Martinez-Guitarte and G. Morcillo. 2010. Effect of acute exposure to cadmium on the expression of heat-shock and hormone-nuclear receptor genes in the aquatic midge *Chironomus riparius*. Sci. Total Environ. 408: 1598-1603.

Playle, R.C. 1997. Physiological and toxicological effects of metals at gills of freshwater fish. In: H.L. Bergman and E.J .Dorward-King (*Eds*.), Proc.of the SETAC Pellston Workshop, 10-14 Feb.1996, Pensacola, FL, 101-105.

Playle, R.C., D.G. Dixon and K. Burnison. 1993a. Copper and cadmium binding to fish gills: Estimates of metal-gill stability constants and modelling of metal accumulation. Can. J. Fish. Aquat. Sci. 50: 2678-2687.

Playle, R.C., D.G. Dixon and K. Burnison. 1993b. Copper and cadmium binding to fish gills: Modification by dissolved organic carbon and synthetic ligands. Can. J. Fish. Aquat. Sci. 50: 2667-2677.

Ploetz, D.M., B.E. Fitts and T.M. Rice. 2007. Differential accumulation of heavy metals in muscle and liver of a marine fish, (king mackerel, *Scomberomorus cavalla cuvier*) from the northern Gulf of Mexico, USA. Bull. Environ. Contam. Toxicol. 78(2): 134-137.

Podgurskaya, O.V. and V.Y. Kavun. 2006. Cadmium concentration and subcellular distribution in organs of the mussel *Crenomytilus grayanus* from upwelling regions of Okhotsk Sea and Sea of Japan. Arch. Environ. Contam Toxicol. 51(4): 567-572.

Pohl, C. 1993. Wechselbeziehungen zwischen spurenmetallkonzentrationen (Cd, Cu, Pb, Zn) im meerwasser und in zooplanktonorganismen (Copepoda) der arktis und des atlantiks. (Correlations between trace metal concentrations (Cd, Cu, Pb, Zn) in seawater and zooplankton organisms (Copepoda) of the Arctic and Atlantic. Govt. Report. Announ. Index. Issue 15.

Pokora, W. and Z. Tukaj. 2010. The combined effect of anthracene and cadmium on photosynthetic activity of three desmodesmus (Chlorophyta) species. Ecotoxicol. Environ. Saf. 73(6): 1207-1213.

Polak-Juszczak, L. 2009. Temporal trends in the bioaccumulation of trace metals in herring, sprat, and cod from the southern Baltic Sea in the 1994-2003 period. Chemosphere 76(10): 1334-1339.

Polar, E. and R. Kucukcezzar. 1986. Influence of some metal chelators and light regimes on bioaccumulation and toxicity of Cd^{2+} in duckweed (*Lemna gibba*). Physiol. Plant 66: 87-93.

Poldoski, J.E. 1979. Cadmium bioaccumulation assays. Their relationship to various ionic equilibria in Lake Superior water. Environ. Sci. Technol. 13: 701.

Portmann, J.E. and K.W. Wilson. 1971. The toxicity of 140 substances to the brown shrimp and other marine animals. Shellfish Information Leaflet No.22 (2nd Ed.), Ministry of Agric. Fish. Food, Fish. Lab. Burnham-on-Crouch, Essex, and Fish Exp. Station Conway, North Wales, 12 p.

Postma, J.F. and C. Davids. 1995. Tolerance induction and life cycle changes in cadmium-exposed *Chironomus riparius* (Diptera) during consecutive generation. Ecotoxicol. Environ. Safety. 30: 195-202.

Postma, J.F., M.C. Buckert-de Jong, N. Staats and C. Davids. 1994. Chronic toxicity of cadmium to *Chironomus reparius* (Diptera: Chironomidae) at different food levels. Arch. Environ. Contam. Toxicol. 26: 143-148.

Postma. J.F., P. Van Nugteren and M.B. Buckert-De Jong. 1996. Increased cadmium excretion in metal-adapted populations of the midge *Chironomus riparius* (Diptera). Environ. Toxicol Chem. 15(3): 332-339.

Poteat, M. and D. Buchwalter. 2013. Calcium uptake in aquatic insects: Influences of phylogeny and metals (Cd and Zn). J. Exp. Bio. 217: 1180-1186.

Poteat, M.D., M. Diaz-Jaramillo and D.B. Buchwalter. 2012. Divalent metal (Ca, Cd, Mn, Zn) uptake and interactions in the aquatic insect *Hydropsyche sparna*. J. Exp. Biol. 215(Pt 9): 1575-1583.

Poteat, M.D., T. Garland, N.S. Fisher, W.X. Wang and D.B. Buchwalter. 2013. Evolutionary patterns in trace metal (Cd and Zn) efflux capacity in aquatic organisms. Environ. Sci. Technol. 47: 7989-7995.

Poulsen, E., H.U. Riisgard and F. Mohlenberg. 1982. Accumulation of cadmium and bioenergetics in the mussel *Mytilus edulis*. Mar. Biol. 68(1): 25-29.

Poulton. B.C., D.P. Monda, D.F. Woodward, M.L. Wildhaber and W.G. Brumbaugh. 1995. Relations between benthic community structure and metals concentrations in aquatic macroinvertebrates: Clark Fork River, Montana. J. Fresh. Ecol. 10(3): 277-293.

Pourang, N. and J.H. Dennis. 2005. Distribution of trace elements in tissues of two shrimp species from the Persian Gulf and roles of metallothionein in their redistribution. Environ. Int. 31(3): 325-341.

Powell, G.M., D.W.R. Nimmo, S.A. Flickinger and S.F. Brinkman. 1998. Use of *Azolla* to assess toxicity and accumulation of metals from artificial and natural sediments containing cadmium, coper, and zinc. ASTM Spec. Tech. Publ. 1333: 184-199.

Powell, J.H. and R.E. Powell. 2001. Trace elements in fish overlying subaqueous tailings in the tropical west Pacific. Water Air Soil Pollut. 125(1-4): 81-104.

Poynton, H.C., J.R.Varshavsky, B. Chang, G. Cavigiolio, S. Chan, P.S.Holman, A.V. Loguinov, D.J. Bauer, K. Komachi, E.C. Theil, E.J. Perkins, O. Hughes and C.D. Vulpe. 2007. *Daphnia magna* ecotoxicogenomics provides mechanistic insights into metal toxicity. Environ. Sci. Technol. 41(3): 1044-1050.

Prafulla, V., L. Francis and P.T. Lakshmanan. 2001. Concentrations of trace metals in the squids, *Loligo duvauceli* and *Doryteuthis sibogae* caught from the southwest coast of India. Asian Fish. Sci. 14(4): 399-410.

Prasad, M.N.V., K. Drej, A. Skawinska and K. Stralka. 1998. Toxicity of cadmium and copper in *Chlamydomonas reinhardtii* wild-type (WT2137) and cell wall deficient mutant strain (CW15). Bull. Environ. Contam. Toxicol. 60: 306-311.

Prasad, M.N.V., P. Malec, A. Waloszek, M. Bojko and K. Strzalka. 2001. Physiological responses of *Lemna trisulca* L. (duckweed) to cadmium and copper bioaccumulation. Plant Sci. 161(5): 881-889.

Prasad, S.M. and A. Singh. 2011. Metabolic responses of *Azolla pinnata* to cadmium stress: Photosynthesis, antioxidative system and phytoremediation. Chem. Ecol. 27(6): 543-555.

Pratap, H.B. and S.E. Bonga. 2004. Mineral composition and cadmium accumulation in *Oreochromis mossambicus* exposed to waterborne cadmium. Bull. Environ. Contam. Toxicol. 72(4): 741-749.

Prato, E. and F. Biandolino. 2007. Combined toxicity of mercury, copper and cadmium on embryogenesis and early larval stages of the *Mytlius galloprovincialis*. Environ. Technol. 28(8): 915-920.

Prato, E., C. Scardicchio and F. Biandolino. 2008. Effects of temperature on the acute toxicity of cadmium to *Corophium insidiosum*. Environ. Monit. Assess. 136(1-3): 161-166.

Prato, E., F. Biandolino and C. Scardicchio. 2009. Effects of temperature on the sensitivity of *Gammarus aequicauda* (Martynov, 1931) to cadmium. Bull. Environ. Contam. Toxicol. 83(4): 469-473.

Presing, M., K.V. Balogh and J. Salanki. 1993. Cadmium uptake and depuration in different organs of *Lymnaea stagnalis* L. and the effect of cadmium on the natural zinc level. Arch. Environ. Contam. Toxicol. 24: 28-34.

Pretto, A., V.L. Loro, V.M. Morsch, B.S. Moraes, C. Menezes, B. Clasen, L. Hoehne and V. Dressler. 2010. Acetylcholinesterase activity, lipid peroxidation, and bioaccumulation in silver catfish (*Rhamdia quelen*) exposed to cadmium. Arch. Environ. Contam. Toxicol. 58(4): 1008-1014.

Pretto, A., V.L. Loro, B. Baldisserotto, M.A. Pavanato, B.S. Moraes, C. Menezes, R. Cattaneo, B. Clasen, I.A. Finamor and V. Dressler. 2011. Effects of water cadmium concentrations on bioaccumulation and various oxidative stress parameters in *Rhamdia quelen*. Arch. Environ. Contam. Toxicol. 60(2): 309-318.

Prevot, P. and M.O. Soyer-Gobillard. 1986. Combined action of cadmium and selenium on two marine dinoflagellates in culture, *Prorocentrum micans* Ehrbg. and *Crypthecodinium cohnii* Biecheler. J. Protozool. 33(1): 42-47.

Pribyl, P., V. Cepak and V. Zachleder. 2005. Cytoskeletal alterations in interphase cells of the green alga *Spirogyra decimina* in response to heavy metals exposure: I. The effect of cadmium. Protoplasma 226(3/4): 231-240.

Price, N.M. and F.M.M. Morel. 1990. Cadmium and cobalt substitution for zinc in a zinc-deficient marine diatom. Nature 344:658-660.

Price, R.E. and L.A. Knight Jr. 1978. Mercury cadmium lead and arsenic in sediments plankton and clams from Lake Washington and Sardis Reservoir Mississippi October 1975-May 1976. Pestic. Monit. J. 11(4): 182-189.

Price, R.K.J. and R.F. Uglow. 1979. Some effects of certain metals on development and mortality within the moult cycle of *Crangon crangon* (L.). Mar. Environ. Res. 2(4): 287-299.

Pringle, B.H., D.E. Hissong, E.L. Katz and S.T. Mulawka. 1968. Trace metal accumulation by estuarine mollusks. Am. Soc. Civil Eng., J. Sanit. Eng. Div. 94(3): 455-476.

Prothro, M.G. 1993. Office of water policy and technical guidance on interpretation and implementation of aquatic metals criteria. Memorandum from Acting Assistant Administrator for Water. Washington, D.C., U/S. EPA Office of Water. 7pp. Attachments 41pp.

Prowe, F., M. Kirf and G.P. Zauke. 2006. Heavy metals in crustaceans from the Iberian Deep Sea Plain. Sci. Mar. 70(2): 271-279.

Pundir, G. and N.M. Malhotra. 2011. Haematological alterations induced by heavy metal cadmium toxicity in *Clarias batrachus*. J. Exp. Zool. India 14(2): 411-415.

Pundir, G., N.M. Malhotra and S.S. Lal. 2012. Toxicopathological changes in liver of *Clarias batrachus* due to cadmium sulphate toxicity. J. Exp. Zool. India 15(1): 253-258.

Puvaneswari, S. and R. Karuppasamy. 2007. Accumulation of cadmium and its effects on the survival and growth of larvae of *Heteropneustes fossilis* (Bloch, 1794). J. Fish. Aquat.Sci. 2(1): 27-37.

Pynnonen, K. 1995. Effect of pH, hardness and maternal pre-exposure on the toxicity of Cd, Cu and Zn to the glochidial larvae of a freshwater clam *Anodonta cygnea*. Water Res. 29(1): 247-254.

Pytharopoulou, S., K. Grintzalis, E. Sazakli, M. Leotsinidis, C.D. Georgiou and D.L. Kalpaxis. 2011. Translational responses and oxidative stress of mussels experimentally exposed to Hg, Cu and Cd: One pattern does not fit at all. Aquat. Toxicol. 105 (1/2): 157-165.

Qian, H., J. Li, L. Sun, W. Chen, G.D. Sheng, W. Liu and Z. Fu. 2009. Combined effect of copper and cadmium on *Chlorella vulgaris* growth and photosynthesis-related gene transcription. Aquat. Toxicol. 94(1): 56-61.

Qian, H., J. Li, X. Pan, H. Jiang, L. Sun and Z. Fu. 2010. Photoperiod and temperature influence cadmium's effects on photosynthesis-related gene transcription in *Chlorella vulgaris*. Ecotoxicol. Environ. Saf. 73(6): 1202-1206.

Qian, H., J. Li, X. Pan, L. Sun, T. Lu, H. Ran and Z. Fu. 2011. Combined effect of copper and cadmium on heavy metal ion bioaccumulation and antioxidant enzymes induction in *Chlorella vulgaris*. Bull. Environ. Contam. Toxicol. 87(5): 512-516.

Qichen, C., Z. Kejien and Z. Guanwen. 1988. A comprehensive investigation of the toxic effects of heavy metals on fish. J. Fish. China/Shuichan Xuebao (Chi.) (Eng. Trans.) (Author communication used). 12(1): 21-33.

Qin, F.J., J. Jin, H.J. Gu, W. Qian and J.Z. Chen. 2011. Effect of nanometer selenium on nonspecific immunity and antioxidase of gift stressed by cadmium. J. Agro-Environ. Sci. 30(6): 1044-1050.

Qin, Q., S. Qin, L. Wang and W. Lei. 2012. Immune responses and ultrastructural changes of hemocytes in freshwater crab *Sinopotamon henanense* exposed to elevated cadmium. Aquat. Toxicol. 106-107: 140-146.

Qiu, C.E., Q.J. Kuang, Y.H. Bi, G.X. Liu and Z.Y. Hu. 2006. Response of *Chlorococcum sp*. AZHB to copper and cadmium stress. Bull. Environ. Contam. Toxicol. 77(5): 772-778.

Qiu, J.W., Z.C. Xie and W.X. Wang. 2005. Effects of calcium on the uptake and elimination of cadmium and zinc in Asiatic clams. Arch. Environ. Contam. Toxicol. 48(2): 278-287.

Qu, R.J., X.H. Wang, M.B. Feng, Y. Li, H.X. Liu, L.S. Wang and Z.Y. Wang. 2013. The toxicity of cadmium to three aquatic organisms (*Photobacterium phosphoreum*, *Daphnia magna* and *Carassius auratus*) under different pH levels. Ecotoxicol. Environ. Saf. 95: 83-90.

Qureshi, S.A., A.B. Saksena and V.P. Singh. 1980. Acute toxicity of four heavy metals to benthic fish food organisms from the River Khan, Ujjain. Int. J. Environ. Studies 15(1): 59-61.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at: https://www.R-project.org/.

Rachlin, J.W. and A. Grosso. 1991. The effects of pH on the growth of *Chlorella vulgaris* and its interactions with cadmium toxicity. Arch. Environ. Contam. Toxicol. 20: 505-508.

Rachlin, J.W. and A. Grosso. 1993. The growth response of the green alga *Chlorella vulgaris* to combined divalent cation exposure. Arch. Environ. Contam. Toxicol. 24: 16-20.

Rachlin, J.W., B. Warkentine and T.E. Jensen. 1982. The growth responses of *Chlorella saccharophila*, *Navicula incerta* and *Nitzschia closterium* to selected concentrations of cadmium. Bull. Torrey Bot. Club 109(2): 129-135.

Rachlin, J.W., T.E. Jensen and B. Warkentine. 1984. The toxicological response of the algae *Anabaena flos-aquae* (Cyanophyceae) to cadmium. Arch. Environ. Contam. Toxicol. 13: 143.

Radenac, G., D. Fichet and P. Miramand, P. 2001. Bioaccumulation and toxicity of four dissolved metals in *Paracentrotus lividus* sea-urchin embryo. Mar. Environ. Res. 51: 151-166.

Radetski, C.M., J.F. Ferard and C. Blaise. 1995. A semistatic microplate-based phytotoxicity test. Environ. Toxicol. Chem. 14(2): 299-302.

Radhakrishnan, M.V. and S. Hemalatha. 2010. Sublethal toxic effects of cadmium chloride to liver of freshwater fish *Channa striatus* (Bloch). Amer. Euras. J. Toxicol. Sci. 2: 54-56.

Radhakrishnan, M.V. and S. Hemalatha. 2011. Bioaccumulation of cadmium in the organs of freshwater fish *Heteropneustes fossilis* (Bloch, 1794). Indian J. Fish. 58(2): 149-151.

Radix, P., M. Leonard, C. Papantoniou, G. Roman, E. Saouter, S. Gallotti-Schmitt, H. Threbaud and P. Vasseur. 1999. Comparison of *Brachionus calyciflorus* 2-d and microtox® chronic 22-h tests with *Daphnia magna* 21-d test for chronic toxicity assessment of chemicals. Environ. Toxicol. Chem. 18(10): 2178-2185.

Rai, U.N., R.D. Tripathi, S. Sinha and P. Chandra. 1995. Chromium and cadmium bioaccumulation and toxicity in *Hydrilla verticillata* (l.f.) Royle and *Chara corallina* Wildenow. J. Environ. Sci. Health. A30: 537-551.

Rai, U.N., R.D. Tripathi, P. Vajpayee, N. Pandey, M.B. Ali and D.K. Gupta. 2003. Cadmium accumulation and its phytotoxicity in *Potamogeton pectinatus* L. (Potamogetonaceae). Bull. Environ. Contam. Toxicol. 70(3): 566-575.

Raimundo, J., M. Caetano and C. Vale. 2004. Geographical variation and partition of metals in tissues of *Octopus vulgaris* along the Portuguese coast. Sci. Total Environ. 325(1-3): 71-81.

Raimundo, J., C. Vale, R. Duarte and I. Moura. 2008. Sub-cellular partitioning of Zn, Cu, Cd and Pb in the digestive gland of native *Octopus vulgaris* exposed to different metal concentrations (Portugal). Sci. Total Environ. 390(2-3): 410-416.

Raimundo, J., C. Vale, R. Duarte and I. Moura. 2010. Association of Zn, Cu, Cd and Pb with protein fractions and sub-cellular partitioning in the digestive gland of *Octopus vulgaris* living in habitats with different metal levels. Chemosphere 81(10): 1314-1319.

Raimundo, J., P. Pereira, M. Caetano, M.T. Cabrita and C. Vale. 2011. Decrease of Zn, Cd and Pb concentrations in marine fish species over a decade as response to reduction of anthropogenic inputs: The example of Tagus estuary. Mar. Pollut. Bull. 62(12): 2854-2858.

Rainbow, P.S. 1985. Accumulation of Zn, Cu and Cd by crabs and barnacles. Estuar. Coast. Shelf Sci. 21: 669-686.

Rainbow, P.S. 2002. Trace metal concentrations in aquatic invertebrates: Why and so what? Environ. Pollut. 120(3): 497-507.

Rainbow, P.S. and W.H. Black. 2005. Cadmium, zinc and the uptake of calcium by two crabs, *Carcinus maenas* and *Eriocheir sinensis*. Aquat. Toxicol. 72(1/2): 45-65.

Rainbow, P.S. and M.K.H Kwan. 1995. Physiological responses and the uptake of cadmium and zinc by the amphipod crustacean *Orchestia gammarellus*. Mar. Ecol. Prog. Ser. 127: 87-102.

Rainbow, P.S. and W.X. Wang. 2001. Comparative assimilation of Cd, Cr, Se, and Zn by the barnacle *Elminius modestus* from phytoplankton and zooplankton diets. Mar. Ecol. Prog. Ser. 218: 239-248.

Rainbow, P.S. and W.X. Wang. 2005. Trace metals in barnacles: The significance of trophic transfer. Sci. China. Ser. C Life Sci./Chinese Acad. Sci. 48(Suppl. 1): 110-117.

Rainbow, P.S. and S.L. White. 1989. Comparative strategies of heavy metal accumulation by crustaceans: Zinc, copper and cadmium in a decapod, and amphipod and a barnacle. Hydrobiol. 174: 245-262.

Rainbow, P.S., A.G. Scott, E.A. Wiggins and R.W. Jackson. 1980. Effects of chelating agents on the accumulation of cadmium by the barnacle *Semibalanus balanoides*, and the complexation of soluble Cd, Zn and Cu. Mar. Ecol. Prog. Ser. 2: 143-152.

Rainbow, P.S., W. Fialkowski, A. Sokolowski, B.D. Smith and M. Wolowicz. 2004a. Geographical and seasonal variation of trace metal bioavailabilities in the Gulf of Gdansk, Baltic Sea using mussels (*Mytilus trossulus*) and barnacles (*Balanus improvisus*) as biomonitors. Mar. Biol. 144(2): 271-286.

Rainbow, P.S., T.Y.T. Ng, D. Shi and W.X. Wang. 2004b. Acute dietary pre-exposure and trace metal bioavailability to the barnacle *Balanus amphitrite*. J. Exp. Mar. Biol. Ecol. 311(2): 315-337.

Rainwater, T.R., T.H. Wu, A.G. Finger, J.E. Canas, L. Yu, K.D. Reynolds, G. Coimbatore, B. Barr, S.G. Platt, G.P. Cobb, T.A. Anderson and S.T. McMurry. 2007. Metals and organochlorine pesticides in caudal scutes of crocodiles from Belize and Costa Rica. Sci. Total Environ. 373: 146-156.

Raissy, M. M. Ansari, E. Rahimi and M. Raissy. 2011. Mercury, arsenic, cadmium and lead in lobster (*Panulirus homarus*) from the Persian Gulf. Toxicol. Ind. Health 27(7): 655-659.

Raj Kumar, J.S.I. 2012. Acute toxicity of cadmium, copper, lead and zinc to tiger shrimp *Penaeus monodon* postlarvae. Int. J. Environ. Sci. 3(1): 305-311.

Ralph, P.J. and M.D. Burchett. 1998. Photosynthetic response of *Halophila ovalis* to heavy metal stress. Environ. Pollut. 103: 91-101.

Ramachandran, S., T.R. Patel and M.H. Colbo. 1997. Effect of copper and cadmium on three Malaysian tropical estuarine invertebrate larvae. Ecotoxicol. Environ. Saf. 36: 183-188.

Ramamoorthy, S. and K. Blumhagen. 1984. Uptake of Zn, Cd, and Hg by fish in the presence of competing compartments. Can. J. Fish. Aquat. Sci. 41: 750.

Ramesha, A.M., T.R.C. Guptha, R.J. Katti, G. Gowda and C. Lingdhal. 1996. Toxicity of cadmium to common carp *Cyprinus carpio* (Linn.). Environ. Ecol. 14(2): 329-333.

Ramesha, A.M., T.R.C. Gupta, C. Lingdhal, K.V.B. Kumar, G. Gowda and K.S. Udupa. 1997. Combined toxicity of mercury and cadmium to the common carp *Cyprinus carpio* (Linn.) Environ. Ecol. 15(1): 194-198.

Ramirez, P., G. Barrera and C. Rosas. 1989. Effects of chromium and cadmium upon respiration and survival of *Callinectes similis*. Bull. Environ. Contam. Toxicol. 43: 850-857.

Ramos, A.A., Y. Inoue and S. Ohde. 2004. Metal contents in Porites corals: Anthropogenic input of river run-off into a coral reef from an urbanized area, Okinawa. Mar. Pollut. Bull. 48(3-4): 281-294.

Ramsak, A., J. Scancar, M. Horvat and A. Ramsak. 2012. Evaluation of metallothioneins in blue mussels (*Mytilus galloprovincialis*) as a biomarker of mercury and cadmium exposure in the Slovenian Waters (Gulf of Trieste): A long-term field study. Acta Adriatica 53(1): 71-85.

Rangsayatorn, N., E.S. Upatham, M. Kruatrachue, P. Pokethitiyook and G.R. Lanza. 2002. Phytoremediation potential of spirulina (*Arthrospira) platensis*: Biosorption and toxicity studies of cadmium. Environ. Pollut. 119(1): 45-53.

Rangsayatorn, N., M. Kruatrachue, P. Pokethitiyook, E.S. Upatham, G.R. Lanza and S. Singhakaew. 2004. Ultrastructural changes in various organs of the fish *Puntius gonionotus* fed cadmium-enriched cyanobacteria. Environ. Toxicol. 19(6): 585-593.

Rank, J., K.K. Lehtonen, J. Strand and M. Laursen. 2007. DNA damage, acetylcholinesterase activity and lysosomal stability in native and transplanted mussels (*Mytilus edulis*) in areas close to coastal chemical dumping sites in Denmark. Aquat. Toxicol. 84(1): 50-61.

Rao, J.I. and M.N. Madhyastha. 1987. Toxicities of some heavy metals to the tadpoles of frog, *Microhyla ornata* (Dumeril and Bibron). Toxicol. Lett. 36: 205-208.

Rao, S.V.R., S.K. Sharma, V.P. Singh and L.P. Mall. 1979. Toxic effect of two heavy metals on phytoplankton photosynthesis. Sci. Cult. 45(7): 286-288.

Rao, V.R., S.V. Mitz, C.T. Hadden and B.W. Cornaby. 1996. Distribution of contaminants in aquatic organisms from East Fork Poplar Creek. Ecotoxicol. Environ. Saf. 33(1): 44-54.

Raposo, J.C., L. Bartolome, E. Cortazar, G. Arana, M. Zabaljauregui, A. Diego, O. Zuloaga, J.M. Madariaga and N. Etxebarria. 2009. Trace metals in oysters, *Crassotrea sps*., from UNESCO protected natural reserve of Urdaibai: Space-time observations and source identification. Bull. Environ. Contam. Toxicol. 83(2): 223-229.

Rasmussen, R.S., M.T. Morrissey and D. Cheney. 2007. Effect of age and tissue weight on the cadmium concentration in Pacific oysters (*Crassostrea gigas*). J. Shellfish Res. 26(1): 173-179.

Rathore, R.S. and B.S. Khangarot. 2002. Effects of temperature on the sensitivity of sludge worm *Tubifex tubifex* Muller to selected heavy metals. Ecotoxicol. Environ. Saf. 53(1): 27-36.

Rathore, R.S. and B.S. Khangarot. 2003. Effects of water hardness and metal concentration on a freshwater *Tubifex tubifex* Muller. Water Air Soil Pollut. 142(1-4): 341-356 .

Raungsomboon, S. and L. Wongrat. 2007. Bioaccumulation of cadmium in an experimental aquatic ecosystem involving phytoplankton, zooplankton, catfish and sediment. Kasetsart J. Nat. Sci. 41(1): 180-185.

Ray, S. and W. White. 1976. Selected aquatic plants as indicator species for heavy metal pollution. J. Environ. Sci. Health 11A(12): 717-725.

Ray, S., D.W. McLeese and M.R. Peterson. 1981. Accumulation of copper, zinc, cadmium and lead from two contaminated sediments by three marine invertebrates - a laboratory study. Bull. Environ. Contam. Toxicol. 26(1): 315-322.

Rayms-Keller, A., K.E. Olson, M. McGaw, C. Oray, J.O. Carlson and B.J. Beaty. 1998. Effect of heavy metals on *Aedes aegypti* (Diptera: Culicidae) larvae. Ecotoxicol. Environ. Saf. 39: 41-17.

Raynal, N.J., A. Hontela and C. Jumarie. 2005. Cadmium uptake in isolated adrenocortical cells of rainbow trout and yellow perch. Comp. Biochem. Physiol. Part C Toxicol. Pharmacol. 140(3-4): 374-382.

Razinger, J., M. Dermastia, J.D. Koce and Z. Zrimec. 2008. Oxidative stress in duckweed (*Lemna minor* L.) caused by short-term cadmium exposure. Environ. Pollut. 153(3): 687-694.

Razinger, J., L. Drinovec and A. Zrimec. 2010. Real-time visualization of oxidative stress in a floating macrophyte *Lemna minor* L. exposed to cadmium, copper, menadione, and AAPH. Environ. Toxicol. 25(6): 573-580.

Re, A., R. Freitas, L. Sampaio, A.M. Rodrigues and V. Quintino. 2009. Estuarine sediment acute toxicity testing with the european amphipod *Corophium multisetosum* Stock, 1952. Chemosphere 76(10): 1323-1333.

Reader, J.P., N.C. Everall, M.D.J. Sayer and R. Morris. 1989. The effects of eight trace metals in acid soft water on survival, mineral uptake and skeletal calcium deposition in yolk-sac fry of brown trout, *Salmo trutta* L. J. Fish Biol. 35: 187-198.

Rebhun, S. and A. Ben-Amotz. 1984. The distribution of cadmium between the marine alga *Chlorella stigmatophora* and sea water medium. Water Res. 18(2): 173-179.

Rebhun, S. and A. Ben-Amotz. 1986. Effect of NaCl concentration on cadmium uptake by the halophilic alga *Dunaliella salina*. Mar. Ecol. Prog. Ser. 30: 215-219.

Rebhun, S. and A. Ben-Amotz. 1988. Antagonistic effect of maganese to cadmium toxicity in the alga *Dunaliella salina*. Mar. Ecol. Prog Ser. 42: 97-104.

Rebouças do Amaral, M.C., M. de Freitas Rebelo, J.P. Torres and W.C. Pfeiffer. 2005. Bioaccumulation and depuration of Zn and Cd in mangrove oysters (*Crassostrea rhizophorae*, Guilding, 1828) transplanted to and from a contaminated tropical coastal lagoon. Mar. Environ. Res. 59(4): 277-285.

Reddy, M.N., V. Srivastava and V. Patil. 2002. Effect of cadmium, lead and zinc on growth of some cyanobacteria. J. Ecobiol. 14(3): 161-167.

Reddy, P.B., B.S. Baghel and S. Srivastava. 2010. Biochemical effects of cadmium on the liver of catfish, *Mystus tengara* (Ham.). Nat. Environ. Pollut. Technol. 9(3): 593-595.

Reddy, P.S. and M. Fingerman. 1994. Effect of cadmium chloride on amylase activity in the red swamp crayfish, *Procambarus clarkii*. Comp. Biochem. Physiol. 109C(3): 309-314.

Reddy, P.S., S.R. Tuberty and M. Fingerman. 1997. Effects of cadmium and mercury on ovarian maturation in the red swamp crayfish, *Procambarus clarkii*. Ecotoxicol. Environ. Safety. 37: 62-65.

Reddy, P.S., P.R. Reddy and S.B. Sainath. 2011. Cadmium and mercury-induced hyperglycemia in the fresh water crab, *Oziotelphusa senex* Senex: Involvement of neuroendocrine system. Ecotoxicol. Environ. Saf. 74(3): 279-283.

Redeker, E.S. and R. Blust. 2004. Accumulation and toxicity of cadmium in the aquatic oligochaete *Tubifex tubifex*: A kinetic modeling approach. Environ. Sci. Technol. 38(2): 537-543.

Redeker, E.S., L. Bervoets and R. Blust. 2004. Dynamic model for the accumulation of cadmium and zinc from water and sediment by the aquatic oligochaete, *Tubifex tubifex*. Environ. Sci. Technol. 38(23): 6193-6200.

Redmond, M.S., K H. Scott, R.C. Swartz and J.K.P. Jones. 1994. Preliminary culture and life-cycle experiments with the benthic amphipod *Ampelisca abdita*. Environ. Toxicol. Chem. 13(8): 1355-1365.

Rehwoldt, R., L.W. Menapace, B. Nerrie and D. Alessandrello. 1972. The effect of increased temperature upon the acute toxicity of some heavy metal ions. Bull. Environ. Contam. Toxicol. 8(2): 91-96.

Rehwoldt, R., L. Lasko, C. Shaw and E. Wirhowski. 1973. The acute toxicity of some heavy metals ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10(5): 291-294.

Reichelt-Brushett, A.J. and P.L. Harrison. 2005. The effect of selected trace metals on the fertilization success of several scleractinian coral species. Coral Reefs 24(4): 524-534.

Reichert, W.L., D.A. Federighi and D.C. Malins. 1979. Uptake and metabolism of lead and cadmium in coho salmon (*Oncorhynchus kisutch*). Comp. Biochem. Physiol. 63C(2): 229-234.

Reid, S.D. and D.G. McDonald. 1991. Metal binding activity of the gills of rainbow trout (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 48: 1061-1068.

Reinfelder, J.R. and N.S. Fisher. 1994a. The assimilation of elements ingested by marine planktonic bivalve larvae. Limnol. Oceanogr. 39(1): 12-20.

Reinfelder, J.R. and N.S. Fisher. 1994b. Retention of elements absorbed by juvenile fish (*Menidia menidia*, *Menidia beryllina*) from zooplankton prey. Limnol. Oceanogr. 39(8): 1783-1789.

Reinfelder, J.R., W.X. Wang, S.N. Luoma and N.S. Fisher. 1997. Assimilation efficiencies and turnover rates of trace elements in marine bivalves: a comparison of oysters, clams and mussels. Mar. Biol. 129: 443-452.

Reish, D.J. 1978. The effects of heavy metals on polychaetous annelids. Rev. Int. Ocean. Med.49: 99-103.

Reish, D.J. 1993. Effects of metals and organic compounds on survival and bioaccumulation in two species of marine gammaridean amphipod, together with a summary of toxicological research on this group. J. Nat. Hist. 27: 781-794.

Reish, D.J. and J.A. LeMay. 1991. Toxicity and bioconcentration of metals and organic compounds by polychaeta. Ophelia Suppl. 5: 653-660.

Reish, D.J., J.M. Martin, F.M. Piltz and J.Q. Word. 1976. The effect of heavy metals on laboratory populations of two polychaetes with comparisons to the water quality conditions and standards in Southern California marine waters. Water Res. 10(4): 299-302.

Resih, D.J., T.V. Gerlinger, C.A. Phillips and P.D. Schmidtbauer. 1977. Toxicity of formulated mine tailings on marine polychaete. Marine Biological Consultants, Inc, Costa Mesa, CA, 133 p.

Reish, D.J., C.E. Pesch, J.H. Gentile, G. Bellan and D. Bellan-Santini. 1978. Interlaboratory calibration experiments using the Polychaetous annelid *Capitella capitata*. Mar. Environ. Res. 1(2): 109-118.

Reish, D.J., S.L. Asato and J.A. Lemay. 1988. The effect of cadmium and DDT on the survival and regeneration in the amphinomid polychaete *Eurythoe complanata*. In: Proc. 7th Symp. Mar. Biol., June 1, 1988, LaPaz BCS, Mexico, pp. 107-111.

Rejomon, G., K.K. Balachandran, M. Nair, T. Joseph, P.K. Dinesh Kumar, C.T. Achuthankutty, K.K.C. Nair and N.G.K. Pillai. 2008. Trace metal concentrations in zooplankton from the eastern Arabian Sea and western Bay of Bengal. Environ. For. 9: 22-32.

Rejomon, G., M. Nair and T. Joseph. 2010. Trace metal dynamics in fishes from the southwest coast of India. Environ. Monit. Assess. 167(1-4): 243-255.

Remacle, J., C. Houba and J. Ninane. 1982. Cadmium fate in bacterial microcosms. Water Air Soil Pollut. 18(4): 455-465.

Ren, J., J. Luo, H. Ma, X. Wang and L.Q. Ma. 2013. Bioavailability and oxidative stress of cadmium to *Corbicula fluminea*. Environ. Sci. Proc. Impacts 15(4): 860-869.

Ren, S., R.W. Mee and P.D. Frymier. 2004. Using factorial experiments to study the toxicity of metal mixtures. Ecotoxicol. Environ. Saf. 59(1): 38-43.

Ren, Z. and Z. Wang. 2010. Differences in the behavior characteristics between *Daphnia magna* and Japanese medaka in an on-line biomonitoring system. J. Environ. Sci. 22(5): 703-708.

Revathi, P., L.A. Vasanthi and N. Munuswamy. 2011. Effect of cadmium on the ovarian development in the freshwater prawn *Macrobrachium rosenbergii* (De Man). Ecotoxicol. Environ. Saf. 74(4): 623-629.

Reynders, H., K. Van Campenhout, L. Bervoets, W.M. De Coen and R. Blust. 2006a. Dynamics of cadmium accumulation and effects in common carp (*Cyprinus carpio*) during simultaneous exposure to water and food (*Tubifex tubifex*). Environ. Toxicol. Chem. 25(6): 1558-1567.

Reynders, H., K. Van der Ven, L.N. Moens, P. Van Remortel, W.M. De Coen and R. Blust. 2006b. Patterns of gene expression in carp liver after exposure to a mixture of waterborne and dietary cadmium using a custom-made microarray. Aquat. Toxicol. 80(2): 180-193.

Reynders, H., L. Bervoets, M. Gelders, W.M. De Coen, and R. Blust. 2008. Accumulation and effects of metals in caged carp and resident roach along a metal pollution gradient. Sci. Total Environ. 391(1): 82-95.

Reynoldson, T.B., P. Rodriguez and M.M Madrid. 1996. A comparison of reproduction, growth and acute toxicity in two populations of *Tubifex tubifex* (Muller, 1774) from the North American Great Lakes and northern Spain. Hydrobiol. 334: 199-206.

Rhea, D.T., D.D. Harper, A.M. Farag and W.G. Brumbaugh. 2006. Biomonitoring in the Boulder River watershed, Montana, USA: Metal concentrations in biofilm and macroinvertebrates, and relations with macroinvertebrate assemblage. Environ. Monit. Assess. 115: 381-393.

Rhodes, L., E. Casillas, B. McKnight, W. Gronlund, M. Myers, O.P. Olson and B. McCain. 1985. Interactive effects of cadmium, polychlorinated biphenyls, and fuel oil on experimentally exposed English sole (*Parophrys vetulus*). Can J. Fish. Aquat. Sci. 42: 1870-1880.

Riba, I., T.A. Del Valls, J.M. Forja and A. Gomez-Parra. 2004. The influence of pH and salinity on the toxicity of heavy metals in sediment to the estuarine clam *Ruditapes philippinarum*. Environ. Toxicol. Chem. 23(5): 1100-1107.

Ribo, J.M. 1997. Interlaboratory comparison studies of the luminescent bacteria toxicity bioassay. Environ. Toxicol. Water Qual. 12: 283-294.

Rice, D.L. 1984. A simple mass transport model for metal uptake by marine macroalgae growing at different rates. Exp. Mar. Biol. Ecol. 82: 175-182.

Rice, M.A. and P.K. Chien. 1979. Uptake, binding and clearance of divalent cadmium in *Glycera dibranchiata* (Annelida: Polychaeta). Mar. Biol. 53: 33-39.

Richards, J.G., P.J. Curtis, B.K. Burnison and R.C. Playle. 2001. Effects of natural organic matter source on reducing metal toxicity to rainbow trout (*Oncorhynchus mykiss*) and on metal binding to their gills. Environ. Toxicol. Chem 20(6): 1159-1166.

Richelle, E., Y. Degoudenne, L. Dejonghe and G. Van de Vyver. 1995. Experimental and field studies on the effect of selected heavy metals on three freshwater sponge species: *Ephydatia fluviatilis*, *Ephydatia muelleri* and *Spongilla lacustris*. Arch. Hydrobiol. 135(2): 209-231.

Riches, C.J., P.K. Robinson and C.E. Rolph. 1996. Effect of heavy metals on lipids from the freshwater alga *Selenastrum capricornutum*. Biochem. Soc. Trans. 24(2): 174S.

Riddell, D.J., J.M. Culp and D.J. Baird. 2005a. Sublethal effects of cadmium on prey choice and capture efficiency in juvenile brook trout (*Salvelinus fontinalis*). Environ. Toxicol. Chem. 24(7): 1751-1758.

Riddell, D.J., J.M. Culp and D.J. Baird. 2005b. Behavioral responses to sublethal cadmium exposure within an experimental aquatic food web. Environ. Toxicol. Chem. 24(2): 431-441.

Ridlington, J.W., D.C. Chapman, D.E. Goeger and P.D. Whanger. 1981. Metallothionein and Cu-chelation: Characterization of metal-binding proteins from the tissues of four marine animals. Comp. Biochem. Physiol. Part B Comp. Biochem. 70(1): 93-104.

Ridout, P.S., A.D. Willcocks, R.J. Morris, S.L. White and P.S. Rainbow. 1985. Concentrations of manganese iron copper zinc and cadmium in the mesopelagic decapod systellaspis-debilis from the east Atlantic Ocean. Mar. Biol. (Berlin) 87(3): 285-288.

Riedel, B. and G. Christensen. 1979. Effect of selected water toxicants and other chemicals upon adenosine triphosphatase activity *in vitro*. Bull. Environ. Contam. Toxicol. 23: 365-368.

Rifici, L.M., D.S. Cherry. J.L. Farris and J. Cairns Jr. 1996. Acute and subchronic toxicity of methylene blue to larval fathead minnows (*Pimephales promelas*): Implications for aquatic toxicity testing. Environ. Toxicol. Chem. 15(8): 1304- 1308.

Riget, F., P. Johansen and G. Asmund. 1996. Influence of length on element concentrations in blue mussels (*Mytilus edulis*). Mar. Pollut. Bull. 32(10): 745-751.

Riisgard, H.V., E. Bjornestad and F. Mohlenberg. 1987. Accumulation of cadmium in the mussel *Mytilus edulis*: Kinetics and importance of uptake via food and sea water. Mar. Biol. 96: 349-353.

Ringwood, A.H. 1989. Accumulation of cadmium by larvae and adults of an Hawaiian bivalve, *Isognomon californicum*, during chronic exposure. Mar. Biol. 102: 499-504.

Ringwood, A.H. 1990. The relative sensitivities of different life stages of *Isognomon californicum* to cadmium toxicity. Arch. Environ. Contam. Toxicol. 19: 338-340.

Ringwood, A.H. 1992a. Comparative sensitivity of gametes and early developmental stages of a sea urchin species (*Echinometra mathaei*) and a bivalve species (*Isognomon californicum*) during metal exposures. Arch. Environ. Contam. Toxicol. 22: 288-295.

Ringwood, A.H. 1992b. Effects of chronic cadmium exposures on growth of larvae of an Hawaiian bivalve, *Isognomon californicum*. Mar. Ecol. Prog. Ser. 83: 63-70.

Ringwood, A.H. 1993. Age-specific differences in cadmium sensitivity and bioaccumulation in bivalve molluscs. Mar. Environ. Res. 35: 35-39.

Risso-de Faverney, C., A. Devaux, M. Lafaurie, J.P. Girard, B. Bailly and R. Rahmani. 2001. Cadmium induces apoptosis and genotoxicity in rainbow trout hepatocytes through generation of reactive oxygen species. Aquat. Toxicol. 53(1): 65-76.

Ritterhoff, J., G.P. Zauke and R. Dallinger. 1996. Calibration of the estuarine amphipods, *Gammarus zaddachi* Sexton (1912), as biomonitors: Toxicokinetics of cadmium and possible role of inducible metal-binding proteins in Cd detoxification. Aquat. Toxicol. 34: 351-369.

Roach, A.C., W. Maher and F. Krikowa. 2008. Assessment of metals in fish from Lake Macquarie, New South Wales, Australia. Arch. Environ. Contam. Toxicol. 54: 292-308.

Roast, S.D., J. Widdows and M.B. Jones. 2001a. Impairment of mysid (*Neomysis integer*) swimming ability: An environmentally realistic assessment of the impact of cadmium exposure. Aquat. Toxicol. 52(3/4): 217-227.

Roast, S.D., J. Widdows and M.B. Jones. 2001b. Effects of salinity and chemical speciation on cadmium accumulation and toxicity to two mysid species. Environ. Toxicol. Chem. 20(5): 1078-1084.

Roast, S.D., J. Widdows and M.B. Jones. 2002a. Behavioural responses of estuarine mysids to hypoxia and disruption by cadmium. Mar. Environ. Res. 54(3-5): 319-323.

Roast, S.D., J. Widdows and M.B. Jones. 2002b. Distribution and swimming behaviour of *Neomysis integer* (Peracarida: Mysidacea) in response to gradients of dissolved oxygen following exposure to cadmium at environmental concentrations. Mar. Ecol. Prog. Ser. 237: 185-194.

Roast, S.D., P.S. Rainbow, B.D. Smith, M. Nimmo and M.B. Jones. 2002c. Trace metal uptake by the chinese mitten crab *Eriocheir sinensis*: The role of osmoregulation. Mar. Environ. Res. 53: 453-464.

Roberto, C., L.M. Giulia, D. Francesco, V. Aldo and S. Trifone. 2010. Carbonic anhydrase activity in *Mytilus galloprovincialis* digestive gland: Sensitivity to heavy metal exposure. Comp. Biochem. Physiol. 152C(3): 241-247.

Roberts, K.S., A. Cryer, J. Kay and J.F. de L.G. Solbe. 1979. A high molecular-weight cadmium-binding fraction isolated from the liver cytosol of trout exposed to environmentally relevant concentrations of the metal. Biochem. Soc. Trans. London. 7(4): 650-651.

Roberts, M.H.Jr., J.E. Warinner, C.F. Tsai, D. Wright and L.E. Cronin. 1982. Comparison of estuarine species sensitivities to three toxicants. Arch. Environ. Contam. Toxicol. 11: 681-692.

Robertson, E.L. and K. Liber. 2007. Bioassays with caged *Hyalella azteca* to determine in situ toxicity downstream of two Saskatchewan, Canada, uranium operations. Environ. Toxicol. Chem. 26(11): 2345-2355.

Robison, A.L. 2011. Influence of predation-based chemical cues on contaminant sensitivity in fathead minnows (*Pimephales promelas*) and *Daphnia pulex*. M.S Thesis, Oklahoma State University, OK.

Robohm, R.A. 1986. Paradoxical effects of cadmium exposure on antibacterial antibody responses in two fish species: Inhibition in cunners (*Tautogolabrus adspersus*) and enhancement in striped bass (*Morone saxatilis*). Vet. Immunol. Immunopathol. 12(1-4): 251-262.

Roccheri, M.C., M. Agnello, R. Bonaventura and V. Matranga. 2004. Cadmium induces the expression of specific stress proteins in sea urchin embryos. Biochem. Biophys. Res. Commun. 321(1): 80-87.

Roch, M. and E.J. Maly. 1979. Relationship of cadmium-induced hypocalcemia with mortality in rainbow trout (*Salmo gairdneri*) and the influence of temperature on toxicity. J. Res. Fish. Bd. Can. 36(11): 1297-1303.

Roch, M. and J.A. McCarter. 1984. Metallothionein induction, growth, and survival of chinook salmon exposed to zinc, copper, and cadmium. Bull. Environ. Contam. Toxicol. 32: 478-485.

Roch, M. and J.A. McCarter. 1986. Metallothionein induction growth and survival of rainbow trout exposed to mixed heavy metal contamination. Eleventh Annual Aquatic Toxicity Workshop, Vancouver, British Columbia, Canada, November 13-15, 1984. Can. Tech. Rep. Fish. Aquat. Sci. 0(1480): 52-54.

Roch, M., P. Noonan, P. and J.A. McCarter. 1986. Determination of no effect levels of heavy metals for rainbow trout using hepatic metallothionein. Water Res. 20(6): 771-774.

Rocha, T.L., T. Gomes, N.C. Mestre, C. Cardoso and M.J. Bebianno. 2015. Tissue specific responses to cadmium-based quantum dots in the marine mussel *Mytilus galloprovincialis*. Aquat Toxicol. 169:10-18.

Rodgher, S. and E.L.G. Espindola. 2008. Effects of interactions between algal densities and cadmium concentrations on *Ceriodaphnia dubia* fecundity and survival. Ecotoxicol. Environ. Saf. 71(3): 765-773.

Rodgher, S., E.L.G. Espindola and A.T. Lombardi. 2010. Suitability of *Daphnia similis* as an alternative organism in ecotoxicological tests: Implications for metal toxicity. Ecotoxicol. 19(6): 1027-1033.

Rodgher, S., E.L.G. Espindola, F.C.F. Simoes and A.E. Tonietto. 2012. Cadmium and chromium toxicity to *Pseudokirchneriella subcapitata* and *Microcystis aeruginosa*. Braz. Arch. Biol. Technol. 55(1): 161-169.

Rodrigues, N.L.V.B. and U. Pawlowsky. 2007. Acute toxicity tests by bioassays applied to the solubilized extracts of solid wastes Class II A - non inerts and Class II B. Eng. Sanit. Ambient., 12(1): 8-16.

Rodriguez, E.M. and D. Medesani. 1994. Pathological lesions in larvae hatched from ovigerous females of *Chasmagnathus granulata* (Decapoda, Brachyura) exposed to cadmium. Experientia 50(10): 975-977.

Rodriguez, F.A., J.F. Gonzalez Mantilla and R. Suarez Martinez. 2009. Accumulation of lead, chromium, and cadmium in muscle of capitan (*Eremophilus mutisii*), a catfish from the Bogota River Basin. Arch. Environ. Contam. Toxicol. 57(2): 359-365.

Roesijadi, G. and G.W. Fellingham. 1987. Influence of Cu, Cd, and Zn preexposure on Hg toxicity in the mussel *Mytilus edulis*. Can. J. Fish. Aquat. Sci. 44: 680-684.

Roesijadi, G., S. Rezvankhah, A. Perez-Matus, A. Mitelberg, K. Torruellas and P.A. Van Veld. 2009. Dietary cadmium and benzo(a)pyrene increased intestinal metallothionein expression in the fish *Fundulus heteroclitus*. Mar. Environ. Res. 67(1): 25-30.

Roh, J.Y., J. Lee and J. Choi, J. 2006. Assessment of stress-related gene expression in the heavy metal-exposed nematode *Caenorhabditis elegans*: A potential biomarker for metal-induced toxicity monitoring and environmental risk assessment. Environ. Toxicol. Chem. 25(11): 2946-2956.

Roh, J.Y., Y.J. Park and J. Choi. 2009. A cadmium toxicity assay using stress responsive *Caenorhabditis elegans* mutant strains. Environ. Toxicol. Pharmacol. 28(3): 409-413.

Roline, R.A. and J.R. Boehmke. 1981. Heavy metals pollution of the Upper Arkansas River, Colorado, and its effects on the distribution of the aquatic macrofauna. REC-ERC-81-15, U.S. Dep. of the Interior, Engineering and Research Center, Denver, CO, 71 p.

Rolli, N.M., S.S. Suvarnakhandi, G.S. Mulgund, R.H. Ratageri and T.C. Taranath. 2010. Biochemical responses and accumulation of cadmium in *Spirodela polyrhiza*. J. Environ. Biol. 31: 529-532.

Roman, G., A. Rudolph and R. Ahumada. 1994. Seasonal studies on cadmium toxicity in *Choromytilus chorus* (Molina 1782). Soc. Biol. Concepcion 65: 23-30.

Rombough, P.J. 1985. The influence of the zona radiata on the toxicities of zinc, lead, mercury, copper and silver ions to embryos of steelhead trout *Salmo gairdneri*. Comp. Biochem. Physiol. 82C(1): 115-117.

Rombough, P.J. and E.T. Garside. 1982. Cadmium toxicity and accumulation in eggs and alevins of Atlantic salmon *Salmo salar*. Can. J. Zool. 60: 2006.

Rombough, P.J. and E.T. Garside. 1984. Disturbed ion balance in alevins of Atlantic salmon *Salmo salar* chronically exposed to sublethal concentrations of cadmium. Can. J. Zool. 62: 1443-1450.

Romeo, M. 1991. Toxicology of trace metals in the marine. Oceanis 17(4): 383-402.

Romeo, M. and M. Gnassia-Barelli. 1995. Metal distribution in different tissues and in subcellular fractions of the Mediterranean clam *Ruditapes decussatus* treated with cadmium, copper, or zinc. Comp. Biochem. Physiol. 111C: 457-463.

Romeo, M., Y. Siau, Z. Sidoumoun and M. Gnassia-Barelli. 1999. Heavy metal distribution in different fish species from the Mauritania coast. Sci. Total Environ. 232: 169-175.

Romera, E., F. Gonzalez, A. Ballester, M.L. Blazquez and J.A. Munoz. 2007. Comparative study of biosorption of heavy metals using different types of algae. Biores. Technol. 98(17): 3344-3353.

Romera, E., F. Gonzalez, A. Ballester, M.L. Blazquez and J.A. Munoz. 2008a. Biosorption of Cd, Ni, and Zn with mixtures of different types of algae. Environ. Eng. Sci. 25(7): 999-1008.

Romera, E., F. Gonzalez, A. Ballester, M.L. Blazquez and J.A. Munoz. 2008b. Biosorption of heavy metals by *Fucus spiralis*. Biores. Technol. 99(11): 4684-4693.

Romero, Y., C. Lodeiros, M. Esclapes, N. Marin, M. Guevara and E. Morales. 2002. Toxic effects of cadmium on microalgae isolated from the northeastern region of Venezuela. Interciencia 27(3): 104-109 .

Ros, J.P.M. and W. Slooff (*Eds*.). 1988. Integrated criteria document cadmium; Appendix 1. Effects. Natl. Inst. of Public Health and Environ. Prot., Bilthoven, the Netherlands, Rep. No.758476004, 358 p.

Rosas, C. and P. Ramirez. 1993. Effect of chromium and cadmium on the thermal tolerance of the prawn *Macrobrachium rosenbergii* expose to hard and soft water. Bull. Environ. Contam. Toxicol. 51: 568-574.

Rosas, C.L., M.N. Gil and M.M. Uhart. 2012. Trace metal concentrations in southern right whale (*Eubalaena australis*) at Peninsula Valdes, Argentina. Mar. Pollut. Bull. 64(6): 1255-1260.

Roseman, E.F., E.L. Mills, M. Rutzke, W.H. Gutenmann and D.J. Lisk. 1994. Absorption of cadmium from water by North American zebra and quagga mussels (Bivalvia: Dreissenidae). Chemosphere 28(4): 737-743.

Rosen, G., A. Osorio-Robayo, I. Rivera-Duarte and D. Lapota. 2008. Comparison of bioluminescent dinoflagellate (Qwiklite) and bacterial (Microtox) rapid bioassays for the detection of metal and ammonia toxicity. Arch. Environ. Contam.T oxicol. 54(4): 605-611.

Rosenberg, R. and J.D. Costlow. 1976. Synergistic effects of cadmium and salinity combined with constant and cycling temperatures on the larval development of two estuarine crab species. Mar. Biol. 38: 291.

Rosko, J.J. and J.W. Rachlin. 1977. The effect of cadmium, copper, mercury, zinc and lead on cell division, growth, and chloropyll a content of the chlorophyte *Chlorella vulgaris*. Bull. Torrey Bot. Club 104: 226.

Rossi, N. and J.L. Jamet. 2008. In situ heavy metals (copper, lead and cadmium) in different plankton compartments and suspended particulate matter in two coupled Mediterranean coastal ecosystems (Toulon Bay, France). Mar. Pollut. Bull. 56: 1862-1870.

Rossmann, R. and J.A. Barres. 1992. Contamination of Green Bay water with lead and cadmium by a 37-m long, 2-m draft research vessel. Sci. Total Environ. 125: 405-415.

Rouleau, C., M. Block and H. Tjalve. 1998. Kinetics and body distribution of waterborne ^{65}Zn(II), ^{109}Cd(II), ^{203}Hg(II), and CH$_3$^{203}Hg(II) in phantom midge larvae (*Chaoborus americanus*) and effects of complexing agents. Environ. Sci. Technol. 32: 1230-1236.

Roux, D.J., P.L. Kempster, E. Truter and L. van der Merwe. 1993. Effect of cadmium and copper on survival and reproduction of *Daphnia pulex*. Water SA 19(4): 269-274.

Rowe, C.L. 1998. Elevated standard metabolic rate in a freshwater shrimp (*Palaemonetes paludosus*) exposed to trace element-rich coal combustion waste. Comp. Biochem. Physiol. 121A(4): 299-304.

Roy, I. and L. Hare. 1999. Relative importance of water and food as cadmium sources to the predatory insect *Sialis elata* (Megaloptera). Can. J. Fish. Aquat. Sci. 56: 1143-1149.

Roy, D., P.N. Greenlaw and B.S. Shane. 1993. Adsorption of heavy metals by green algae and ground rice hulls. J. Environ. Sci. Health. 28A(1): 37-50.

Ruan, J. 2006. Contents of and assessment on heavy metals in aquatic organisms in the Yuandang Lake of Xiamen. Mar. Sci. Bull./Haiyang Tongbao 25(5): 84-89.

Ruangsomboon, S. and L. Wongrat. 2006. Bioaccumulation of cadmium in an experimental aquatic food chain involving phytoplankton (*Chlorella vulgaris*), zooplankton (*Moina macrocopa*), and the predatory catfish *Clarias macrocephalus* x *C. gariepinus*. Aquat. Toxicol. 78(1): 15-20.

Rubinstein, N.I., E. Lores and N.R. Gregory. 1983. Accumulation of PCBs, mercury and cadmium by *Nereis virens*, *Mercenaria mercenaria* and *Palaemontes pugio* from contaminated harbor sediments. Aquat. Toxicol. 3(3): 249-260.

Ruelaqs-Inzunza, J. and F. Paez-Osuna. 2008. Trophic distribution of Cd, Pb, and Zn in a food web from Altata-Ensenada del Pabellon subtropical lagoon, SE Gulf of California. Arch. Environ. Contam. Toxicol.: 584-596.

Ruelas-Inzunza, J., F. Paez-Osuna and D. Garcia-Flores. 2010. Essential (Cu) and nonessential (Cd and Pb) metals in ichthyofauna from the coasts of Sinaloa state (SE Gulf of California). Environ. Monit. Assess. 162(1-4): 251-263.

Ruelle, R. and K.D. Keenlyne. 1993. Contaminants in Missouri River pallid sturgeon. Bull. Environ. Contam. Toxicol. 50(6): 898-906.

Rumolo, P., D.S. Manta, M. Sprovieri, R. Coccioni, L. Ferraro and E. Marsella. 2009. Heavy metals in benthic foraminifera from the highly polluted sediments of the Naples Harbour (southern Tyrrhenian Sea, Italy). Sci. Total Environ. 407(21): 5795-5802.

Saavedra, Y., A. Gonzalez, P. Fernandez and J. Blanco. 2004. Interspecific variation of metal concentrations in three bivalve mollusks from Galicia. Arch. Environ. Contam. Toxicol. 47(3): 341-351.

Safadi, R.S. 1998. The use of freshwater planarians in acute toxicity test with heavy metals. Verh. Internat. Verein. Limnol. 26: 2391-2392.

Saglam, D., G. Atli and M. Canli. 2013. Investigations on the osmoregulation of freshwater fish (*Oreochromis niloticus*) following exposures to metals (Cd, Cu) in differing hardness. Ecotoxicol. Environ. Saf. 92: 79-86.

Saglamtimur, B., B. Cicik and C. Erdem. 2003. Effects of different concentrations of copper alone and a copper+cadmium mixture on the accumulation of copper in the gill, liver, kidney and muscle tissues of *Oreochromis niloticus* (L.). Turk. J. Vet. Anim. Sci. 27: 813-820.

Sahu R.K., R.A.M. Naraian and C. Vishal. 2007. Accumulation of metals in naturally grown weeds (aquatic macrophytes) grown on an industrial effluent channel. Clean Soil Air Water 35(3): 261-265.

Saiki, M.K., B.A. Martin, L.D. Thompson and D. Welsh. 2001. Copper, cadmium, and zinc concentrations in juvenile chinook salmon and selected fish-forage organisms (aquatic insects) in the upper Sacramento River, California. Water Air Soil Pollut. 132(1-2): 127-139.

Sajwan, K.S. and W.H. Ornes. 1994. Phytoavailability and bioaccumulation of cadmium in duckweed plants (*Spirodela polyrhiza* L. Schleid). J. Environ. Sci. Health. A29(5): 1035-1044.

Sajwan, K.S., K.S. Kumar, S. Paramasivam, S.S. Compton and J.P. Richardson. 2008. Elemental status in sediment and American oyster collected from Savannah marsh/estuarine ecosystem: A preliminary assessment. Arch. Environ. Contam. Toxicol. 54: 245-258.

Salahshur, S., A.R. Bakhtiari and P. Kochanian. 2012. Use of *Solen brevis* as a biomonitor for Cd, Pb and Zn on the intertidal zones of Bushehr-Persian Gulf, Iran. Bull. Environ. Contam. Toxicol. 88(6): 951-955.

Salanki, J., K.V. Balogh and E. Berta. 1982. Heavy metals in animals of Lake Balaton. Water Res. 16: 1147-1152.

Salazar-Lugo, R.D., A.B. Vargas and L.M. Rojas. 2011. Effect of chronic cadmium exposure on structure of head kidney of neotropical fish *Colossoma macropomum*. Toxicol. Lett. Suppl. (0): S135.

Salazar-Medina, A.J., L. Garcia-Rico., K.D. Garcia-Orozco, E. Valenzuela-Soto, C.A. Contreras-Vergara, R. Arreola, A. Arvizu-Flores and R.R. Sotelo-Mundo. 2010. Inhibition by Cu^{2+} and Cd^{2+} of a mu-class glutathione S-transferase from shrimp *Litopenaeus vannamei*. J. Biochem. Mol. Toxicol. 24(4): 218-222.

Saleem, M., G.H. Kazi and M. Memon. 1999. Heavy metal concentration in the fish and shellfish of Karachi harbour area. Pak. J. Mar. Biol. 5(2): 143-154.

Salice, C.J. and T.J. Miller. 2003. Population-level responses to long-term cadmium exposure in two strains of the freshwater gastropod *Biomphalaria glabrata*: Results from a life-table response experiment. Environ. Toxicol. Chem. 22(3): 678-688.

Salice, C., T. Miller and G. Roesijadi. 2009. Demographic responses to multigeneration cadmium exposure in two strains of the freshwater gastropod, *Biomphalaria glabrata*. Arch. Environ. Contam. Toxicol. 56(4): 785-795.

Salice, C.J., T.A. Anderson, G. Roesijadi and C.J. Salice. 2010. Adaptive responses and latent costs of multigeneration cadmium exposure in parasite resistant and susceptible strains of a freshwater snail. Ecotoxicol. 19(8): 1466-1475.

Salvado, V., X.D. Quintana and M. Hidalgo. 2006. Monitoring of nutrients, pesticides, and metals in waters, sediments, and fish of a wetland. Arch. Environ. Contam. Toxicol. 51: 377-386.

Samecka-Cymerman, A. and A.J. Kempers. 2007. Heavy metals in aquatic macrophytes from two small rivers polluted by urban, agricultural and textile industry sewages SW Poland. Arch. Environ. Contam. Toxicol. 53(2): 198-206.

Samecka-Cymerman, A., K. Kolon, and A.J. Kempers. 2002. Heavy metals in aquatic bryophytes from the Ore mountains (Germany). Ecotoxicol. Environ. Saf. 52(3): 203-210.

Samuel, Y. and A.J. Thatheyus. 2003. Cadmium induced changes in the total protein and carbohydrate content of the tissues of *Oreochromis mossambicus*. Biochem. Cell. Arch. 3(1/2): 113-118.

Sanchez, B.C. 2009. Development of novel biomarkers of fish exposure to environmental contaminants. Ph.D. Thesis, Purdue University, West Lafayette, IN.

Sanchez-Chardi, A., M.J. Lopez-Fuster and J. Nadal. 2007. Bioaccumulation of lead, mercury, and cadmium in the greater white-toothed shrew, *Crocidura russula*, from the Ebro Delta (NE Spain): Sex- and age-dependent variation. Environ. Pollut. 145(1): 7-14.

Sanchiz, C., A.M. Garcia-Carrascosa and A. Pastor. 1999. Bioaccumulation of Hg, Cd, Pb and Zn in four marine phanerogams and the alga *Caulerpa prolifera* (Forsskal) Lamouroux from the east coast of Spain. Bot. Mar. 42(2): 157-164.

Sanchiz, C., A.M. Garcia-Carrascosa and A. Pastor. 2001. Relationships between sediment physico-chemical characteristics and heavy metal bioaccumulation in Mediterranean soft-bottom macrophytes. Aquat. Bot. 69(1): 63-73.

Sanchiz, C., A.M. Garcia-Carrascosa and A. Pastor. 2002. Mercury, cadmium, lead and zinc bioaccumulation in soft-bottom marine macrophytes from the east coast of Spain. In: F. Briand (*Ed.*), Metal and radionuclides bioaccumulation in marine organisms, Ancona, 27-30 October 2002, p. 53-57.

Sandau, E., P. Sandau and O. Pulz. 1996. Heavy metal sorption by microalagae. Acta Biotechnol. 16(4): 227-235.

Sandhu, N., M.M. Vijayan and N. Sandhu. 2011. Cadmium-mediated disruption of cortisol biosynthesis involves suppression of corticosteroidogenic genes in rainbow trout. Aquat. Toxicol. 103(1-2): 92-100.

Sandhu, N., J.C. McGeer and M.M. Vijayan. 2014. Exposure to environmental levels of waterborne cadmium impacts corticosteroidogenic and metabolic capacities, and compromises secondary stressor performance in rainbow trout. Aquat. Toxicol. (In Press).

Sandrini, J.Z., R. Regoli, D. Fattorini, A. Notti, A.F. Inacio, A.R. Linde-Arias, J. Laurino, A.C.D. Bainy, L.F.F. Marins and J.M. Monserrat. 2006. Short-term responses to cadmium exposure in the estuarine polychaete *Laeonereis acuta* (Polychaeta, Nereididae): Subcellular distribution and oxidative stress generation. Environ. Toxicol. Chem. 25(5): 1337-1344.

Sangalang, G.B. and H.C. Freeman. 1979. Tissue uptake of cadmium in brook trout during chronic sublethal exposure. Arch. Environ. Contam. Toxicol. 8: 77.

Sangalang, G.B. and M.J. O’Halloran. 1972. Cadmium-induced testicular injury and alterations of androgen synthesis in brook trout. Nature 240: 470.

Sangalang, G.B. and M.J. O’Halloran. 1973. Adverse effects of cadmium on brook trout testis and on *in vitro* testicular androgen synthesis. Biol. Reprod. 9: 394.

Sanger, R.C., T.S. Galloway and M.H. Depledge. 2002. The effects of cadmium on *Mytilus edulis*: Metallothionein, micronuclei and heart rate. Mar. Environ. Res. 54(3-5): 368-369.

Santiago-Fandino, V.J.R. 1983. The effects of nickel and cadmium on the growth rate of *Hydra littoralis* and an assessment of the rate of uptake of ^{63}Ni and ^{14}C by the same organism. Water Res. 17: 917.

Santojanni, A., G. Gorbi and F. Sartore. 1998. Prediction of fecundity in chronic toxicity tests on *Daphnia magna*. Water Res. 32(1): 3146-3156.

Santoro, A., G. Blo, S. Mastrolitti and F. Fagioli. 2009. Bioaccumulation of heavy metals by aquatic macroinvertebrates along the Basento River in the south of Italy. Water Air Soil Pollut. 201(1-4): 19-31.

Santos, M.C., M. Wagner, B. Wu, J. Scheider, J. Oehlmann, S. Cadore and J.S. Becker. 2009. Biomonitoring of metal contamination in a marine prosobranch snail (*Nassarius reticulatus*) by imaging laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Talanta 80(2): 428-433.

Sapozhnikova, Y., N. Zubcov, S. Hungerford, L.A. Roy, N. Boicenco, E. Zubcov and D. Schlenk. 2005. Evaluation of pesticides and metals in fish of the Dniester River, Moldova. Chemosphere 60(2): 196-205.

Sarma, S.S.S., F. Martinez-Jeronimo, T. Ramirez-Perez and S. Nandini. 2006. Effect of cadmium and chromium toxicity on the demography and population growth of *Brachionus calyciflorus* and *Brachionus patulus* (Rotifera). J. Environ. Sci. Health 41A(4): 543-558.

Saro, L., I. Lopes, N. Martins and R. Ribeiro. 2012. Testing hypotheses on the resistance to metals by *Daphnia longispina*: Differential acclimation, endpoints association, and fitness costs. Environ. Toxicol. Chem. 31(4): 909-915.

Sarosiek, B., M. Pietrusewicz, J. Radziwoniuk and J. Glogowski. 2009. The effect of copper, zinc, mercury and cadmium on some sperm enzyme activities in the common carp (*Cyprinus carpio* L.). Reprod. Biol. 9(3): 295-301.

Sasikumar, G., P.K. Krishnakumar and G.S. Ghat. 2006. Monitoring trace metal contaminants in green mussel, *Perna viridis* from the coastal waters of Karnataka, southwest coast of India. Arch. Environ. Contam. Toxicol. 51: 206-214.

Sasmaz, A., E. Obek and H. Hasar. 2008. The accumulation of heavy metals in *Typha latifolia* L. grown in a stream carrying secondary effluent. Ecol. Eng. 33(3-4): 278-284.

Sassi, A., A. Annabi, K. Kessabi, A. Kerkeni, K. Said and I. Messaoudi. 2010. Influence of high temperature on cadmium-induced skeletal deformities in juvenile mosquitofish (*Gambusia affinis*). Fish Physiol. Biochem. 36(3): 403-409.

Sastry, K.V. and V. Shukla. 1994. Influence of protective agents in the toxicity of cadmium to a freshwater fish (*Channa punctatus*). Bull. Environ. Contam. Toxicol. 53: 711-717.

Sastry, K.V. and K. Sunita. 1982. Effect of cadmium and chromium on the intestinal absorption of glucose in the snakehead fish, *Channa punctatus*. Toxicol. Letters. 10: 293.

Satake, K., Z. Iwatsuki and M. Nishikawa. 1984. Inorganic elements in some aquatic bryophytes from streams in New Caledonia. J. Hattori Bot. Lab. 57: 71-82.

Satoh, A., L.Q. Vudikaria, N. Kurano and S. Miyachi. 2005. Evaluation of the sensitivity of marine microalgal strains to the heavy metals, Cu, As, Sb, Pb and Cd. Environ. Int. 31(5): 713-722.

Sauter, S., K.S. Buxton, K.J. Maceket and S.R. Petrocelli. 1976. Effects of exposure to heavy metals on selected freshwater fish. Toxicity of copper, cadmium, chromium and lead to eggs and fry of seven fish species. EPA-600/3-76-105. National Technical Information Service, Springfield, VA.

Sauvant, M.P., D. Pepin, C.A. Groliere and J. Bohatier. 1995. Effects of organic and inorganic substances on the cell proliferation of L-929 *Fibroblasts* and *Tetrahymena* toxicological bioassays. Bull. Environ. Contam. Toxicol. 55: 171-178.

Sauvant, M.P., D. Pepin, J. Bohatier, C.A. Groliere and J. Guillot. 1997. Toxicity assessment of 16 inorganic environmental pollutants by six bioassays. Ecotoxicol. Environ. Safety. 37: 131-140.

Sauve, S., M. Hendawi, P. Brousseau and M. Fournier. 2002a. Phagocytic response of terrestrial and aquatic invertebrates following in vitro exposure to trace elements. Ecotoxicol. Environ. Saf. 52(1): 21-29.

Sauve, S., P. Brousseau, J. Pellerin, Y. Morin, L. Senecal, P. Goudreau and M. Fournier. 2002b. Phagocytic activity of marine and freshwater bivalves: In vitro exposure of hemocytes to metals (Ag, Cd, Hg and Zn). Aquat. Toxicol. 58(3-4): 189-200.

Sawle, A.D., E. Wit, G. Whale and A.R. Cossins. 2010. An information-rich alternative, chemicals testing strategy using a high definition toxicogenomics and zebrafish (*Danio rerio*) embryos. Toxicol. Sci. 118(1): 128-139.

Saxena, A. and A. Saxena. 2012. Bioaccumulation and glutathione-mediated detoxification of copper and cadmium in *Sphagnum squarrosum* Crome Samml. Environ. Monit. Assess. 184(7): 4097-4103.

Saxena, K.K., A.K. Dubey and R.R.S. Chauhan. 1993. Experimental studies on toxicity of zinc and cadmium to *Heteropneustes fossilis* (Bl.). J. Freshwater Biol. 5(4): 343-346.

Sayeh, N.A. and D. Richardson. 2010. *Leptorhynchoides thecatus* (Acanthocephala) as a possible bio-indicator of cadmium exposure in *Micropterus salmoides* (largemouth bass). M.S. Thesis, Quinnipiac University, Hamden, CT.

Saygideger, S. and M. Dogan. 2004. Lead and cadmium accumulation and toxicity in the presence of EDTA in *Lemna minor* L. and *Ceratophyllum demersum* L. Bull. Environ. Contam. Toxicol. 73(1): 182-189.

Saygideger, S. and M. Dogan. 2005. Variation of lead, cadmium, copper, and zinc in aquatic macrophytes from the Seyhan River, Adana, Turkey. Bull. Environ. Contam. Toxicol. 74(3): 545-551.

Saygideger, S., O. Gulnaz, E.S. Istifli and N. Yucel. 2005. Adsorption of Cd(II), Cu(II) and Ni(II) ions by *Lemna minor* L.: Effect of physicochemical environment. J. Hazard. Mater. 126(1-3): 96-104.

Sayk, F. and C. Schmidt. 1986. Algae fluorescence auto meter, a computer-controlled measuring apparatus biotest. Z. Wasser-Abwasser-Forsch. 19: 182-184.

Schaeffer, D.J., M. Goehner, E. Grebe, L.G. Hansen, K. Hankenson, E.E. Herricks, G. Matheus, A. Miz, R. Reddy and K. Trommater. 1991. Evaluation of the reference toxicant addition procedure for testing the toxicity of environmental samples. Bull. Environ. Contam. Toxicol. 47: 540-546.

Schafer, H., A. Wenzel, U. Fritsche, G. Roderer and W. Traunspurger. 1993. Long-term effects of selected xenobiotica on freshwater green algae: Development of a flow-through test system. Sci. Total Environ.(Supplemental Part 1): 735-740.

Schafer, H., H. Hettler, U. Fritsche, G. Pitzen, G. Roderer and A. Wenzel. 1994. Biotests using unicellular algae and ciliates for predicting long-term effects of toxicants. Ecotoxicol. Environ. Saf. 27: 64-81.

Scherer, E., R.E. McNicol and R.E. Evans. 1997. Impairment of lake trout foraging by chronic exposure to cadmium: A black-box experiment. Aquat. Toxicol. 37: 1-7.

Schlenk, D. and W.H. Benson. 2005. Target Organ Toxicity in Marine and Freshwater Teleosts: Organs. Second Edition. Taylor and Frances. London. 416 pp.

Schiff, K., S. Bay and C. Stransky. 2002. Characterization of stormwater toxicants from an urban watershed to freshwater and marine organisms. Urban Water 4(3): 215-227.

Schindler, D.W. 1987. Detecting ecosystem responses to anthropogenic stress. Can. J. Fish. Aquat. Sci. 44 (Suppl. 1): 6-25.

Schindler, D.W. 1988. Experimental studies of chemical stressors on whole lake ecosystems. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie, 23: 11-41.

Schindler, D.W., K.H. Mills, D.F. Malley, D.L. Findlay, J.A. Shearer, I.J. Davies, M.A. Turner, G.A. Linsey and D.R. Cruikshank. 1985. Long-term ecosystem stress—the effects of years of experimental acidification on a small lake: Sci. 228(6): 1395-1401.

Schintu, M., L. Durante, B. Marras, D. Puddu, P. Meloni, A. Contu and F. Briand (*Eds*.). 2007. Trace metals in algae from the south-western coast of Sardinia (Italy). Monaco (38): 312.

Schmidt, C. 1987. Possible use and results of an algal fluorescence bioassay. Ergeb. Limnol. 29: 107-116.

Schmitt, C.J. 2004. Concentrations of arsenic, cadmium, copper, lead, selenium, and zinc in fish from the Mississippi River basin, 1995. Environ. Monit. Assess. 90(1-3): 289-321.

Schmitt, C.J., J.L. Zajicek, T.W. May and D.F. Cowman. 1999. Organochlorine residues and elemental contaminants in U.S. freshwater fish, 1976-1986: National contaminant biomonitoring program. Rev. Environ. Contam. Toxicol. 162: 43-104.

Schmitt, C.J., J.J. Whyte, W.G. Brumbaugh and D.E. Tillitt. 2005. Biochemical effects of lead, zinc, and cadmium from mining on fish in the tri-states district of northeastern Oklahoma, USA. Environ. Toxicol. Chem. 24(6): 1483-1495.

Schmitt, C.J., W.G. Brumbaugh, G.L. Linder and J.E. Hinck. 2006. A screening-level assessment of lead, cadmium, and zinc in fish and crayfish from northeastern Oklahoma, USA. Environ. Geochem. Health. 28(5): 445-471.

Schmitt, C.J., W.G. Brumbaugh and T.W. May. 2007. Accumulation of metals in fish from lead-zinc mining areas of southeastern Missouri, USA. Ecotoxicol. Environ. Saf. 67: 14-30.

Schmitt, C.J., W.G. Brumbaugh and T.W. May. 2009a. Concentrations of cadmium, cobalt, lead, nickel, and zinc in blood and fillets of northern hog sucker (*Hypentelium nigricans*) from streams contaminated by lead-zinc mining: Implications for monitoring. Arch. Environ. Contam. Toxicol. 56: 509-524.

Schmitt, C.J., W.G. Brumbaugh, J.M. Besser and T.W. May. 2009b. Concentrations of metals in aquatic invertebrates from the Ozark National Scenic Riverways, Missouri. Govt. Reports Announ. Index, Issue 02.

Schoenert, R., P. Couture, C. Thellen and R. Van Coillie. 1983. The sensitivity of six strains of unicellular algae *Selenastrum capricornutum* to six reference toxicants. Tech. Rep. Fish. Aquat. Sci. 1151: 200-202.

Schor-Fumbarov, T., Z. Keilin and E. Tel-Or. 2003. Characterization of cadmium uptake by the water lily *Nymphaea aurora*. Int. J. Phytoremed. 5(2): 169-179.

Schorr, M.S. and J.C. Backer. 2006. Localized effects of coal mine drainage on fish assemblages in a Cumberland plateau stream in Tennessee. J. Fresh. Ecol. 21(1): 17-24.

Schroeder, J. 2008. Development of models for the prediction of short-term and long-term toxicity to *Hyalella azteca* from separate exposures to nickel and cadmium. University of Waterloo (Canada) Canada.

Schubauer-Berigan, M.K., J.R. Dierkes, P.D. Monson and G.T. Ankley. 1993. pH-dependent toxicity of Cd, Cu, Ni, Pb and Zn to *Ceriodaphnia dubia*, *Pimephales promelas*, *Hyalella azteca* and *Lumbriculus variegatus*. Environ. Toxicol. Chem. 12: 1261-1266.

Schuster, C.N. and B.H. Pringle. 1969. Trace metal accumulation by the American oyster, *Crassostrea virginica*. Proc. Nat. Shellfish Assoc. 59: 91.

Schuwerack, P.M., J.W. Lewis and P. Jones, P. 2009. The dynamics of protein and metal metabolism in acclimated and Cd-exposed freshwater crabs (*Potamonautes warreni*). Ecotoxicol. Environ. Saf. 72(4): 1220-1227.

Schwartz, M.L., P.J. Curtis and R.C. Playle. 2004. Influence of natural organic matter source on acute copper, lead, and cadmium toxicity to rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 23(12): 2889-2899.

Scott, K.J., P.P. Yevich and W.S. Boothman. Manuscript. Toxicological methods using the benthic amphipod *Ampelisca abdita* Mills. Contribution 576. U.S. EPA, Environmental Research Laboratory, Narragansett, RI.

Secor, C.L., E.L. Mills, J. Harshbarger, H.T. Kuntz, W.H. Gutenmann and D.J. Lisk. 1993. Bioaccumulation of toxicants, element and nutrient composition, and soft tissue histology of zebra mussels (*Dreissena polymorpha*) from New York State waters. Chemosphere 26(8): 1559-1575.

Sedlacek, J., E.T. Gjessing and T. Kallqvist. 1989. Influence of different aquatic humus fractions on uptake of cadmium to alga *Selenastrum capriconutum* Printz. Sci. Total Environ. 81/82: 711-718.

Seebaugh, D.R. and W.G. Wallace. 2009. Assimilation and subcellular partitioning of elements by grass shrimp collected along an impact gradient. Aquat. Toxicol. 93(2-3): 107-115.

Seebaugh, D.R., W.J. L'Amoreaux and W.G. Wallace. 2011. Digestive toxicity in grass shrimp collected along an impact gradient. Aquat. Toxicol. 105(3/4): 609-617.

Seebaugh, D.R., W.G. Wallace, W.J. L'Amoreaux and G.M. Stewart. 2012. Carbon assimilation and digestive toxicity in naive grass shrimp (*Palaemonetes pugio*) exposed to dietary cadmium. Bull. Environ. Contam. Toxicol. 88(3): 449-455.

Segner, H. and D. Lenz. 1993. Cytotoxicity assays with the rainbow trout R1 cell line. Toxicol. In Vitro 7(4), 537-540.

Segovia-Zavala, J.A., F. Delgadillo-Hinojosa, A. Munoz-Barbosa, E.A. Gutierrez-Galindo and R. Vidal-Talamantes. 2004. Cadmium and silver in *Mytilus californianus* transplanted to an anthropogenic influenced and coastal upwelling areas in the Mexican northeastern Pacific. Mar. Pollut. Bull. 48(5/6): 458-464.

Sehgal, R. and A.B. Saxena. 1987. Determination of acute toxicity levels of cadmium and lead to the fish *Lebistes reticulatus* (Peters). Int. J. Environ. Stud. 29: 157-161.

Sekine, Y. and K. Noriko. 1985. Studies on the accumulation and transfer of pollutants through food chain. 6. Study on the optimum condition on simulation test and effect of culturing density on the toxicity of cadmium for killifish throughout the year. Sagami Joshi Daigaku Kiyo 49: 9-21.

Sekkat, N., A. Le Du, J.M. Jouany and M. Guerbet. 1992. Study of the interactions between copper, cadmium, and ferbam using the protozoan *Colpidium campylum* bioassay. Ecotoxicol. Environ. Safety. 24: 294-300.

Selby, D.A., J.M. Ihnat and J.J. Messer. 1985. Effects of subacute cadmium exposure on a hardwater mountain stream microcosm. Water Res. 19(5): 645-655.

Selck, H. and V.E. Forbes. 2004. The relative importance of water and diet for uptake and subcellular distribution of cadmium in the deposit-feeding polychaete, *Capitella sp*. I. Mar. Environ. Res. 57(4): 261-279.

Selck, H., V.E. Forbes and T.L. Forbes. 1998. Toxicity and toxicokinetics of cadmium in *Capitella sp.*I: relative importance of water and sediment as routes of cadmium uptake. Mar. Ecol. Prog. Series. 164: 167-178.

Sellin, M.K. and A.S. Kolok. 2006a. Cd Exposures in fathead minnows: Effects on adult spawning success and reproductive physiology. Arch. Environ. Contam. Toxicol. 51(4): 594-599.

Sellin, M.K. and A.S. Kolok. 2006b. Cadmium exposures during early development: Do they lead to reproductive impairment in fathead minnows? Environ. Toxicol. Chem. 25(11): 2957-63.

Sellin, M.K., T.M. Eidem and A.S. Kolok. 2007. Cadmium exposures in fathead minnows: Are there sex-specific differences in mortality, reproductive success, and Cd accumulation? Arch. Environ. Contam. Toxicol. 52(4): 535-540.

Semsari, S. and S. Megateli. 2007. Effect of cadmium toxicity on survival and phototactic behaviour of *Daphnia magna*. Environ. Technol. 28(7): 799-806.

Sen, H. and U. Sunlu. 2007. Effects of cadmium (CdCl(2)) on development and hatching of eggs in European squid (*Loligo vulgaris* Lamarck, 1798) (Cephalopoda: Loliginidae). Environ. Monit. Assess. 133(1-3): 371-378.

Senadheera, S.P.S.D. and K.A.S. Pathiratne. 2003. Bioaccumulation potential of three toxic heavy metals in shrimp, *Penaeus monodon* from different fractions of the culture environment. Sri Lanka J. Aquat. Sci. 8: 27-39.

Senger, M.R., D.B. Rosemberg, E.P. Rico, M.B. Arizi, R.D. Dias, M.R. Bogo and C.D. Bonan. 2006. In vitro effect of zinc and cadmium on acetylcholinesterase and ectonucleotidase activities in zebrafish (*Danio rerio*) brain. Toxicol. In Vitro 20(6): 954-958.

Serafim, A. and M.J. Bebianno. 2007. Kinetic model of cadmium accumulation and elimination and metallothionein response in *Ruditapes decussatus*. Environ. Toxicol. Chem. 26(5): 960-969.

Serafim, A. and M.J. Bebianno. 2010. Effect of a polymetallic mixture on metal accumulation and metallothionein response in the clam *Ruditapes decussatus*. Aquat. Toxicol. 99(3): 370-378.

Serafim, M.A., R.M. Company, M.J. Bebianno and W.J. Langston. 2002. Effect of temperature and size on metallothionein synthesis in the gill of *Mytilus galloprovincialis* exposed to cadmium. Mar. Environ. Res. 54(3-5): 361-365.

Serfozo, J. 1993. Necrotic effects of the xenobiotics' accumulation in the central nervous system of a crayfish (*Astacus leptodactylus* Eschz.). Acta Biol. Szeged. 39: 23-28.

Servizi, J.A. and D.W. Martens. 1978. Effects of selected heavy metals on early life of sockeye and pink salmon. International Pacific Salmon Fisheries Commission, Progress Report No. 39, New Westminster, B.C., Canada.

Seth, C.S., P.K. Chaturvedi and V. Misra. 2007. Toxic effect of arsenate and cadmium alone and in combination on giant duckweed (*Spirodela polyrrhiza* L.) in response to its accumulation. Environ. Toxicol. 22(6): 539-549.

Seyfreid, P.L. and C.B.L. Horgan. 1983. Effect of cadmium on lake water bacteria as determined by the luciferase assay of adenosine triphosphate. In: W.E. Bishop, et al. (*Eds.*), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802, American Society for Testing and Materials, Philadelphia, PA, p. 425.

Shanker, A.K. 2008. Mode of action and toxicity of trace elements. In: M.N.V. Prasad (*Ed.*), Trace Elements as Contaminants and Nutrients: Consequences in Ecosystems and Human Health, John Wiley & Sons, Inc., Hoboken, NJ.

Shanmukhappa, H. and K. Neelakantan. 1990. Influence of humic acid on the toxicity of copper, cadmium and lead to the unicellular alga, *Synechosystis aquatilis*. Bull. Environ. Contam. Toxicol. 44: 840-843.

Sharma, B. and R. Patino. 2008. Exposure of *Xenopus laevis* tadpoles to cadmium reveals concentration-dependent bimodal effects on growth and monotonic effects on development and thyroid gland activity. Toxicol. Sci. 105(1): 51-58.

Sharma, B. and R. Patino. 2009. Effects of cadmium on growth, metamorphosis and gonadal sex differentiation in tadpoles of the African clawed frog, *Xenopus laevis*. Chemosphere 76(8): 1048-1055.

Sharma, B. and R. Patino. 2010. Effects of cadmium, estradiol-17beta and their interaction on gonadal condition and metamorphosis of male and female african clawed frog, *Xenopus laevis*. Chemosphere 79(5): 499-505.

Sharma, M.S. and C.S. Selvaraj. 1994. Zinc, lead and cadmium toxicity to selected freshwater zooplankters. Pollut. Res. 13(2): 191-201.

Sharma, V.K., K.B. Rhudy and F.J. Millero. 2000. Diurnal variation of Texas "brown tide" (*Aureoumbra lagunensis*) in relation to metals. J. Environ. Sci. Health. 35A(7): 1077-1088.

Sharp, J.R. 1988. The effect of salinity of cadmium toxicity and fin regeneration of penfish, *Lagodon rhomboides*. Trans. Missouri Acad. Sci. 22: 136.

Sharp, J.R. and J.L. Kaszubski. 1989. The influence of exposure duration on the embryotoxicity of cadmium to the freshwater teleost, *Etheostoma spectabile*. Trace Subst. Environ. Health. 23: 277-289.

Shaw, J.R., T.D. Dempsey, C.Y. Chen., J.W. Hamilton and C.L. Folt. 2006. Comparative toxicity of cadmium, zinc, and mixtures of cadmium and zinc to daphnids. Environ. Toxicol. Chem. 25(1): 182-189.

Shaw, J.R., J.K. Colbourne, J.C. Davey, S.P. Glaholt, T.H. Hampton, C.Y. Chen, C.L. Folt and J.W. Hamilton. 2007. Gene response profiles for *Daphnia pulex* exposed to the environmental stressor cadmium reveals novel crustacean metallothioneins. BMC Genomics 8: 477.

Shazili, N.A.M. 1995. Effects of salinity and pre-exposure on acute cadmium toxicity to seabass, *Lates calcarifer*. Bull. Environ. Contam. Toxicol. 54(1): 22-28.

Shazili, N.A.M. and D. Pascoe. 1986. Variable sensitivity of rainbow trout (*Salmo gairdneri*) eggs and alevins to heavy metals. Bull. Environ. Contam. Toxicol. 36: 468-474.

Shcherban, E.P. 1977. Toxicity of some heavy metals for *Daphnia magna* Strauss, as a function of temperature. Hydrobiol. 13(4): 75.

Sheela, M., G. Mallika and S. Muniandy. 1995. Impact of cadmium on food utilization, growth and body composition in the fish *Oreochromis mossambicus*. Environ. Ecol. 13(2): 410-414.

Sheir, S.K. and R.D. Handy. 2010. Tissue injury and cellular immune responses to cadmium chloride exposure in the common mussel *Mytilus edulis*: Modulation by lipopolysaccharide. Arch. Environ. Contam. Toxicol. 59(4): 602-613.

Sherman, R.E., S.P. Gloss and L.W. Lion. 1987. A comparison of toxicity test conducted in the laboratory and in experimental ponds using cadmium and the fathead minnow (*Pimephales promelas*). Water Res. 21(3): 317-323.

Shevchenko, V., A. Lisitzin and A. Vinogradova. 2003. Heavy metals in aerosols over the seas of the Russian Arctic. Sci. Total Environ. 306: 11-25.

Shi, D. and W.X. Wang. 2004. Understanding the differences in Cd and Zn bioaccumulation and subcellular storage among different populations of marine clams. Environ. Sci. Technol. 38(2): 449-456.

Shiber, J.G. and T.A. Shatila. 1978. Lead cadmium copper nickel and iron in limpets mussels and snails from the coast of Ras Beirut Lebanon. Mar. Environ. Res. 1(2): 125-134.

Shilla, D., D. Qadah and M. Kalibbala. 2008. Distribution of heavy metals in dissolved, particulate and biota in the Scheldt Estuary, Belgium. Chem. Ecol. 24(1): 61-74.

Shirakashi, S. and M. El-Matbouli. 2010. Effect of cadmium on the susceptibility of *Tubifex tubifex* to *Myxobolus cerebralis* (Myxozoa), the causative agent of whirling disease. Dis. Aquat. Org. 89(1): 63-70.

Shirvani, E. and S. Jamili. 2009. Assessing Cd, Pb accumulation in the tissues of *Chalcalbumus chalcoides* in Anzali Port. Res. J. Environ. Sci. 3(5): 522-529.

Shivaraj, K.M. and H.S. Patil. 1988. Toxicity of cadmium and copper to a freshwater fish *Puntius arulius*. Environ. Ecol. 6(1): 5-8.

Shuhaimi-Othman, M. and D. Pascoe. 2007. Bioconcentration and depuration of copper, cadmium, and zinc mixtures by the freshwater amphipod *Hyalella azteca*. Ecotoxicol. Environ. Saf. 66(1): 29-35.

Shuhaimi-Othman, M., N. Yakub, N.S. Umirah and A. Abas. 2011. Toxicity of eight metals to Malaysian freshwater midge larvae *Chironomus javanus* (Diptera, Chironomidae). Toxicol. Ind. Health 27(10): 879-886.

Shuhaimi-Othman, M., Y. Nadzifah, N.S. Umirah and A.K. Ahmad. 2012a. Toxicity of metals to tadpoles of the common Sunda toad, *Duttaphrynus melanostictus*. Toxicol. Environ. Chem. 94(2): 364-376.

Shuhaimi-Othman, M., Y. Nadzifah, N.S. Umirah and A.K. Ahmad. 2012b. Toxicity of metals to an aquatic worm, *Nais elinguis* (Oligochaeta, Naididae). Res. J. Environ. Toxicol. 6(4): 122-132.

Shukla, J.P. and K. Pandey. 1988. Toxicity and long term effects of a sublethal concentration of cadmium on the growth of the fingerlings of *Ophiocephalus punctatus* (Bl.). Acta Hydrochim. Hydrobiol. 16(5): 537-540.

Shukla, O.P., S. Dubey and U.N. Rai. 2007a. Preferential accumulation of cadmium and chromium: Toxicity in *Bacopa monnieri* L. under mixed metal treatments. Bull. Environ. Contam. Toxicol. 78(3): 252-257.

Shukla, V., P. Rathi, P. and K.V. Sastry. 2002. Effect of cadmium individually and in combination with other metals on the nutritive value of fresh water fish, *Channa punctatus*. J. Environ. Biol. 23(2): 105-110.

Shukla, V., M. Dhankhar, J. Prakash and K.V. Sastry. 2007b. Bioaccumulation of Zn, Cu and Cd in *Channa punctatus*. J. Environ. Biol. 28(2): 395-397.

Shulkin, V.M. and B.J. Presley. 2003. Metal concentrations in mussel *Crenomytilus grayanus* and oyster *Crassostrea gigas* in relation to contamination of ambient sediments. Environ. Int. 29(4): 493-502.

Shulkin, V.M., V.Y. Kavun, A.V. Tkalin and B.J. Presley. 2002. The influence of metal concentration in bottom sediments on metal accumulation by *Mytilids crenomytilus grayanus* and *Modiolus kurilensis*. Biol. Morya./Mar. Biol. 28(1): 53-60.

Siboni, N., M. Fine, V. Bresler and Y. Loya. 2004. Coastal coal pollution increases Cd concentrations in the predatory gastropod *Hexaplex trunculus* and is detrimental to its health. Mar. Pollut. Bull. 49(1-2): 111-118.

Sick, L.V. and G. Baptist. 1979. Cadmium incorporation by the marine copepod *Pseudodiaptomous coronatus*. Limnol. Oceanogr. 24: 453.

Sidoumou, Z., M. Gnassia-Barelli and M. Romeo. 1997. Cadmium and calcium uptake in the mollusc *Donax rugosus* and effect of a calcium channel blocker. Bull. Environ. Contam. Toxicol. 58: 318-325.

Sidoumou, Z., M. Gnassia-Barelli, Y. Siau, V. Morton and M. Romeo. 2006. Heavy metal concentrations in molluscs from the Senegal coast. Environ. Int. 32(3): 384-387.

Sieratowicz, A., D. Stange, U. Schulte-Oehlmann and J. Oehlmann. 2011. Reproductive toxicity of bisphenol a and cadmium in *Potamopyrgus antipodarum* and modulation of bisphenol a effects by different test temperature. Environ. Pollut. 159(10): 2766-2774.

Sieratowicz, A., U. Schulte-Oehlmann, A. Wigh and J. Oehlmann. 2013. Effects of test media on reproduction in *Potamopyrgus antipodarum* and of pre-exposure population densities on sensitivity to cadmium in a reproduction test. J. Environ. Sci. Health Part A Tox. Hazard. Subst. Environ. Eng. 48(5): 481-488.

Sikorska, J. and J. Wolnicki, J. 2006. Cadmium toxicity to rudd (*Scardinius erythrophthalmus* L.) larvae after short-term exposure. Arch. Pol. Fish. 14(1): 15-27.

Silva, J., L. Troncoso, E. Bay-Schmith and A. Larrain. 2001. Utilization of *Odontesthes regia* (Atherinidae) from the south eastern Pacific as a test organism for bioassays: Study of its sensitivity to six chemicals. Bull. Environ. Contam. Toxicol. 66(5): 570-575.

Silva, K.T. and A. Pathiratne. 2008. *In vitro* and *in vivo* effects of cadmium on cholinesterases in Nile tilapia fingerlings: Implications for biomonitoring aquatic pollution . Ecotoxicol. 17(8): 725-731.

Silva, S.J., K.R. Carman, J.W. Fleeger, T. Marshall and S.J. Marlborough. 2009. Effects of phenanthrene- and metal-contaminated sediment on the feeding activity of the harpacticoid copepod, *Schizopera knabeni*. Arch. Environ. Contam. Toxicol. 56(3): 434-441.

Silvestre, F., G. Trausch, A. Pequeux and P. Devos. 2004. Uptake of cadmium through isolated perfused gills of the chinese mitten crab, *Eriocheir sinensis*. Comp. Biochem. Physiol. 137A(1): 189-196.

Silvestre, F., G. Trausch and P. Devos. 2005. Hyper-osmoregulatory capacity of the Chinese mitten crab (*Eriocheir sinensis*) exposed to cadmium; Acclimation during chronic exposure. Comp. Biochem. Physiol. 140C(1): 29-37.

Simas, T.C., A.P. Ribeiro and J.G. Ferreira. 2001. Shrimp - a dynamic model of heavy-metal uptake in aquatic macrofauna. Environ. Toxicol. Chem. 20(11): 2649-2656.

Simoes-Goncalves, M.L.S., M.F.C. Vilhena and M.A. Sampayo. 1988. Effect of nutrients, temperature and light on uptake of cadmium by *Selenastrum capricornutum* Printz. Water Res. 22(11): 1429-1435.

Simoes-Goncalves, M.L.S., M.F.C. Vilhena, L.M.V.F. Machado, C.M.R. Pescada and M.L. de Moura. 1989. Effect of speciation on uptake and toxicity of cadmium to shrimp *Crangon crangon* (L.). Bull. Environ. Contam. Toxicol. 43: 287-294.

Simon, D.F., T.A. Davis, M.L. Tercier-Waeber, R. England, K.J. Wilkinson and T.A.Davis. 2011. *In situ* evaluation of cadmium biomarkers in green algae. Environ. Pollut. 159(10): 2630-2636.

Simonetti, P., S.E. Botte, S.M. Fiori and J.E. Marcovecchio. 2012. Heavy-metal concentrations in soft tissues of the burrowing crab *Neohelice granulata* in Bahia Blanca estuary, Argentina. Arch. Environ. Contam. Toxicol. 62(2): 243-253.

Simonova, E., M. Henselová, E. Masarovičová and J. Kohanová. 2007. Comparison of tolerance of *Brassica juncea* and *Vigna radiata* to cadmium. Biologia Plantarum 51(3): 488-492.

Sindhe, V.R., M.U. Veeresh and R.S. Kulkarni. 2002. Ovarian changes in response to heavy metal exposure to the fish, *Notopterus notopterus* (Pallas). J. Environ. Biol. 23(2): 137-141.

Singh, A.K., K.S. Rana and V. Tiwari. 2003. Changes in haematocrit values of *Labeo rohita* (Ham.) under the toxicity of cadmium chloride. Uttar Pradesh J. Zool. 23(2): 161-162.

Singh, A.P., A.K. Singh and J.P.N. Singh. 2007a. Cadmium induced changes on the secretion of branchial mucous cells of peppered loach, *Lepdocephalichthys guntea*. J. Exp. Zool. India 10(1): 65-68.

Singh, A., P. Malodia, M. Kachhawaha, N. Ansari, S.K. Jain and P.K. Khatri. 2011. Effect of EDTA, phosphate, pH and metal species on cadmium and nickel uptake by aquatic macrophyte *Spirodela polyrhiza*. Asian J. Water Environ. Pollut. 8(2): 51-60.

Singh, H.V. 2005. Toxic effects of cadmium chloride on growth and oogonium formation in *Oedogonium hatei*. J. Phytol. Res. 18(2): 255-257.

Singh, J., K. Kant, H.B. Sharma and K. Rana. 2008. Bioaccumulation of cadmium in tissues of *Cirrihna mrigala* and *Catla catla*. Asian J. Exp. Sci. 22(3): 411-414.

Singh, J., S. Sachdeva, K.S. Rana, S. Arya and J. Singh. 2010. Effect of heavy metals cadmium and chromium on carbohydrate metabolism of fresh water fish, *Channa punctatus*. Asian J. Exp. Sci. 24(2): 305-310.

Singh, R.K., S.L. Chavan and P.H. Sapkale. 2007b. Heavy metal concentrations in water, sediments and body tissues of red worm (*Tubifex spp*.) collected from natural habitats in Mumbai, India. Environ. Monit. Assess. 129: 471-481.

Singh, S.M. and P.N. Ferns. 1978. Accumulation of heavy metals in rainbow trout *Salmo gairdneri* (Richardson) maintained on a diet containing activated sewage sludge. J. Fish Biol. 13: 277-286.

Singh, S., S. Eapen and S.F. D'Souza. 2006. Cadmium accumulation and its influence on lipid peroxidation and antioxidative system in an aquatic plant, *Bacopa monnieri* L. Chemosphere 62(2): 233-246.

Sinha, M.P., M. Kumar, R.S. Toppno and R. Srivastava. 2001. Calorific changes in liver, ovary and muscle of hill stream fish *Garra mullya* (sykes) due to cadmium toxicity. J. Ecophysiol. Occup. Health 1(3/4): 375-384.

Sinha, S., M. Gupta and P. Chandra. 1994. Bioaccumulation and toxicity of Cu and Cd in *Vallisneria spiralis* (L.). Environ. Monit. Assess. 33(1): 75-84.

Siva Kiran, R.R., G.M. Madhu, S.V. Satyanarayana and P. Bindiya. 2012. Bioaccumulation of cadmium in blue green algae *Spirulina* (*Arthrospira*) *indica*. J. Bioremed. Biodegrad. 3(3): 1-4.

Skinner, C., N.J. Turoczy., P.L. Jones, D. Barnett and R. Hodges. 2004. Heavy metal concentrations in wild and cultured blacklip abalone (*Haliotis rubra* Leach) from southern Australian waters. Food Chem. 85(3): 351-356.

Skorkowski, E.F., N. Niedzwiecka, A. Mika, A. Bialk-Bielinska and P. Stepnowski. 2011. Effect of cadmium and glutathione on malic enzyme activity in brown shrimps (*Crangon crangon*) from the Gulf of Gdansk (Baltic Sea, Poland). Oceanologia 53(3): 793-805.

Skowronski, T. and M. Przytocka-Jusiak. 1981. Effect of cadmium on the growth of *Chlorella vulgaris* and *Stichococcus baccillaris*. Acta Microbiol. Pol. 30(2): 213-221.

Skowronski, T. and M. Przytocka-Jusiak. 1986. Cadmium removal by green alga *Stichococcus bacillaris*. Chemosphere 15(1): 77-79.

Skowronski, T., M. Jakubowski and B. Pawlik. 1985. Cadmium toxicity to green alga *Stichococcus bacillaris*. Acta Microbiol. Polonica. 34(3/4): 309.

Skowronski, T., B. Pawlik and M. Jakubowski. 1988. Reduction of cadmium toxicity to green microalga *Stichococcus bacillaris* by manganese. Bull. Environ. Contam. Toxicol. 41: 915-920.

Skowronski, T., S. Szubinska, B. Pawlik, M. Jakubowski, R. Bilewicz and E. Cukrowsak. 1991. The influence of pH on cadmium toxicity to the green alga *Stichococcus bacillaris* and on the cadmium forms present in the culture medium. Environ. Pollut. 74: 89-100.

Slobodskova, V.V., E.E. Solodova, E.N. Slinko and V.P. Chelomin. 2010. Evaluation of the genotoxicity of cadmium in gill cells of the clam *Corbicula japonica* using the Comet Assay. Russ. J. Mar. Biol. 36(4): 311-315.

Sloman, K.A., D.W. Baker, C.G. Ho, D.G. McDonald and C.M. Wood. 2003a. The effects of trace metal exposure on agonistic encounters in juvenile rainbow trout, *Oncorhynchus mykiss*. Aquat. Toxicol. 63(2): 187-196.

Sloman, K.A., G.R. Scott, Z. Diao, C. Rouleau, C.M. Wood and D.G. McDonald. 2003b. Cadmium affects the social behaviour of rainbow trout, *Oncorhynchus mykiss*. Aquat. Toxicol. 65(2): 171-185.

Sloof, J.E., A. Viragh and B. Van der Veer. 1995. Kinetics of cadmium uptake by green algae. Water Air Soil Pollut. 83: 105-122.

Slooff, W. 1983. Benthic macroinvertebrates and water quality assessment: Some toxicological considerations. Aquat. Toxicol. 4: 73.

Slooff, W. and R. Baerselman. 1980. Comparison of the usefulness of the Mexican axoloth (*Ambystoma mexicanum*) and the clawed toad (*Xenopus laevis*) in toxicological bioassays. Bull. Environ. Contam. Toxicol. 24: 439.

Slooff, W.J., J.H. Canton and J.L.M. Hermens. 1983a. Comparison of the susceptibility of 22 freshwater species to 15 chemical compounds. I. (Sub)acute toxicity tests. Aquat. Toxicol. 4(2): 113-128.

Slooff, W., D. De Zwart and J.M. Marquenie. 1983b. Detection limits of a biological monitoring system for chemical water pollution based on mussel activity. Bull. Environ. Contam. Toxicol. 30(4): 400-405.

Smith, D.A., G.G. Schurig, S.A. Smith and S.D. Holladay. 1999a. Inhibited cytotoxic leukocyte activity in tilapia (*Oreochromis niloticus*) following exposure to immunotoxic chemicals. Int. J. Toxicol. 18(3): 167-172.

Smith, D.A., G.G. Schurig, S.A. Smith and S.D. Holladay. 1999b. Tilapia (*Oreochromis niloticus)* and rodents exhibit similar patterns of inhibited antibody production following exposure to immunotoxic chemicals. Vet. Hum. Toxicol. 41(6): 368-373.

Smith, D.P., J.H. Kennedy and K.L. Dickson. 1991. An evaluation of a naidid oligochaete as a toxicity test organism. Environ. Toxicol. Chem. 10: 1459-1465.

Smith, I.R., A.F. Johnson, D. MacLennan and H. Manson. 1992. Chemical contaminants, lymphocystis, and dermal sarcoma in walleyes spawning in the Thames River, Ontario. Trans. Am. Fish. Soc. 121(5): 608-616.

Smith, J.D., E.C.V. Butler, B.R. Grant, G.W. Little, N. Millis and P.J. Milne. 1981. Distribution and significance of copper, lead, zinc and cadmium in the Corio Bay ecosystem. Aust. J. Mar. Freshwater Res. 32(2): 151-164.

Smith, R.A., R.B. Alexander and M.G. Wolman. 1987. Water-quality trends in the nation's rivers. Science 235(4796): 1607-1615.

Smith, S. and M.K.H. Kwan. 1989. Use of aquatic macrophytes as a bioassay method to assess relative toxicity, uptake and accumulated forms of trace metals. Hydrobiol. 188/189: 345-351.

Smokorowski, K.E., D.C. Lasenby and R.D. Evans. 1998. Quantifying the uptake and release of cadmium and copper by the opossum shrimp *Mysis relicta* preying upon the cladoceran *Daphnia magna* using stable isotope tracers. Can. J. Fish. Aquat. Sci. 55: 909-915.

Smolders, R., M. Baillieul and R. Blust. 2005. Relationship between the energy status of *Daphnia magna* and its sensitivity to environmental stress. Aquat. Toxicol. 73(2): 155-170.

Snell, T.W. and M.J. Carmona. 1995. Comparative toxicant sensitivity of sexual and asexual reproduction in the rotifer *Brachionus calyciflorus*. Environ. Toxicol. Chem. 14: 415-420.

Snell, T.W. and B.D. Moffat. 1992. A 2-d life cycle test with the rotifer *Brachionus calyciflorus*. Environ. Toxicol. Chem. 11: 1249-1257.

Snell, T.W. and G. Persoone. 1989a. Acute toxicity bioassays using rotifers. I. A test for brackish and marine environments with *Brachionus plicatilis*. Aquat. Toxicol. 14: 65-80.

Snell, T.W. and G. Persoone. 1989b. Acute toxicity bioassays using rotifers. II. A freshwater test with *Brachionus rubens*. Aquat. Toxicol. 14: 81-92.

Snell, T.W., B.D. Moffat, C. Janssen and G. Persoone. 1991a. Acute toxicity test using rotifers. III. Effects of temperature, strain and exposure time on the sensitivity of *Brachionus plicatilis*. Environ. Toxicol. Water Quality. 6: 63-75.

Snell, T.W., B.D. Moffat, C. Janssen and G. Persoone. 1991b. Acute toxicity tests using rotifers. Ecotoxicol. Environ. Saf. 21: 308-317.

Snodgrass, J.W., R.E. Casey, D. Joseph and J.A. Simon. 2008. Microcosm investigations of stormwater pond sediment toxicity to embryonic and larval amphibians: Variation in sensitivity among species. Environ. Pollut. 154(2): 291-297.

Soares, S.S., H. Martins, C. Gutierrez-Merino and M. Aureliano. 2008. Vanadium and cadmium in vivo effects in teleost cardiac muscle: Metal accumulation and oxidative stress markers. Comp. Biochem. Physiol. C 147(2): 168-178.

Sobahn, R. and S.P.K. Sternberg. 1999. Cadmium removal using cladophora. J. Environ. Sci. Health. A34(1): 53-72.

Sobral, O., C. Chastinet, A. Nogueira, A.M.V.M. Soares, F. Goncalves and R. Ribeiro. 2001. *In vitro* development of parthenogenetic eggs: A fast ecotoxicity test with *Daphnia magna*? Ecotoxicol. Environ. Saf. 50(3): 174-179.

Sobrino-Figueroa, A. and C. Caceres-Martinez. 2009. Alterations of valve closing behavior in juvenile catarina scallops (*Argopecten ventricosus* Sowerby, 1842) exposed to toxic metals. Ecotoxicol. 18: 983-987.

Sobrino-Figueroa, A.S., C. Caceres-Martinez, A.V. Botello and G. Nunez-Nogueira. 2007. Effect of cadmium, chromium, lead and metal mixtures on survival and growth of juveniles of the scallop *Argopecten ventricosus* (Sowerby II, 1842). J. Environ. Sci. Health 42A: 1443-1447.

Softeland, L., E. Holen and P.A. Olsvik. 2010. Toxicological application of primary hepatocyte cell cultures of Atlantic cod (*Gadus morhua*)--effects of BNF, PCDD and Cd. Comp. Biochem. Physiol. Part C Toxicol. Pharmacol. 151(4): 401-411.

Sofyan, A., G. Rosita, D.J. Price and W.J. Birge. 2007a. Cadmium uptake by *Ceriodaphnia dubia* from different exposures: Relevance to body burden and toxicity. Environ. Toxicol. Chem. 26(3): 470-477.

Sofyan, A., D.J. Price and W.J. Birge. 2007b. Effects of aqueous, dietary and combined exposures of cadmium to *Ceriodaphnia dubia*. Sci. Total Environ. 385(1-3): 108-116.

Sokolova, I., A. Ivanina and I. Kurochkin. 2012. Effects of temperature and cadmium exposure on the mitochondria of oysters (*Crassostrea virginica*) exposed to hypoxia and subsequent reoxygenation. Comp. Biochem. Physiol. 163(Suppl.0): S8.

Sokolova, I.M., A.H. Ringwood and C. Johnson. 2005a. Tissue-specific accumulation of cadmium in subcellular compartments of eastern oysters *Crassostrea virginica* Gmelin (Bivalvia: Ostreidae). Aquat. Toxicol. 74(3): 218-228.

Sokolova, I.M., E.P. Sokolov and K.M. Ponnappa. 2005b. Cadmium exposure affects mitochondrial bioenergetics and gene expression of key mitochondrial proteins in the eastern oyster *Crassostrea virginica* Gmelin (Bivalvia: Ostreidae). Aquat. Toxicol. 73(3): 242-255.

Sokolowski, A., D. Fichet, P. Garcia-Meunier, G. Radenac, M. Wolowicz and G. Blanchard. 2002. The relationship between metal concentrations and phenotypes in the Baltic clam *Macoma balthica* (L.) from the Gulf of Gdansk, southern Baltic. Chemosphere 47(5): 475-484.

Sola, C., M. Burgos, A. Plazuelo, J. Toja, M. Plans and N. Prat. 2004. Heavy metal bioaccumulation and macroinvertebrate community changes in a Mediterranean stream affected by acid mine drainage and an accidental spill (Guadiamar River, SW Spain). Sci. Total Environ. 333(1-3): 109-126.

Solanke, A.K. 2012. Toxicity of cadmium in fresh water fish *Cyprinus carpio*. Environ. Ecol. 30(1): 32-33.

Sole-Rovira M., C. Fernández-Díaz, J.P. Cañavate and J. Blasco. 2005. Effects on metallothionein levels and other stress defences in Senegal sole larvae exposed to cadmium. Bull. Environ. Contam. Toxicol. 74(3): 597-603.

Soltan, M.E. and M.N. Rashed. 2003. Laboratory study on the survival of water hyacinth under several conditions of heavy metal concentrations. Adv. Environ. Res. 7(2): 321-334.

Sommer, C. and S. Winkler. 1982. The effect of heavy metals on the rates of photosynthesis and respiration of *Fontinalis antipyretica* Hedw. Arch. Hydrobiol. 93(4): 503-524.

Song, Y.Y., X.T. Yuan, S.L. Zhang, D.Z. Yang, H. Guo and Y.B. Zhou. 2011. Single and joint toxic effects of benzo(a)pyrene and cadmium on development of three-setiger juvenile of polychaete *Pernereis aibuhitensis* Grube. Mar. Environ. Sci. 30(3): 333-336.

Sooksawat, N., M. Meetam, M. Kruatrachue, P. Pokethitiyook and K. Nathalang. 2013. Phytoremediation potential of charophytes: Bioaccumulation and toxicity studies of cadmium, lead and zinc. J. Environ. Sci. (China) 25(3): 596-604.

Sorgeloos, P., C. Remiche-Van der Wielen and G. Persoone. 1978. The use of *Artemia nauplii* for toxicity tests - a critical analysis. Ecotoxicol. Environ. Saf. 2(3/4): 249-255.

Sornom, P., E. Gismondi, C. Vellinger, S. Devin, J.F. Ferard and J.N. Beisel. 2012. Effects of sublethal cadmium exposure on antipredator behavioural and antitoxic responses in the invasive amphipod *Dikerogammarus villosus*. PLoS ONE 7(8): e42435.

Sorvari, J. and M. Sillanpaa. 1996. Influence of metal complex formation on heavy metal and free EDTA and DTPA acute toxicity determined by *Daphnia magna*. Chemosphere. 33(6): 1119-1127.

Sosnowski, S. and J. Gentile. 1978. Toxicological comparison of natural and cultured populations of *Acartia tonsa* to cadmium, copper and mercury. J. Fish. Res. Board Can. 35: 1366.

Soto-Jimenez, M.F., F. Amezcua and R. Gonzalez-Ledesma. 2010. Nonessential metals in striped marlin and Indo-Pacific sailfish in the southeast Gulf of California, Mexico: concentration and assessment of human health risk. Arch. Environ. Contam. Toxicol. 58(3): 810-818.

Souid, G., N. Souayed, F. Yaktiti and K. Maaroufi. 2013. Effect of acute cadmium exposure on metal accumulation and oxidative stress biomarkers of *Sparus aurata*. Ecotoxicol. Environ. Saf. 89: 1-7.

Soukupova, I., M. Beklova, Z. Svobodova, P. Majzlik, J. Sochor, V. Adam, L. Trnkova and R. Kizek. 2011. Effect of cadmium(II) ions on level of biologically active compounds in carps and invertebrates. Toxicol. Lett. 205(Suppl. 0): S69-S70.

Southwest Texas State University. 2000. Comparison of EPA target toxicity aquatic test organisms to the fountain darter. Federal Assisstance Agreement No. X-986345-01. Edwards Aquifer Research and Data Center, San Marcos, TX.

Sovenyi, J. and J. Szakolczai. 1993. Studies on the toxic and immunosuppressive effects of cadmium on the common carp. Acta Veter. Hungarica. 41(3-4): 415-426.

Sowdeswari, R., P.S. Bhavan and P. Ananthi. 2012. Acute toxicity of heavy metals (cadmium chloride, chromium trioxide and lead nitrate) and their effects on the freshwater prawn *Macrobrachium rosenbergii*. Int. J. Pharma Bio Sci. 3(3): 863-874.

Spann, N., D.C. Aldridge, J.L. Griffin and O.A.H. Jones. 2011. Size-dependent effects of low level cadmium and zinc exposure on the metabolome of the asian clam, *Corbicula fluminea*. Aquat. Toxicol. 105(3-4): 589-599.

Specht, W.L., D.S. Cherry, R.A. Lechleitner and J. Cairns Jr. 1984. Structural, functional, and recovery responses of stream invertebrates to fly ash effluent. Can. J. Fish. Aquat. Sci. 41(6): 884-896.

Spehar, R.L. 1976a. Cadmium and zinc toxicity to flagfish, *Jordanella floridae*. J. Fish. Res. Board Can. 33: 1939.

Spehar, R.L. 1976b. Cadmium and zinc toxicity to *Jordanella floridae*. EPA-600/3-76-096. National Technical Information Service, Springfield, VA.

Spehar, R.L. 1982. Memorandum to J.G. Eaton. U.S. EPA, Duluth, Minnesota. February 24.

Spehar, R.L. and A.R. Carlson. 1984a. Derivation of site-specific water quality criteria for cadmium and the St. Louis River Basin, Duluth, Minnesota. PB84-153196. National Technical Information Service, Springfield, VA.

Spehar, R.L. and A.R. Carlson. 1984b. Derivation of site-specific water quality criteria for cadmium and the St. Louis River Basin, Duluth, Minnesota. Environ. Toxicol. Chem. 3(4): 651-665.

Spehar, R.L. and J.T. Fiandt. 1986. Acute and chronic effects of water quality criteria-based metal mixtures on three aquatic species. Environ. Toxicol. Chem. 5: 917-931.

Spehar, R.L., R.L. Anderson and J.T. Fiandt. 1978. Toxicity and bioaccumulation of cadmium and lead in aquatic invertebrates. Environ. Pollut. 15: 195.

Sprague, J.B. 1969. Measurement of pollutant toxicity to fish i. bioassay methods for acute toxicity. Water Res. 3(11): 793-821.

Sprague, J.B. 1985. Factors that modify toxicity. In: Fundamentals of aquatic toxicology. Rand, G.M. and S.R. Petrocelli (*Eds.*). Hemisphere Publishing Company, New York, NY, pp. 124-163.

Sprenger, M.D., A.W. McIntosh and S. Hoenig. 1988. Concentrations of trace elements in yellow perch (*Perca flavescens*) from six acidic lakes. Water Air Soil Pollut. 37: 375-388.

Spry, D.J. and J.G. Wiener. 1991. Metal bioavailability and toxicity to fish in low-alkalinity lakes: A critical review. Environ. Pollut. 24-304.

Srinivas, M., R.T. Reddy, P.V. Desai and R. Roy. 2007. Alterations in some aspects of the carbohydrate metabolism in freshwater mussel (*Lamellidens marginalis*) due to zinc and cadmium toxicity. In: Natl.Semin.on 'Frontiers in Zoology' and Symp.on 'Ocean as Source of Nutrients and Drugs for 21st Century, Diversity and Life Processes from Ocean and Land, Feb.22-24, 2006, Goa Univ., Goa, India, 101-104.

Srivastav, S.K., A.K. Srivastav, R. Rai and D. Mishra. 2009. Ultimobranchial gland of a freshwater teleost, *Heteropneustes fossilis*, in response to cadmium treatment. Environ. Toxicol. 24(6): 589-593.

Srivastava, A. and K.J. Appenroth. 1995. Interaction of EDTA and iron on the accumulation of Cd^{2+} in duckweeds (Lemnaceae). J. Plant Physiol. 146: 173-176.

Srivastava, R.K., H.S. Singh and S. Srivastava. 2001. Physiological changes in a freshwater catfish, *Heteropneustes fossilis* following exposure to cadmium. J. Ecophysiol. Occup. Health 1(3/4): 235-244.

St. Louis, V.L. 1993. Element concentrations in chironomids and their abundance in the littoral zone of acidified lakes in Northwestern Ontario. Can. J. Fish. Aquat. Sci. 50: 953-963.

Stackhouse, R.A. and W.H. Benson. 1988. The influence of humic acid on the toxicity and bioavailability of selected trace metals. Aquat. Toxicol. 13: 99-108.

Stanley, J.K., B.W. Brooks and T.W. LaPoint. 2005. A comparison of chronic cadmium effects on *Hyalella azteca* in effluent-dominated stream mesocosms to similar laboratory exposures in effluent and reconstituted hard water. Environ. Toxicol. Chem. 24(4): 902-908.

Stanley, R.A. 1974. Toxicity of heavy metals and salts to Eurasian watermilfoil (*Myriophyllum spicatum* L.). Arch. Environ. Contam. Toxicol. 2: 331.

Stary, J. and K. Kratzer. 1982. The cumulation of toxic metals on alga. Int. J. Environ. Anal. Chem. 12: 65.

Stary, J., K. Kratzer, B. Havlik, J. Prasilova and J. Hanusova. 1982. The cumulation of zinc and cadmium in fish (*Poecilia reticulata*). Int. J. Environ. Anal. Chem. 11(2): 117-120.

Stary, J., B. Havlik, K. Kratzer, J. Prasilova and J. Hanusova. 1983. Cumulation of zinc, cadmium and mercury on the alga *Scenedesmus obliquus*. Acta. Hydrochim. Hydrobiol. 11(4): 401-409.

Staub, B.P., W.A. Hopkins, J. Novak and J.D. Congdon. 2004. Respiratory and reproductive characteristics of eastern mosquitofish (*Gambusia holbrooki*) inhabiting a coal ash settling basin. Arch. Environ. Contam. Toxicol. 46(1): 96-101.

Stawarz, R., M. Zakrzewski, A. Marencik and S. Hraska. 2003. Heavy-metal concentration in the toad *Bufo bufo* from a region of Mochovce, Slovakia. Ekologia (Bratisl.)/Ecol. (Bratisl.) 22(3): 292-297.

Stebbing, A.R.D. 1976. The effects of low metal levels on a colonial hydroid. J. Mar. Biol. Assoc. U.K. 56: 1977.

Steele, R.L. and G.B. Thursby. 1983. A toxicity test using life stages of *Champia parvula* (Rhodophyta). In: W.E. Bishop, et al. (*Eds*.), Aquatic Toxicology and Hazard Assessment: Sixth Symposium. ASTM STP 802. American Society for Testing and Materials, Philadelphia, PA, p. 73.

Stefano, B., C. Ilaria and F. Silvano. 2008. Cholinesterase activities in the scallop *Pecten jacobaeus*: Characterization and effects of exposure to aquatic contaminants. Sci. Total Environ. 392(1): 99-109.

Stepanyan, I.E., A.S. Tsarukyan, Y.P. Petrov and I.E. Stepanyan. 2011. Effect of molybdenum, chrome and cadmium ions on metamorphosis and erythrocytes morphology of the marsh frog *Pelophylax ridibundus* (Amphibia: Anura). J. Environ. Sci. Technol. 4(2): 172-181.

Stephan, C.E. 1981. Early life stage tests by Sauter, et al. April 28th Memo to R.W. Andrew, D.A. Benoit, J.G. Eaton and Q.H. Pickering, 5 p.

Stephan, C.E. 1995. Derivation of conversion factors for the calculation of dissolved freshwater aquatic life criteria for metals. U.S. Environmental Protection Agency, Environmental Research Lab-Duluth, MN, 35pp.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. National Technical Information Service No. PB85-227049, Springfield, VA, 98 pp.

Stephan, C.E., W.H. Peltier, D.J. Hansen, C.G. Delos and G.A. Chapman. 1994. Appendix C: Guidance concerning the use of "clean techniques" and QA/QC when measuring trace metals, interim guidance on determination and use of water-effect ratios for metals. U.S. Environmental Protection Agency, Washington, DC, p. 98-108.

Stephenson, M. and G.L. Macki. 1989. Net cadmium flux in *Hyalella azteca* (Crustacea: Amphipoda) populations from five central Ontario lakes. Sci. Total Environ. 87/88: 463-475.

Stephenson, M. and M.A. Turner. 1993. A field study of cadmium dynamics in periphyton and in *Hyalella azteca* (Crustacea: Amphipoda). Water Air Soil Pollut. 68: 341-361.

Stern, M.S. and D.H. Stern. 1980. Effects of fly ash heavy metals on *Daphnia magna*. PB81-198327. National Technical Information Service, Springfield, VA.

Stoiber, T. 2011. Analysis of toxicity biomarkers for understanding copper and cadmium stress in freshwater algae. Ph.D. Thesis, The University of Wisconsin, Madison, WI.

Stoiber, T.L., M.M. Shafer and D.E. Armstrong. 2010. Differential effects of copper and cadmium exposure on toxicity endpoints and gene expression in *Chlamydomonas reinhardtii*. Environ. Toxicol. Chem. 29(1): 191-200.

Stoiber, T.L., M.M. Shafer and D.E. Armstrong. 2012. Relationships between surface-bound and internalized copper and cadmium and toxicity in *Chlamydomonas reinhardtii*. Environ. Toxicol. Chem. 31(2): 324-335.

Stokes, P.M. and S.I. Dreier. 1981. Copper requirement of a copper-tolerant isolate of *Scenedesmus* and the effect of copper depletion on tolerance. Can. J. Bot. 59: 1817-1823.

Stolyar, O.B., N.S. Loumbourdis. H.I. Falfushinska and L.D. Romanchuk. 2008. Comparison of metal bioavailability in frogs from urban and rural sites of western Ukraine. Arch. Environ. Contam. Toxicol. 54(1): 107-113.

Stom, D.I. and L.D. Zubareva. 1994. Comparative resistance of *Daphnia* and *Epischura* to toxic substances in acute exposure. Hydrobiol. 30(3): 35-38.

Storelli, M.M. and G.O. Marcotrigiano. 2001. Heavy metal monitoring in fish, bivalve molluscs, water, and sediments from Varano Lagoon, Italy. Bull. Environ. Contam. Toxicol. 66(3): 365-370.

Storelli, M.M. and G.O. Marcotrigiano. 2004. Content of mercury and cadmium in fish (*Thunnus alalunga*) and cephalopods (*Eledone moschata*) from the southeastern Mediterranean Sea. Food Add. Contam. 21(11): 1051-1056.

Storelli, M.M., A. Storelli, R. D'Addabbo, C. Marano, R. Bruno and G.O. Marcotrigiano. 2005a. Trace elements in loggerhead turtles (*Caretta caretta*) from the eastern Mediterranean Sea: Overview and evaluation. Environ. Pollut. 135(1): 163-170.

Storelli, M.M., R. Giacominelli-Stuffler, A. Storelli and G.O. Marcotrigiano. 2005b. Accumulation of mercury, cadmium, lead and arsenic in swordfish and bluefin tuna from the Mediterranean Sea: A comparative study. Mar. Pollut. Bull. 50(9): 1004-1007.

Storelli, M.M., G. Barone, R. Garofalo and G.O. Marcotrigiano. 2007. Metals and organochlorine compounds in eel (*Anguilla anguilla*) from the Lesina Lagoon, Adriatic Sea (Italy). Food Chem. 100(4): 1337-1341.

Storelli, M.M., G. Barone, A. Storelli and G.O. Marcotrigiano. 2008. Total and subcellular distribution of trace elements (Cd, Cu and Zn) in the liver and kidney of green turtles (*Chelonia mydas*) from the Mediterranean Sea. Chemosphere 70(5): 908-913.

Stout, L.M., E.N. Dodova, J.F. Tyson and K. Nuesslein. 2010. Phytoprotective influence of bacteria on growth and cadmium accumulation in the aquatic plant *Lemna minor*. Water Res. 44(17): 4970-4979.

Strady, E., G. Blanc, M. Baudrimont, J. Schaefer, S. Robert, V. Lafon and E. Strady. 2011a. Roles of regional hydrodynamic and trophic contamination in cadmium bioaccumulation by Pacific oysters in the Marennes-Oleron Bay (France). Chemosphere 84(1): 80-90.

Strady, E., J. Schafer, M. Baudrimont and G. Blanc. 2011b. Tracing cadmium contamination kinetics and pathways in oysters (*Crassostrea gigas*) by multiple stable Cd isotope spike experiments. Ecotoxicol. Environ. Saf. 74(4): 600-606.

Stratus Consulting, Inc. 1999. Sensitivity of bull trout (*Salvelinus confluentus*) to cadmium and zinc in water characteristic of the Coeur D'Alene River Basin: Acute toxicity report. Final Report to U.S. EPA Region X, 55 pp.

Straus, T. 2011. Linking Cd accumulation and effect in resistant and sensitive freshwater invertebrates. M.S. Thesis, Wilfrid Laurier University, Canada.

Stripp, R.A., M. Heit, D.C. Bogen, J. Bidanset and L. Trombetta. 1990. Trace element accumulation in the tissues of fish from lakes with different pH values. Water Air Soil Pollut. 51: 75-87.

Stromberg, P.C., J.G. Ferrante and S. Carter. 1983. Pathology of lethal and sublethal exposure of fathead minnows, *Pimephales promelas*, to cadmium: A model for aquatic toxicity assessment. J. Toxicol. Environ. Health 11(2): 247-259.

Stromgren, T., S.E. Sorstrom, L. Schou, I. Kaarstad, T. Aunaas, O.G. Brakstad and O. Johansen. 1995. Acute toxic effects of produced water in relation to chemical composition and dispersion. Mar. Environ. Res. 40(2): 147-169.

Stubblefield, W.A. 1990. An evaluation of the acute toxicity of cadmium chloride (CdCl2) to brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and mountain whitefish (*Prosopium williamsoni)*. Report, EA Engineering, Science and Technology, Inc, Corvallis, OR, 55 p.

Stubblefield, W.A., B.L. Steadman, T.W. La Point and H.L. Bergman. 1999. Acclimation-induced changes in the toxicity of zinc and cadmium to rainbow trout. Environ. Toxicol. Chem. 18(12): 2875-2881.

Stuhlbacher, A. and L. Maltby. 1992. Cadmium resistance in *Gammarus pulex* (L.). Arch. Environ. Contam. Toxicol. 22: 319-324.

Stuhlbacher, A., M.C. Bradley, C. Naylor and P. Calow. 1992. Induction of cadmium tolerance in two clones of *Daphnia magna* Straus. Comp. Biochem. Physiol. 101C(3): 571-577.

Stuhlbacher, A., M.C. Bradley, C. Naylor and P. Calow. 1993. Variation in the development of cadmium resistance in *Daphnia magna* Straus; Effect of temperature, nutrition, age and genotype. Environ. Pollut. 80(2): 153-158.

Suarez, C., E. Torres, M. Perez-Rama, C. Herrero and J. Abalde. 2010. Cadmium toxicity on the freshwater microalga chlamydomonas *Moewusii gerloff*: biosynthesis of thiol compounds. Environ. Toxicol. Chem. 29(9): 2009-2015.

Suedel, B.C., J.H. Rodgers Jr. and E. Deaver. 1997. Experimental factors that may affect toxicity of cadmium to freshwater organisms. Arch. Environ. Contam. Toxicol. 33(2): 188-193.

Sullivan, B.K., E. Buskey, D.C. Miller and P.J. Ritacco. 1983. Effects of copper and cadmium on growth, swimming and predator avoidance in *Eurytemora affinis* (Copepoda). Mar. Biol. 77(3): 299-306.

Sullivan, J.K. 1977. Effects of salinity and temperature on the acute toxicity of cadmium to the estuarine crab *Paragrapsus gaimardii* (Milne Edwards). Aust. J. Mar. Fresh. Res. 28(6): 739-743.

Sun, F.H. and Q.X. Zhou. 2007. Metal accumulation in the polychaete *Hediste japonica* with emphasis on interaction between heavy metals and petroleum hydrocarbons. Environ. Pollut. 149 (1): 92-98.

Sun, F.H. and Q.X. Zhou. 2008. Oxidative stress biomarkers of the polychaete *Nereis diversicolor* exposed to cadmium and petroleum hydrocarbons. Ecotoxicol. Environ. Saf. 70(1): 106-114.

Sun, F.H., Q.X. Zhou, Q.R. Zhang and Q. Zhou. 2006. Influences of petroleum on accumulation of copper and cadmium in the polychaete *Nereis diversicolor*. J. Environ. Sci. (China) 18(1): 109-114.

Sun, Y.B, Q.X. Zhou, W.T. Liu, J. An, Z.Q. Xu and L. Wang. 2009. Joint effects of arsenic and cadmium on plant growth and metal bioaccumulation: A potential Cd-hyperaccumulator and As-excluder *Bidens pilosa* L. J. Hazard. Mater. 165(1-3): 1023-1028.

Sun, Z., S. Chen, J. Chen, H. Gao and D. Li. 2007. Acute toxicity of four heavy metals to *Apostichopus japonicus* juvenile. Mar. Sci. Bull. 26(5): 80-85.

Sunda, W.G. and S.A. Huntsman. 1996. Antagonisms between cadmium and zinc toxicity and manganese limitation in a coastal diatom. Limnol. Oceanogr. 41(3): 373-387.

Sunda, W.G., D.W. Engel and R.M. Thuotte. 1978. Effect of chemical speciation on toxicity of cadmium to grass shrimp, *Palaemonetes pugio*: Importance of free cadmium ion. Environ. Sci. Technol. 12(4): 409-413.

Sunderman Jr., F.W., M.C. Plowman and S.M. Hopfer. 1991. Embryotoxicity and teratogenicity of cadmium chloride in *Xenopus laevis*, assayed by the FETAX procedure. Ann. Clin. Lab. Sci. 21(6): 381-391.

Sunil, P.P.G, N. Siriwardena, K.J. Rana and D.J. Baird. 1995. A method for partitioning cadmium bioaccumulated in small aquatic organisms. Environ. Toxicol. Chem. 14(9): 1575-1577.

Sunila, I. and R. Lindstrom. 1985. Survival, growth and shell deformities of copper- and cadmium-exposed mussels (*Mytilus edulis* L.) in brackish water. Estuar. Coast. Shelf Sci. 21(4): 555-565.

Sunlu, U. 2006. Trace metal levels in mussels (*Mytilus galloprovincialis* L. 1758) from Turkish Aegean Sea coast. Environ. Monit. Assess. 114(1-3): 273-286.

Sura, P., N. Ristic, P. Bronowicka and M. Wrobel. 2006. Cadmium toxicity related to cysteine metabolism and glutathione levels in frog *Rana ridibunda* tissues. Comp. Biochem. Physiol. 142C(1/2): 128-135.

Suresh, A., B. Sivaramakrishna and K. Radhakrishnaiah. 1993a. Effect of lethal and sublethal concentrations of cadmium on energetics in the gills of fry and fingerlings of *Cyprinus carpio*. Bull. Environ. Contam. Toxicol. 51: 920-926.

Suresh, A., B. Sivaramakrishna and K. Radhakrishnaiah. 1993b. Patterns of cadmium accumulation in the organs of fry and fingerlings of freshwater fish *Cyprinus carpio* following cadmium exposure. Chemosphere 26(5): 945-953.

Suresh, N. 2009. Effect of cadmium chloride on liver, spleen and kidney melano macrophage centres in *Tilapia mossambica*. J. Environ. Biol. 30(4): 505-508.

Suryawanshi, G.D. 2006a. Accumulation and depuration of cadmium in oyster *Crassostrea cattuckensis* from Bhatye Estuary in Ratnagiri coast. Nat. Environ. Pollut. Technol. 5(4): 569-574.

Suryawanshi, G.D. 2006b. Zinc and cadmium content in the estuarine oyster from Ratnagiri coast of Maharashtra. J. Ecotoxicol. Environ. Monit. 16(6): 581-585.

Suryawanshi, G.D. and Z.A. Langekar. 2006. Zinc and cadmium toxicity to estuarine rock oyster *Crassostrea cattuckensis* on Ratnagiri coast. Nat. Environ. Pollut. Technol. 5(3): 463-467.

Suter, G.W., II, S.B. Norton and S.M. Cormier. 2002. A method for inferring the causes of observed impairments in aquatic ecosystems. Environ. Toxicol. Chem. 21(6): 1101-1111.

Suzuki, K.T., H. Sunaga, E. Kobayashi and S. Hatakeyama. 1987. Environmental and injected cadmium are sequestered by two major isoforms of basal copper, zinc-metallothionein in gibel (*Carassius auratus langsdorfi*) liver. Comp. Biochem. Physiol. 87C(1): 87-93.

Svecevicius, G. 2007. The use of fish avoidance response in identifying sublethal toxicity of heavy metals and their mixtures. Acta Zool. Litu. 17(2): 139-143.

Swansburg, E.O., W.L. Fairchild, B.J. Fryer and J.J.H. Ciborowski. 2002. Mouthpart deformities and community composition of chironomidae (Diptera) larvae downstream of metal mines in New Brunswick, Canada. Environ. Toxicol. Chem. 21(12): 2675-2684.

Swartz, R.C., D.W. Schults, G.R. Ditsworth, W.A. DeBen and F.A. Cole. 1985. Sediment toxicity, contamination, and macrobenthic communities near a large sewage outfall. In: T.P. Boyle (*Ed*.), Validation and Predictability of Laboratory Methods for Assessing the Fate and Effects of Contaminants in Aquatic Ecosystems, ASTM STP 865, Philadelphia, PA, 152-175.

Swinehart, J.H. 1990. Final Technical Report for U.S.G.S. Grant: The effects of humic substances on the interactions of metal ions with organisms and liposomes. Department of Chemistry, University of California, Davis, CA 95616, 103 pp.

Szarek-Gwiazda, E.W.A. and A. Amirowicz. 2006. Bioaccumulation of trace elements in roach, silver bream, rudd, and perch living in an inundated opencast sulphur mine. Aquat. Ecol. 40(2): 221-236.

Szarek-Gwiazda, E., A. Amirowicz and R. Gwiazda. 2006. Trace element concentrations in fish and bottom sediments of an eutrophic dam reservoir. Oceanol. Hydrobiol. Stud. 35(4): 331-352.

Szczerbik, P., T. Mikolajczyk, M. Sokolowska-Mikolajczyk, M. Socha, J. Chyb and P. Epler. 2006. Influence of long-term exposure to dietary cadmium on growth, maturation and reproduction of goldfish (subspecies: Prussian carp *Carassius auratus gibelio* B.). Aquat. Toxicol. 77(2): 126-135.

Szebedinszky, C., J.C. McGeer, D.G. McDonald and C.M. Wood. 2001. Effects of chronic Cd exposure via the diet or water on internal organ-specific distribution and subsequent gill Cd uptake kinetics in juvenile rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem. 20(3): 597-607.

Szefer, P., S.W. Fowler, K. Ikuta, F.P. Osuna, A.A. Ali, B.S. Kim, H.M. Fernandes, M.J. Belzunce, B. Guterstam, H. Kunzendorf, M. Wolowicz, H. Hummel and M. Deslous-Paoli. 2006. A comparative assessment of heavy metal accumulation in soft parts and byssus of mussels from subarctic, temperate, subtropical and tropical marine environments. Environ. Pollut. 139: 70-78.

Szivak, I., R. Behra and L. Sigg. 2009. Metal-induced reactive oxygen species production in *Chlamydomonas reinhardtii* (Chlorophyceae). J. Phycol. 45(2): 427-435.

Tabari, S., S.S. Saravi, G.A. Bandany, A. Dehghan and M. Shokrzadeh. 2010. Heavy metals (Zn, Pb, Cd and Cr) in fish, water and sediments sampled form Southern Caspian Sea, Iran. Toxicol. Ind. Health 26(10): 649-656.

Takamura, N., F. Kasai and M.M. Watanabe. 1989. Effects of Cu, Cd and Zn on photosynthesis of freshwater benthic algae. J. Appl. Phycol. 1: 39-52.

Talas, Z.S., I. Orun, I. Ozdemir, K. Erdogan, A. Alkan and I. Yilmaz. 2008. Antioxidative role of selenium against the toxic effect of heavy metals (Cd+2, Cr+3) on liver of rainbow trout (*Oncorhynchus mykiss* Walbaum 1792). Fish. Physiol. Biochem. 34(3): 217-222.

Talavera, A.L., S.C. Gardner, R. Riosmena, B. Acosta, A.F. Rees, M. Frick, A. Panagopoulou and K. Williams. 2008. Metal profiles used as environmental markers of green turtle (*Chelonia mydas*) foraging resources. NOAA Tech. Mem. NMFS SEFSC. 569, p. 112.

Talavera, M.O., H.M.A. Armienta, J.G. Abundis and N.F. Mundo. 2006. Geochemistry of leachates from the El Fraile sulfide tailings piles in Taxco, Guerrero, southern Mexico. Environ. Geochem. Health 28(3): 243-255.

Talbot, V. 1985. Relationship between cadmium concentrations in seawater and those in the mussel *Mytilus edulis*. Mar. Biol. 85: 51-54.

Talbot, V. 1987. Relationship between lead concentrations in seawater and in the mussel *Mytilus edulis*: A water-quality criterion. Mar. Biol. 94: 557-560.

Tan, C.Y., X.Q. Shan, G.Z. Xu, Y.M. Lin and Z.L. Chen, Z. L. 2011. Phytoaccumulation of cadmium through *Azolla* from aqueous solution. Ecolog. Eng. 37(11): 1942-1946.

Tan, C., W.H. Fan and W.X. Wang. 2012. Role of titanium dioxide nanoparticles in the elevated uptake and retention of cadmium and zinc in *Daphnia magna*. Environ. Sci. Technol. 46(1): 469-476.

Tan, F., M. Wang, W. Wang and Y. Lu. 2008. Comparative evaluation of the cytotoxicity sensitivity of six fish cell lines to four heavy metals in vitro. Toxicol. In Vitro 22(1): 164-170.

Tan, F., M. Wang, W. Wang, A. Alonso Aguirre and Y. Lu. 2010a. Validation of an *in vitro* cytotoxicity test for four heavy metals using cell lines derived from a green sea turtle (*Chelonia mydas*). Cell Biol. Toxicol. 26(3): 255-263.

Tan, Q. and W. X. Wang. 2009. The influence of ambient and body calcium on cadmium and zinc accumulation in *Daphnia magna*. Environ. Toxicol. Chem. 27: 1605-1613.

Tan, Q.G. and W.X. Wang. 2011. Acute toxicity of cadmium in *Daphnia magna* under different calcium and pH conditions: Importance of influx rate. Environ. Sci. Technol. 45(5): 1970-1976.

Tan, X.Y., Z. Luo, G.Y. Zhang, X.J. Liu and M. Jiang. 2010b. Effect of dietary cadmium level on the growth, body composition and several hepatic enzymatic activities of juvenile yellow catfish, *Pelteobagrus fulvidraco*. Aquacult. Res. 41(7): 1022-1029. Tang, S. 2013. Toxicity of cadmium quantum dots compared to cadmium and zinc ions in zebrafish (*Danio rerio*) and water flea (*Daphnia pulex*). Ph.D. Dissertation. Texas Tech University, Lubbock, TX. 150 pp.

Tang, S. 2013. Toxicity of cadmium quantum dots compared to cadmium and zinc ions in zebrafish (*Danio rerio*) and water flea (*Daphnia pulex*). Ph.D. Dissertation. Texas Tech University, Lubbock, TX. 150 pp.

Tanhan, P., P. Sretarugsa, P. Pokethitiyook, M. Kruatrachue and E.S. Upatham. 2005. Histopathological alterations in the edible snail, *Babylonia areolata* (spotted Babylon), in acute and subchronic cadmium poisoning. Environ. Toxicol. 20(2): 142-149.

Tao, M., G. Wu, G. Gu and C. Lu. 2002. Toxicity of Cd2+ on the photosynthetic and respiratory rate and atpase activity of *Nymphoides peltatum* (Gmel.) O'Ktze. J. Nanjing Norm. Univ. (Nat.Sci.) 25(3): 94-98.

Tao, M., G. Gu, G. Wu and L. Lu. 2004. The toxic effects of Cd2+ on photosynthesis, respiration rate and atpase activity in *Nymphoides peltatum* (Gmel.) O. ktze. J. Nat. Sci. Nanjing Normal Univ. 6: 37-40.

Tapia, J., L. Vargas-Chacoff, C. Bertran, G. Carrasco, F. Torres, R. Pinto, S. Urzćṛa, A. Valderrama and L. Letelier. 2010. Study of the content of cadmium, chromium and lead in bivalve molluscs of the Pacific Ocean (Maule Region, Chile). Food Chem. 121(3): 666-671.

Taraldsen, J.E. and T.J. Norberg-King. 1990. New method for determining effluent toxicity using duckweed (*Lemna minor*). Environ. Toxicol. Chem. 9: 761-767.

Tarasov, V.A., S.K. Abilev, R.M. Velibekov and M.M. Aslanyan. 2003. Efficiency of batteries of tests for estimating potential mutagenicity of chemicals. Russ. J. Genet. 39(10): 1191-1200.

Taravati, S., A. Askary Sary and M. Javaheri Baboli. 2012. Determination of lead, mercury and cadmium in wild and farmed *Barbus sharpeyi* from Shadegan Wetland and Azadegan aquaculture site, South of Iran. Bull. Environ. Contam. Toxicol. 89(1): 78-81.

Tarzwell, C.M. and C. Henderson. 1960. Toxicity of less common metals to fishes. Ind. Wastes 5: 12.

Tasha, L.S., M.S. Martin and E.A. David. 2010. Differential effects of copper and cadmium exposure on toxicity endpoints and gene expression in *Chlamydomonas reinhardtii*. Environ. Toxicol. Chem. 29(1): 191-200.

Tawari-Fufeyin, P., P. Opute and I. Ilechie. 2007. Toxicity of cadmium to *Parachanna obscura*: As evidenced by alterations in hematology, histology, and behavior. Toxicol. Environ. Chem. 89(2): 243-248.

Taylor, A.M. and W.A. Maher. 2012. Exposure-dose-response of *Anadara trapezia* to metal contaminated estuarine sediments. 1. Cadmium spiked sediments. Aquat. Toxicol. 109: 234-242.

Taylor, A.N. 2010. Impacts of cadmium contamination and fish presence on wetland invertebrate communities: An application of population measures and multi-metric tests. Ecolog. Indicators 10(6): 1206-1212.

Taylor, G., D.J. Baird and A.M.V.M. Soares. 1998. Surface binding of contaminants by algae: Consequences for lethal toxicity and feeding to *Daphnia magna* Straus. Environ. Toxicol. Chem. 17(3): 412-419.

Taylor, N.S., R.J.M. Weber, T.A. White and M.R. Viant. 2010. Discriminating between different acute chemical toxicities via changes in the daphnid metabolome. Toxicol. Sci. 118(1): 307-317.

Tehseen, W.M., L.G. Hansen, D.J. Schaeffer and H.A. Reynolds. 1992. A scientific basis for proposed quality assurance of a new screening method for tumor-like growths in the planarian, *Dugesia dorotocephala*. Qual. Assur. Good Prac. Regul. Law 1(3): 217-229.

Tekin-Ozan, S. and I. Kir. 2008. Seasonal variations of heavy metals in some organs of carp (*Cyprinus carpio* L., 1758) from Beysehir Lake (Turkey). Environ. Monit. Assess. 138: 201-206.

Temara, A., G. Ledent, M. Warnau, H. Paucot, M. Jangoux and P. Dubois. 1996a. Experimental cadmium contamination of *Asterias rubens* (Echinodermata). Mar. Ecol. Prog. Ser. 140: 83-90.

Temara, A., M. Warnau, G. Ledent, M. Jangoux and P. Dubois. 1996b. Allometric variations in heavy metal bioconcentration in the asteroid *Asterias rubens* (Echinodermata). Bull. Environ. Contam. Toxicol. 56: 98-105.

Temara, A., M. Warnau, M. Jangoux and P. Dubois. 1997. Factors influencing the concentrations of heavy metals in the asteroid *Asterias rubens* L. (Echinodermata). Sci. Total Environ. 203: 51-63.

Templeman, M.A. and M.J. Kingsford. 2010. Trace element accumulation in *Cassiopea sp.* (Scyphozoa) from urban marine environments in Australia. Mar. Environ. Res. 69(2): 63-72.

TenBrook, P.L., R.S. Tjeerdema, P. Hann and J. Karkoski. 2009. Methods for deriving pesticide aquatic life criteria. Rev. Environ. Contam. Toxicol. 199: 19-109.

Ten Hoopen, H.J.G., P.J. Nobel, A. Schaap, A. Fuchs and J.A. Roels. 1985. Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. I. Development of cadmium tolerance in batch cultures. Antonie van Leeuwenhoek 51: 344-346.

Tepe, Y. 2009. Metal concentrations in eight fish species from Aegean and Mediterranean Seas. Environ. Monit. Assess. 159(1-4): 501-509.

Tepe, Y., M. Turkmen and A. Turkmen. 2008. Assessment of heavy metals in two commercial fish species of four Turkish seas. Environ. Monit. Assess. 146(1-3): 277-284.

Terra, N.R., I.R. Feiden, J.M. Fachel, J.S. Moreira and C. Lemke. 2007. Chronic assays with *Daphnia magna*, 1820, Straus in sediment samples from Cai River, Rio Grande Do Sul, Brazil. Acta Limnol. Brasil. 19(1): 31-39.

Tessier, A., Y. Couillard, P.G.C. Campbell and J.C. Auclair. 1993. Modeling Cd partitioning in oxic lake sediments and Cd concentrations in the freshwater bivalve *Anodonta grandis*. Limnol Oceanogr. 38(1): 1-17.

Tessier, L., G. Vaillancourt and L. Pazdernik. 1994a. Comparative study of the cadmium and mercury kinetics between the short-lived gastropod *Viviparus georgianus* (Lea) and pelecypod *Elliptio complanata* (Lightfoot), under laboratory conditions. Environ. Pollut. 85: 271-282.

Tessier, L., G. Vaillancourt and L. Pazdernik. 1994b. Temperature effects on cadmium and mercury kinetics in freshwater molluscs under laboratory conditions. Arch. Environ. Contam. Toxicol. 26: 179-184.

Tessier, L., G. Vaillancourt and L. Pazdernik. 1996. Laboratory study of Cd and Hg uptake by two freshwater molluscs in relation to concentration, age and exposure time. Water Air Soil Pollut. 86: 347-357.

Tevlin, M.P. 1978. An improved experimental medium for freshwater toxicity studies using *Daphnia magna*. Water Res. 12(11): 1017-1024.

Thaker, A.A. and A.A. Haritos. 1989. Cadmium bioaccumulation and effects on soluble peptides, proteins and enzymes in the hepatopancreas of the shrimp *Callianassa tyrrhena*. Comp. Biochem. Physiol. Part C 94(1): 63-70.

Thaker, A.A. and A.A. Haritos. 1993. Cadmium bioaccumulation and effects on soluble peptides, proteins and enzymes in the hepatopancreas of the shrimp *Callianassa tyrrhena*. In: Final Reports on Research Projects (Activity G), UNEP Mediterranean Action Plan, Athens, Greece, MAP Tech. Rep. Ser. No. 48, 13-32 (Publ. as 57).

Thebault, M.T., A. Biegniewska, J.P. Raffin and E.F. Skorkowski. 1996. Short term cadmium intoxication of the shrimp *Palaemon serratus*: Effect on adenylate metabolism. Comp. Biochem. Physiol. Part C 113(3): 345-348.

Theede, H., N. Scholz and H. Fischer. 1979. Temperature and salinity effects on the acute toxicity of cadmium to *Laomedea loveni* (Hydrozoa). Mar. Ecol. Prog. Ser. 1: 13-19.

Thellen, C., C. Blaise, Y. Roy and C. Hickey. 1989. Round robin testing with the *Selenastrum capricornutum* microplate toxicity assay. Hydrobiol. 188/189: 259-268.

Thilaga, R.D. and V. Sivakumar. 2006. Accumulation of heavy metals in the gastropod *Bullia vittata* at Gulf of Mannar. J. Ecotoxicol. Environ. Monit. 16(3): 221-226.

Thirumathal, K., A.A. Sivakumar, J. Chandrakantha and K.P. Suseela. 2002. Effect of heavy metal (cadmium borate) on the biochemical composition of *Chironomus larvae* (Diptera: Chironomidae). Indian J. Environ. Ecoplann. 6(2): 255-258.

Thomann, R.V., F. Shkreli and S. Harrison. 1997. A pharmacokinetic model of cadmium in rainbow trout. Environ. Toxicol. Chem. 16(11): 2268-2274.

Thomas, D.G., A. Cryer, J.F. Solbe and J. Kay. 1983. A comparison of the accumulation and protein binding of environmental cadmium in the gills, kidney and liver of rainbow trout (*Salmo gairdneri* Richardson). Comp. Biochem. Physiol. Part C 76(2): 241-246.

Thomas, D.G., M.W. Brown, D. Shurben, J.F. Solbe, A. Cryer and J. Kay. 1985. A comparison of the sequestration of cadmium and zinc in the tissues of rainbow trout (*Salmo gairdneri*) following exposure to the metals singly or in combination. Comp. Biochem. Physiol. Part C 82(1): 55-62.

Thomas, S. and N. Indra. 2008. Bioaccumulation of cadmium in various tissues of *Labeo rohita* (Ham.) following cadmium exposure. Bioscan 3(1): 23-25.

Thompson, P.A. and P. Couture. 1991. Short- and long-term changes in growth and biochemical composition of *Selenastrum capricornutum* populations exposed to cadmium. Aquat. Toxicol. 21: 135-144.

Thompson, S.E., C.A. Burton, D.J. Quinn and Y.C Nig. 1972. Concentration factors of the chemical elements in edible aquatic organisms. UCRL-50564. Rev. 1. National Technical Information Service, Springfield, VA.

Thongra-Ar, W. 1997. Toxicity of cadmium, zinc and copper on sperm cell fertilization of sea urchin, *Diadema setosum*. J. Sci. Soc. Thailand 23(4): 297-306.

Thongra-Ar, W. and O. Matsuda. 1995. Effects of cadmium and zinc on growth of *Thalassiosira weissflogii* and *Heterosigma akiashiwo*. In*:* A. Snidvongs, W. Utoomprukporn and M. Hungspreugs (*Eds*.), 1995, Proceedings of the NRCT-JSPS Joint Seminar on Marine Science, December 2-3, 1993, Chulalongkorn University, Songkhla, Thailand. Bangkok: Department of Marine Science, pp. 90-96.

Thophon, S., M. Kruatrachue, E.S. Upatham., P. Pokethitiyook., S. Sahaphong and S. Jaritkhuan. 2003. Histopathological alterations of white seabass, *Lates calcarifer*, in acute and subchronic cadmium exposure. Environ. Pollut. 121(3): 307-320.

Thophon, S., P. Pokethitiyook, K. Chalermwat, E.S. Upatham and S. Sahaphong. 2004. Ultrastructural alterations in the liver and kidney of white sea bass, *Lates calcarifer*, in acute and subchronic cadmium exposure. Environ. Toxicol. 19(1): 11-19.

Thorp, J.H. and S.P. Gloss. 1986. Field and laboratory tests on acute toxicity of cadmium to freshwater crayfish. Bull. Environ. Contam. Toxicol. 37: 355-361.

Thorp, J.H., J.P. Giesy and S.A. Wineriter. 1979. Effects of chronic cadmium exposure on crayfish survival, growth, and tolerance to elevated temperatures. Arch. Environ. Contam. Toxicol. 8(4): 449-456.

Thorpe, G.J. 1988. A toxicological assessment of cadmium toxicity to the larvae of two estuarine crustaceans, *Rhithropanopeus harrisii* and *Palaemonetes pugio*. Ph.D. Thesis, Duke University, Durham, NC, 120 p.

Thorpe, G.J. and J.D. Costlow. 1989. The relation of the acute (96-h) uptake and subcellular distribution of cadmium and zinc to cadmium toxicity in larvae of *Rhithropanopeus harrisii* and a *Palaemonetes pugio*. In: U.M. Cowgill and L.R. Williams (*Eds*.), Aquatic Toxicology and Hazard Assessment, ASTM STP 1027, Philadelphia, PA, 12: 82-94.

Thorsson, M.H., J.E. Hedman, C. Bradshaw, J.S. Gunnarsson and M. Gilek. 2008. Effects of settling organic matter on the bioaccumulation of cadmium and BDE-99 by Baltic Sea benthic invertebrates. Mar. Environ. Res. 65(3): 264-281.

Thursby, G.B. and R.L. Steele. 1986. Comparison of short- and long-term sexual reproduction tests with the marine red alga *Champia Parvula*. Environ. Toxicol. Chem. 5: 1013-1018.

Thwala, M., B.K. Newman and D.P. Cyrus. 2011. Influence of salinity and cadmium on the survival and osmoregulation of *Callianassa kraussi* and *Chiromantes eulimene* (Crustacea: Decapoda). Afr. J. Aquat. Sci. 36(2): 181-189.

Tiam, S.K., A. Feurtet-Mazel, F. Delmas, N. Mazzella, S. Morin, G. Daffe and P. Gonzalez. 2012. Development of Q-PCR approaches to assess water quality: Effects of cadmium on gene expression of the diatom *Eolimna minima*. Water Res. 46(4): 934-942.

Tichy, M., M. Rucki, I. Hanzlikova and Z. Roth. 2007. The *Tubifex tubifex* assay for the determination of acute toxicity. Atla 35(2): 229-237.

Tilton, S.C., C.M. Foran and W.H. Benson. 2003. Effects of cadmium on the reproductive axis of Japanese medaka (*Oryzias latipes*). Comp. Biochem. Physiol. Part C 136(3): 265-276.

Timmermans, K.R. 1992. Ecotoxicity of trace metals for chironomids. Neth. J. Aquat. Ecol. 26(2-4): 559-561.

Timmermans, K.R., E. Spijkerman and M. Tonkes. 1992. Cadmium and zinc uptake by two species of aquatic invertebrate predator from dietary and aqueous sources. Can. J. Fish. Aquat. Sci. 49: 655-662.

Timmermans, K.R., W. Peeters and M. Tonkes. 1992. Cadmium, zinc, lead and copper in *Chironomus riparius* (Meigen) larvae (Diptera, Chironomidae): Uptake and effects. Hydrobiol. 241: 119-134.

Titus, J.A. and R.M. Pfister. 1984. Bacteria and cadmium interactions in natural and laboratory model aquatic systems. Arch. Environ. Contam. Toxicol. 13: 271-277.

Tiwari, M., N.S. Nagpure, D.N. Saksena and W.S. Lakra. 2010. Time kinetic study of metallothionein mRNA expression due to cadmium exposure in freshwater murrel, *Channa punctata* (Bloch). J. Ecophysiol. Occup. Health 10(1/2): 85-96.

Tkalec, M., T. Prebeg, V. Roje, B. Pevalek-Kozlina and N.Ljubesic. 2008. Cadmium-induced responses in duckweed *Lemna minor* L. Acta Physiol. Plant. 30(6): 881-890.

Todd, A.S., D.M. McKnight, C.L. Jaros and T.M. Marchitto. 2007. Effects of acid rock drainage on stocked rainbow trout (*Oncorhynchus mykiss*): An in-situ, caged fish experiment. Environ. Monit. Assess. 130(1-3): 111-127.

Tokunaga, T. and A. Kishikawa. 1982. Acute visible and invisible injuries to submerged plants by water pollutants. C. A. Sel. Environ. Pollut. 97: 121482v.

Tomasik, P., C.M. Magadza, S. Mhizha and A. Chirume. 1995a. The metal-metal interactions in biological systems. Part III. *Daphnia magna*. Water Air Soil Pollut. 82: 695-711.

Tomasik, P., C.M. Magadza, S. Mhizha, A. Chirume, M.F. Zaranyika and S. Muchiriri. 1995b. Metal-metal interaction in biological systems. Part IV. Freshwater snail *Bulinus globosus*. Water Air Soil Pollut. 83: 123-145.

Topcuoglu, S., C. Kirbasoglu and N. Balkis. 2004. Heavy metal concentrations in marine algae from the Turkish coast of the Black Sea, during 1979-2001. J. Black Sea/Medit. Environ. 10(1): 21-44.

Topperwien, S., H. Xue, R. Behra and L. Sigg. 2007a. Cadmium accumulation in *Scenedesmus vacuolatus* under freshwater conditions. Environ. Sci. Technol. 41(15): 5383-5388.

Topperwien, S., R. Behra and L. Sigg. 2007b. Competition among zinc, manganese, and cadmium uptake in the freshwater alga *Scenedesmus vacuolatus*. Environ. Toxicol. Chem. 26(3): 483-490.

Torres, E., A. Cid, C. Herrero and J. Abalde. 1998. Removal of cadmium ions by the marine diatom *Phaeodactylum tricornutum* Bohlin accumulation and long-term kinetics of uptake. Biores. Tech. 63: 213-220.

Tortell, P.D. and N.M. Price. 1996. Cadmium toxicity and zinc limitation in centric diatoms of the genus *Thalassiosira*. Mar. Ecol. Prog. Ser. 138: 245-254.

Toth, T., O. Zsiros, M. Kis, G. Garab and L. Kovacs. 2012. Cadmium exerts its toxic effects on photosynthesis via a cascade mechanism in the cyanobacterium, *Synechocystis* PCC 6803. Plant Cell Environ. 35(12): 2075-2086.

Toudal, K. and H.U. Riisgard. 1987. Acute and sublethal effects of cadmium on ingestion, egg production and life-cycle development in the copepod *Acartia tonsa*. Mar. Ecol. Prog. Ser. 37: 141-146.

Toussaint, M.W., T.R. Shedd, W.H. Van der Schalie and G.R. Leather. 1995. A comparison of standard acute toxicity test with rapid-screening toxicity test. Environ. Toxicol. Chem. 14(5): 907-915.

Tran, D., A. Boudou and J.C. Massabuau. 2001. How water oxygenation level influences cadmium accumulation pattern in the Asiatic clam *Corbicula fluminea*: A laboratory and field study. Environ. Toxicol. Chem. 20(9): 2073-2080.

Tran, D., A. Boudou and J.C. Massabuau. 2002. Relationship between feeding-induced ventilatory activity and bioaccumulation of dissolved and algal-bound cadmium in the Asiatic clam *Corbicula fluminea*. Environ. Toxicol. Chem. 21(2): 327-333.

Trannum, H.C., F. Olsgard, J.M. Skei., J. Indrehus, S. Overas and J. Eriksen. 2004. Effects of copper, cadmium and contaminated harbour sediments on recolonisation of soft-bottom communities. J. Exper. Mar. Biol. Ecol. 310(1): 87-114.

Trehan, K. and Maneesha. 1994. Cadmium mediated control of nitrogenase activity and other enzymes in a nitrogen fixing cyanobacterium. Acta Microbiol. Hungarica 41(4): 441-449.

Trevors, J.T., G.W. Stratton and G.M. Gadd. 1986. Cadmium transport, resistance, and toxicity in bacteria, algae, and fungi. Can. J. Microbiol. 32: 447-464.

Trieff, N.M., L.A. Romana, A. Esposito, R. Oral, F. Quiniou, M. Iaccarino, N. Alcock, V.M.S. Ramanujam and G. Pagano. 1995. Effluent from bauxite factory induces developmental and reproductive damage in sea urchins. Arch. Environ. Contam. Toxicol. 28(2): 173-177.

Trinchella, F., M. Cannetiello, P. Simoniello, S. Filosa and R. Scudiero. 2010. Differential gene expression profiles in embryos of the lizard *Podarcis sicula* under in ovo exposure to cadmium. Comp. Biochem. Physiol. Part C 151(1): 33-39.

Tryfonas, A.E., J.K. Tucker, P.E. Brunkow, K.A. Johnson, S. Hussein and Z.Q. Lin. 2006. Metal accumulation in eggs of the red-eared slider (*Trachemys scripta elegans*) in the lower Illinois River. Chemosphere 63(1): 39-48.

Tsui, M.T. and W.X. Wang. 2007. Biokinetics and tolerance development of toxic metals in *Daphnia magna*. Environ. Toxicol. Chem. 26(5): 1023-1032.

Tucker, R.K. 1979. Effects of in vivo cadmium exposure on ATPases in gill of the lobster, *Homarus americanus*. Bull. Environ. Contam. Toxicol. 23: 33.

Tucker, R.K. and A. Matte. 1980. In vitro effects of cadmium and lead on ATPases in the gill of the rock crab, *Cancer irroratus*. Bull. Environ. Contam. Toxicol. 24: 847.

Tuerkmen, M., A. Tuerkmen, Y. Tepe, Y. Toere and A. Ates. 2009. Determination of metals in fish species from Aegean and Mediterranean Seas. Food Chem. 113(1): 233-237.

Tueros, I., A. Borja, J. Larreta, J.G. Rodriguez, V. Valencia and E. Millan. 2009. Integrating long-term water and sediment pollution data, in assessing chemical status within the European water framework directive. Mar. Pollut. Bull. 58(9): 1389-1400.

Tuezen, M., D. Mendil, H. Sari, M. Suicmez and E. Hasdemir. 2004. Investigation of trace metal levels in fish species from the Black Sea and the River Yesilirmak, Turkey by atomic absorption spectrometry. Fresenius Environ. Bull. 13(5): 472-474.

Tukaj, Z., A. Bascik-Remisiewicz, T. Skowronski and C. Tukaj. 2007. Cadmium effect on the growth, photosynthesis, ultrastructure and phytochelatin content of green microalga *Scenedesmus armatus*: A study at low and elevated CO_2 concentration. Environ. Exp. Bot. 60(3): 291-299.

Turan, C., M. Dural, A. Oksuz and B. Oeztuerk. 2009. Levels of heavy metals in some commercial fish species captured from the Black Sea and Mediterranean coast of Turkey. Bull. Environ. Contam. Toxicol. 82(5): 601-604.

Turk Culha, S., L. Bat, M. Culha, A. Efendioglu, M.B. Andac, B. Bati and F. Briand (*Eds*.). 2007. Heavy metals levels in some fishes and molluscs from Inop Peninsula of the Southern Black Sea, Turkey. Monaco (38), p. 323.

Turkmen, A., M. Turkmen, Y. Tepe and I. Akyurt. 2005. Heavy metals in three commercially valuable fish species from Iskenderun Bay, northern east Mediterranean Sea, Turkey. Food Chem. 91(1): 167-172.

Turkmen, A., Y. Tepe and M. Turkmen. 2008. Metal levels in tissues of the European anchovy, *Engraulis encrasicolus* L., 1758, and picarel, *Spicara smaris* L., 1758, from Black, Marmara and Aegean Seas. Bull. Environ. Contam. Toxicol. 80(6): 521-525.

Turkmen, A., Y. Tepe, M. Turkmen and E. Mutlu. 2009. Heavy metal contaminants in tissues of the garfish, *Belone belone* L., 1761, and the bluefish, *Pomatomus saltatrix* L., 1766, from Turkey waters. Bull. Environ. Contam. Toxicol. 82(1): 70-74.

Turner, A., S.S. Pedroso and M.T. Brown. 2008. Influence of salinity and humic substances on the uptake of trace metals by the marine macroalga, *Ulva Lactuca*: Experimental observations and modelling using WHAM. Mar. Chem.110(3-4): 176-184.

Turoczy, N.J., B.D. Mitchell, A.H. Levings and V.S. Rajendram. 2001. Cadmium, copper, mercury, and zinc concentrations in tissues of the king crab (*Pseudocarcinus gigas*) from southeast Australian waters. Environ. Int. 27(4): 327-334.

Tuzen, M. 2009. Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey. Food Chem. Toxicol. 47(8): 1785-1790.

Tuzen, M., B. Verep, A.O. Ogretmen and M. Soylak. 2009. Trace element content in marine algae species from the Black Sea, Turkey. Environ. Monit. Assess. 151(1-4): 363-368.

Twagilimana, L., J. Bohatier, C. Groliere, F. Bonnemoy and D. Sargos. 1998. A new low-cost microbiotest with the protozoan *Spirostomum teres*: Culture conditions and assessment of sensitivity of the ciliate to 14 pure chemicals. Ecotoxicol. Environ. Safety. 41: 231-244.

Tyurin, A.N. and N.K. Khristoforova. 1993. Effect of toxicants on the development of the chiton *Ischnochiton hakodadensis*. Russ. Mar. Biol. 29(5/6): 100-106.

U.S. EPA. 1976. Quality criteria for water. EPA-440/9-76-023. National Technical Information Service, Springfield, VA.

U.S. EPA. 1979. Water-related fate of 129 priority pollutants. Washington, DC: U.S. Environmental Protection Agency, Office of Water Planning and Standards. EPA-440/4-79-029.

U.S. EPA. 1980. Ambient water quality criteria for cadmium. EPA-440/5-80-025. National Technical Information Service, Springfield, VA.

U.S. EPA. 1983a. Water quality standards regulation. Federal Regist. 48:51400-51413.

U.S. EPA. 1983b. Water quality standards handbook. Office of Water Regulations and Standards, Washington, DC.

U.S. EPA. 1983c. Methods for chemical analysis of water and wastes. EPA-600/4-79-020 (Revised March 1983). National Technical Information Service, Springfield, VA.

U.S. EPA. 1985a. Appendix B - Response to public comments on "guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. Federal Regist. 50:30793-30796.

U.S. EPA. 1985b. Technical support document for water quality-based toxics control. Office of Water, Washington, DC.

U.S. EPA. 1985c. Ambient water quality criteria for cadmium. EPA-440/5-84-032 (Revised late 1984). National Technical Information Service, Springfield , VA, 127 pp.

U.S. EPA. 1986a. Quality criteria for water 1986. EPA-440/5-86-001. Office of Water, Washington, DC.

U.S. EPA. 1986b. Chapter I - Stream design flow for steady-state modeling. In: Technical guidance manual for performing waste load allocation. Edited by Book VI-Design conditions. Office of Water, Washington, DC.

U.S. EPA. 1991. Technical support document for water quality-based toxics control. EPA-505/2-90-001. Office of Water, Washington, DC.

U.S. EPA. 1993a. Locating and estimating air emissions from sources of cadmium and cadmium compounds. U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA-454/R-93-040.

U.S. EPA. 1993b. Water quality criteria: Aquatic life criteria for metals. Federal Register. 58(108): 32131-32133.

U.S. EPA. 1994. Interim guidance on determination and use of water-effect ratios for metals. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA-823-B-94-001

U.S. EPA. 1994b. Method 200.8 - Determination of trace elements in waters and wastes by inductively coupled plasma - mass spectrometry. Revision 5.4. Environmental Monitoring Systems Laboratory, Office of Research and Development.U.S. Environmental Protection Agency. Cincinnati, OH. 57 pp.

U.S. EPA. 1996a. 1995 Updates: Water quality criteria documents for the protection of aquatic life in water. U.S. EPA, Office of Water. EPA-820-B-96-001, U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. EPA. 1996b. OPPTS Harmonized Test Guidelines. Series 850 Ecological Effects Test Guidelines. Volume I: Guidelines 850.1000-850.1950. United States Environmental Protection Agency. Office of Prevention, Pesticides and Toxic Substances. Washington, DC. 20460.

U.S. EPA. 1998. Guidelines for ecological risk assessment. EPA/630/R-95/002F. United States Environmental Protection Agency. Risk Assessment Forum. Office of Research and Development, Washington, DC.

U.S. EPA. 1999a. National recommended water quality criteria -- correction. EPA-822-Z-99-001. Office of Water, Washington, DC.

U.S. EPA. 1999b. Integrated approach to assessing the bioavailability and toxicity of metals in surface water and sediments. EPA-822-E-99-001. Office of Water, Washington, DC.

U.S. EPA. 1999c. 1999 Update of ambient water quality criteria for ammonia. EPA-822-R-99-014. National Technical Information Service, Springfield, VA.

U.S. EPA. 2000a. A SAB report: Review of the biotic ligand model of the acute toxicity of metals. EPA-SAB-EPEC-00-006, U.S. Environmental Protection Agency. Washington, DC.

U.S. EPA. 2000b. Bioaccumulation testing and interpretation for the purpose of sediment quality assessment: Status and needs. EPA-823-R-00-001, U.S. EPA, Office of Water, Washington, DC.

U.S. EPA. 2001. Update of ambient water quality criteria for cadmium. EPA-822-R-01-001. Office of Water, Washington, DC.

U.S. EPA. 2004. Issue paper on the bioavailability and bioaccumulation of metals. U.S. Environmental Protection Agency. Risk Assessment Forum. Washington, DC, 122 pp.

U.S. EPA. 2007a. ECOTOXicology database. Office of Research and Development National Health and Environmental Effects Research Laboratory's (NHEERL's) Mid-Continent Ecology Division (MED). Available at: http://cfpub.epa.gov/ecotox/

U.S. EPA. 2007b. Wastes - Hazardous Waste - Test Methods. 7000 Series Methods. Availabe at: http://www.epa.gov/osw/hazard/testmethods/sw846/online/7_series.htm

U.S. EPA. 2009a. Draft 2009 Update aquatic life ambient water quality criteria for ammonia – freshwater. EPA-822-D-09-001. Office of Water, Washington, DC.

U.S. EPA. 2009b. National recommended water quality criteria. Office of Water, Washington, DC. Available at: http://www2.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

U.S. EPA. 2013. The revised deletion process for the site-specific recalculation procedure for aquatic life criteria. EPA 822-R-13-001. National Technical Information Service, Springfield, VA.

U.S. EPA. 2014. Water quality standards handbook. EPA-820-B-14-008. Office of Water, Washington, DC.

U.S. EPA. 2016. Coal ash basics. Office of Water, Washington, DC. Available at: http://www.epa.gov/coalash/coal-ash-basics (info accessed February 2016).

U.S. Geological Survey (USGS). 2007. Flow of cadmium from rechargeable batteries in the United States, 1996-2007. Scientific Investigations Report: 2007-5198. Availabe at: http://pubs.er.usgs.gov/publication/sir20075198.

U.S. Geological Survey (USGS). 2013. Mineral commodity summaries 2013. U.S. Department of the Interior. U.S. Geological Survey. Reston, VA, 198 pp.

Udoidiong, O.M. and P.M. Akpan. 1991. Toxicity of cadmium, lead and lindane to *Egeria radiata* Lamarck (Lamellibranchia, Donacidae). Rev. Hydrobiol. Trap. 24(2): 111-117.

Ugolini, A., V. Pasquali, D. Baroni and G. Ungherese. 2012. Behavioural responses of the supralittoral amphipod *Talitrus saltator* (Montagu) to trace metals contamination. Ecotoxicol. 21(1): 139-147.

Uluozlu, O.D., M. Tuzen, D. Mendil and M. Soylak. 2007. Trace metal content in nine species of fish from the Black and Aegean Seas, Turkey. Food Chem. 104(2): 835-840.

Uluturhan, E. and F. Kucuksezgin. 2007. Heavy metal contaminants in red pandora (*Pagellus erythrinus*) tissues from the eastern Aegean Sea, Turkey. Water Res. 41(6): 1185-1192.

University of Wisconsin-Superior. 1995. Results of freshwater simulation tests concerning dissolved metal. Final Report to U.S. EPA. ERL-Duluth, MN, 93pp.

Ura, K., T. Kai, S. Sakata, T. Iguchi and K. Arizono. 2002. Aquatic acute toxicity testing using the nematode *Caenorhabditis elegans*. J. Health Sci. 48(6): 583-586.

Urech, J. 1979. Melimex, an experimental heavy metal pollution study: effects of increased heavy metal load on crustacea plankton. Schweiz. Z. Hydrol. 41(2): 247-260.

Urek, R.O. and L. Tarhan. 2011. Response of the antioxidant systems of the cyanobacterium *Spirulina maxima* to cadmium. Curr. Opin. Biotechnol. 22(Suppl. 1): S74-S75.

Urena, R., M. Joao Bebianno, J. Del Ramo and A. Torreblanca. 2010. Metallothionein in the freshwater gastropod *Melanopsis dufouri* chronically exposed to cadmium: A methodological approach. Ecotoxicol. Environ. Saf. 73(5): 779-787.

Uruc Parlak, K. and D.D. Yilmaz. 2013. Ecophysiological tolerance of *Lemna gibba* L. exposed to cadmium. Ecotoxicol. Environ. Saf. 91: 79-85.

Usero, J., C. Izquierdo, J. Morillo and I. Gracia. 2004. Heavy metals in fish (*Solea vulgaris*, *Anguilla anguilla* and *Liza aurata*) from salt marshes on the southern Atlantic coast of Spain. Environ. Int. 29(7): 949-956.

Uthe, J.F., C.L. Chou, D.G. Robinson and R.L. Levaque Chaaron. 1982. Cadmium in American lobster (*Homarus americanus*) from the area of a lead smelter. Can. Tech. Rept. Fish. Aquat. Sci. No. 1163: 194-197.

Uysal, Y. and F. Taner. 2007. The effect of cadmium ions on the growth rate of the freshwater macrophyte duckweed *Lemna minor*. Ekoloji 16(62): 9-15.

Uysal, Y. and F. Taner. 2012. Determination of growth rate change and accumulation efficiency of *Lemna minor* exposed to cadmium and lead ions. Asian J. Chem. 24(3): 1217-1222.

Valencia, R., M. Gerpe, J. Trimmer, T. Buckman, A.Z. Mason and P.E. Olsson. 1998. The effect of estrogen on cadmium distribution in rainbow trout (*Oncorhynchus mykiss*). Mar. Environ. Res. 46(1-5): 167-171.

Valova, Z., P. Jurajda, M. Janac, I. Bernardova and H. Hudcova. 2010. Spatiotemporal trends of heavy metal concentrations in fish of the River Morava (Danube basin). J. Environ. Sci. Health 45A(14): 1892-1899.

van Aardt, W.J. and J. Booysen. 2004. Water hardness and the effects of Cd on oxygen consumption, plasma chlorides and bioaccumulation in *Tilapia sparrmanii*. Water SA 30(1): 57-64.

van Aardt, W.J. and R. Erdmann. 2004. Heavy metals (Cd, Pb, Cu, Zn) in mudfish and sediments from three hard-water dams of the Mooi River catchment, South Africa. Water SA 30(2): 211-218.

Van Campenhout, K., H.G. Infante, P.T. Hoff, L. Moens, G. Goemans, C. Belpaire, F. Adams, R. Blust and L. Bervoets. 2010. Cytosolic distribution of Cd, Cu and Zn, and metallothionein levels in relation to physiological changes in gibel carp (*Carassius auratus* gibelio) from metal-impacted habitats. Ecotoxicol. Environ. Saf. 73(3): 296-305.

Van den Hurk, P., M. Faisal and M.H. Roberts Jr. 1998. Interaction of cadmium and benzo[a]pyrene in mummichog (*Fundulus heteroclitus*): Effects on acute mortality. Mar. Environ. Res. 46(1-5): 525-528.

Van der Heever, J.A. and J.U. Grobbelaar. 1996. The use of *Selenastrum capricornutum* growth potential as a measure of toxicity of a few selected compounds. Water SA 22(2): 183-191.

van Geen, A. and S.N. Luoma. 1999. A record of estuarine water contamination from the Cd content of foraminiferal tests in San Francisco Bay, California. Mar. Chem. 64: 57-69.

Van Gemert, J.M, H.J.G. Ten Hoopen, J.A. Roels and A. Fuchs. 1985. Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. II. Light-limited growth in continuous culture. Antonie van Leeuwenhoek 51: 347-351.

Van Ginneken, L., M.J. Chowdhury and R. Blust. 1999. Bioavailability of cadmium and zinc to the common carp, *Cyprinus carpio*, in complexing environments: A test for the validity of the free ion activity model. Environ. Toxicol. Chem. 18(10): 2295-2304.

Van Ginneken, L., L. Bervoets and R. Blust. 2001. Bioavailability of Cd to the common carp, *Cyprinus carpio*, in the presence of humic acid. Aquat. Toxicol. 52(1): 13-27.

Van Hattum, B., N.M. Van Straalen and H.A.J. Govers. 1996. Trace metals in populations of freshwater isopods: Influence of biotic and abiotic variables. Arch. Environ. Contam. Toxicol. 31(3): 303-318.

van Hattum, B., P. de Voogt, L. van den Bosch, N.M. van Straalen, E.N.G. Joosse and H. Govers. 1998. Bioaccumulation of cadmium by the freshwater isopod *Asellus aquaticus* from aqueous and dietary sources. Environ. Pollut. 62: 129-151.

Van Leeuwen, C.J., P.S. Griffioen, W.H.A. Vergouw and J.L. Maas-Diepeveen. 1985a. Differences in susceptibility of early life stages of rainbow trout (*Salmo gairdneri*) to environmental pollutants. Aquat. Toxicol. 7: 59-78.

Van Leeuwen, C.J., W.J. Luttmer and P.S. Griffioen. 1985b. The use of cohorts and populations in chronic toxicity studies with *Daphnia magna*: A cadmium example. Ecotoxicol. Environ. Safety. 9: 26-39.

Van Leeuwen, C.J., G. Niebeek and M. Rijkeboer. 1987. Effects of chemical stress on the population dynamics of *Daphnia magna*: A comparison of two test procedures. Ecotoxicol. Environ. Safety. 14: 1-11.

Van Steveninck, R.F.M., M.E. Van Steveninck and D.R. Fernando. 1992. Heavy-metal (Zn, Cd) tolerance in selected clones of duck weed (*Lemna minor*). Plant Soil. 146: 271-280.

Vanegas, C., S. Espina, A.V. Botello and S. Villanueva. 1997. Acute toxicity and synergism of cadmium and zinc in white shrimp, *Penaeus setiferus*, juveniles. Bull. Environ. Contam. Toxicol. 58: 87-92.

Vardanyan, L.G. and B.S. Ingole. 2006. Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems. Environ. Int. 32(2): 208-218.

Vardy, D.W., A.R. Tompsett, J.L. Sigurdson, J.A. Doering, X. Zhang, J.P. Giesy and M. Hecker. 2011. Effects of subchronic exposure of early life stages of white sturgeon (*Acipenser transmontanus*) to copper, cadmium, and zinc. Environ. Toxicol. Chem. 30(11): 2497-2505.

Vashchenko, M.A. and P.M. Zhadan. 1993. Ecological assessment of marine environment using two sea urchin tests: Disturbance of reproduction and sediment embryotoxicity. Sci. Total Environ. 134 (Suppl. 2): 1235-1245.

Vasseur, P and P. Pandard. 1988. Influence of some experimental factors on metals toxicity to *Selenastrum capricornutum*. Toxic. Assess. 3: 331-343.

Vassiliev, T., R. Bayer, W. Congelton, R. Bushway and J. Vetelino. 2005. Heavy metal concentrations in lobster (*Homarus americanus*). J. Shell. Res. 24(2): 680-681.

Vazquez-Sauceda, M.L., G. Aguirre-Guzman, J.G. Sanchez-Martinez and R. Perez-Castaneda. 2011. Cadmium, lead and zinc concentrations in water, sediment and oyster (*Crassostrea virginica*) of San Andres Lagoon, Mexico. Bull. Environ. Contam. Toxicol. 86(4): 410-414.

Vecchia, F.D., N. La Rocca, I. Moro, S. De Faveri, C. Andreoli and N. Rascio. 2005. Morphogenetic, ultrastructural and physiological damages suffered by submerged leaves of *Elodea canadensis* exposed to cadmium. Plant Sci. 168(2): 329-338.

Vedamanikam, V.J. and N.A.M. Shazilli. 2008a. The effect of multi-generational exposure to metals and resultant change in median lethal toxicity tests values over subsequent generations. Bull. Environ. Contam. Toxicol. 80(1): 63-67.

Vedamanikam, V.J. and N.A.M. Shazilli. 2008b. Comparative toxicity of nine metals to two Malaysian aquatic dipterian larvae with reference to temperature variation. Bull. Environ. Contam. Toxicol. 80(6): 516-520.

Veldhuizen-Tsoerkan, M.B., D.A. Holwerda and D.I. Zandee. 1991. Anoxic survival time and metabolic parameters as stress indices in sea mussels exposed to cadmium or polychlorinated biphenyls. Arch. Environ. Contam. Toxicol. 20: 259-265.

Vellinger, C., M. Parant, P. Rousselle and P. Usseglio-Polatera. 2012a. Antagonistic toxicity of arsenate and cadmium in a freshwater amphipod (*Gammarus pulex*). Ecotoxicol. 21(7): 1817-1827.

Vellinger, C., M. Parant, P. Rousselle, F. Immel, P. Wagner and P. Usseglio-Polatera. 2012b. Comparison of arsenate and cadmium toxicity in a freshwater amphipod (*Gammarus pulex*). Environ. Pollut. 160: 66-73.

Vellinger, C., V. Felten, P. Sornom, P. Rousselle, J.N. Beisel and P. Usseglio-Polatera. 2012c. Behavioural and physiological responses of *Gammarus pulex* exposed to cadmium and arsenate at three temperatures: Individual and combined effects. PLoS One 7(6): e39153.

Vellinger, C., E. Gismondi, V. Felten, P. Rousselle, K. Mehennaoui, M. Parant and P. Usseglio-Polatera. 2013. Single and combined effects of cadmium and arsenate in *Gammarus pulex* (Crustacea, Amphipoda): Understanding the links between physiological and behavioural responses. Aquat. Toxicol. 140-141: 106-116.

Venanzi, G., M. Lupattelli, N. Pocceschi and B. Romano. 1989. Effects of heavy metals on some photosynthetic characteristics in *Lemna trisulca* L. Riv. Idrobiol. 28(3): 247-254.

Venkateswara Rao, J., K. Srikanth, R. Pallela and R.T. Gnaneshwar. 2009. The use of marine sponge, *Haliclona tenuiramosa* as bioindicator to monitor heavy metal pollution in the coasts of Gulf of Mannar, India. Environ. Monit. Assess. 156(1-4): 451-459.

Venkatrayulu, C., M. Komali, L.V.K.S. Bhaskar, V. Kalarani and D.C. Reddy. 2005. Hepatogonadal changes in the female fresh water field crab, *Oziotelphusa senex senex* (Fabricius) in response to cadmium toxicity. Proc. AP Akad. Sci. 9(1): 29-34.

Verbost, P.M., G. Flik, R.A.C. Lock and S.E.W. Bonga. 1987. Cadmium inhibition of Ca^{2+} uptake in rainbow trout gills. Am. J. Physiol. 253 (Regulatory Integrative Comp. Physiol. 22): R216-R221.

Vergauwen, L. 2012. Effect of temperature on cadmium toxicity in zebrafish: From transcriptome to physiology. Ph.D Thesis, Universiteit Antwerpen (Belgium). UMI# 3535434.

Vergauwen, L., A. Hagenaars, G. De Boeck, R. Blust and D. Knapen. 2012. Effect of temperature on cadmium toxicity in zebrafish: From transcriptome to physiology. Comp. Biochem. Physiol. Part A 163(Suppl. 0): S14.

Vergauwen, L., D. Knapen, A. Hagenaars and R. Blust. 2013. Hypothermal and hyperthermal acclimation differentially modulate cadmium accumulation and toxicity in the zebrafish. Chemosphere 91(4): 521-529.

Verma, S.R., K. Kumar and R.C. Dalela. 1980. Short term toxicity tests with heavy metals for predicting safe concentrations. Toxicol. Letters 1: 113.

Verma, Y. 2005. Effect of cadmium on fin regeneration in the freshwater fish, *Oreochromis mossambicus.* Bull. Environ. Contam. Toxicol. 74(5): 837-844.

Vernberg, W.B., P.J. DeCoursey and J. O'Hara. 1974. Multiple environmental factor effects on physiology and behavior of the fiddler crab, *Uca pugilator*. *In*: F.J. Vernberg and W.B. Vernberg (*Eds*.), Pollution and Physiology of Marine Organisms. Academic Press, New York. p. 381-425.

Vernberg, W.B., P.J. DeCoursey, M. Kelly and D.M. Johns. 1977. Effects of sublethal concentrations of cadmium on adult *Paleomonetes pugio* under static and flow-through conditions. Bull. Environ. Contam. Toxicol. 17(1): 16-24.

Verriopoulos, G. and M. Moraitou-Apostolopoulou. 1981. Effects of some environmental factors on the toxicity of cadmium to the copepod *Tisbe holothuriae*. Arch. Hydrobiol. 91: 287.

Verriopoulos, G. and M. Moraitou-Apostolopoulou. 1982. Differentiation of the sensitivity to copper and cadmium in different life stages of a copepod. Mar. Pollut. Bull. 13: 123.

Verslycke, T., M. Vangheluwe, D. Heijerick, K. De Schamphelaere, P. Van Sprang and C.R. Janssen. 2003. The toxicity of metal mixtures to the estuarine mysid *Neomysis integer* (Crustacea: Mysidacea) under changing salinity. Aquat. Toxicol. 64(3): 307-315.

Versteeg, D.J. 1990. Comparison of short- and long-term toxicity test results for the green alga, *Selenastrum capricornutum*. In*:* Plants for Toxicity Assessment. ASTM STP 1091. W. Wang, J.W. Gorsuch and W.R. Lower (*Eds*.), American Society for Testing and Materials, Philadelphia, PA, pp. 40-48.

Viarengo, A., G. Mancinelli, M. Pertica, R. Fabbri and M. Orunesu. 1993. Effects of heavy metals on the Ca^{2+}-ATPase activity present in gill cell plasma-membrane of mussels (*Mytilus galloprovincialis* Lam.). Comp. Biochem. Physiol. Part C 106(3): 655-660.

Vieira, C., S. Morais, S. Ramos, C. Delerue-Matos and M.B. Oliveira. 2011. Mercury, cadmium, lead and arsenic levels in three pelagic fish species from the Aatlantic Ocean: Intra- and inter-specific variability and human health risks for consumption. Food Chem. Toxicol. 49(4): 923-932.

Vigneault. B. and P.G.C. Campbell. 2005. Uptake of cadmium by freshwater green algae: Effects of pH and aquatic humic substances. J. Phycol. 41(1): 55-61.

Villar, C., J. Stripeikis, D. Colautti, L. D'Huicque, M. Tudino and C. Bonetto. 2001. Metals contents in two fishes of different feeding behaviour in the lower Parana River and Rio de la Plata Estuary. Hydrobiol. 457(1-3): 225-233.

Vinagre, C., S. Franca, M.J. Costa and H.N. Cabral. 2004. Accumulation of heavy metals by flounder, *Platichthys flesus* (Linnaeus 1758), in a heterogeneously contaminated nursery area. Mar. Pollut. Bull. 49(11/12): 1109-1113.

Vincent, C.D., A.J. Lawlor and E. Tipping. 2001. Accumulation of Al, Mn, Fe, Cu, Zn, Cd and Pb by the bryophyte *Scapania undulata* in three upland waters of different pH. Environ. Pollut. 114(1): 93-100.

Vincent, S., T. Ambrose and M. Selvanayagam. 1994. Susceptibility of *Catla catla* (Ham.) to the toxic effects of the heavy metals, cadmium and chromium. Uttar Pradesh J. Zool. 14(1): 25-28.

Vincent, S., T. Ambrose and M. Selvanayagam. 2002. Impact of cadmium on food utilization of the Indian major carp, *Catla catla* (Ham). J. Environ. Biol. 23(2): 209-212.

Vincent-Hubert, F., A. Arini and C. Gourlay-France. 2011. Early genotoxic effects in gill cells and haemocytes of *Dreissena polymorpha* exposed to cadmium, B[a]P and a combination of B[a]P and Cd. Mutat. Res. 723(1): 26-35.

Vincent-Hubert, F., M. Revel and J. Garric. 2012. DNA strand breaks detected in embryos of the adult snails, *Potamopyrgus antipodarum*, and in neonates exposed to genotoxic chemicals. Aquat. Toxicol. 122-123: 1-8.

Vinodhini, R. and M. Narayanan. 2008. Bioaccumulation of heavy metals in organs of fresh water fish *Cyprinus carpio* (common carp). Int. J. Environ. Sci. Technol. 5(2): 179-182.

Viparelli, F., S.M. Monti, G. De Simone, A. Innocenti, A. Scozzafava, Y. Xu, F.M. Morel, C.T. Supuran. 2010. Inhibition of the R1 fragment of the cadmium-containing zeta-class carbonic anhydrase from the diatom *Thalassiosira weissflogii* with anions. Bioorg. Med. Chem. Lett. 20(16): 4745-4748.

Visviki, I. and J.W. Rachlin. 1991. The toxic action and interactions of copper and cadmium to the marine alga *Dunaliella minuta*, in both acute and chronic exposure. Arch. Environ. Contam. Toxicol. 20: 271-275.

Visviki, I. and J.W. Rachlin. 1994. Acute and chronic exposure of *Dunaliella salina* and *Chlamydomonas bullosa* to copper and cadmium: Effects on growth. Arch. Environ. Contam. Toxicol. 26: 149-153.

Voets, J., L. Bervoets and R. Blust. 2004. Cadmium bioavailability and accumulation in the presence of humic acid to the zebra mussel, *Dreissena polymorpha*. Environ. Sci. Technol. 38(4): 1003-1008.

Voets, J., E.S. Redeker, R. Blust and L. Bervoets. 2009. Differences in metal sequestration between zebra mussels from clean and polluted field locations. Aquat. Toxicol. 93(1): 53-60.

Vogiatzis, A.K. and N.S. Loumbourdis. 1998. Cadmium accumulation in liver and kidneys and hepatic metallothionein and glutathione levels in *Rana ridibunda*, after exposure to $CdCl_2$. Arch. Environ. Contam. Toxicol. 34: 64-68.

Vogt, C., D. Belz, S. Galluba, C. Nowak, M. Oetken and J. Oehlmann. 2007. Effects of cadmium and tributyltin on development and reproduction of the non-biting midge *Chironomus riparius* (Diptera): Baseline experiments for future multi-generation studies. J. Environ. Sci. Health. 42A(1): 1-9.

Vogt, C., M. Hess, C. Nowak, J.B. Diogo, J. Oehlmann and M. Oetken. 2010. Effects of cadmium on life-cycle parameters in a multi-generation study with *Chironomus riparius* following a pre-exposure of populations to two different tributyltin concentrations for several generations. Ecotoxicol. 19(7): 1174-1182.

Voigt, H.R. 2003. Concentrations of mercury and cadmium in some coastal fishes from the Finnish and Estonian parts of the Gulf of Finland. Proc. Est. Acad. Sci. (Biol. Ecol.) 52(3): 305-318.

Voigt, H. 2007. Heavy metal concentrations in four-horn sculpin *Triglopsis quadricornis* (L.) (Pisces), its main food organism *Saduria entomon* L. (Crustacea), and in bottom sediments in the Archipelago Sea and the Gulf of Finland (Baltic Sea). Proc. Est. Acad. Sci. (Biol. Ecol.) 56(3): 224-238.

Voyer, R.A. 1975. Effect of dissolved oxygen concentration on the acute toxicity of cadmium to the mummichog, *Fundulus heteroclitus*. Trans. Am. Fish. Soc. 104: 129.

Voyer, R.A. and D.G. McGovern. 1991. Influence of constant and fluctuating salinity on responses of *Mysidopsis bahia* exposed to cadmium in a life-cycle test. Aquat. Toxicol. 19: 215-230.

Voyer, R.A. and G. Modica. 1990. Influence of salinity and temperature on acute toxicity of cadmium to *Mysidopsis bahia* Molenock. Arch. Environ. Contam. Toxicol. 19: 124-131.

Voyer, R.A., C.E. Wentworth Jr., E.P. Barry and R.J. Hennekey. 1977. Viability of embryos of the winter flounder *Pseudopleuronectes americanus* exposed to combinations of cadmium and salinity at selected temperatures. Mar. Biol. 44(2): 117-124.

Voyer, R.A., J.F. Heltsche and R.A. Kraus. 1979. Hatching success and larval mortality in an estuarine teleost, *Menidia menidia* (Linnaeus), exposed to cadmium in constant and fluctuating salinity regimes. Bull. Environ. Contam. Toxicol. 23(1): 475-481.

Voyer, R.A., J.A. Cardin, J.F. Heltshe and G.L. Hoffman. 1982. Viability of embryos of the winter flounder *Pseudopleuronectes americanus* exposed to mixtures of cadmium and silver in combination with selected fixed salinities. Aquat. Toxicol. 2: 223.

Vranken, G., R. Vanderhaeghen and C. Heip. 1985. Toxicity of cadmium to free-living marine and brackish water nematodes (*Monhystera microphthalma*, *Monhystera disjuncta*, *Pellioditis marina*). Dis. Aquat. Org. 1: 49-58.

Vuori, K.M. 1993. Influence of water quality and feeding habits on the whole-body metal concentrations in lotic trichopteran larvae. Limnol. 23(4): 301-308.

Vuori, K.M. 1994. Rapid behavioral and morphological responses of hydropsychid larvae (Trichoptera, Hydropsychidae) to sublethal cadmium exposure. Environ. Pollut. 84: 291-299.

Vykusova, B. and Z. Svobodova. 1987. Comparison of the sensitivity of male and female guppies (*Poecilia reticulata* Peters) to toxic substances. Bull. Vurh Vodnany. (CZE)(ENG ABS) 23(3): 20-23.

Vymazal, J. 1984. Short-term uptake of heavy metals by periphyton algae. Hydrobiol. 119: 171-179.

Vymazal, J. 1990a. Toxicity and accumulation of lead with respect to algae and cyanobacteria: A review. Acta Hydrochim. Hydrobiol. 18(5): 513-535.

Vymazal, J. 1990b. Uptake of lead, chromium, cadmium and cobalt by *Cladophora glomerata*. Bull. Environ. Contam. Toxicol. 44: 468-472.

Vymazal, J. 1995. Influence of pH on heavy metals uptake by *Cladophora glomerata*. Pol. Arch. Hydrobiol. 42(3): 231-237.

Wachs, B. 1982. Concentration of heavy metals in fishes from the River Danube. Z. Wasser-Abwasser-Forsch. 15(2): 43-49.

Walker, P.A., N.R. Bury and C. Hogstrand. 2007. Influence of culture conditions on metal-induced responses in a cultured rainbow trout gill epithelium. Environ. Sci. Technol 41: 6505-6513.

Wall, S.B. 1999. Sublethal effects of cadmium and diazinon on reproduction and larval behavior in zebrafish (*Brachydanio rerio*). Ph.D Thesis, Texas Tech University, Lubbock, TX, 125 p.

Wall, S.B., J.J. Isley and T.W. La Point. 1996. Fish bioturbation of cadmium-contaminated sediments: Factors affecting Cd availability to *Daphnia magna*. Environ. Toxicol. Chem. 15(3): 294-298.

Wallace, W.G. and G.R. Lopez. 1997. Bioavailability of biologically sequestered cadmium and the implications of metal detoxification. Mar. Ecol. Prog. Ser. 147: 149-157.

Wallenstein, F.M., D.F. Torrao, A.I. Neto, M. Wilkinson and A.S. Rodrigues. 2009. Accumulation of metals in *Fucus spiralis* subject to increased temperature and acidity. Phycologia 48(4): Suppl.

Walsh, G.E., L.L. McLaughlin, M.J. Yoder, P.H. Moody, E.M. Lores, J. Forester and P.B. Wessinger-Duvall. 1988. *Minutocellus polymorphus*: a new marine diatom for use in algal toxicity tests. Environ. Toxicol. Chem. 7: 925-929.

Walsh, K., R.H. Dunstan and R.N. Murdoch. 1995. Differential bioaccumulation of heavy metals and organopollutants in the soft tissue and shell of the marine gastropod, *Austrocochlea constricta*. Arch. Environ. Contam. Toxicol. 28: 35-39.

Walsh, R.S. and K.A. Hunter. 1992. Influence of phosphorus storage on the uptake of cadmium by the marine alga *Macrocystis pyrifera*. Limnol. Oceanogr. 37(7): 1361-1369.

Wang, B. 2011. A study of the New York/New Jersey coastal water: Bio-optical characteristics of the harbor estuary and the effects of heavy metals on brown tide alga of the Bight. Ph.D. Thesis, New Jersey Institute of Technology, Newark, NJ.

Wang, B., L. Axe, Z.H. Michalopoulou and L. Wei. 2012b. Effects of Cd, Cu, Ni, and Zn on brown tide alga *Aureococcus anophagefferens* growth and metal accumulation. Environ. Sci. Technol. 46(1): 517-524.

Wang, C., L.Y. Wang and Q. Sun. 2010b. Response of phytochelatins and their relationship with cadmium toxicity in a floating macrophyte *Pistia stratiotes* L. at environmentally relevant concentrations. Water Environ. Res. 82(2): 147-154.

Wang, C., Q.Sun, and L. Wang. 2009e. Cadmium toxicity and phytochelatin production in a rooted-submerged macrophyte *Vallisneria spiralis* exposed to low concentrations of cadmium. Environ. Toxicol. 24(3): 271-278.

Wang, C.S. and W.P. Yin. 1987. Accumulation of heavy metals in *Arca granosa*. Acta Oceanol. Sin. 6(3): 421-427.

Wang, C.Y., X.L. Wang, B.Y. Sun and R.G. Su. 2008a. Ecotoxicological effect of Cu, Pb, Zn and Cd on *Prorocentrum donghaiense* Lu. Chin. Environ. Sci. 28(3): 264-268

Wang, D., P. Liu, Y. Yang and L. Shen. 2010a. Formation of a combined Ca/Cd toxicity on lifespan of nematode *Caenorhabditis elegans*. Ecotoxicol. Environ. Saf. 73(6): 1221-1230.

Wang, J., C.Y. Chuang and W.X. Wang. 2005a. Metal and oxygen uptake in the green mussel *Perna viridis* under different metabolic conditions. Environ. Toxicol .Chem. 24(10): 2657-2664.

Wang, J., M. Zhang, J. Xu and Y, Wang. 1995. Reciprocal effect of Cu, Cd, Zn on a kind of marine alga. Water Res. 29(1): 209-214.

Wang, J., Q. Wang, J. Li, Q. Shen, F. Wang and L. Wang. 2012c. Cadmium induces hydrogen peroxide production and initiates hydrogen peroxide-dependent apoptosis in the gill of freshwater crab, *Sinopotamon henanense*. Comp. Biochem. Physiol. 156C (3/4): 195-201.

Wang, J., Q. Zhou, Q. Zhang, and Y. Zhang. 2008b. Single and joint effects of petroleum hydrocarbons and cadmium on the polychaete *Perinereis aibuhitensis* Grube. J. Environ. Sci. 20(1): 68-74.

Wang, L., L. Pan and J. Miao. 2010c. Single and joint toxicity of mercury, cadmium and benzo(a) pyrene, polychlorinated biphenyls1254 for juvenile *Chlamys farreri*. Mar. Environ. Sci. 29(4): 535-540.

Wang, L., L. Pan, N. Liu, D. Liu, C. Xu and J. Miao. 2011b. Biomarkers and bioaccumulation of clam *Ruditapes philippinarum* in response to combined cadmium and benzo(a)pyrene exposure. Food Chem. Toxicol. 49(12): 3407-3417.

Wang, L., L. Song, D. Ni, H. Zhang and W. Liu. 2009b. Alteration of metallothionein mRNA in bay scallop *Argopecten irradians* under cadmium exposure and bacteria challenge. Comp. Biochem. Physiol. Part C 149(1): 50-57.

Wang, L., S.M. Harris, H.M. Espinoza, V. McClain and E.P. Gallagher. 2012a. Characterization of phospholipid hydroperoxide glutathione metabolizing peroxidase (gpx4) isoforms in Coho salmon olfactory and liver tissues and their modulation by cadmium. Aquat. Toxicol. 114/115: 134-141.

Wang, L., T. Xu, W.W. Lei, D.M. Liu, Y.J. Li, R.J. Xuan and J.J. Ma. 2011d. Cadmium-induced oxidative stress and apoptotic changes in the testis of freshwater crab, *Sinopotamon henanense*. PLoS One 6(11): e27853

Wang, L., Y. Liu, W.N. Wang, W.J. Mai, Y. Xin, J. Zhou, W.Y. He, A.L. Wang and R.Y. Sun. 2011a. Molecular characterization and expression analysis of elongation factors 1A and 2 from the Pacific white shrimp, *Litopenaeus vannamei*. Mol. Biol. Rep. 38(3): 2167-2178.

Wang, L.L., B. Xia, B.J. Chen, C.H. Li and X.X. Tang. 2012d. Cadmium bioaccumulation and bioelimination in *Patinopecten yessoensis*. Mar. Environ. Sci. 31(2): 159-162.

Wang, L.L., B. Xia, B.J. Chen, C.H. Li and X.X. Tang. 2012e. Effects of cadmium stress on antioxidant defense system of *Patinopecten yessoensis*. Mar. Environ. Sci. 31(1): 39-42.

Wang, M.H. and G.Z. Wang. 2009b. Biochemical response of the copepod *Tigriopus japonicus* Mori experimentally exposed to cadmium. Arch. Environ. Contam. Toxicol. 57(4): 707-717.

Wang, M.J. 2010. Prediction of cadmium toxicity in marine phytoplankton. Ph.D. Thesis, Hong Kong University of Science and Technology, Hong Kong.

Wang, M.J. and W.X. Wang. 2008. Temperature-dependent sensitivity of a marine diatom to cadmium stress explained by subcelluar distribution and thiol synthesis. Environ. Sci. Technol. 42(22): 8603-8608.

Wang, M.J. and W.X. Wang. 2009a. Cadmium in three marine phytoplankton: Accumulation, subcellular fate and thiol induction. Aquat. Toxicol. 95: 99-107.

Wang, M.J. and W.X. Wang. 2011. Cadmium sensitivity, uptake, subcellular distribution and thiol induction in a marine diatom: Exposure to cadmium. Aquat. Toxicol. 101(2): 377-386.

Wang, N., C.G. Ingersoll, C.D. Ivey, D.K. Hardesty, T.W. May, T. Augspurger, A.D. Roberts, E. Van Genderen and M.C. Barnhart. 2010d. Sensitivity of early life stages of freshwater mussels (Unionidae) to acute and chronic toxicity of lead, cadmium, and zinc in water. Environ. Toxicol. Chem. 29(9): 2053-2063.

Wang, N., C.G. Ingersoll, R.A. Dorman, W.G. Brumbaugh, C.A. Mebane, J.L. Kunz and D.K. Hardesty. 2014a. Chronic sensitivity of white sturgeon (*Acipenser transmontanus*) and rainbow trout (*Oncorhynchus mykiss*) to cadmium, copper, lead, or zinc in laboratory water-only exposures. Environ. Toxicol. Chem. 33(10): 2246-2258.

Wang, Q., B. Liu, H. Yang, X. Wang and Z. Lin. 2009c. Toxicity of lead, cadmium and mercury on embryogenesis, survival, growth and metamorphosis of *Meretrix meretrix* larvae. Ecotoxicol. 18(7): 829-837.

Wang, Q., X. Wang, X. Wang, H. Yang and B. Liu. 2010e. Analysis of metallotionein expression and antioxidant enzyme activities in *Meretrix meretrix* larvae under sublethal cadmium exposure. Aquat. Toxicol. 100(4): 321-328.

Wang, R.L., G.Z. Ma and Z.Q. Fang. 2006. Safety assessment and acute toxicity of copper, cadmium and zinc to white clound mountain minnow *Tanichthys albonubes*. Fish. Sci. 25(3): 117-120.

Wang, S., D. Zhang and X. Pan. 2013. Effects of cadmium on the activities of photosystems of *Chlorella pyrenoidosa* and the protective role of cyclic electron flow. Chemosphere 93(2): 230-237.

Wang, W. 1986. Toxicity tests of aquatic pollutants by using common duckweed. Environ. Pollut. (Series B). 11: 1-14.

Wang, W., M.A. Lampi, X.D. Huang, K. Gerhardt, D.D. George and B.M. Greenberg. 2009a. Assessment of mixture toxicity of copper, cadmium, and phenanthrenequinone to the marine bacterium *Vibrio fischeri*. Environ. Toxicol. 24(2): 166-177.

Wang, W.X. and C. Ke. 2002. Dominance of dietary intake of cadmium and zinc by two marine predatory gastropods. Aquat. Toxicol. 56(3): 153-165.

Wang, W.X. and N.S. Fisher. 1996. Assimilation of trace elements and carbon by the mussel *Mytilus edulis*: Effects of food composition. Limnol. Oceanogr. 41(2): 197-207.

Wang, W.X. and N.S. Fisher. 1998. Accumulation of trace elements in a marine copepod. Limnol. Oceanogr. 43(2): 273-283.

Wang, W.X. and R.C.H. Dei. 2001. Metal uptake in a coastal diatom influenced by major nutrients (N, P, and Si). Water Res. 35(1): 315-321.

Wang, W.X. and R.C.K. Wong. 2003. Combined effects of food quantity and quality on Cd, Cr, and Zn assimilation to the green mussel, *Perna viridis*. J. Exp. Mar. Biol. Ecol. 290(1): 49-69.

Wang, W.X., N.S. Fisher and S.N. Luoma. 1996. Kinetic determinations of trace element bioaccumulation in the mussel *Mytilus edulis*. Mar. Ecol. Prog. Ser. 140: 91-113.

Wang, W.X., R.C.H. Dei and H. Hong. 2005b. Seasonal study on the Cd, Se, and Zn uptake by natural coastal phytoplankton assemblages. Environ. Toxicol. Chem. 24(1): 161-169.

Wang, W.Y. 2008. Investigation of heavy metal content in fish at Chongqing section of the Yangtze River before water storage in the three Gorges Reservoir. Water Res. Protect. 24(5): 34-37.

Wang, X. and G.P. Zauke. 2004. Size-dependent bioaccumulation of metals in the amphipod *Gammarus zaddachi* (Sexton 1912) from the River Hunte (Germany) and its relationship to the permeable body surface area. Hydrobiol. 515(1-3): 11-28.

Wang, Y., M.C.O. Ferrari, Z. Hoover, A.M. Yousafzai, D.P. Chivers and S. Niyogi. 2014b. The effects of chronic exposure to environmentally relevant levels of waterborne cadmium on reproductive capacity and behavior in fathead minnows. Arch. Environ. Contam. Toxicol. 67: 181-191.

Wang, Z., C. Yan and X. Zhang. 2009d. Acute and chronic cadmium toxicity to a saltwater cladoceran *Moina monogolica* Daday and its relative importance. Ecotoxicol.18(1): 47-54.

Wang, Z.H., X.N. Wang and Q. Lin. 2011c. The content variation characteristics and risk analysis for cadmium, copper, lead and zinc in some species of shellfish. J. Agro-Environ. Sci. 30(6): 1208-1213.

Wani, G.P. 1986. Toxicity of heavy metals to embryonic stages of *Cyprinus carpio* Communis. Pollut. Res. 5(2): 47-51.

Wanick, R.C., T.D.S. Paiva, C.N. De Carvalho and I.D. Da Silva-Neto. 2008. Acute toxicity of cadmium to freshwater ciliate *Paramecium bursaria*. Biociencias 16(2): 104-109.

Wanty, R.B., P.L. Verplanck, C.A. San Juan, S.E. Church, T.S. Schmidt, D.L. Fey, E.H. DeWitt and T.L. Klein. 2009. Geochemistry of surface water in alpine catchments in central Colorado, USA: Resolving host-rock effects at different spatial scales. Appl. Geochem. 24: 600-610.

Ward, C.K. and M.T. Mendonca. 2006. Chronic exposure to coal fly ash causes minimal changes in corticosterone and testosterone concentrations in male southern toads *Bufo terrestris*. Arch. Environ. Contam. Toxicol. 51(2): 263-269.

Ward, D.J., V. Perez-Landa, D.A. Spadaro, S.L. Simpson and D.F. Jolley. 2011. An assessment of three harpacticoid copepod species for use in ecotoxicological testing. Arch. Environ. Contam. Toxicol. 61(3): 414-425.

Ward, T.J. and W.E. Robinson. 2005. Evolution of cadmium resistance in *Daphnia magna*. Environ. Toxicol. Chem. 24(9): 2341-2349.

Waring, J.S., W.A. Maher and F. Krikowa. 2006. Trace metal bioaccumulation in eight common coastal Australian polychaeta. J. Environ. Monit. 8(11): 1149-1157.

Warnau, M., G. Ledent, A. Temara, V. Alva, M. Jangoux and P. Dubois. 1995a. Allometry of heavy metal bioconcentration in the echinoid *Paracentrotus lividus*. Arch. Environ. Contam. Toxicol. 29: 393-399.

Warnau, M., G. Ledent, A. Temara, M Jangoux and P. Dubois. 1995b. Experimental cadmium contamination of the echinoid *Paracentrotus lividus*: Influence of exposure mode and distribution of the metal in the organism. Mar. Ecol. Prog. Ser. 116: 117-124.

Warnau, M., J.L. Teyssie and S.W. Fowler. 1995c. Effect of feeding on cadmium bioaccumulation in the echinoid *Paracentrotus lividus* (Echinodermata). Mar. Ecol. Prog. Ser. 126: 305-309.

Warnau, M., S.W. Fowler and J.L. Teyssie. 1996a. Biokinetics of selected heavy metals and radionuclides in two marine macrophytes: The seagrass *Posidonia oceanica* and the alga *Caulerpa taxifolia*. Mar. Environ. Res. 41(4): 343-362.

Warnau, M., M. Iaccarino, A. De Biase, A. Temara, M. Jangoux, P. Dubois and G. Pagano. 1996b. Spermiotoxicity and embryotoxicity of heavy metals in the echinoid *Paracentrotus lividus*. Environ. Toxicol. Chem. 15(11): 1931-1936.

Warnau, M., J.L. Teyssie and S.W. Fowler. 1997. Cadmium bioconcentration in the echinoid *Paracentrotus lividus*: Influence of the cadmium concentration in seawater. Mar. Environ. Res. 43(4): 303-314.

Warnick, S.L. and H.L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquatic insects. J. Water Pollut. Control Fed. 41: 280.

Warren, L.A., A. Tessier and L. Hare. 1998. Modelling cadmium accumulation by benthic invertebrates *in situ*: The relative contributions of sediment and overlying water reservoirs to organism cadmium concentrations. Limnol. Oceanogr. 43(7): 1442-1454.

Watling, H.R. 1981. Effects of metals on the development of oyster embryos. South African J. Sci. 77: 134.

Watling, H.R. 1982. Comparative study on the effects of zinc, cadmium, and copper on the larval growth of three oyster species. Bull. Environ. Contam. Toxicol. 28: 195.

Watling, H.R. 1983a. Accumulation of seven metals by *Crassostrea gigas*, *Crassostrea margaritacea*, *Perna perna*, and *Choromytilus meridionalis*. Bull. Environ. Contam. Toxicol. 30: 317.

Watling, H.R. 1983b. Comparative study on the effects of metals on the settlement of *Crassostrea gigas*. Bull. Environ. Contam. Toxicol. 31: 344.

Watson, C.F. 1988. Sublethal effects of cadmium exposure on freshwater teleosts. Dissertation. Northeast Louisiana University, LA pp. 136.

Watson, M.R. 1973. Pollution control in metal finishing. Noyes Data Corp., Park Ridge, NJ.

Wayland, M. and R. Crosley. 2006. Selenium and other trace elements in aquatic insects in coal mine-affected streams in the Rocky Mountains of Alberta, Canada. Arch. Environ. Contam. Toxicol. 50: 511-522.

Weber, L.P., M.G. Dube, C.J. Rickwood, K. Driedger, C. Portt, C. Brereton and D.M. Janz. 2008. Effects of multiple effluents on resident fish from Junction Creek, Sudbury, Ontario. Ecotoxicol. Environ. Saf. 70(3): 433-445.

Weber, O. 1985. Concentration of metals in fish from the River Rednitz. C. A. Sel. Environ. Pollut. 18: 3-(ABS NO.103:66335Q).

Weber Jr., W.J. and W. Stumm. 1963. Mechanism of hydrogen ion buffering in natural waters. J. Am. Water Works Assoc. 55: 1553.

Webster, R.E., A.P. Dean and J.K. Pittman. 2011. Cadmium exposure and phosphorus limitation increases metal content in the freshwater alga *Chlamydomonas reinhardtii*. Environ. Sci. Technol. 45(17): 7489-7496.

Wehr, J.D. and B.A. Whitton. 1983. Aquatic cryptogams of natural acid springs enriched with heavy metals: The Kootenay Paint Pots, British Columbia. Hydrobiol. 98: 97-105.

Wei, L., J.R. Donat, G. Fones and B.A. Ahner. 2003. Interactions between Cd, Cu, and Zn influence particulate phytochelatin concentrations in marine phytoplankton: Laboratory results and preliminary field data. Environ. Sci. Technol. 37(16): 3609-3618.

Weimin, Y., G.E. Batley and M. Ahsanullah. 1994. Metal bioavailability to the soldier crab *Mictyris longicarpus*. Sci. Total Environ. 141(1-3): 27-44.

Weir, S.M. and C.J. Salice. 2012. High tolerance to abiotic stressors and invasion success of the slow growing freshwater snail, *Melanoides tuberculatus*. Biol. Invasions 14(2): 385-394.

Weis, J.S., P. Weis and J. Ricci. 1981. Effects of cadmium, zinc, salinity, and temperature on the teratogenicity of methylmercury to the killifish (*Fundulus heteroclitus*). Rapp. P. V. Reun. Cons. Int. Explor. Mer. 178: 64-70.

Wentsel, R., A. McIntosh, W.P. McCafferty, G. Atchison and V. Anderson. 1977. Avoidance response of midge larvae (*Chironomus tentans*) to sediments containing heavy metals. Hydrobiol. 55(2): 171-175.

Werner, I., S.J. Teh, S. Datta, X.Q. Lu and T.M. Young. 2004. Biomarker responses in *Macoma nasuta* (Bivalvia) exposed to sediments from northern San Francisco Bay. Mar. Environ. Res. 58(2-5): 299-304.

Werner, J. 2007. Development of methods to assess metallothionein expression in lake trout (*Salvelinus namaycush*) during a reproductive cycle and the effects of cadmium and ethynylestradiol. Ph.D.Thesis, Univ. of Manitoba, Canada, 194 p.

Westerman, A.G. 1977. Lethal and teratogenic effects of inorganic mercury and cadmium on embryonic development of anurans. M.S. Thesis, University of Kentucky, Lexington, KY.

Westerman, A.G. and W.J. Birge. 1978. Accelerated rate of albinism in channel catfish exposed to metals. Prog. Fish Cult. 40: 143.

Westernhagen, H.V. and V. Dethlefsen. 1975. Combined effects of cadmium and salinity on development and survival of flounder eggs. J. Mar. Biol. Assoc. U.K. 55: 945.

Westernhagen, H.V., V. Dethlefsen and H. Rosenthal. 1975. Combined effects of cadmium and salinity on development and survival of garpike eggs. Helgol. Wiss. Meeresunters. 27(3): 268-282.

Westernhagen, H.V., V. Dethlefsen, H. Rosenthal, G. Furstenberg and J. Klinckmann. 1978. Fate and effects of cadmium in an experimental marine ecosystem. Helgol. Wiss. Meeresunters. 31(4): 471-484.

Westernhagen, H.V., V. Dethlefsen and H. Rosenthal. 1979. Combined effects of cadmium, copper and lead on developing herring eggs and larvae. Helgol. Wiss. Meeresunters. 32(3): 257-258.

White, A.J., M. Harwell, D. Marcovich, H. Kalb, A.S. Rohde, K. Gayheart and K. Shanker. 2008. Metal concentrations in loggerhead sea turtle eggs from the Florida Gulf and Atlantic Coasts. NOAA Tech. Mem. NMFS SEFSC No. 582, p. 163.

White, D.H. and M.T. Finley. 1978a. Effects of dietary cadmium in mallard ducks. In: D.D. Hemphill (*Ed.*), Trace Substances in Environmental Health-XII. University of Missouri, Columbia, MO, p. 220.

White, D.H. and M.T. Finley. 1978b. Uptake and retention of dietary cadmium in mallard ducks. Environ. Res. 17: 53.

White, D.H., M.T. Finley and J.F. Ferrell. 1978. Histopathologic effects of dietary cadmium on kidneys and testes of mallard ducks. J. Toxicol. Environ. Health 4(4): 551-558.

White, S.L. and P.S. Rainbow. 1982. Regulation and accumulation of copper, zinc and cadmium by the shrimp *Palaemon elegans*. Mar. Ecol. Prog. Ser. 8: 95.

White, S.L. and P.S. Rainbow. 1986. Accumulation of cadmium by *Palaemon elegans* (Crustacea: Decapoda). Mar. Ecol. Prog. Ser. 32: 17-25.

Whyte, J.J., R.E. Jung, C.J. Schmitt and D.E. Tillitt. 2000. Ethoxyresorufin-o-deethylase (EROD) activity in fish as a biomarker of chemical exposure. Crit. Rev. Toxicol. 30(4): 347-570.

Wicklum, D. and R.W. Davies. 1996. The effects of chronic cadmium stress on energy acquisition and allocation in a freshwater benthic invertebrate predator. Aquat. Toxicol. 35: 237-252.

Wicklum, D., D.E.C. Smith and R.W. Davies. 1997. Mortality, preference, avoidance, and activity of a predatory leech exposed to cadmium. Arch. Environ. Contam. Toxicol. 32: 178-183.

Wicklund, A. and P. Runn. 1988. Calcium effects on cadmium uptake, redistribution, and elimination in minnows, *Phoxinus phoxinus*, acclimated to different calcium concentrations. Aquat. Toxicol. 13: 109-122.

Wicklund, A., P. Runn and L. Norrgren. 1988. Cadmium and zinc interactions in fish: effects of zinc on the uptake, organ distribution, and elimination of ^{109}Cd in the zebrafish, *Brachydanio rerio*. Arch. Environ. Contam. Toxicol. 17: 345-354.

Widmeyer, J.R. and L.I. Bendell-Young. 2007. Influence of food quality and salinity on dietary cadmium availability in *Mytilus trossulus*. Aquat. Toxicol. 81(2): 144-151.

Wier, C.F. and W.M. Walter. 1976. Toxicity of cadmium in the freshwater snail, *Physa gyrina* Say. J. Environ. Qual. 5: 359.

Wiesner, L., B. Guenther and C. Fenske. 2001. Temporal and spatial variability in the heavy-metal content of *Dreissena polymorpha* (Pallas) (Mollusca: Bivalvia) from the Kleines Haff (northeastern Germany). Hydrobiol. 443(1-3): 137-145.

Wigginton, A.J. 2005. Some effects of cadmium on select crayfish in the family Cambaridae. Ph.D. Thesis, Univ. Kentucky, Lexington, KY. http://uknowledge.uky.edu/gradschool_diss/271

Wigginton, A.J. and W.J. Birge. 2007. Toxicity of cadmium to six species in two genera of crayfish and the effect of cadmium on molting success. Environ. Toxicol. Chem. 26(3): 548-554.

Wikfors, G.H. and R. Ukeles. 1982. Growth and adaptation of estuarine unicellular algae in media with excess copper, cadmium or zinc, and effects of metal-contaminated algal food on *Crassostrea virginica* larvae. Mar. Ecol. Prog. Ser. 7: 191.

Wilczok, A., U. Mazurek, D. Tyrawska and B. Sosak-Swiderska. 1994. Effect of cadmium on the cell division of *Chlorella vulgaris* Beij. 1890, strain A-8. Pol. Arch. Hydrobiol. 41(1): 123-131.

Wildgust, M.A. and M.B. Jones. 1998. Salinity change and the toxicity of the free cadmium ion [$Cd^{2+}_{(aq)}$] to *Neomysis integer* (Crustacea: Mysidacea). Aquat. Toxicol. 41: 187-192.

Williams, A.B., O.O. Ayejuyo and J.A. Adekoya. 2007. Trends in trace metal burdens in sediment, fish species and filtered water of Igbede River, Lagos, Nigeria. J. Appl. Sci. 7(13): 1821-1823.

Williams, C.J., D. Aderhold and R.G.J. Edyvean. 1998. Comparison between biosorbents for the removal of metal ions from aqueous solutions. Water Res. 32: 216-224

Williams, C.R. and E.P. Gallagher. 2013. Effects of cadmium on olfactory mediated behaviors and molecular biomarkers in coho salmon (*Oncorhynchus kisutch*). Aquat. Toxicol. 140-141: 295-302.

Williams, D.R. and J.P. Giesy Jr. 1978. Relative importance of food and water sources to cadmium uptake by *Gambusia affinis* (Poeciliidae). Environ. Res. 16: 326.

Williams, J.H., A.M. Farag, M.A. Stansbury, P.A. Young, H.L. Bergman and N.S. Petersen. 1996. Accumulation of hsp70 in juvenile and adult rainbow trout gill exposed to metal-contaminated water and/or diet. Environ. Toxicol. Chem. 15(8): 1324-1328.

Williams, J.J., J. Dutton, C.Y. Chen and N.S. Fisher. 2010. Metal (as, Cd, Hg, and CH_3Hg) bioaccumulation from water and food by the benthic amphipod *Leptocheirus plumulosus*. Environ. Toxicol. Chem. 29(8): 1755-1761.

Williams, K.A., D.W.J. Green and D. Pascoe. 1985. Studies on the acute toxicity of pollutants to freshwater macroinvertebrates; 1: Cadmium. Arch. Hydrobiol. 102(4): 461-471.

Williams, K.A., D.W.J. Green, D. Pascoe and D.E. Gower. 1986. The acute toxicity of cadmium to different larval stages of *Chironomus riparius* (Diptera: Chironomidae) and its ecological significance for pollution regulation. Oecologia 70(3): 362-366.

Williams, K.A., D.W.J. Green, D. Pascoe and D.E. Gower. 1987. Effect of cadmium on oviposition and egg viability in *Chironomus riparius* (Diptera: Chironomidae). Bull. Environ. Contam. Toxicol. 38: 86-90.

Williams, P.L and D.B. Dusenbery. 1990. Aquatic toxicity testing using the nematode, *Caenorhabditis elegans*. Environ. Toxicol. Chem. 9: 1285-1290.

Williams, T.D., A. Diab, F. Ortega, V.S. Sabine, R.E. Godfrey, F. Falciani, J.K. Chipman and S.G. George. 2008. Transcriptomic responses of European flounder (*Platichthys flesus*) to model toxicants. Aquat. Toxicol. 90(2): 83-91.

Williamson, K.J. and P.O. Nelson. 1983. Bacterial bioassay for level I toxicity assessment. EPA-600/3-83-017, NTIS, Corvallis, OR.

Wilson, D.N. 1988. Cadmium – Marked trends and influences. In: Cadmium 87th proceedings of the 6th International Cadmium conference, London, Cadmium Association, pp. 9–16.

Windom, H.L., K.T. Tenore and D.L. Rice. 1982. Metal accumulation by the polychaete *Capitella capitata*: Influences of metal content and nutritional quality of detritus. Can. J. Fish. Aquat. Sci. 39(1): 191-196.

WindWard Environmental. 2001. Results of 2000 toxicity testing. B.J. Cassady (*Ed.*), Development of site-specific water quality criteria for the segment of the South Fork Coeur d'Alene River from Daisy Gulch to Wallace, ID, 56 p.

Winger, P.V. and J.K. Andreasen. 1985. Contaminant residues in fish and sediments from lakes in the Atchafalaya River Basin (Louisiana). Arch. Environ. Contam. Toxicol. 14(5): 579-586.

Winger, P.V., C. Sieckman, T.W. May and W.W. Johnson. 1984. Residues of organochlorine insecticides, polychlorinated biphenyls, and heavy metals in biota from Apalachicola River, Florida, 1978. J. AOAC Int. 67(2): 325-333.

Winner, R.W. 1984. The toxicity and biaccumulation of cadmium and copper as affected by humic acid. Aquat. Toxicol. 5: 267.

Winner, R.W. 1986. Interactive effects of water hardness and humic acid on the chronic toxicity of cadmium to *Daphnia pulex*. Aquat. Toxicol. 8: 281-293.

Winner, R.W. 1988. Evaluation of the relative sensitivities of 7-d *Daphnia magna* and *Ceriodaphnia dubia* toxicity tests for cadmium and sodium pentachlorophenate. Environ. Toxicol. Chem. 7: 153-159.

Winner, R.W. and J.D. Gauss. 1986. Relationship between chronic toxicity and bioaccumulation of copper, cadmium and zinc as affected by water hardness and humic acid. Aquat. Toxicol. 8: 149-161.

Winner, R.W. and T.C. Whitford. 1987. The interactive effects of a cadmium stress, a selenium deficiency and water temperature on the survival and reproduction of *Daphnia magna* Straus. Aquat. Toxicol. 10: 217-224.

Winter, S. 1996. Cadmium uptake kinetics by freshwater mollusc soft body under hard and soft water conditions. Chemosphere 32(10): 1937-1948.

Witeska, M. 2001. Changes in the common carp blood cell picture after acute exposure to cadmium. Acta Zool. Litu. 11(4): 366-371.

Witeska, M. and I. Baka. 2002. The effect of long-term cadmium exposure on common carp blood. Fresenius Environ. Bull. 11(12a): 1059-1065.

Witeska, M. and M. Wakulska. 2007. The effects of heavy metals on common carp white blood cells in vitro. Alt. Lab. Anim. 35(1): 87-92.

Witeska, M., B. Jezierska and J. Chaber. 1995. The influence of cadmium on common carp embryos and larvae. Aquaculture 129: 129-132.

Witeska, M., E. Kondera, J. Lipionoga and A. Jastrzebska. 2010. Changes in oxygen consumption rate and red blood parameters in common carp *Cyprinus carpio* L. after acute copper and cadmium exposures. Fresenius Environ. Bull. 19(1): 115-122.

Witzel, B. 1998. Uptake, storage and loss of cadmium and lead in the woodlouse *Porcellio scaber* (Crustacea, Isopoda). Water Air Soil Pollut. 108: 51-68.

Wo, K.T., P.K.S. Lam and R.S.S. Wu. 1999. A comparison of growth biomarkers for assessing sublethal effects of cadmium on a marine gastropod, *Nassarius festivus*. Mar. Pollut. Bull. 39(1-12): 165-173.

Wolfe, D.A., E.R. Long and G.B. Thursby. 1996. Sediment toxicity in the Hudson-Raritan Estuary: Distribution and correlations with chemical contamination. Estuaries 19(4): 901-912.

Wolff, G., G.C. Pereira, E.M. Castro, J. Louzada and F.F. Coelho. 2012. The use of *Salvinia auriculata* as a bioindicator in aquatic ecosystems: Biomass and structure dependent on the cadmium concentration. Braz. J. Biol. 72(1): 71-77.

Won, E.J., R.O. Kim, J.S. Rhee, G.S. Park, J. Lee, K.H. Shin, Y.M. Lee and J.S. Lee. 2011. Response of glutathione S-gransferase (GST) genes to cadmium exposure in the marine pollution indicator worm, *Perinereis nuntia*. Comp. Biochem. Physiol. Part C 154(2): 82-92.

Wong, C.K. 1989. Effects of cadmium on the feeding behavior of the freshwater cladoceran *Moina macrocopa*. Chemosphere 18(7/8): 1681-1687.

Wong, C.K. and P.K. Wong. 1990. Life table evaluation of the effects of cadmium exposure on the freshwater cladoceran, *Moina macrocopa*. Bull. Environ. Contam. Toxicol. 44: 135-141.

Wong, K.H. and K.Y. Chan. 1979. A study of cadmium, copper and lead uptake by the unicellular green alga *Chlorella salina* Cu-1. In: Stand. Methodol. Water Pollut. Proc. Conf.:168-173.

Wong, M.H. and K.C. Au. 1984. Contents of cadmium iron manganese and zinc in the tissue of *Katelysia hiantina* collected from Tolo Harbor Hong-Kong an almost land-locked sea. Hydrobiol. Bull. 18(2): 95-102.

Wong, M.H. and M.W. Li. 1977. An ecological survey of the heavy metal contamination of the edible clam *Paphia sp*. on the iron-ore tailings of Tolo Harbour, Hong Kong. Hydrobiol. 56(3): 265-272.

Wong, P.T.S. 1987. Toxicity of cadmium to freshwater microorganisms, phytoplankton, and invertebrates. Adv. Environ. Sci. Tech. 19: 117-138.

Wong, P.T.S. and Y.K. Chau. 1988. Toxicity of metal mixtures to phytoplankton. In: M. Astruc and J.N. Lester (*Eds*.), Heavy Met.Hydrol.Cycle, Selper Ltd., London, UK, 231-236.

Wong, P.T.S., Y.K. Chau and P.L. Luxon. 1978. Toxicity of a mixture of metals on freshwater algae. J. Fish. Res. Board Can. 35: 479-481.

Wong, P.T.S., Y.K. Chau and D. Patel. 1982. Physiological and biochemical responses of several freshwater algae to a mixture of metals. Chemosphere 11(4): 367-376.

Wong, S.L. and J.L. Beaver. 1980. Algal bioassays to determine toxicity of metal mixtures. Hydrobiol. 74: 199-208.

Wood, C.M., W.J. Adams, G.T. Ankley, D.R. Dibona, S.N. Luoma, R.C. Playle, W.A. Stubblefield, H.L. Bergman, R.J. Erickson, J.S. Mattice and C.E. Schlekat. 1997. Environmental toxicology of metals In: H.L. Bergman and E.J. Dorward-King (*Eds.*), Reassessment of metals criteria for aquatic life protection: Priorities for research and implementation. SETAC Press, Pensacola, FL, 4: 31-56.

Wood, C.M., N.M. Franklin and S. Niyogi. 2006. The protective role of dietary calcium against cadmium uptake and toxicity in freshwater fish: an important role for the stomach. Environ. Chem. 3(6): 389-394.

Wood, C.M., A.P. Farrell and C.J. Brauner. 2012. Homeostatis and toxicology of non-essential metals: Volume 31B. Fish Physiology, Academic Press/Elsevier, Waltham, MA.

Wood, K.G. 1974. Trace metal uptake by *Cladophora* Chlorophyta. Marshall, K.E. Xix Congress International Association of Limnology, Winnipeg, Canada, Aug. 22-29, 1974. 238p. Freshwater Institute, Department of Environment: Winnipeg, Manitoba, Canada.

Woodall, C., N. Maclean and F. Crossley. 1988. Responses of trout fry (*Salmo gairdneri*) and *Xenopus laevis* tadpoles to cadmium and zinc. Comp. Biochem. Physiol. Part C 89(1): 93-99.

Woodard, V.H. 2005. Feasibility for utilization of a freshwater pulmonate snail, *Physa acuta*, as a model organism for environmental toxicity testing, with special reference to cadmium ion toxicity. Ph.D. Thesis, The University of Texas at Arlington, TX.

Woodling, J.D. 1993. Survival and mortality of brown trout (*Salmo trutta*) exposed to *in situ* acute toxic concentrations of cadmium and zinc. Dissertation. University of Colorado at Boulder, CO, pp. 130.

Woodling, J.D., S.F. Brinkman and B.J. Horn. 2001. Nonuniform accumulation of cadmium and copper in kidneys of wild brown trout (*Salmo trutta*) populations. Arch. Environ. Contam. Toxicol. 40(3): 381-385.

Woodward, D.F., A.M. Farag, H.L. Bergman, A.J. DeLonay, E.E. Little, C.E. Smith and F.T. Barrow. 1995b. Metals-contaminated benthic invertebrates in the Clark Fork River, Montana: effects on age-0 brown trout and rainbow trout. Can. J. Fish. Aquat. Sci. 52: 1994-2004.

Woodward, D.F., J.A. Hansen, H.L. Bergman, E.E. Little and A.J. DeLonay. 1995a. Brown trout avoidance of metals in water characteristic of the Clark Fork River, Montana. Can. J. Fish. Aquat. Sci. 52(9): 2031-2037.

Woodworth, J. and D. Pascoe. 1982. Cadmium toxicity to rainbow trout, *Salmo gairdneri* Richardson: A study of eggs and alevins. J. Fish Biol. 21: 47.

Woodworth, J. and D. Pascoe. 1983. Cadmium uptake and distribution in sticklebacks related to the concentration and method of exposure. Ecotoxicol. Environ. Safety. 7: 525-530.

World Health Organisation (WHO). 1992. Environmental Health Criteria 134 - Cadmium International Programme on Chemical Safety (IPCS) Monograph.

World Health Organization (WHO). 2010. Cadmium- Environmental Aspects: Environmental Health Criteria 135. Geneva, World Health Organization.

Wren, C.D., S. Harris and N. Hattruo. 1995. Ecotoxicology of mercury and cadmium. In: D.J. Hoffman, B.A. Rattner, G.A. Burton and J. Cairns (*Eds.*). Handbook of ecotoxicology. Lewis Publisher, Boca Raton, FL, pp. 392-423.

Wren, M.J. and D. McCarroll. 1990. A simple and sensitive bioassay for the detection of toxic materials using a unicellular green alga. Environ. Pollut. 64: 87-91.

Wright, D.A. 1977. The effect of salinity on cadmium uptake by the tissues of the shore crab, *Carcinus maenas*. Exp. Biol. 67: 137.

Wright, D.A. 1988. Dose-related toxicity of copper and cadmium in striped bass larvae from the Chespeake Bay: Field considerations. Water Sci. Tech. 20(6/7): 39-48.

Wright, D.A. and J.W. Frain. 1981. Cadmium toxicity in *Marinogammarus obtusatus*: effect of external calcium. Environ. Res. 24: 338.

Wright, D.A. and P.M. Welbourn. 1994. Cadmium in the aquatic environment: A review of ecological, physiological, and toxicological effects on biota. Environ. Rev. 2: 187-214.

Wright, D.A., M.J. Meteyer and F.D. Martin. 1985. Effect of calcium on cadmium uptake and toxicity in larvae and juveniles of striped bass (*Morone saxatilis*). Bull. Environ. Contam. Toxicol. 34(2): 196-204.

Wu, H. and W.X. Wang. 2010. NMR-based metabolomic studies on the toxicological effects of cadmium and copper on green mussels *Perna viridis*. Aquat. Toxicol. 100(4): 339-345.

Wu, H. and W.X. Wang. 2011. Tissue-specific toxicological effects of cadmium in green mussels (*Perna viridis*): Nuclear magnetic resonance-based metabolomics study. Environ. Toxicol. Chem. 30(4): 806-812.

Wu, H., X. Liu, J. Zhao and J. Yu. 2011a. NMR-based metabolomic investigations on the differential responses in adductor muscles from two pedigrees of Manila clam *Ruditapes philippinarum* to cadmium and zinc. Mar. Drugs 9(9): 1566-1579.

Wu, J.P. and H.C. Chen. 2004. Effects of cadmium and zinc on oxygen consumption, ammonium excretion, and osmoregulation of white shrimp (*Litopenaeus vannamei*). Chemosphere 57(11): 1591-1598.

Wu, J.P. and H.C. Chen. 2005a. Effects of cadmium and zinc on the growth, food consumption, and nutritional conditions of the white shrimp, *Litopenaeus vannamei* (Boone). Bull. Environ. Contam. Toxicol. 74(2): 234-241.

Wu, J.P. and H.C. Chen. 2005b. Metallothionein induction and heavy metal accumulation in white shrimp *Litopenaeus vannamei* exposed to cadmium and zinc. Comp. Biochem. Physiol. Part C 140(3/4): 383-394.

Wu, J.P., H.C. Chen and D.J. Huang. 2008c. Histopathological and biochemical evidence of hepatopancreatic toxicity caused by cadmium and zinc in the white shrimp, *Litopenaeus vannamei*. Chemosphere 73(7): 1019-1026.

Wu, J.P., H.C. Chen and D.J. Huang. 2009. Histopathological alterations in gills of white shrimp, *Litopenaeus vannamei* (Boone) after acute exposure to cadmium and zinc. Bull. Environ. Contam. Toxicol. 82(1): 90-95.

Wu, J.P., H.C. Chen and M.H. Li. 2011b. The preferential accumulation of cadmium in the head portion of the freshwater planarian, *Dugesia japonica* (Platyhelminthes: Turbellaria). Metallomics 3(12): 1368-1375.

Wu, J.P., H.C. Chen and M.H. Li. 2012. Bioaccumulation and toxicodynamics of cadmium to freshwater planarian and the protective effect of N-acetylcysteine. Arch. Environ. Contam. Toxicol. 63(2): 220-229.

Wu, R.S.S., P.K.S. Lam and B. Zhou. 1997. A settlement inhibition assay with cyprid larvae of the barnacle *Balanus amphitrite*. Chemosphere 35(9): 1867-1874.

Wu, S.M. and A.N. Deng. 2006. Effect of cadmium on hematological functions in tilapia (*Oreochromis mossambicus*). Bull. Environ. Contam. Toxicol. 76(5): 891-898.

Wu, S.M. and W.L. Yang. 2008. A new view explaining how cadmium-treated parents have higher Cd-resistant offspring: The case of tilapia larvae (*Oreochromis mossambicus*). Comp. Biochem. Physiol. Part C 148(4): 469.

Wu, S.M., A.N. Deng and Y.C. Lee. 2006b. Changes of cortisol and metallothionein upon cadmium exposure and handling stressed in tilapia (*Oreochromis mossambicus*). J. Fish. Soc. Taiwan 33(1): 1-9.

Wu, S.M., K.J. Jong and Y.J. Lee. 2006c. Relationships among metallothionein, cadmium accumulation, and cadmium tolerance in three species of fish. Bull. Environ. Contam. Toxicol. 76(4): 595-600.

Wu, S.M., M.J. Shih and Y.C. Ho. 2007. Toxicological stress response and cadmium distribution in hybrid tilapia (*Oreochromis sp.*) upon cadmium exposure. Comp. Biochem. Physiol. 145(2): 218-226.

Wu, S.M., H.C. Lin and W.L. Yang. 2008a. The effects of maternal Cd on the metallothionein expression in tilapia (*Oreochromis mossambicus*) embryos and larvae. Aquat. Toxicol. 87(4): 296-302.

Wu, S.M., P.R. Tsai and C.J. Yan. 2012b. Maternal cadmium exposure induces mt2 and smtB mRna expression in zebrafish (*Danio rerio*) females and their offspring. Comp. Biochem. Physiol. 156C(1): 1-6.

Wu, X.H., X.J. Jiang, B.L. Zhang and Y.M. Qu. 1999. Toxic effects of several heavy metal on amphioxus and living activity of *Branchiostoma belcheri* Tsingtaoensis Tchang Et Koo. Oceanol. Limnol. Sin. 30(6): 604-608.

Wu, X., Y. Jia, H. Zhu and H. Wang. 2010. Bioaccumulation of cadmium bound to humic acid by the bivalve *Meretrix meretirx* Linnaeus from solute and particulate pathways. J. Environ. Sci. 22(2): 198-203.

Wu, X., Y.Jia and H. Zhu. 2012a. Bioaccumulation of cadmium bound to ferric hydroxide and particulate organic matter by the bivalve *M. meretrix*. Environ. Pollut. 165: 133-139.

Wu, Y.G., Y. Xiong, C.X. Un and L. Yuan. 2006a. The joint-biotoxicity effect of different forms of nitrogen on heavy metals in water by the phototacti behavior of *Daphnia*. J. Agro-Environ. Sci. 25(6): 1560-1565.

Wu, Y., C. Lin and L. Yuan. 2008b. Phototaxis index of *Daphnia carinata* as an indicator of joint toxicity of copper, cadmium, zinc, nitrogen and phosphorus in aqueous solutions. Ecol. Indic. 8(1): 69-74.

Wundram, M., D. Selmar and M. Bahadir. 1996. The *Chlamydomonas* test: A new phytotoxicity test based on the inhibition of algal photosynthesis enables the assessment of hazardous leachates from waste disposals in salt mines. Chemosphere 32(8): 1623-1632.

Xia, J.R., Y.J. Li, J. Lu and B. Chen. 2004. Effects of copper and cadmium on growth, photosynthesis, and pigment content in *Gracilaria lemaneiformis*. Bull. Environ. Contam. Toxicol. 73(6): 979-986.

Xiaorong, W., J. Mei, S. Hao and X. Ouyong. 1997. Effects of chelation on the bioconcentration of cadmium and copper by carp (*Cyprinus carpio* L.). Bull. Environ. Contam. Toxicol. 59: 120-124.

Xie, F., M.A. Lampi, D.G. Dixon and B.M. Greenberg. 2007. Assessment of the toxicity of mixtures of nickel or cadmium with 9,10-phenanthrenequinone to *Daphnia magna*: Impact of a reactive oxygen-mediated mechanism with different redox-active metals. Environ. Toxicol. Chem. 26(7): 1425-1432.

Xie, L. and D.B. Buchwalter. 2011. Cadmium exposure route affects antioxidant responses in the mayfly *Centroptilum triangulifer*. Aquat. Toxicol. 105(3/4): 199-205.

Xie, L. and P.L. Klerks. 2004. Changes in cadmium accumulation as a mechanism for cadmium resistance in the least killifish *Heterandria formosa*. Aquat. Toxicol. 66(1): 73-81.

Xie, L.T., D. Lambert, C. Martin, D.J. Cain, S.N. Luoma and D. Buchwalter. 2008. Cadmium biodynamics in the oligochaete *Lumbriculus variegatus* and its implications for trophic transfer. Aquat. Toxicol. 86: 265-271.

Xie, L., D.H. Funk and D.B. Buchwalter. 2010. Trophic transfer of Cd from natural periphyton to the grazing mayfly *Centroptilum triangulifer* in a life cycle test. Environ. Pollut. 158(1): 272-277.

Xie, W.Y., Q. Huang, G. Li, C. Rensing and Y.G. Zhu. 2013. Cadmium accumulation in the rootless macrophyte *Wolffia globosa* and its potential for phytoremediation. Int. J. Phytoremediat. 15(4): 385-397.

Xin, J., B. Huang, Z. Yang, J. Yuan, H. Dai and Q. Qiu. 2010. Responses of different water spinach cultivars and their hybrid to Cd, Pb and Cd-Pb exposures. J. Hazard. Mater. 175(1-3): 468-476.

Xu, N., G. Shi, K. Du, X. Zhang, X. Zeng and H. Zhou. 2002. The study on effect of Hg, Cd and their combined pollution in leaves of *Lemna minor* L. Nanjing Shida Xuebao (Ziran Kexue Ban) 25: 109-115.

Xu, Q., G. Shi, X. Wang and G. Wu. 2006b. Generation of active oxygen and change of antioxidant enzyme activity in *Hydrilla verticillata* under Cd, Cu and Zn stress. Acta Hydrobiol. 30(1): 107-112.

Xu, Q., S. Fang and Z. Wang. 2006a. Heavy metal distribution in tissues and eggs of Chinese alligator (*Alligator sinensis*). Arch. Environ. Contam. Toxicol. 50(4): 580-586.

Xu, Q., H. Min, S. Cai, Y. Fu, S. Sha, K. Xie and K. Du. 2012. subcellular distribution and toxicity of cadmium in *Potamogeton crispus* L. Chemosphere 89(1): 114-120.

Xu, X., X. Wang, Y. Li and Y. Wang. 2010. Acute toxicity and synergism of binary mixtures of antifouling biocides with heavy metals to embryos of sea urchin *Glyptocidaris crenularis*. Hum. Exp. Toxicol. 30(8): 1009-1021.

Xu, Y., Y. Wang, B. Zhou and X.X. Tang. 2013. Study on single and joint toxic effects of cadmium and lead on *Ruditapes philippinarum*. Mar. Environ. Sci./Haiyang Huanjing Kexue. Dalian 32(1): 6-10.

Xuan, R., L. Wang, M. Sun, G. Ren and M. Jiang. 2011. Effects of cadmium on carbohydrate and protein metabolisms in the freshwater crab *Sinopotamon yangtsekiense*. Comp. Biochem. Physiol. Part C 154(3): 268-274.

Xuan, R., H. Wu, C. Lin, D. Ma, Y. Li, T. Xu and L. Wang. 2013. Oxygen consumption and metabolic responses of freshwater crab *Sinopotamon henanense* to acute and sub-chronic cadmium exposure. Ecotoxicol. Environ. Saf. 89: 29-35.

Xue, H. and L. Sigg. 1998. Cadmium speciation and complexation by natural organic ligands in freshwater. Anal. Chem. Acta. 363: 249-259.

Yager, C.M. and H.W. Harry. 1964. The uptake of radioactive zinc, cadmium and copper by the freshwater snail, *Taphius glabratus*. Malacol. 1: 339.

Yamamoto, Y. and M. Inoue. 1985. Lethal tolerance of acute cadmium toxicity in rainbow trout previously exposed to cadmium. Bull. Japan. Soc. Sci. Fish. 51(10): 1733-1735.

Yamamura, M. and K.T. Suzuki. 1983. Metallothionein induced in the frog *Xenopus laevis*. Experientia 39: 1370-1373.

Yamamura, M., K.T. Suzuki, S. Hatakeyama and K. Kubota. 1983a. Tolerance to cadmium and cadmium-binding proteins induced in the midge larva, *Chironomus yoshimatsui* (Diptera, Chironomidae). Comp. Biochem. Physiol. Part C 75(1): 21-24.

Yamamura, M., S. Hatakeyama and K.T. Suzuki. 1983b. Cadmium uptake and induction of cadmium-binding protein in the waterflea (*Moina macrocopa*). Bull. Environ. Contam. Toxicol. 30(3): 298-302.

Yan, N.D., P.G. Welsh, H. Lin, D.J. Taylor and J.M. Filion. 1996. Demographic and genetic evidence of the long-term recovery of *Daphnia galeata* Mendotae (Crustacea: Daphniidae) in Sudbury Lakes following additions of base: The role of metal toxicity. Can. J. Fish. Aquat. Sci. 53: 1328-1344.

Yan, Q.L. and W.X. Wang. 2002. Metal exposure and bioavailability to a marine deposit-feeding sipuncula, *Sipunculus nudus*. Environ. Sci. Technol. 36(1): 40-47.

Yang, H., G. Shi, H. Wang and Q. Xu. 2010. Involvement of polyamines in adaptation of *Potamogeton crispus* L. to cadmium stress. Aquat. Toxicol. 100(3): 282-288.

Yang, Q.L., C.L. Yao and Z.Y. Wang. 2012a. Acute temperature and cadmium stress response characterization of small heat shock protein 27 in large yellow croaker, *Larimichthys crocea*. Comp. Biochem. Physiol. Part C 155(2): 190-197.

Yang, W.W., A.J. Miao and L.Y. Yang. 2012b. Cd^{2+} toxicity to a green alga *Chlamydomonas reinhardtii* as influenced by its adsorption on TiO_2 engineered nanoparticles. PLoS ONE 7(3): e32300.

Yang, Z. and L. Kong. 1997. Bioavailability of copper and cadmium speciation in sediment for aquatic organism under varying temperature. Zhongguo Huanjing Kexue 17(2): 160-162.

Yap, C.K., A. Ismail, S.G. Tan and H. Omar. 2002. Correlations between speciation of Cd, Cu, Pb and Zn in sediment and their concentrations in total soft tissue of green-lipped mussel *Perna viridis* from the west coast of Peninsular Malaysia. Environ. Int. 28(1-2): 117-126.

Yap, C.K., A. Ismail and S.G. Tan. 2003b. Background concentrations of Cd, Cu, Pb and Zn in the green-lipped mussel *Perna viridis* (Linnaeus) from Peninsular Malaysia. Mar. Pollut. Bull. 46(8): 1044-1048.

Yap, C.K., A. Ismail, S.G. Tan and H. Omar. 2003a. Accumulation, depuration and distribution of cadmium and zinc in the green-lipped mussel *Perna viridis* (Linnaeus) under laboratory conditions. Hydrobiol. 498(1-3): 151-160.

Yap, C.K., A. Ismail and S.G. Tan. 2004a. Heavy metal (Cd, Cu, Pb and Zn) concentrations in the green-lipped mussel *Perna viridis* (Linnaeus) collected from some wild and aquacultural sites in the west coast of Peninsular Malaysia. Food Chem. 84(4): 569-575.

Yap, C.K., S.G. Tan, A. Ismail and H. Omar. 2004b. Allozyme polymorphisms and heavy metal levels in the green-lipped mussel *Perna viridis* (Linnaeus) collected from contaminated and uncontaminated sites in Malaysia. Environ. Int. 30(1): 39-46.

Yap, C.K, F.B. Edward, B.H. Pang, A. Ismail, S.G. Tan and H.A. Jambari. 2009. Distribution of heavy metal concentrations in the different soft tissues of the freshwater snail *Pomacea insularum* (D'orbigny, 1839; Gastropoda), and sediments collected from polluted and unpolluted sites from Malaysia. Toxicol. Environ. Chem. 91(1): 17-27.

Yarsan, E., R. Baskaya, A. Yildiz, L. Altintas and S. Yesilot. 2007. Copper, lead, cadmium and mercury concentrations in the mussel *Elliptio*. Bull. Environ. Contam. Toxicol. 79: 218-220.

Yasuno, M., S. Hatakeyama and Y. Sugaya. 1985. Characteristic distribution of chironomids in the rivers polluted with heavy metals. Verh. Internat. Verein Limnol. 22(4): 2371-2377.

Yeh, H.C., I.M. Chen, P. Chen and W.H. Wang. 2009. Heavy metal concentrations of the soldier crab (*Mictyris brevidactylus*) along the inshore area of Changhua, Taiwan. Environ. Monit. Assess. 153(1-4): 103-109.

Yigit, S. and A. Altindag. 2002. Accumulation of heavy metals in the food web components of Burdur Lake, Turkey. Fresenius Environ. Bull. 11(12a): 1048-1052.

Yilmaz, D.D. and K.U. Parlak. 2011. Changes in proline accumulation and antioxidative enzyme activities in *Groenlandia densa* under cadmium stress. Ecolog. Indicat. 11(2): 417-423.

Yilmaz, F. 2006. Bioaccumulation of heavy metals in water, sediment, aquatic plants and tissues of *Cyprinus carpio* from Kizilirmak, Turkey. Fresenius Environ. Bull. 15(5): 360-369.

Yilmaz, M., A. Gul and E. Karakose. 2004. Investigation of acute toxicity and the effect of cadmium chloride ($CdCl_2.H_2O$) metal salt on behavior of the guppy (*Poecilia reticulata*). Chemosphere 56(4): 375-380.

Yim, J.H., K.W. Kim and S.D. Kim. 2006. Effect of hardness on acute toxicity of metal mixtures using *Daphnia magna*: Prediction of acid mine drainage toxicity. J. Hazard. Mater. 138(1): 16-21.

Yin, L., Y. Zhou, X. Fan and R. Lu. 2002. Induction of phytochelatins in *Lemna aequinoctialis* in response to cadmium exposure. Bull. Environ. Contam. Toxicol. 68(4): 561-568.

Yipmantin, A., H.J. Maldonado, M. Ly, J.M. Taulemesse and E. Guibal. 2011. Pb(II) and Cd(II) biosorption on *Chondracanthus chamissoi* (a red alga). J. Hazard. Mater. 185(2/3): 922-929.

Yoga, G.P.2002. Effect of cadmium exposure on lipid peroxidation in tilapia. Limnotek 9(1): 23-32.

Yorulmazlar, E. and A. Gul. 2003. Investigation of acute toxicity of cadmium sulfate ($CdSO_4.H_2O$) and behavioral changes of grass carp (*Ctenopharyngodon idellus* Val., 1844). Chemosphere 53(8): 1005-1010.

You, J., S. Pehkonen, D.P. Weston and M.J. Lydy. 2008. Chemical availability and sediment toxicity of pyrethroid insecticides to *Hyalella azteca*: Application to field sediment with unexpectedly low toxicity. Environ. Toxicol. Chem. 27(10): 2124-2130.

Young, L.B. and H.H. Harvey. 1988. Metals in chironomidae larvae and adults in relation to lake pH and lake oxygen deficiency. Verh. Int. Ver. Limnol. 23: 246-251.

Youssef, D.H. and F.T. Tayel. 2004. Metal accumulation by three *Tilapia spp*. from some Egyptian waters. Chem. Ecol. 20(1): 61-71.

Yu, R.Q. and W.X. Wang. 2002. Kinetic uptake of bioavailable cadmium, selenium, and zinc by *Daphnia magna*. Environ. Toxicol. Chem. 21(11): 2348-2355.

Yu, Z.G., J. Zhang, F.Y. Shi and C.Y. Wu. 1999. New method for evaluating toxicity of heavy metals on marine macroalgae. Oceanol. Limnol. Sin. 30(2): 199-205.

Yuan, L., E. Michels and L. De Meester. 2003. Changes in phototactic behavior of *Daphnia magna* clone C1 242 in response to copper, cadmium and pentachlorophenol. J. Environ. Sci. 15(6): 841-847.

Yuan, X., A. Chen, Y. Zhou, H. Liu and D. Yang. 2010. The influence of cadmium on the antioxidant enzyme activities in polychaete *Perinereis aibuhitensis* Grube (Annelida: Polychaeta). Chin. J. Oceanol. Limnol. 28(4): 849-855.

Zabotkina, E.A., T.B. Lapirova and E.A. Nazarova. 2009. Influence of cadmium ions on some morphofunctional and immune- physiological parameters of perch (*Perca fluviatilis*, Perciformes, Percidae) underyearlings. J. Ichthyol. 49(1): 111-118

Zadory, L. 1983. Monitoring heavy metal pollution and genetic consequences in aquatic invertebrates. Heavy Metal Environ., 4th Int.Conf., Volume 2, CEP Consult., Edinburgh, UK, 1183-1186.

Zadory, L. 1984. Freshwater molluscs as accumulation indicators for monitoring heavy metal pollution. Fresenius J. Anal. Chem. 317: 375-379.

Zaki, M.S. and A.H. Osman. 2003. Clinicopathological and pathological studies on *Tilipia nilotica* exposed to cadmium chloride (0.25 ppm.). Bull. Natl. Res.Ctr 28(1): 87-100.

Zanders, I.P. and W.E. Rojas. 1992. Cadmium accumulation, LC50 and oxygen consumption in the tropical marine amphipod *Elasmopus rapax*. Mar. Biol.(Berlin) 113(3): 409-413.

Zanders, I.P. and W.E. Rojas. 1996. Salinity effects on cadmium accumulation in various tissues of the tropical fiddler crab *Uca rapax*. Environ. Pollut. 94(3): 293-299.

Zanella, E.F. 1982. Shifts in caddisfly species composition in Sacramento River invertebrate communities in the presence of heavy metal contamination. Bull. Environ. Contam. Toxicol. 29: 306-312.

Zaosheng, W., Y. Changzhou and V.H. Ross. 2010. Effects of dietary cadmium exposure on reproduction of saltwater cladoceran *Moina monogolica* Daday: Implications in water quality criteria. Environ. Toxicol. Chem. 29(2): 365-372.

Zaroogian, G.E. 1979. Studies on the depuration of cadmium and copper by the American oyster *Crassostrea virginica*. Bull. Environ. Contam. Toxicol. 23: 117.

Zaroogian, G.E. 1980. *Crassostrea virginica* as an indicator of cadmium pollution. Mar. Biol. (Berlin). 58(4): 275-284.

Zaroogian, G.E. and S. Cheer. 1976. Cadmium accumulation by the American oyster, *Crassostrea virginica*. Nature. 261: 408.

Zaroogian, G.E. and G. Morrison. 1981. Effect of cadmium body burdens in adult *Crassostrea virginica* on fecundity and viability of larvae. Bull. Environ. Contam. Toxicol. 27: 344.

Zauke, G.P. and I. Schmalenbach. 2006. Heavy metals in zooplankton and decapod crustaceans from the Barents Sea. Sci. Total Environ. 359(1-3): 283-294.

Zauke, G.P., R. Von Lemm, H.G. Meurs and W. Butte. 1995. Validation of estuarine gammarid collectives (Amphipoda: Crustacea) as biomonitors for cadmium in semi-controlled toxicokinetic flow-through experiments. Environ. Pollut. 90(2): 209-219.

Zauke, G.P., B. Clason, V.M. Savinov and T. Savinova. 2003. Heavy metals of inshore benthic invertebrates from the Barents Sea. Sci. Total Environ. 306(1-3): 99-110.

Zbigniew, T. and P. Wojciech. 2006. Individual and combined effect of anthracene, cadmium, and chloridazone on growth and activity of SOD izoformes in three *Scenedesmus* species. Ecotoxicol. Environ. Saf. 65(3): 323-331.

Zbikowski, R., P. Szefer and A. Latala. 2006. Distribution and relationships between selected chemical elements in green alga *Enteromorpha sp*. from the southern Baltic. Environ. Pollut. 143(3): 435-448.

Zeng J. and W.X. Wang. 2011. Temperature and irradiance influences on cadmium and zinc uptake and toxicity in a freshwater cyanobacterium, *Microcystis aeruginosa*. J. Hazard. Mater. 190(1-3): 922-929.

Zeng, J., L. Yang and W.X. Wang. 2009. Cadmium and zinc uptake and toxicity in two strains of *Microcystis aeruginosa* predicted by metal free ion activity and intracellular concentration. Aquat. Toxicol. 91(3): 212-220.

Zeng, L.X., G.Z. Chen and H.H. Wu. 2007. Toxicity effects of Cd and Cu on the respiration and excretion metabolism of asian clam. J. Agro-Environ. Sci. 26(1): 175-178.

Zhang, C., Y.X. Zhai, J.S. Ning, D.R. Shang and J.L. Wang. 2007d. A review; research on cadmium in aquatic animals. Fish. Sci./Shuichan Kexue 26(8): 465-470.

Zhang, H., C. Cai, C. Shi, H. Cao, Z. Han and X. Jia. 2012a. Cadmium-induced oxidative stress and apoptosis in the testes of frog *Rana limnocharis*. Aquat. Toxicol. 122/123(0): 67-74.

Zhang, H., H. Cao, Y. Meng, G. Jin and M. Zhu. 2012b. The toxicity of cadmium (Cd2+) towards embryos and pro-larva of Soldatov's catfish (*Silurus soldatovi*). Ecotoxicol. Environ. Saf. 80(0): 258-265.

Zhang, J.P., J. Chen, Y.H. Hu and Y.W. Mo. 2007b. Effects of cadmium stress on photosynthetic function of leaves of *Lemna minor* L. J. Agro-Environ. Sci. 26(6): 2027-2032.

Zhang, L. and W.X. Wang. 2005. Effects of Zn pre-exposure on Cd and Zn bioaccumulation and metallothionein levels in two species of marine fish. Aquat. Toxicol. 73(4): 353-369.

Zhang, L. and W.X. Wang. 2007b. Gastrointestinal uptake of cadmium and zinc by a marine teleost *Acanthopagrus schlegeli*. Aquat. Toxicol. 85(2): 143-153.

Zhang, L. and W.X. Wang. 2007c. Size-dependence of the potential for metal biomagnification in early life stages of marine fish. Environ. Toxicol. Chem. 26(4): 787-794.

Zhang, L. and W.X. Wang. 2007a. Waterborne cadmium and zinc uptake in a euryhaline teleost *Acanthopagrus schlegeli* acclimated to different salinities. Aquat. Toxicol. 84(2): 173-181

Zhang, L., J. Gan, C. Ke, X. Liu, J. Zhao, L. You, J. Yu and H. Wu. 2012c. Identification and expression profile of a new cytochrome P50 isoform (CYP414A1) in the hepatopancreas of *Venerupis* (Ruditapes) *philippinarum* exposed to benzo(a)pyrene, cadmium and copper. Environ. Toxicol. Pharmacol. 33(1): 85-91.

Zhang, L., L. Qiu, H. Wu, X. Liu, L. You, D. Pei, L. Chen, Q. Wang and J. Zhao. 2012d. Expression profiles of seven glutathione S-transferase (GST) genes from *Venerupis philippinarum* exposed to heavy metals and benzo(a)pyrene. Comp. Biochem. Physiol. 155C(3): 517-527.

Zhang, L., X. Liu, L. You, D. Zhou, J. Yu, J. Zhao, J. Feng and H. Wu. 2011. Toxicological effects induced by cadmium in gills of manila clam *Ruditapes philippinarum* using NMR-based metabolomics. Clean Soil Air Water 39(11): 989-995.

Zhang, M., J. Wang and J. Bao. 1992. Study on the relationship between speciation of heavy metals and their ecotoxicity. Chin. J. Oceanol. Limnol. 10(3): 215-222.

Zhang, R., Z.Z. Xu, W.H. Fan, Y.Y. Jiang, J. Zhao and S.C. Tang. 2012e. Biological effect of cadmium in *Daphnia magna*: Influence of nitrogen and phosphorus. Fresenius Environ. Bull. 21(10): 2891-2895.

Zhang, S., M. Liu, G. Li, W. Bao and H. Gu. 1995. Influence of toxicity of heavy metal ions to growth of *Phaeodactylum tricornutum*. Oceanol. Limnol. Sin. 26(6): 582-585.

Zhang, X., H. Sun, Z. Zhang, Q. Niu, Y. Chen and J.C. Crittenden. 2007a. Enhanced bioaccumulation of cadmium in carp in the presence of titanium dioxide nanoparticles. Chemosphere 67: 160-166

Zhang, X., B. Zhao, Q. Pang, H. Yi, M. Xue and B. Zhang. 2010a. Toxicity and behavioral effects of cadmium in planarian (*Dugesia japonica* Ichikawa Et Kawakatsu). Fresenius Environ. Bull. 19(12): 2895-2900.

Zhang, Y.M., D.J. Huang, Y.Q. Wang, J.H. Liu, R.L. Yu and J. Long. 2005. Heavy metal accumulation and tissue damage in goldfish *Carassius auratus*. Bull. Environ. Contam. Toxicol. 75(6): 1191-1199.

Zhang, Y., D. Huang, D. Zhao, J. Long, G. Song and A. Li. 2007c. Long-term toxicity effects of cadmium and lead on *Ibufo raddei* tadpoles. Bull. Environ. Contam. Toxicol. 79(2): 178-183.

Zhang, Y., J. Song, H. Yuan, Y. Xu and Z. He. 2010c. Concentrations of cadmium and zinc in seawater of Bohai Bay and their effects on biomarker responses in the bivalve *Chlamys farreri*. Arch. Environ. Contam. Toxicol. 59(1): 120-128.

Zhang, Z., Z. Rengel and K. Meney. 2010b. Cadmium accumulation and translocation in four emergent wetland species. Water Air Soil Pollut. 212(1-4): 239-249.

Zheng, S., B. Chen, Z. Wang, X. Qiu, X. Yu, D. Freestone, Z. Liu, H. Huang, W. Yu and X. Xu. 2010. Reproductive toxic effects of sublethal cadmium on the marine polychaete *Perinereis nuntia*. Ecotoxicol. Environ. Saf. 73(6): 1196-1201.

Zheng, X.Y., W.M. Long, Y.P. Guo and E.B. Ma. 2008. Acute toxicities of Cd^{2+} on *Propsilocerus akamusi* (Diptera: Chironomidae). J. Agro-Environ. Sci. 27(1): 86-91.

Zheng, X., W. Long, Y. Guo and E. Ma. 2011. Effects of cadmium exposure on lipid peroxidation and the antioxidant system in fourth-instar larvae of *Propsilocerus akamusi* (Diptera: Chironomidae) under laboratory conditions. J. Econ. Entomol. 104(3): 827-832.

Zhong, H. and W.X. Wang. 2006. Influences of aging on the bioavailability of sediment-bound Cd and Zn to deposit-feeding sipunculans and soldier crabs. Environ. Toxicol. Chem. 25(10): 2775-2780.

Zhou, K., Z. Yao, Q. Lai and H. Wang. 2007. Acute toxicity effects of Zn super(2+) and Cd super(2+) on juveniles of clam (*Cyclina Sinensis*). Mar. Fish. 29(1): 63-67.

Zhou, Q., P.S. Rainbow and B.D. Smith. 2003. Tolerance and accumulation of the trace metals zinc, copper and cadmium in three populations of the polychaete *Nereis diversicolor*. J. Mar. Biol. Assoc. 83: 65-72.

Zhou, W., P. Juneau and B. Qiu. 2006. Growth and photosynthetic responses of the bloom-forming cyanobacterium *Microcystis aeruginosa* to elevated levels of cadmium. Chemosphere 65(10): 1738-1746.

Zhou, Y., H. Lui and B. Dong. 1990. Growth response of *Isochrysis galbana* 3011 to seven kinds of heavy metals. Aquat. Sci. Fish. Abstr., 1 p.

Zhu, B., K.S. Gao, K.J. Wang, C.H. Ke and H.Q. Huang. 2012. Gonad differential proteins revealed with proteomics in oyster (*Saccostrea cucullata*) using alga as food contaminated with cadmium. Chemosphere 87(4): 397-403.

Zhu, Y., J. Wang, Y. Bai and R. Zhang. 2004. Cadmium, chromium, and copper induce polychromatocyte micronuclei in carp (*Cyprinus carpio* L.). Bull. Environ. Contam. Toxicol. 72(1): 78-86.

Zhu, Y., J. Jiang, Q. Huang, Z. Sun and H. Wang. 2007. The heavy metal content in organisms at Lake Dongting and its ecological assessment. J. Lake Sci. 19(6): 690-697.

Zhu, Y.L., J.H. Jiang, Q. Huang, Z.D. Sun, H.J. Wang and Y.K. Zhou. 2008. Contents, distribution and correlation of Cd, Pb, Hg, as in water, sediment and organisms from east Dongting Lake and Datong Lake. J. Agro-Environ. Sci. 27(4): 1377-1384.

Zhuang, D. and Y. Lin. 1991. The effects of nutrients and heavy metals on the plankton in marine enclosed ecosystem. Acta Oceanol. Sin. 10(4): 637-640.

Zia, S. and D.G. McDonald. 1994. Role of the gills and gill chloride cells in metal uptake in the freshwater-adapted rainbow trout, *Oncorhynchus mykiss*. Can. J. Fish. Aquat. Sci. 51: 2482-2492.

Zimmermann, S., F. Alt, J. Messerschmidt, A. Von Bohlen, H. Taraschewski and B. Sures. 2002. Biological availability of traffic-related platinum-group elements (palladium, platinum, and rhodium) and other metals to the zebra mussel (*Dreissena polymorpha*) in water containing road dust. Environ. Toxicol. Chem. 21(12): 2713-2718.

Zitova, A., M. Cross, R. Hernan, J. Davenport and D. Papkovsky. 2009. Respirometric acute toxicity screening assay using *Daphnia magna*. Chem. Ecol. 25(3): 217-227.

Zohouri, M.A., G.G. Pyle and C.M. Wood. 2001. Dietary Ca inhibits waterborne Cd uptake in Cd-exposed rainbow trout, *Oncorhynchus mykiss*. Comp. Biochem. Physiol.130C(3): 347-356.

Zolotukhina, E.Y., I.V. Dogushina and K.V. Neverov. 1993. Effect of some heavy metal ions on cholorophyll photostability in marine green macroalgae. Vestn. Mosk. Univ. Ser. 1: Mat. Mekh. 64-71.

Zou, E. and S. Bu. 1994. Acute toxicity of copper, cadmium, and zinc to the water flea, *Moina irrasa* (Cladocera). Bull. Environ. Contam. Toxicol. 52: 742-748.

Zuiderveen, J.A. and W.J. Birge. 1997. The relationship between chronic values in toxicity tests with *Ceriodaphnia dubia*. In: Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment (sixth volume), ASTM STP 1317, F.J. Dwyer, T.R. Doane and M.L. Hinman (*Eds*.), American Society for Testing and Materials. pp. 551-556.

Zynudheen, A.A. and G. Ninan. 2007. Incidence of lead, cadmium and mercury in freshwater fish from Saurashtra region of Gujarat (India). Fish. Technol. Soc. Fish. Technol. (India) 44(2): 199-204.

Appendix A Acceptable Freshwater Acute Toxicity Data

Appendix Table A-1. Acceptable Freshwater Acute Toxicity Data

(Values normalized to total hardness=100 mg/L as $CaCO_3$ using pooled hardness slope of 0.9789 and expressed as total cadmium).
(Underlined values are used in SMAV calculation and values in bold represent new/revised values since 2001 AWQC document).
(Species are organized phylogenetically).

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Hydra, (formerly, *Hydra attenuata*) *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**251.1**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	85.1	128.1	**150.0**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	145	172.0	**119.5**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**251.1**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	73.8	83.18	**112.0**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	125	76.44	**61.43**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**251.1**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	61.83	**222.7**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	84.31	**303.7**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	66.32	**238.9**	-	-	Clifford 2009

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**251.1**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	58.45	**210.6**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	43.84	**157.9**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	57.33	**206.5**	-	**184.8**	Clifford 2009
Hydra (Monecious species), *Hydra oligactis*	S, M	-	210	320.00	**154.8**	-	**154.8**	Karntanut and Pascoe 2002
Green hydra (non-budding), *Hydra viridissima*	S, U	Cadmium chloride	19.5 (19-20)	3.0	**14.86**	-	-	Holdway et al. 2001
Green hydra (Monecious species), *Hydra viridissima*	S, M	-	210	210.0	**101.6**	-	**38.85**	Karntanut and Pascoe 2002
Hydra (male clone, Zurich strain), *Hydra vulgaris*	S, M	Cadmium chloride	204	310	**154.2**	-	-	Karntanut and Pascoe 2000
Hydra (non-budding), *Hydra vulgaris*	S, U	Cadmium chloride	19.5 (19-20)	82.5	**408.7**	-	-	Holdway et al. 2001
Hydra (male clone, Zurich strain), *Hydra vulgaris*	S, M	-	210	520	**251.5**	-	-	Karntanut and Pascoe 2002
Hydra (Dioecious strain), *Hydra vulgaris*	S, M	-	210	160	**77.38**	-	**187.1**	Karntanut and Pascoe 2002
Planarian, *Dendrocoelum lacteum*	R,M	Cadmium chloride	87	23,220	**26,607**	28,454	**26,607**	Ham et al. 1995

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Planarian (10-15 mm), *Dugesia dorotocephala*	S, U	Cadmium sulfate	170 (160-180)	690	**410.4**	-	**410.4**	Garcia-Medina et al. 2013
Worm (adult), *Lumbriculus variegatus*	S, M	Cadmium nitrate	290	780	275.0	264.2	275.0	Schubauer-Berigan et al. 1993
Worm (adult, 1.0 cm), *Nais elinguis*	R, M	Cadmium chloride	17.89	27	**145.5**	-	**145.5**	Shuhaimi-Othman et al. 2012b
Oligochaete, *Branchiura sowerbyi*	S, M	Cadmium sulfate	5.3	240	4,255	-	-	Chapman et al. 1982
Oligochaete (2.0 cm, 2.05 mg), *Branchiura sowerbyi*	S, U	Cadmium chloride	185	58,020	**31,767**	4,754	**11,627**	Ghosal and Kaviraj 2002
Oligochaete, *Limnodrilus hoffmeisteri*	S, M	Cadmium sulfate	5.3	170	3,014[i]	-	-	Chapman et al. 1982
Oligochaete (30-44 mm), *Limnodrilus hoffmeisteri*	F, M	Cadmium	152	2,400	1,593	1,568	1,593	Williams et al. 1985
Oligochaete, *Quistadrilus multisetosus*	S, M	Cadmium sulfate	5.3	320	5,674	6,338	5,674	Chapman et al. 1982
Oligochaete, *Rhyacodrilus montana*	S, M	Cadmium sulfate	5.3	630	11,171	12,479	11,171	Chapman et al. 1982
Oligochaete, *Spirosperma ferox*	S, M	Cadmium sulfate	5.3	350	6,206	6,933	6,206	Chapman et al. 1982
Oligochaete, *Spirosperma nikolskyi*	S, M	Cadmium sulfate	5.3	450	7,979	8,913	7,979	Chapman et al. 1982
Oligochaete, *Stylodrilus heringianus*	S, M	Cadmium sulfate	5.3	550	9,752	10,894	9,752	Chapman et al. 1982

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium sulfate	5.3	320	5,674	-	-	Chapman et al. 1982
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium chloride	128	3,200	2,513	-	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium chloride	128	1,700	1,335	-	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	-	1,032	NA[d]	-	-	Fargasova 1994a
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (15ºC)	56,000	**24,059**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (20ºC)	51,900	**22,297**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (25ºC)	61,470	**26,409**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (30ºC)	28,550	**12,266**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	12	130	**1,036**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	45	440	**961.3**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	173	7,950	**4,648**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	305	8,500	**2,853**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	250	1,658	**676.0**	-	-	Redeker and Blust 2004
Tubificid worm (4-5 wk), *Tubifex tubifex*	S, M	Cadmium chloride	-	400	NA[d]	2,753	**4,193**	Maestre et al. 2009
Earthworm, (formerly, *Varichaeta pacifica*) *Varichaetadrilus pacificus*	S, M	Cadmium sulfate	5.3	380	6,738	7,527	6,738	Chapman et al. 1982
Leech (1-20 mm), *Glossiphonia complanata*	R, M	Cadmium chloride	122.8	480	392.5	389.5	392.5	Brown and Pascoe 1988

Species	Method[a]	Chemical	Hardness (mg/L CaCO$_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Leech (cocoon), *Nephelopsis obscura*	S, M	Cadmium chloride	-	832.6	-	-	**NA**[e]	Wicklum et al. 1997
Pond snail (juvenile, stage I, 4 wk), *Lymnaea stagnalis*	S, M	Cadmium chloride	250	752	**306.6**	-	-	Coeurdassier et al. 2004
Pond snail (juvenile, stage II, 9 wk), *Lymnaea stagnalis*	S, M	Cadmium chloride	250	1,515	**617.7**	-	-	Coeurdassier et al. 2004
Pond snail (adult, 20 wk), *Lymnaea stagnalis*	S, M	Cadmium chloride	250	1,585	**646.3**	-	-	Coeurdassier et al. 2004
Pond snail (juvenile, 25 mm), *Lymnaea stagnalis*	R, M	Cadmium chloride	135 (130-140)	367.5[f] (347 reported-dissolved)	**273.9**	-	**427.9**	Pais 2012
Snail, *Aplexa hypnorum*	F, M	Cadmium chloride	44.8	93	204.1	210.3	204.1	Holcombe et al. 1984; Phipps and Holcombe 1985
Snail, *Gyraulus sp.*	R, M	Cadmium chloride	24	>467.7[f] (>455 reported dissolved)	**>1,891**	-	-	Mebane et al. 2012
Snail, *Gyraulus sp.*	R, M	Cadmium chloride	21	>75.04[f] (>73 reported dissolved)	**>345.7**	-	**>808.4**	Mebane et al. 2012
Snail (adult, 3.3-15 mm), *Physa acuta*	R, U	Cadmium chloride	44	963.6	**2,152**	-	**2,152**	Woodard 2005
Pouch snail (adult), *Physa gyrina*	S, M	-	200	1,370	695.0[c]	-	-	Wier and Walter 1976
Pouch snail (juvenile), *Physa gyrina*	S, M	-	200	410	208.0	202.6	208.0	Wier and Walter 1976
Mussel (juvenile), *Actinonaias pectorosa*	S, M	-	82	46.40	56.34	-	-	Keller, Unpublished
Mussel (juvenile), *Actinonaias pectorosa*	S, M	-	84	69	81.83	68.38	67.90	Keller, Unpublished

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Neosho mucket (juvenile, 5 d), *Lampsilis rafinesqueana*	R, M	Cadmium nitrate	44 (40-48)	20	**44.67**	-	**44.67**	Wang et al. 2010d
Fatmucket (glochidia), *Lampsilis siliquoidea*	S, M	Cadmium nitrate	44 (40-48)	>227	**>507.0**[c]	-	-	Wang et al. 2010d
Fatmucket (juvenile, 5 d), *Lampsilis siliquoidea*	R, M	Cadmium nitrate	44 (40-48)	16	**35.73**	-	-	Wang et al. 2010d
Fatmucket (juvenile, 2 mo.), *Lampsilis siliquoidea*	R, M	Cadmium nitrate	44 (40-48)	>62	**>138.5**[c]	-	-	Wang et al. 2010d
Fatmucket (juvenile, 6 mo.), *Lampsilis siliquoidea*	R, M	Cadmium nitrate	44 (40-48)	199	**444.4**[c]	-	**35.73**	Wang et al. 2010d
Southern fatmucket, *Lampsilis straminea claibornensis*	S, M	-	40	38	93.17	96.44	93.17	Keller, Unpublished
Yellow sandshell, *Lampsilis teres*	S, M	-	40	11	26.97	-	-	Keller, Unpublished
Yellow sandshell (juvenile), *Lampsilis teres*	S, M	-	40	33	80.91	48.35	46.71	Keller, Unpublished
Mussel (juvenile), *Lasmigona subviridis*	R, M	Cadmium chloride	84	57.77	**68.51**	-	**68.51**	Black 2001
Mussel, *Utterbackia imbecillis*	S, M	Cadmium chloride	90	114.7	127.1	-	-	Keller, Unpublished
Mussel, *Utterbackia imbecillis*	S, M	Cadmium chloride	90	111.8	123.9	-	-	Keller, Unpublished
Mussel (juvenile), *Utterbackia imbecillis*	S, M	Cadmium chloride	86	93.0	107.8	-	-	Keller, Unpublished
Mussel (juvenile), *Utterbackia imbecillis*	S, M	Cadmium chloride	92	81.9	88.85	-	-	Keller, Unpublished
Mussel (juvenile, 12 d), *Utterbackia imbecillis*	S, M	Cadmium chloride	39	9	22.62	-	-	Keller and Zam 1991

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mussel (juvenile, 12 d), *Utterbackia imbecillis*	S, M	Cadmium chloride	90	107	118.6	-	-	Keller and Zam 1991
Mussel (juvenile), *Utterbackia imbecillis*	R, M	Cadmium chloride	84	20.42	**24.22**	86.82	**71.76**	Black 2001
Southern rainbow mussel (juvenile), *Villosa vibex*	S, M	-	40	30	73.55	-	-	Keller, Unpublished
Southern rainbow mussel (juvenile), *Villosa vibex*	S, M	-	186	125	68.08	71.16	70.76	Keller, Unpublished
Cladoceran, *Alona affinis*	S, U	Cadmium nitrate	109	546	501.7	500.1	501.7	Ghosh et al. 1990
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90	54	59.86	-	-	Bitton et al. 1996
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	R, M	Cadmium chloride	80	54.5	67.79	-	-	Diamond et al. 1997
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90	55.9	61.96	-	-	Lee et al. 1997
Cladoceran (3rd-4th instar), *Ceriodaphnia dubia*	S, M	Cadmium chloride	80	64.26	**79.93**	-	-	Black 2001
Cladoceran (neonate), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90	40.1	**44.45**	-	-	Jun et al. 2006
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M	Cadmium chloride	40	31.47	**77.16**	63.46	**64.03**	Shaw et al. 2006
Cladoceran (1st instar larva, <24 hr), *Ceriodaphnia reticulata*	S, U	Cadmium chloride	240	184	78.08	-	-	Elnabarawy et al. 1986
Cladoceran (<6hr), *Ceriodaphnia reticulata*	S, U	Cadmium chloride	120	110	92.00	83.08	84.76	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia ambigua*	S, M	Cadmium chloride	40	10.12	**24.81**	-	**24.81**	Shaw et al. 2006

Species	**Method[a]**	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Acute Value (µg/L)**	**Normalized Acute Value[b] (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	<1.6	NA[d]	-	-	Anderson 1948
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	45	65	142.0	-	-	Biesinger and Christensen 1972
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	27.07	NA[d]	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	28.36	NA[d]	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	35.45	NA[d]	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	51	9.9	19.13	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	104	33	31.75	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	105	34	32.41	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	197	63	32.44	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	209	49	23.81	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium chloride	105	30	28.60	-	-	Canton and Slooff 1982
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium chloride	209.2	30	14.56	-	-	Canton and Slooff 1982
Cladoceran (1st instar larva, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	240	178	75.54	-	-	Elnabarawy et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	20	16.73	-	-	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	40	33.46	-	-	Hall et al. 1986
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	76	59	**77.17**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	74	84	**112.8**	-	-	Nebeker et al. 1986a

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	41	99	**236.9**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	38	164	**422.8**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	76	71	**92.87**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	74	178	**239.0**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	74	116	**155.7**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	71	101	**141.2**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	71	4	**5.592**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	41	8	**19.15**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	38	16	**41.25**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	74	146	**196.0**	-	-	Nebeker et al. 1986a
Cladoceran (genotype A), *Daphnia magna*	S, M	Cadmium chloride	170	3.6	2.141	-	-	Baird et al. 1991
Cladoceran (genotype A-1), *Daphnia magna*	S, M	Cadmium chloride	170	9.0	5.353	-	-	Baird et al. 1991
Cladoceran (genotype A-2), *Daphnia magna*	S, M	Cadmium chloride	170	9.0	5.353	-	-	Baird et al. 1991
Cladoceran (genotype B), *Daphnia magna*	S, M	Cadmium chloride	170	4.5	2.676	-	-	Baird et al. 1991
Cladoceran (genotype E), *Daphnia magna*	S, M	Cadmium chloride	170	27.1	16.12	-	-	Baird et al. 1991
Cladoceran (genotype S-1), *Daphnia magna*	S, M	Cadmium chloride	170	115.9	68.93	-	-	Baird et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	10	37.9	**361.0**	-	-	Hickey and Vickers 1992

Species	**Method[a]**	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Acute Value (µg/L)**	**Normalized Acute Value[b] (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Cladoceran (<24 hr, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	129.4	<u>76.96</u>	-	-	Stuhlbacher et al. 1992, 1993
Cladoceran (<24 hr, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	24.5	<u>14.57</u>	-	-	Stuhlbacher et al. 1992, 1993
Cladoceran (neonate, 3 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	228.8	136.1[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 3 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	25.4	15.11[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 6 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	49.1	29.20[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 6 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	250.1	148.7[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 10 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	131.2	78.03[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 10 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	319.3	189.9[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 20 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	326.3	194.1[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 20 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	139.9	83.21[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 30 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	146.7	87.25[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 30 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	355.3	211.3[c]	-	-	Stuhlbacher et al. 1993
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	250	280	<u>114.2</u>	-	-	Crisinel et al. 1994

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	360	NA[d]	-	-	Fargasova 1994a
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170	9.5	5.650	-	-	Guilhermino et al. 1996
Cladoceran (clone S-1), *Daphnia magna*	S, M	Cadmium sulfate	46.1	112	239.0	-	-	Barata et al. 1998
Cladoceran (clone S-1), *Daphnia magna*	S, M	Cadmium sulfate	90.7	106	116.6	-	-	Barata et al. 1998
Cladoceran (clone S-1), *Daphnia magna*	S, M	Cadmium sulfate	179	233	131.8	-	-	Barata et al. 1998
Cladoceran (clone A), *Daphnia magna*	S, M	Cadmium sulfate	46.1	30.1	64.22	-	-	Barata et al. 1998
Cladoceran (clone A), *Daphnia magna*	S, M	Cadmium sulfate	90.7	23.4	25.74	-	-	Barata et al. 1998
Cladoceran (clone A), *Daphnia magna*	S, M	Cadmium sulfate	179	23.6	13.35	-	-	Barata et al. 1998
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	18	66	**353.6**	-	-	Baer et al. 1999
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	18	69	**369.6**	-	-	Baer et al. 1999
Cladoceran (<24 hr), *Daphnia magna*	S, M	-	170	3.3	**1.963**	-	-	Barata and Baird 2000
Cladoceran (≤ 24 hr; Source 1), *Daphnia magna*	S, M	Cadmium chloride	170	26	**15.46**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 2), *Daphnia magna*	S, M	Cadmium chloride	170	34	**20.22**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 3), *Daphnia magna*	S, M	Cadmium chloride	170	39	**23.20**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 4), *Daphnia magna*	S, M	Cadmium chloride	170	48	**28.55**	-	-	Ward and Robinson 2005

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (≤ 24 hr; Source 5), *Daphnia magna*	S, M	Cadmium chloride	170	55	**32.71**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 6), *Daphnia magna*	S, M	Cadmium chloride	170	63	**37.47**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 7), *Daphnia magna*	S, M	Cadmium chloride	170	100	**59.48**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 8), *Daphnia magna*	S, M	Cadmium chloride	170	>120	**>71.37**	-	-	Ward and Robinson 2005
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	40	101.20	**248.1**	-	-	Shaw et al. 2006
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	44	3	**6.700**	-	-	Yim et al. 2006
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	150	4	**2.689**	-	-	Yim et al. 2006
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	-	41.1	**NA[d]**	-	-	Jemec et al. 2007
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	93	318.76	**342.2**	-	-	Mohammed 2007
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, M	Cadmium chloride	240	77.6	**32.91**	-	-	Xie et al. 2007
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170	79.05	**47.02**	-	-	Ferreira et al. 2008a
Cladoceran (<24 hr, clone O), *Daphnia magna*	S, M	Cadmium chloride	-	250	**NA[d]**	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone E), *Daphnia magna*	S, M	Cadmium chloride	-	260	**NA[d]**	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone R), *Daphnia magna*	S, M	Cadmium chloride	-	285	**NA[d]**	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone F), *Daphnia magna*	S, M	Cadmium chloride	-	320	**NA[d]**	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone B), *Daphnia magna*	S, M	Cadmium chloride	-	330	**NA[d]**	-	-	Haap and Kohler 2009

Species	Method[a]	Chemical	Hardness (mg/L CaCO$_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<24 hr, clone X), *Daphnia magna*	S, M	Cadmium chloride	-	355	**NA**[d]	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone K), *Daphnia magna*	S, M	Cadmium chloride	-	550	**NA**[d]	-	-	Haap and Kohler 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	85 (80-90)	19.87	**23.29**	-	-	Kim et al. 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U	-	170 (160-180)	571.5	**339.9**	-	**-**	Perez and Beiras 2010
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	~170	20.1	**11.95**	-	-	Loureiro et al. 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=0.46 mg/L (pH=8.1)	7.5	**NA**[d]	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=8.1)	14.2	**NA**[d]	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=192 mg/L (pH=8.1)	24.8	**NA**[d]	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=5.8)	>170	**NA**[d]	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=7.0)	46.2	**NA**[d]	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=8.2)	17.5	**NA**[d]	27.14	**40.62**	Tan and Wang 2011
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium nitrate	-	90.23	NA[d]	-	-	Canton and Adema 1978
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	57	47	81.47	-	-	Bertram and Hart 1979
Cladoceran (neonate), *Daphnia pulex*	S, M	Cadmium chloride	65	62	**94.51**	-	-	Niederlehner 1984
Cladoceran (1st instar larva, <24 hr), *Daphnia pulex*	S, U	Cadmium chloride	240	319	135.4	-	-	Elnabarawy et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	80	66.91	-	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	100	83.64	-	-	Hall et al. 1986

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium chloride	53.5	70.1	129.3	-	-	Stackhouse and Benson 1988
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85	66	77.37	-	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85	99	116.1	-	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85	70	82.06	-	-	Roux et al. 1993
Cladoceran (≤ 24 hr), *Daphnia pulex*	S, M	Cadmium chloride	40	44.96	**110.2**	-	-	Shaw et al. 2006
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	17.0	16.86	**95.53**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	24.0	23.61	**95.43**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	30.0	46.09	**149.7**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	47.0	24.73	**51.78**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	67.1	71.94	**106.3**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	119	116.9	**98.59**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	175	155.1	**89.68**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	19.0	26.98	**137.1**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32.0	46.09	**140.6**	-	-	Clifford 2009; Clifford and McGeer 2010

NMED Exhibit 70

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	66.9	70.82	**104.9**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	112	89.93	**80.47**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	158	68.57	**43.81**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	46.09	**140.6**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	33.72	**102.9**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	42.72	**130.3**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	46.09	**140.6**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	52.83	**161.2**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	43.84	**133.7**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	48.34	**147.4**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	73.07	**222.9**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	62.95	**192.0**	-	-	Clifford 2009; Clifford and McGeer 2010

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	52.83	**161.2**	93.77	**109.2**	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia similis*	S, M	Cadmium nitrate	44	57.89	**129.3**	-	**129.3**	Rodgher et al. 2010
Cladoceran, *Diaphanosoma brachyurum*	S, U	Cadmium chloride	67.1	69.80	**103.1**	-	**103.1**	Mano et al. 2011
Cladoceran, *Moina macrocopa*	S, U	Cadmium chloride	82	71.25	86.51	87.16	86.51	Hatakeyama and Yasuno 1981b
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	11.1	7	60.19	-	-	Giesy et al. 1977
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	43.5	24.5	55.33	61.10	57.71	Spehar and Carlson 1984a,b
Cyclopoid copepod, *Cyclops varicans*	S, U	Cadmium nitrate	109	493	453.0	451.6	453.0	Ghosh et al. 1990
Copepod (0.58 mm), *Diaptomus forbesi*	S, U	Cadmium chloride	185	5,700	**3,121**	-	**3,121**	Ghosal and Kaviraj 2002
Isopod, (formerly, *Asellus bicrenata*) *Caecidotea bicrenata*	F, M	Cadmium chloride	220	2,129	983.8	955.0	983.8	Bosnak and Morgan 1981
Isopod, *Lirceus alabamae*	F, M	Cadmium chloride	152	150	99.54	97.98	99.54	Bosnak and Morgan 1981
Amphipod (4 mm), *Crangonyx pseudogracilis*	R, U	Cadmium chloride	50	1,700	3,350	3,439	3,350	Martin and Holdich 1986
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	43.5	68.3	154.3	159.2	154.3	Spehar and Carlson 1984a,b

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Amphipod (large juvenile & young adult), *Hyalella azteca*	S, M	Cadmium chloride	34	8	**23.00**	-	**23.00**	Nebeker et al. 1986b
Prawn (post larva), *Macrobrachium rosenbergii*	R, U	Cadmium chloride	-	36.12	-	-	**NA[e]**	Sowdeswari et al. 2012
Crayfish (adult, 1.8 g), *Orconectes immunis*	F, M	Cadmium chloride	44.4	>10,200	>22,579	>23,281	>22,579	Phipps and Holcombe 1985
Crayfish (adult, 4.58 g), *Orconectes juvenilis*	R, M	Cadmium chloride	44.1	2,440	**5,437[c]**	-	-	Wigginton and Birge 2007
Crayfish (3rd-5th instar, 0.2 g), *Orconectes juvenilis*	R, M	Cadmium chloride	44	60	**134.0**	-	**134.0**	Wigginton 2005; Wigginton and Birge 2007
Crayfish, *Orconectes limosus*	S, M	Cadmium chloride	-	400	-	NA[e]	NA[e]	Boutet and Chaisemartin 1973
Crayfish (adult, 7.06 g), *Orconectes placidus*	R, M	Cadmium chloride	44.1	487	**1,085[c]**	-	-	Wigginton and Birge 2007
Crayfish (3rd-5th instar, 0.2 g), *Orconectes placidus*	R, M	Cadmium chloride	54.6	37	**66.89**	-	**66.89**	Wigginton 2005; Wigginton and Birge 2007
Crayfish, *Orconectes virilis*	F, M	Cadmium chloride	26	6,100	22,800	-	-	Mirenda 1986
Crayfish (adult, 12.8 g), *Orconectes virilis*	R, M	Cadmium chloride	42.5	3,300	**7,625[i]**	23,988	22,800	Wigginton and Birge 2007
Crayfish (adult, 15.5 g), *Procambarus acutus*	R, M	Cadmium chloride	44.5	368	**812.8**	-	**812.8**	Wigginton and Birge 2007
Crayfish (adult, 5.14 g), *Procambarus alleni*	R, M	Cadmium chloride	45.8	3,070	**6,592**	-	**6,592**	Wigginton and Birge 2007

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Red swamp crayfish (juvenile), *Procambarus clarkii*	S, M	Cadmium chloride	30	1,040	3,379[c]	-	-	Naqvi and Howell 1993
Red swamp crayfish (adult, 18.5 g), *Procambarus clarkii*	R, M	Cadmium chloride	52.9	2,660	**4,960[c]**	-	-	Wigginton and Birge 2007
Red swamp crayfish (3rd to 5th instar, 0.02 g), *Procambarus clarkii*	R, M	Cadmium chloride	42.1	624	**1,455**	3,536	**1,455**	Wigginton 2005; Wigginton and Birge 2007
Mayfly, *Baetis tricaudatus*	R, M	Cadmium chloride	24	>456.4[f] (>444 reported dissolved)	**>1,845[g]**	-	-	Mebane et al. 2012
Mayfly, *Baetis tricaudatus*	R, M	Cadmium chloride	21	76.07[f] (74 reported dissolved)	**350.4**	-	**350.4**	Mebane et al. 2012
Mayfly, *Ephemerella subvaria*	S, U	Cadmium sulfate	44	2,000	4,467	4,607	4,467	Warnick and Bell 1969
Mayfly (formerly, *Ephemerella grandis grandis*) *Drunella grandis grandis*	F, M	Cadmium chloride	-	28,000	-	NA[e]	NA[e]	Clubb et al. 1975
Mayfly (nymph, 24 mm), *Hexagenia rigida*	S, M	Cadmium	79.1	6,200	**7,798**	-	**7,798**	Leonhard et al. 1980
Mayfly (nymph), *Rhithrogena hageni*	F, M	Cadmium sulfate	48	10,794[f] (10,500 reported dissolved)	**22,138**	-	**22,138**	Brinkman and Vieira 2007; Brinkman and Johnston 2008
Stonefly, *Pteronarcella badia*	F, M	Cadmium chloride	-	18,000	-	NA[e]	NA[e]	Clubb et al. 1975
Little green stonefly, *Sweltsa sp.*	R, M	Cadmium chloride	26	>5,386[f] (>5,239 reported dissolved)	**>20,132**	-	**>20,132**	Mebane et al. 2012

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Caddisfly, *Arctopsyche sp.*	R, M	Cadmium chloride	28	>470.8[f] (>458 reported dissolved)	**>1,637**	-	**>1,637**	Mebane et al. 2012
Midge (larva), *Culicoides furens*	S, U	-	-	300	-	-	-	Vedamanikam and Shazilli 2008a
Midge (larva), *Culicoides furens*	S, M	Cadmium chloride	- (35ºC)	245.2	-	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Culicoides furens*	S, M	Cadmium chloride	- (25ºC)	245.2	-	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Culicoides furens*	S, M	Cadmium chloride	- (10ºC)	183.9	-	-	**NA[e]**	Vedamanikam and Shazilli 2008b
Midge (3rd-4th instar larva), *Chironomus plumosus*	S, U	Cadmium chloride	80	12,700	**15,798**	-	-	Fargasova 2001, 2003
Midge (larva), *Chironomus plumosus*	S, U	-	-	400	**NA[d]**	-	-	Vedamanikam and Shazilli 2008a
Midge (larva), *Chironomus plumosus*	S, M	Cadmium chloride	- (35ºC)	367.8	**NA[d]**	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Chironomus plumosus*	S, M	Cadmium chloride	- (25ºC)	245.2	**NA[d]**	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Chironomus plumosus*	S, M	Cadmium chloride	- (10ºC)	183.9	**NA[d]**	-	**15,798**	Vedamanikam and Shazilli 2008b
Midge (10-12 mm), *Chironomus riparius*	F, M	-	152	>229,500	>152,301	-	-	Williams et al. 1985
Midge (4th instar larva), *Chironomus riparius*	R, M	Cadmium chloride	124	140,000	113,398[i]	-	-	Pascoe et al. 1990
Midge (3rd instar larva), *Chironomus riparius*	S, U	Cadmium chloride	170 (160-180)	128,840	**76,629[i]**	-	-	Lee et al. 2006a
Midge (3rd-4th instar larva), *Chironomus riparius*	S, M	Cadmium nitrate	10	331,000	**3,152,504[i]**	-	-	Gillis and Wood 2008
Midge (3rd-4th instar larva), *Chironomus riparius*	S, M	Cadmium nitrate	140	1,106,000	**795,496[i]**	195,967	>152,301	Gillis and Wood 2008
Bryozoa (ancenstrulae 2-3 d), *Pectinatella magnifica*	S, U	-	205	700	346.6	337.4	346.6	Pardue and Wood 1980

Species	Method^{a}	Chemical	Hardness (mg/L CaCO$_3$)	Acute Value (µg/L)	Normalized Acute Value^{b} (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Bryozoa (ancenstrulae 2-3 d), *Lophopodella carteri*	S, U	-	205	150	74.28	72.29	74.28	Pardue and Wood 1980
Bryozoa (ancenstrulae 2-3 d), *Plumatella emarginata*	S, U	-	205	1,090	539.7	525.3	539.7	Pardue and Wood 1980
Westslope cutthroat trout, *Oncorhynchus clarkii lewisi*	R, M	Cadmium chloride	32	1.542^{f} (1.5 reported dissolved)	**4.703^{i}**	-	-	Mebane et al. 2012
Westslope cutthroat trout, *Oncorhynchus clarkii lewisi*	R, M	Cadmium chloride	31	1.234^{f} (1.2 reported dissolved)	**3.883^{i}**	-	-	Mebane et al. 2012
Westslope cutthroat trout (young of the year), *Oncorhynchus clarkii lewisi*	R, M	Cadmium chloride	21	0.9663^{f} (0.94 reported dissolved)	**4.452^{i}**	-	-	Mebane et al. 2012
Rio Grande cutthroat trout (fry, 0.26 g), *Oncorhynchus clarkii virginalis*	F, M	Cadmium sulfate	44.9	2.467^{f} (2.40 reported dissolved)	**5.401**	-	**5.401**	Brinkman 2012
Coho salmon (adult), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	17.5	77.03^{c}	-	-	Chapman 1975
Coho salmon (parr), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	2.7	11.88	-	-	Chapman 1975
Coho salmon (yearling), *Oncorhynchus kisutch*	S, U	Cadmium	90	10.4	11.53^{i}	-	-	Lorz et al. 1978
Coho salmon (juvenile), *Oncorhynchus kisutch*	S, U	Cadmium chloride	41	3.4	8.137^{i}	12.58	11.88	Buhl and Hamilton 1991
Rainbow trout (4 mo.), *Oncorhynchus mykiss*	F, U	-	-	0.95	**NA^{d}**	-	-	Chapman 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	6	NA^{d}	-	-	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	7	NA^{d}	-	-	Kumada et al. 1973
Rainbow trout (smolt), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	4.1	17.28^{c}	-	-	Chapman 1975

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Rainbow trout (130 mm), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	31	1.75	5.506	-	-	Davies 1976a
Rainbow trout (2 mo.), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	-	6.60	NA[d]	-	-	Hale 1977
Rainbow trout (smolt, 68.19 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	>2.9	>12.22[c]	-	-	Chapman 1978
Rainbow trout (swim-up fry, 0.17 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.3	5.479	-	-	Chapman 1978
Rainbow trout (parr, 6.96 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.0	4.214	-	-	Chapman 1978
Rainbow trout (alevin), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	>27	>113.8[c]	-	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	S, U	Cadmium chloride	-	6.0	NA[d]	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	S, M	Cadmium chloride	43.5	2.3	5.194[i]	-	-	Spehar and Carlson 1984a;b
Rainbow trout (8.8 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	44.4	3.0	6.641	-	-	Phipps and Holcombe 1985
Rainbow trout (fry), *Oncorhynchus mykiss*	F, M	Cadmium chloride	9.2	<0.5	<5.167[g]	-	-	Cusimano et al. 1986
Rainbow trout (juvenile, 18.3 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	52	1.88	**3.565**	-	-	Stubblefield 1990
Rainbow trout (juvenile), *Oncorhynchus mykiss*	S, U	Cadmium chloride	41	1.50	3.590[i]	-	-	Buhl and Hamilton 1991
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	47	2.66	**5.569**	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	204	3.15	**1.567**	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	427	7.56	**1.825**[k]	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	49	3.02	**6.070**	-	-	Davies et al. 1993

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	224	6.12	**2.779**	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	422	5.70	**1.392**[k]	-	-	Davies et al. 1993
Rainbow trout (fry, 1.0 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	29	2.79	**9.371**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	258 (aged solution)	8.54	**3.376**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	281	13.4	**4.873**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 1.0 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	28	2.09	**7.265**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	276 (aged solution)	10.5	**3.886**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	281	10.0	**3.637**	-	-	Davies and Brinkman 1994b
Rainbow trout (juvenile, 4.5 g), *Oncorhynchus mykiss*	F, M	Cadmiun nitrate	140	22	**15.82**[j]	-	-	Hollis et al. 1999
Rainbow trout (263 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	30.7	0.71	2.255	-	-	Stratus Consulting 1999
Rainbow trout (659 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	29.3	0.47	1.563	-	-	Stratus Consulting 1999
Rainbow trout (1,150 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	31.7	0.51	1.570	-	-	Stratus Consulting 1999
Rainbow trout (1,130 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	30.2	0.38	1.227	-	-	Stratus Consulting 1999
Rainbow trout (299 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	30.0	1.29	4.191	-	-	Stratus Consulting 1999
Rainbow trout (289 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	89.3	2.85	3.183	-	-	Stratus Consulting 1999
Rainbow trout (juvenile, 12 g), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	20	2.07	**10.00**[j]	-	-	Hollis et al. 2000a
Rainbow trout (juvenile, 8-12 g), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	120	19.00	**15.89**[j]	-	-	Niyogi et al. 2004b

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Rainbow trout (swim-up fry, 0.131 g), *Oncorhynchus mykiss*	F, M	-	103	3.7	**<u>3.594</u>**	-	-	Besser et al. 2007
Rainbow trout (juvenile, 0.496 g), *Oncorhynchus mykiss*	F, M	-	103	5.2	**<u>5.051</u>**	-	-	Besser et al. 2007
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	S, M	Cadmium chloride	-	0.753	**NA[d]**	-	-	Birceanu et al. 2008
Rainbow trout (swim-up fry, 0.2-0.4 g), *Oncorhynchus mykiss*	R, M	Cadmium chloride	19.7	0.864[f] (0.84 reported-dissolved)	**4.237[i]**	-	-	Mebane et al. 2007; 2008
Rainbow trout (swim-up fry, 0.2-0.4 g), *Oncorhynchus mykiss*	R, M	Cadmium chloride	29.4	0.915[f] (0.89 reported-dissolved)	**3.032[i]**	-	-	Mebane et al. 2007; 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48)	2.75	**6.142[i]**	-	-	Niyogi et al. 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48) (pH=5.8)	3.21	**7.169[i]**	-	-	Niyogi et al. 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48) (pH=8.8)	3.08	**6.879[i]**	-	-	Niyogi et al. 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48) (Alkalinity=90 mg/L)	1.02	**2.278[i]**	-	-	Niyogi et al. 2008
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	21	0.8224[f] (0.8 reported dissolved)	**3.789[i]**	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	7	0.4934[f] (0.48 reported dissolved)	**6.663[i]**	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	13	1.018[f] (0.99 reported dissolved)	**7.500[i]**	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	24	1.336[f] (1.3 reported dissolved)	**5.401[i]**	-	-	Mebane et al. 2012

Species	**Method**[a]	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Acute Value (µg/L)**	**Normalized Acute Value**[b] **(µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	32	0.9560[f] (0.93 reported dissolved)	**2.916**[i]	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	29	0.8532[f] (0.83 reported dissolved)	**2.866**[i]	-	-	Mebane et al. 2012
Rainbow trout (young of the year), *Oncorhynchus mykiss*	R, M	Cadmium chloride	21	0.3495[f] (0.34 reported dissolved)	**1.610**[i]	-	-	Mebane et al. 2012
Rainbow trout (1 dph, 0.08 g, 14.3 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	103	>52.31[f] (>49.40 reported dissolved)	**>50.81**[c]	-	-	Calfee et al. 2014
Rainbow trout (18 dph, 0.1 g, 24.33 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	104	3.061[f] (2.89 reported dissolved)	**2.945**	-	-	Calfee et al. 2014
Rainbow trout (32 dph, 0.12 g, 26.67 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	107	5.115[f] (4.83 reported dissolved)	**4.786**	-	-	Calfee et al. 2014
Rainbow trout (46 dph, 0.22 g, 32.1 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	107	2.933[f] (2.77 reported dissolved)	**2.745**	-	-	Calfee et al. 2014
Rainbow trout (60 dph, 0.33 g, 37.1 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	104	3.929[f] (3.71 reported dissolved)	**3.780**	-	-	Calfee et al. 2014
Rainbow trout (74 dph, 0.42 g, 40.3 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	96	4.808[f] (4.54 reported dissolved)	**5.003**	-	-	Calfee et al. 2014
Rainbow trout (95 dph, 0.7 g, 45.43 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	103	3.135[f] (2.96 reported dissolved)	**3.045**	-	-	Calfee et al. 2014
Rainbow trout (1 dph), *Oncorhynchus mykiss*	F, M	Cadmium chloride	100	>12.71[f] (>12 reported dissolved)	**>12.71**[c]	-	-	Wang et al. 2014a
Rainbow trout (juvenile, 26 dph), *Oncorhynchus mykiss*	F, M	Cadmium chloride	100	5.401[f] (5.1 reported dissolved)	**5.400**	4.265	**3.727**	Wang et al. 2014a
Chinook salmon (at hatch), *Oncorhynchus tshawytscha*	F, U	-	-	>25	**NA**[d]	-	-	Chapman 1973

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	F, U	-	-	1.9	**NA**[d]	-	-	Chapman 1973
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	25	1.41	5.477	-	-	Chapman 1978; 1982
Chinook salmon (alevin, 0.05 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>26	>109.6[g]	-	-	Chapman 1978
Chinook salmon (swim-up fry, 0.23 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	1.8	7.586	-	-	Chapman 1978
Chinook salmon (parr, 11.58 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	3.5	14.75[c]	-	-	Chapman 1978
Chinook salmon (smolt, 32.46 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>2.9	>12.22[c]	-	-	Chapman 1978
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium sulfate	21	1.1	5.068	-	-	Finlayson and Verrue 1982
Chinook salmon (9-13 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	211	26	12.52[i]	-	-	Hamilton and Buhl 1990
Chinook salmon (18-21 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	343	57	17.05[i]	8.708	**5.949**	Hamilton and Buhl 1990
Lake whitefish (yearling, 140 mm, 22 g), *Coregonus clupeaformis*	F, M	-	81	530	**651.3**	-	**651.3**	McNicol 1997
Mountain whitefish (209 g), *Prosopium williamsoni*	F, M	Cadmium chloride	52	>8.29	**>15.72**	-	**>15.72**	Stubblefield 1990
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	43.5	1.4	3.162[i]	-	-	Spehar and Carlson 1984a;b
Brown trout (fingerling, 22.4 g), *Salmo trutta*	F, M	Cadmium chloride	48	2.85	**5.845**	-	-	Stubblefield 1990

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Brown trout (fingerling), *Salmo trutta*	F, M	Cadmium sulfate	37.6	2.37	**6.173**	-	-	Davies and Brinkman 1994c
Brown trout (fry), *Salmo trutta*	F, M	Cadmium sulfate	29.2	1.23	**4.104**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (fry), *Salmo trutta*	F, M	Cadmium sulfate	67.6	3.9	**5.721**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (fry), *Salmo trutta*	F, M	Cadmium sulfate	151	10.1	**6.746**	3.263	**5.642**	Brinkman and Hansen 2004a; 2007
Bull trout (76.1 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	30.7 (pH=7.5)	0.91	2.891	-	-	Stratus Consulting 1999
Bull trout (200 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	29.3 (pH=7.5)	0.99	3.292	-	-	Stratus Consulting 1999
Bull trout (221 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	31.7 (pH=7.5)	1.00	3.079	-	-	Stratus Consulting 1999
Bull trout (218 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	30.2 (pH=7.5)	0.90	2.905	-	-	Stratus Consulting 1999
Bull trout (84.2 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	30.0 (pH=6.5)	2.89	9.390	-	-	Stratus Consulting 1999
Bull trout (72.7 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	89.3 (pH=7.5)	6.06	6.769	4.353	4.190	Stratus Consulting 1999
Brook trout (yearling, 21 cm, 110 g), *Salvelinus fontinalis*	F, M	-	45 (44-46)	>405	**>884.8**	-	-	Drummond and Benoit 1976
Brook trout (100 g), *Salvelinus fontinalis*	F, M	Cadmium chloride	47.4	5,080	10,548	<3.623	**3,055**[h]	Holcombe et al. 1983
Goldfish, *Carassius auratus*	S, U	Cadmium chloride	20	2,340	11,307[i]	-	-	Pickering and Henderson 1966
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	20	2,130	10,293[i]	-	-	McCarty et al. 1978
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	140	46,800	33,661[i]	-	-	McCarty et al. 1978
Goldfish (8.8 g), *Carassius auratus*	F, M	Cadmium chloride	44.4	748.0	1,656	1,707	1,656	Phipps and Holcombe 1985

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Grass carp (18 mm, 17 g), *Ctenopharyngodon idellus*	S, U	Cadmium sulfate	-	9,420	-	-	NA[e]	Yorulmazlar and Gul 2003
Common carp (fry), *Cyprinus carpio*	S, U	Cadmium nitrate	100	4,300	4,299	-	-	Suresh et al. 1993a
Common carp (fingerling), *Cyprinus carpio*	S, U	Cadmium nitrate	100	17,100	17,097	-	-	Suresh et al. 1993a
Common carp (yolk absorbed), *Cyprinus carpio*	R, U	Cadmium chloride	-	140	NA[d]	-	-	Ramesha et al. 1997
Common carp (fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,840	NA[d]	-	-	Ramesha et al. 1997
Common carp (advanced fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,910	NA[d]	-	-	Ramesha et al. 1997
Common carp (fingerling), *Cyprinus carpio*	R, U	Cadmium chloride	-	4,560	NA[d]	-	-	Ramesha et al. 1997
Common carp (fry, 3.34 cm, 0.33 g), *Cyprinus carpio*	S, U	Cadmium chloride	185	220,770	**120,874**	-	-	Ghosal and Kaviraj 2002
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	<125	43,170	**34,693**	-	-	Datta et al. 2003
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	187.5 (125-250)	48,390	**26,148**	-	-	Datta et al. 2003
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	312.5 (250-375)	116,450	**38,164**	-	-	Datta et al. 2003
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	>375	310,480	**85,122**	8,573	**30,781**	Datta et al. 2003
Red shiner (adult, 0.80-2.0 g), *Cyprinella lutrensis*	S, M	Cadmium sulfate	85.5	6,620	7,716	7,762	7,716	Carrier 1987; Carrier and Beitinger 1988a

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Zebrafish (3-7 d, larva), *Danio rerio*	R, U	Cadmium chloride	177.5	2,113	**1,205**	-	-	Blechinger et al. 2002
Zebrafish (adult), *Danio rerio*	R, M	Cadmium nitrate	141 (28°C)	4,047[f] (3,822 reported dissolved)	**2,891**	-	-	Alsop and Wood 2011
Zebrafish (larva), *Danio rerio*	R, M	Cadmium nitrate	141 (26.6°C)	1,832[f] (1,730 reported dissolved)	**1,309**	-	-	Alsop and Wood 2011
Zebrafish (larva), *Danio rerio*	R, M	Cadmium nitrate	7.8 (26.6°C)	125.2[f] (121.8 reported dissolved)	**1,521**	-	-	Alsop and Wood 2011
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (18°C)	13,657	**5,569**	-	-	Vergauwen 2012; Vergauwen et al. 2013
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (26°C)	11,510	**4,693**	-	-	Vergauwen 2012; Vergauwen et al. 2013
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (30°C)	14,005	**5,710**	-	-	Vergauwen 2012; Vergauwen et al. 2013
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (34°C)	14,241	**5,807**	-	**2,967**	Vergauwen 2012; Vergauwen et al. 2013
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	20	1,050	5,074[i]	-	-	Pickering and Henderson 1966
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	20	630	3,044[i]	-	-	Pickering and Henderson 1966
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	360	72,600	20,716[i]	-	-	Pickering and Henderson 1966
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	360	73,500	20,973[i]	-	-	Pickering and Henderson 1966
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	11,200	5,654	-	-	Pickering and Gast 1972
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	12,000	6,058	-	-	Pickering and Gast 1972
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	6,400	3,231	-	-	Pickering and Gast 1972

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	2,000	1,010	-	-	Pickering and Gast 1972
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	4,500	2,272	-	-	Pickering and Gast 1972
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	40	21.5	52.71[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	48	11.7	24.00[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	39	19.3	48.51[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	45	42.4	92.63[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	44	29.0	64.77[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	47	54.2	113.5[i]	-	-	Spehar 1982
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,060	2,972[i]	-	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	2,900	2,817[i]	-	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,100	3,011[i]	-	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	262.5	7,160	2,783[i]	-	-	Birge et al. 1983
Fathead minnow (30 d), *Pimephales promelas*	S, M	Cadmium chloride	43.5	1,280	2,891[i]	-	-	Spehar and Carlson 1984a;b
Fathead minnow (0.6 g), *Pimephales promelas*	F, M	Cadmium chloride	44.4	1,500	3,320	-	-	Phipps and Holcombe 1985
Fathead minnow (larva), *Pimephales promelas*	S, U	Cadmium chloride	120	>150	>125.5[i]	-	-	Hall et al. 1986
Fathead minnow (30 d), *Pimephales promelas*	F, M	Cadmium nitrate	44	13.2	29.48	-	-	Spehar and Fiandt 1986
Fathead minnow (juvenile), *Pimephales promelas*	S, M	Cadmium chloride	141	3,420	2,443[i]	-	-	Sherman et al. 1987
Fathead minnow (juvenile), *Pimephales promelas*	S, M	Cadmium chloride	141	3,510	2,507[i]	-	-	Sherman et al. 1987

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Fathead minnow (0.8-2.0 g), *Pimephales promelas*	S, M	Cadmium sulfate	85.5	3,580	4,173[i]	-	-	Carrier 1987; Carrier and Beitinger 1988a
Fathead minnow (<24 hr), *Pimephales promelas*	S, M	Cadmium nitrate	290 (pH=6-6.5)	73	25.47[i]	-	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 hr), *Pimephales promelas*	S, M	Cadmium nitrate	290 (pH=7-7.5)	60	21.16[i]	-	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 hr), *Pimephales promelas*	S, M	Cadmium nitrate	290 (pH=8-8.8)	65	22.92[i]	-	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 hr), *Pimephales promelas*	S, U	Cadmium nitrate	60	210	346.2[i]	-	-	Rifici et al. 1996
Fathead minnow (1-2 d), *Pimephales promelas*	S, U	Cadmium nitrate	60	180	296.7[i]	59.08	**1,582**	Rifici et al. 1996
Colorado pikeminnow (larva, 9 mm), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	78	39.76	-	-	Buhl 1997
Colorado pikeminnow (juvenile, 43 mm), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	108	55.06	45.59	46.79	Buhl 1997
Northern pikeminnow (juvenile, 56 mm), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25	1,092	4,241	-	-	Andros and Garton 1980
Northern pikeminnow (juvenile, 60 mm), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25	1,104	4,288	4,493	4,265	Andros and Garton 1980
Bonytail (larva), *Gila elegans*	S, U	Cadmium chloride	199	148	75.45	-	-	Buhl 1997
Bonytail (juvenile), *Gila elegans*	S, U	Cadmium chloride	199	168	85.64	78.32	80.38	Buhl 1997
White sucker, *Catostomus commersoni*	F, M	Cadmium chloride	18	1,110	5,947	6,344	5,947	Duncan and Klaverkamp 1983

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Razorback sucker (larva), *Xyrauchen texanus*	S, U	Cadmium chloride	199	139	70.86	-	-	Buhl 1997
Razorback sucker (juvenile), *Xyrauchen texanus*	S, U	Cadmium chloride	199	160	81.56	74.08	76.02	Buhl 1997
Channel catfish (7.4 g), *Ictalurus punctatus*	F, M	Cadmium chloride	44.4	4,480	9,917	10,225	9,917	Phipps and Holcombe 1985
Flagfish, *Jordanella floridae*	F, M	Cadmium chloride	44	2,500	5,583	5,759	5,583	Spehar 1976a;b
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	900	7,739	-	-	Giesy et al. 1977
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	2,200	18,918	-	-	Giesy et al. 1977
Mosquitofish (juvenile), *Gambusia affinis*	S, U	Cadmium chloride	-	2,354	**NA**[d]	-	-	Annabi et al. 2009
Mosquitofish (adult), *Gambusia affinis*	S, U	Cadmium chloride	-	1,447	**NA**[d]	13,146	12,100	Annabi et al. 2009
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	20	1,270	6,137	-	-	Pickering and Henderson 1966
Guppy (3-4 wk), *Poecilia reticulata*	R, M	Cadmium chloride	105	3,800	3,622	-	-	Canton and Slooff 1982
Guppy (3-4 wk), *Poecilia reticulata*	R, M	Cadmium chloride	209.2	11,100	5,388	-	-	Canton and Slooff 1982
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	-	18,635	**NA**[d]	4,981	4,929	Yilmaz et al. 2004
Threespine stickleback, *Gasterosteus aculeatus*	S, U	Cadmium chloride	115	6,500	5,668	-	-	Pascoe and Cram 1977
Threespine stickleback, *Gasterosteus aculeatus*	R, M	Cadmium chloride	107	23,000	21,522	11,002	11,045	Pascoe and Mattey 1977
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	40	4	9.807	-	-	Palawski et al. 1985

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	285	10	3.587	5.916	5.931	Palawski et al. 1985
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	20	2,840	13,724[i]	-	-	Pickering and Henderson 1966
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	360	66,000	18,832[i]	-	-	Pickering and Henderson 1966
Green sunfish, *Lepomis cyanellus*	F, M	Cadmium chloride	335	20,500	6,276	-	-	Jude 1973
Green sunfish (juvenile), *Lepomis cyanellus*	S, M	Cadmium sulfate	85.5	11,520	13,427[i]	5,997	6,276	Carrier 1987; Carrier and Beitinger 1988b
Bluegill (juvenile, 1.5-3.5 g), *Lepomis macrochirus*	F, M	Cadmium sulfate	20	1,700	**8,215**	-	-	Lemke 1965
Bluegill (juvenile, 1.5-3.5 g), *Lepomis macrochirus*	F, M	Cadmium sulfate	20	>2,100	**>10,148**	-	-	Lemke 1965
Bluegill (juvenile, 1.5-3.5 g), *Lepomis macrochirus*	F, M	Cadmium sulfate	350	22,200	**6,512**	-	-	Lemke 1965
Bluegill, *Lepomis macrochirus*	S, U	Cadmium chloride	20	1,940	9,375[i]	-	-	Pickering and Henderson 1966
Bluegill, *Lepomis macrochirus*	F, M	Cadmium chloride	207	21,100	10,349	-	-	Eaton 1980
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	18	2,300	12,322[i]	-	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	18	2,300	12,322[i]	-	-	Bishop and McIntosh 1981
Bluegill (1.0 g), *Lepomis macrochirus*	F, M	Cadmium chloride	44.4	6,470	14,322	12,194	9,574	Phipps and Holcombe 1985
Yellow perch (juvenile, 8-12 g), *Perca flavescens*	F, M	Cadmium nitrate	120	8,140	**6,808**	-	**6,808**	Niyogi et al. 2004b
Nile tilapia (adult, 13.1 cm, 77.2 g), *Oreochromis niloticus*	S, M	Cadmium chloride	36.17	24,660	**66,720**	-	**66,720**	Garcia-Santos et al. 2006

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mozambique tilapia, *Oreochromis mossambica*	R, U	Cadmium chloride	28.4	6,000	20,570	-	-	Gaikwad 1989
Mozambique tilapia (1.52 g), *Oreochromis mossambica*	R, U	Cadmium sulfate	17	1,000	**5,666**	21,569	**10,795**	James and Sampath 1999
White sturgeon (2 dph, 0.03g), *Acipenser transmontanus*	F, M	Cadmium chloride	103	>49.98[f] (>47.2 reported dissolved)	**>48.55[c]**	-	-	Calfee et al. 2014
White sturgeon (30 dph, 0.17g, 30.6 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	106	>375.9[f] (>355 reported dissolved)	**>355.0[c]**	-	-	Calfee et al. 2014
White sturgeon (61 dph, 1.15 g, 62.5 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	108	<36.43[f] (<34.4 reported dissolved)	**<33.78**	-	-	Calfee et al. 2014
White sturgeon (72 dph, 1.89 g, 75.6 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	105	>158.3[f] (>149.5 reported dissolved)	**>150.9[c]**	-	-	Calfee et al. 2014
White sturgeon (89 dph, 3.73 g, 97.57 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	104	>289.6[f] (>273.5 reported dissolved)	**>278.6[c]**	-	-	Calfee et al. 2014
White sturgeon (2 dph), *Acipenser transmontanus*	F, M	Cadmium chloride	100	>11.65[f] (>11 reported dissolved)	**>11.65[c]**	-	-	Wang et al. 2014a
White sturgeon (larva, 27 dph), *Acipenser transmontanus*	F, M	Cadmium chloride	100	>11.65[f] (>11 reported dissolved)	**>11.65[c]**	-	**<33.78**	Wang et al. 2014a
Mottled sculpin (swim-up fry, 0.033 g), *Cottus bairdi*	F, M	Cadmium chloride	103	7.9	**7.673**	-	-	Besser et al. 2006; 2007
Mottled sculpin (juvenile, 0.104 g), *Cottus bairdi*	F, M	Cadmium chloride	103	17	**16.51[c]**	-	-	Besser et al. 2006; 2007
Mottled sculpin (juvenile, 0.260 g), *Cottus bairdi*	F, M	Cadmium chloride	103	23	**22.34[c]**	-	-	Besser et al. 2006; 2007

Species	Method[a]	Chemical	Hardness (mg/L CaCO$_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mottled sculpin (yearling, 2.3 g), *Cottus bairdi*	F, M	Cadmium chloride	103	>67	**>65.08**[c]	-	-	Besser et al. 2006; 2007
Mottled sculpin (newly hatched), *Cottus bairdi*	F, M	Cadmium chloride	103	2.9	**2.817**	-	-	Besser et al. 2006; 2007
Mottled sculpin (fry), *Cottus bairdi*	F, M	Cadmium sulfate	48.7	1.973[f] (1.92 reported-dissolved)	**3.990**	-	**4.418**	Brinkman and Vieira 2007
Shorthead sculpin, *Cottus confusus*	R, M	Cadmium chloride	21	0.9560[f] (0.93 reported dissolved)	**4.404**	-	**4.404**	Mebane et al. 2012
African clawed frog, *Xenopus laevis*	R, U	Cadmium chloride	116	3,597	3,110	-	-	Sunderman et al. 1991
African clawed frog (blastula stage 8-11), *Xenopus laevis*	R, U	Cadmium nitrate	~100	1,600	**1,600**	3,093	**2,231**	Gungordu et al. 2010
Northwestern salamander (larva), *Ambystoma gracile*	F, M	Cadmium chloride	45	468.4	1,023	1,055	1,023	Nebeker et al. 1995

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured

[b] Normalized to a hardness of 100 mg/L using the pooled acute slope of 0.9789.

[c] Data not used to calculate SMAV because more sensitive lifestage available.

[d] Not used to calculate SMAV because other normalized data available.

[e] Freshwater data not normalized so no SMAV calculated.

[f] Study reported a dissolved value only and this value was converted to total cadmium with a conversion factor of 1.028, 1.059 and 1.093 for total hardness levels of 50, 100 and 200 mg/L, respectively for freshwater species and 1.006 for saltwater species.

[g] Not used to calculate SMAV because either a more definitive value available or value is considered an outlier.

[h] Carroll et al. 1979 not used in the 2016 AWQC update because the authors noted that the Cd measured concentration in the control water was greater than the LC$_{50}$ value of 1.5 µg/L and had 100% survival.

[i] Data not used to calculate SMAV because flow-through measured test(s) available.

[j] Cadmium nitrate salt was not used in the SMAV calcualtion for rainbow trout because the values appear to be outliers. This difference may be based on the use of nitrate, which resulted in LC$_{50}$ values for salmonids that averaged 3 to 4 times higher than tests with chloride or sulfate, which are the dominant forms of cadmium in surface water.

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference

[k] High hardness values for Davies et al. (1993) were not used in the SMAV calculation for rainbow trout because the dilution water maniupluated total hardness with Mg only, and the protective effects of Ca were not in the dilution water (values abnormally low).

Appendix Table A-2. Acute Values used to develop the Acute Hardness Correction Slope

Species	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Reference
Hydra circumcincta	27.0	69.69	Clifford 2009
Hydra circumcincta	85.1	128.1	Clifford 2009
Hydra circumcincta	145	172.0	Clifford 2009
Limnodrilus hoffmeisteri	5.3	170	Chapman et al. 1982
Limnodrilus hoffmeisteri	152	2,400	Williams et al. 1985
Villosa vibex	40	30	Keller, Unpublished
Villosa vibex	186	125	Keller, Unpublished
Daphnia magna	51	9.9	Chapman et al. Manuscript, 1980
Daphnia magna	104	33	Chapman et al. Manuscript, 1980
Daphnia magna	105	34	Chapman et al. Manuscript, 1980
Daphnia magna	197	63	Chapman et al. Manuscript, 1980
Daphnia magna	209	49	Chapman et al. Manuscript, 1980
Daphnia pulex	17.0	16.86	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	24.0	23.61	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	30.0	46.09	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	47.0	24.73	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	67.1	71.94	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	119	116.9	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	175	155.1	Clifford 2009; Clifford and McGeer 2010
Chironomus riparius	10	331,000	Gillis and Wood 2008
Chironomus riparius	140	1,106,000	Gillis and Wood 2008
Oncorhynchus mykiss	31	1.75	Davies 1976a
Oncorhynchus mykiss	23	1.3	Chapman 1975; 1978
Oncorhynchus mykiss	23	1.0	Chapman 1978
Oncorhynchus mykiss	43.5	2.3	Spehar and Carlson 1984a;b
Oncorhynchus mykiss	44.4	3.0	Phipps and Holcombe 1985
Oncorhynchus mykiss	52	1.88	Stubblefield 1990
Oncorhynchus mykiss	29	2.79	Davies and Brinkman 1994b
Oncorhynchus mykiss	281	13.4	Davies and Brinkman 1994b
Oncorhynchus mykiss	28	2.09	Davies and Brinkman 1994b
Oncorhynchus mykiss	281	10.0	Davies and Brinkman 1994b
Oncorhynchus mykiss	30.7	0.71	Stratus Consulting 1999
Oncorhynchus mykiss	29.3	0.47	Stratus Consulting 1999
Oncorhynchus mykiss	31.7	0.51	Stratus Consulting 1999
Oncorhynchus mykiss	30.2	0.38	Stratus Consulting 1999
Oncorhynchus mykiss	30.0	1.29	Stratus Consulting 1999
Oncorhynchus mykiss	89.3	2.85	Stratus Consulting 1999
Oncorhynchus mykiss	103	3.7	Besser et al. 2007
Oncorhynchus mykiss	103	5.2	Besser et al. 2007
Oncorhynchus mykiss	19.7	0.864	Mebane et al. 2007; 2008
Oncorhynchus mykiss	29.4	0.915	Mebane et al. 2007; 2008
Oncorhynchus mykiss	44	2.75	Niyogi et al. 2008
Oncorhynchus mykiss	21	0.8224	Mebane et al. 2012
Oncorhynchus mykiss	7	0.4934	Mebane et al. 2012

Species	**Hardness (mg/L $CaCO_3$)**	**Acute Value (µg/L)**	**Reference**
Oncorhynchus mykiss	13	1.018	Mebane et al. 2012
Oncorhynchus mykiss	24	1.336	Mebane et al. 2012
Oncorhynchus mykiss	32	0.9560	Mebane et al. 2012
Oncorhynchus mykiss	29	0.8532	Mebane et al. 2012
Oncorhynchus mykiss	21	0.3495	Mebane et al. 2012
Salmo trutta	43.5	1.4	Spehar and Carlson 1984a;b
Salmo trutta	48	2.85	Stubblefield 1990
Salmo trutta	37.6	2.37	Davies and Brinkman 1994c
Salmo trutta	29.2	1.23	Brinkman and Hansen 2004a; 2007
Salmo trutta	67.6	3.9	Brinkman and Hansen 2004a; 2007
Salmo trutta	151	10.1	Brinkman and Hansen 2004a; 2007
Carassius auratus	20	2,130	McCarty et al. 1978
Carassius auratus	140	46,800	McCarty et al. 1978
Danio rerio	141	1,832	Alsop and Wood 2011
Danio rerio	7.8	125.2	Alsop and Wood 2011
Pimephales promelas	201	11,200	Pickering and Gast 1972
Pimephales promelas	201	12,000	Pickering and Gast 1972
Pimephales promelas	201	6,400	Pickering and Gast 1972
Pimephales promelas	201	2,000	Pickering and Gast 1972
Pimephales promelas	201	4,500	Pickering and Gast 1972
Pimephales promelas	103	3,060	Birge et al. 1983
Pimephales promelas	103	2,900	Birge et al. 1983
Pimephales promelas	103	3,100	Birge et al. 1983
Pimephales promelas	262.5	7,160	Birge et al. 1983
Pimephales promelas	43.5	1,280	Spehar and Carlson 1984a;b
Pimephales promelas	44.4	1,500	Phipps and Holcombe 1985
Pimephales promelas	44	13.2	Spehar and Fiandt 1986
Pimephales promelas	85.5	3,580	Carrier 1987; Carrier and Beitinger 1988a
Lepomis cyanellus	335	20,500	Jude 1973
Lepomis cyanellus	85.5	11,520	Carrier 1987; Carrier and Beitinger 1988b
Lepomis macrochirus	20	1,700	Lemke 1965
Lepomis macrochirus	350	22,200	Lemke 1965
Lepomis macrochirus	207	21,100	Eaton 1980
Lepomis macrochirus	18	2,300	Bishop and McIntosh 1981
Lepomis macrochirus	18	2,300	Bishop and McIntosh 1981
Lepomis macrochirus	44.4	6,470	Phipps and Holcombe 1985

Appendix Table A-3. Acute Freshwater Total to Dissolved Conversion Factors for Cadmium based on Hardness.

Hardness (mg/L as $CaCO_3$)	Conversion Factor[a]
25	1.0020
50	0.9730
75	0.9560
100	0.9440
150	0.9270
200	0.9150
250	0.9057
300	0.8980
350	0.8916
400	0.8860

a The conversion factor (CF) is calculated as: CF = 1.136672 - (ln (hardness) x 0.041838).

Appendix B Acceptable Estuarine/Marine Acute Toxicity Data

Appendix Table B-1. Acceptable Estuarine/Marine Acute Toxicity Data
(Underlined values are used in SMAV calculation and values in bold represent new/revised values since 2001 AWQC document).
(Species are organized phylogenetically).

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Nematode (juvenile, 2.5 d), (formerly, *Pellioditis marina*) *Rhabditis marina*	S, U	Cadmium chloride	30	**9,100**	-	**9,100**	Vranken et al. 1985
Polychaete worm (adult), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	12,000	-	-	Reish et al. 1976
Polychaete worm (juvenile), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	12,500	-	-	Reish et al. 1976
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (20°C)	**18,540**	-	-	Reish et al. 1977
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (20°C)	**5,600**	-	-	Reish et al. 1977
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (15°C)	**>5,600**	-	-	Reish et al. 1977
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (15°C)	**30,030**	-	-	Reish et al. 1977
Polychaete worm, *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	14,100	12,836	**12,052**	Reish and LeMay 1991
Polychaete, *Nereis grubei*	S, U	Cadmium chloride	-	4,700	4,700	4,700	Reish and LeMay 1991
Polychaete worm, (formerly, *Nereis virens*) *Alitta virens*	S, U	Cadmium chloride	20	11,000	-	-	Eisler 1971
Polychaete worm, *Alitta virens*	S, U	Cadmium chloride	20	9,300	10,114	10,114	Eisler and Hennekey 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32	**1,770**	-	-	Reish et al. 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32 (20°C)	**1,370**	-	-	Reish et al. 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32 (15°C)	**4,790**	-	-	Reish et al. 1977

Species	**Method[a]**	**Chemical**	**Salinity (g/kg)**	**Acute Value (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32 (15°C)	**19,090**	-	-	Reish et al. 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32	**4,200**	-	**3,925**	Reish 1978
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (20°C)	**2,720**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (20°C)	**2,240**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (15°C)	**3,330**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (15°C)	**6,030**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (10°C)	**3,690**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (10°C)	**2,130**	-	**3,142**	Reish et al. 1977
Polychaete worm (adult), *Capitella capitata*	S, U	Cadmium chloride	-	7,500[c]	-	-	Reish et al. 1976
Polychaete worm (larva), *Capitella capitata*	S, U	Cadmium chloride	-	200	-	-	Reish et al. 1976
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (20°C)	**5,030[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (20°C)	**5,140[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (15°C)	**16,300[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (15°C)	**6,000[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (10°C)	**28,444[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (10°C)	**5,880[c]**	-	-	Reish et al. 1977
Polychaete worm, *Capitella capitata*	S, U	Cadmium chloride	-	2,800[c]	200	200	Reish and LeMay 1991

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Starlet sea anemone (adult, female), *Nematostella vectensis*	S, M	Cadmium chloride	10	**1,284**	-	-	Harter and Matthews 2005
Starlet sea anemone (adult, female), *Nematostella vectensis*	S, M	Cadmium chloride	12	**1,092**	-	**1,184**	Harter and Matthews 2005
Cone worm, *Pectinaria californiensis*	S, U	Cadmium chloride	-	2,600	2,600	2,600	Reish and Lemay 1991
Oligochaete, (formerly, *Limnodriloides verrucosus*) *Tectidrilus verrucosus*	R, U	Cadmium sulfate	-	10,000	10,000	10,000	Chapman et al. 1982
Oligochaete worm, *Monopylephorus cuticulatus*	R, U	Cadmium sulfate	-	135,000	135,000	135,000	Chapman et al. 1982
Oligochaete worm, *Tubificoides gabriellae*	R, U	Cadmium sulfate	-	24,000	24,000	24,000	Chapman et al. 1982
Atlantic oyster drill, *Urosalpinx cinerea*	S, U	Cadmium chloride	-	6,600	6,600	6,600	Eisler 1971
Gastropod (2-15 cm), (formerly, *Morula granulata*) *Tenguella granulata*	R, U	Cadmium chloride	32	**2,060**	-	**2,060**	Devi 1997
Dog whelk (29.6 mm, 601 mg), *Nucella lapillus*	R, U	Cadmium chloride	34	**23,200**	-	**23,200**	Leung and Furness 1999
Eastern mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	10,500	-	-	Eisler 1971
Eastern mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	35,000	19,170	19,170	Eisler and Hennekey 1977

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Barnacle (larva-nauplii II), *Amphibalanus amphitrite*	S, U	Cadmium nitrate	37	**490**	-	**490**	Piazza et al. 2012
Blue mussel, *Mytilus edulis*	S, U	Cadmium chloride	-	25,000[c]	-	-	Eisler 1971
Blue mussel, *Mytilus edulis*	S, M	Cadmium chloride	-	1,620[c]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	3600[c]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	4300[c]	-	-	Ahsanullah 1976
Blue mussel (embryo), *Mytilus edulis*	S, U	Cadmium chloride	33.8	1,200	-	-	Martin et al. 1981
Blue mussel (juvenile), *Mytilus edulis*	R, U	Cadmium chloride	25	960	1,073	1,073	Nelson et al. 1988
Blue mussel (embryo), *Mytilus trossolus*	S, M	Cadmium chloride	-	**505.0**[f] (502 reported-dissolved)	-	**505.0**	Nadella et al. 2009
Bay scallop (juvenile), *Argopecten irradians*	S, U	Cadmium chloride	-	1,480	1,480	1,480	Nelson et al. 1976
Scallop (juvenile, 35 d, 3 mm), *Argopecten ventricosus*	R, U	Cadmium chloride	36	**396**	-	**396**	Sobrino-Figueroa et al. 2007
Pacific oyster (embryo), *Crassostrea gigas*	S, U	Cadmium chloride	33.8	611	-	-	Martin et al. 1981
Pacific oyster (larva, 6 d), *Crassostrea gigas*	R, U	Cadmium chloride	34	85	-	-	Watling 1982
Pacific oyster (larva, 16 d), *Crassostrea gigas*	R, U	Cadmium chloride	34	**>100**	227.9	**173.2**	Watling 1982
American oyster (larva), *Crassostrea virginica*	S, U	Cadmium chloride	25	3,800	3,800	3,800	Calabrese et al. 1973

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Brown mussel (20-24 mm), (formerly, *Perna indica*) *Perna perna*	S, U	Cadmium chloride	-	**2,213**	-	-	Baby and Menon 1986
Brown mussel (20-24 mm), *Perna perna*	R, U	Cadmium chloride	32	**1,357**	-	-	Baby and Menon 1987
Brown mussel (20-24 mm), *Perna perna*	R, U	Cadmium sulfate	32	**818.0**	-	-	Baby and Menon 1987
Brown mussel (20-24 mm), *Perna perna*	R, U	Cadmium nitrate	32	**701.3**	-	**1,146**	Baby and Menon 1987
Green mussel (20-25 mm), *Perna viridis*	S, U	Cadmium chloride	-	**2,500**	-	-	Mohan et al. 1986
Green mussel, *Perna viridis*	R, U	Cadmium chloride	33	**1,570**	-	**1,981**	Chan 1988
Mangrove oysters (embryo), *Isognomon californicum*	S, U	Cadmium chloride	34	**500**	-	-	Ringwood 1990
Mangrove oysters (larva, 3 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**500**	-	-	Ringwood 1990
Mangrove oysters (larva, 10 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**500**	-	-	Ringwood 1990
Mangrove oysters (larva, 24 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**4,000**[c]	-	-	Ringwood 1990
Mangrove oysters (larva, 36 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**4,000**[c]	-	-	Ringwood 1990
Mangrove oysters (embryo), *Isognomon californicum*	S, U	Cadmium chloride	24	**300**	-	-	Ringwood 1990
Mangrove oysters (larva, 3 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**380**			Ringwood 1990
Mangrove oysters (larva, 10 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**400**			Ringwood 1990

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mangrove oysters (larva, 24 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**2,000**[c]			Ringwood 1990
Mangrove oysters (larva, 36 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**2,000**[c]	-	**422.6**	Ringwood 1990
Horse clam (newly hatched embryos), *Tresus capax*	S, U	Cadmium sulfate	30	**60**	-	**60**	Cardwell et al. 1979
Horse clam, Pacific gaper (newly hatched embryos), *Tresus nuttalli*	S, U	Cadmium sulfate	29	**590**	-	**590**	Cardwell et al. 1979
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,200	-	-	Eisler 1971
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	850	-	-	Eisler 1977
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,500	1,672	1,672	Eisler and Hennekey 1977
Horseshoe crab (1st instar larva, 3.3 mm), *Limulus polyphemus*	R, U	Cadmium chloride	20	**167,700**	-		Botton 2000
Horseshoe crab (embryo), *Limulus polyphemus*	R, U	Cadmium chloride	20	**171,900**	-	**169,787**	Botton 2000
California market squid (larva), *Loligo opalescens*	S, M	Cadmium chloride	30	>10,200	>10,200	>10,200	Dinnel et al. 1989
Copepod, *Pseudodiaptomus coronatus*	S, U	Cadmium chloride	-	1,708	1,708	1,708	Gentile 1982
Calanoid copepod, *Eurytemora affinis*	S, U	Cadmium chloride	-	1,080[c]	-	-	Gentile 1982

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Calanoid copepod (newly hatched nauplii), *Eurytemora affinis*	S, U	Cadmium chloride	-	147.7	147.7	147.7	Sullivan et al. 1983
Copepod, *Acartia clausi*	S, U	Cadmium chloride	-	144	144	144	Gentile 1982
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	337	-	-	Sosnowski and Gentile 1978
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	90	-	-	Sosnowski and Gentile 1978
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	220	-	-	Sosnowski and Gentile 1978
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	122	-	-	Sosnowski and Gentile 1978
Calanoid copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	15 (18ºC)	93	-	-	Toudal and Riisgard 1987
Calanoid copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	20 (13ºC)	151	-	-	Toudal and Riisgard 1987
Calanoid copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	21 (21ºC)	29	118.7	118.7	Toudal and Riisgard 1987
Harpacticoid copepod, (formerly, *Nitocra spinipes*) *Nitokra spinipes*	S, U	Cadmium chloride	-	1,800	-	-	Bengtsson 1978
Harpacticoid copepod, *Nitokra spinipes*	F, U	Cadmium chloride	3	430	-	-	Bengtsson and Bergstrom 1987
Harpacticoid copepod, *Nitokra spinipes*	F, U	Cadmium chloride	7	660	-	-	Bengtsson and Bergstrom 1987
Harpacticoid copepod, *Nitokra spinipes*	F, U	Cadmium chloride	15	780	794.5	794.5	Bengtsson and Bergstrom 1987
Harpacticoid copepod, (formerly, *Amphiascus tenuiremis*) *Saramphiascus tenuiremis*	S, M	Cadmium nitrate	30.7	224	224	224	Green et al. 1993

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Harpacticoid copepod (nauplii), *Tigriopus brevicornis*	S, U	Cadmium chloride	34.5-35	**17.4**	-	-	Forget et al. 1998
Harpacticoid copepod (copepodid), *Tigriopus brevicornis*	S, U	Cadmium chloride	34.5-35	**29.7**	-	-	Forget et al. 1998
Harpacticoid copepod (ovigerous female), *Tigriopus brevicornis*	S, U	Cadmium chloride	34.5-35	**47.9**	-	**29.14**	Forget et al. 1998
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	10-17	15.5	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	30	110	-	-	Gentile et al. 1982; Lussier et al. 1985
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	20	**23**[i]	-	-	Roberts et al. 1982
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	6	14.7[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	14	38.0[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	22	70.4[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	30	77.3[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	38	90.3[i]	-	-	De Lisle and Roberts 1988
Mysid (<24 hr), *Americamysis bahia*	S, M	-	10 (20ºC)	30.9[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	10 (25ºC)	20.7[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	10 (30ºC)	<11.1[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	30 (20ºC)	82.0[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	30 (25ºC)	32.8[i]	-	-	Voyer and Modica 1990

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mysid (<24 hr), *Americamysis bahia*	S, M	-	30 (30ºC)	<11.1[i]	41.29	41.29	Voyer and Modica 1990
Mysid (juvenile, 24 hr), (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	F, M	Cadmium chloride	30	110	110	110	Gentile et al. 1982
Mysid (adult), *Neomysis americana*	S, M	Cadmium chloride	20	**28.14**	-	**28.14**	Roberts et al. 1982
Mysid (adult, 18 mm), *Praunus flexuosus*	R, U	Cadmium chloride	30	**410.3**	-	**410.3**	Roast et al. 2001b
Isopod (adult), *Excirolana vancouverensis*	R, U	Cadmium chloride	28	**>8,000**	-	**>8,000**	Boese et al. 1997
Isopod, (formerly, *Jaeropsis sp.*) *Joeropsis sp.*	S, U	Cadmium chloride	35	410.0	410.0	410.0	Hong and Reish 1987
Wood borer, *Limnoria tripunctata*	S, U	Cadmium chloride	35	7,120	7,120	7,120	Hong and Reish 1987
Amphipod (adult), *Ampelisca abdita*	F, M	Cadmium chloride	-	2,900	2,900	2,900	Scott et al. Manuscript
Amphipod, *Chelura terebrans*	S, U	Cadmium chloride	35	630	630	630	Hong and Reish 1987
Amphipod, *Corophium insidiosum*	S, U	Cadmium chloride	35	1,270	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Corophium insidiosum*	S, U	Cadmium chloride	-	680	-	-	Reish 1993
Amphipod, *Corophium insidiosum*	R, U	Cadmium chloride	28	**960**	-	**-**	Boese et al. 1997

Species	**Method[a]**	**Chemical**	**Salinity (g/kg)**	**Acute Value (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Amphipod (2-4 mm), *Corophium insidiosum*	S, M	Cadmium chloride	35.9 (10ºC)	**2,110**	-	-	Prato et al. 2008
Amphipod (2-4 mm), *Corophium insidiosum*	S, M	Cadmium chloride	35.9 (25ºC)	**700**	929.3	**1,041**	Prato et al. 2008
Amphipod (juvenile), *Diporeia spp.*	S, M	Cadmium chloride	20 (4ºC)	49,400[g]	-	-	Gossiaux et al. 1992
Amphipod (juvenile), *Diporeia spp.*	S, M	Cadmium chloride	20 (10ºC)	17,500[g]	-	-	Gossiaux et al. 1992
Amphipod (juvenile), *Diporeia spp.*	S, M	Cadmium chloride	20 (15ºC)	6,700	6,700	6,700	Gossiaux et al. 1992
Amphipod, *Elasmopus bampo*	S, U	Cadmium chloride	35	570	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Elasmopus bampo*	S, U	Cadmium chloride	-	900	716.2	716.2	Reish 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M	Cadmium chloride	30 (held 11 days before testing)	41,900	-	-	Meador 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M	Cadmium chloride	30 (held 17 days before testing)	36,100	-	-	Meador 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M	Cadmium chloride	30 (held 121 days before testing)	14,500	-	-	Meador 1993
Amphipod, *Eohaustorius estuarius*	R, U	Cadmium chloride	28	**12,510**	27,992	**22,887**	Boese et al. 1997
Amphipod, *Grandidierella japonica*	S, U	Cadmium chloride	35	1,170	-	-	Hong and Reish 1987
Amphipod, *Grandidierella japonica*	R, U	Cadmium chloride	28	**340**	1,170	**630.7**	Boese et al. 1997
Amphipod, *Leptocheirus plumulosus*	R, U	Cadmium chloride	20	**1,450**	-	**-**	Boese et al. 1997

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Amphipod (500 um), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	360	-	-	McGee et al. 1998
Amphipod (700 um), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	650	-	-	McGee et al. 1998
Amphipod (1,000 um), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	880	590.5	739.2	McGee et al. 1998
Amphipod, *Rhepoxynius abronius*	R, U	Cadmium chloride	28	**1,510**	-	**1,510**	Boese et al. 1997
Scud (adult), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	13,000[c]	-	-	Wright and Frain 1981
Scud (young), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	3,500	3,500	3,500	Wright and Frain 1981
Northern pink shrimp (subadult), (formerly, *Penaeus duorarum*) *Farfantepenaeus duorarum*	F, M	Cadmium chloride	-	3,500[c]	-	-	Nimmo et al. 1977b
Northern pink shrimp (2nd post larva), *Farfantepenaeus duorarum*	S, U	Cadmium chloride	25	310.5	310.5	310.5	Cripe 1994
White shrimp (juvenile), (formerly, *Penaeus setiferus*) *Litopenaeus setiferus*	S, M	Cadmium chloride	11	**990**	-	**990**	Vanegas et al. 1997
Whiteleg shrimp (post larva), *Litopenaeus vannamei*	R, U	Cadmium chloride	34	**2,490**	-	-	Frias-Espericueta et al. 2001
White shrimp (post larva, 7.13 mg), *Litopenaeus vannamei*	R, U	-	15	**1,070**	-	**1,632**	Wu and Chen 2004
Tiger shrimp (juvenile), *Penaeus monodon*	R, M	Cadmium chloride	28	**1,720**	-	**1,720**	Raj Kumar 2012

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Daggerblade grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	3,280	-	-	Khan et al. 1988
Daggerblade grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	1,830	-	-	Khan et al. 1988
Daggerblade grass shrimp (juvenile), *Palaemonetes pugio*	S, M	Cadmium chloride	10	1,300	1,983	1,983	Burton and Fisher 1990
Grass shrimp, *Palaemonetes vulgaris*	S, U	Cadmium chloride	-	420[i]	-	-	Eisler 1971
Grass shrimp, *Palaemonetes vulgaris*	F, M	Cadmium chloride	-	760	760	760	Nimmo et al. 1977b
Sand shrimp, *Crangon septemspinosa*	S, U	Cadmium chloride	-	320	320	320	Eisler 1971
American lobster (larva), *Homarus americanus*	S, U	Cadmium nitrate	-	78	78	78	Johnson and Gentile 1979
Longwrist hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	320	-	-	Eisler 1971
Longwrist hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	1,300	645.0	645.0	Eisler and Hennekey 1977
Rock crab (zoea), (formerly, *Cancer irroratus*) *Cancer plebejus*	F, M	Cadmium chloride	-	250	250	250	Johns and Miller 1982
Dungeness crab (zoeae), *Cancer magister*	S, U	Cadmium chloride	33.8	247	-	-	Martin et al. 1981
Dungeness crab (zoeae), *Cancer magister*	S, M	Cadmium chloride	30	200	222.3	222.3	Dinnel et al. 1989
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	35	11,600	-	-	Frank and Robertson 1979

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	15	4,700	-	-	Frank and Robertson 1979
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	1	320	2,594	2,594	Frank and Robertson 1979
Lesser blue crab (intermolt, 1-5 g), *Callinectes similis*	R, U	Cadmium chloride	30	**6,350**	-	**6,350**	Ramirez et al. 1989
Green shore crab, *Carcinus maenas*	S, U	Cadmium chloride	-	4,100	4,100	4,100	Eisler 1971
Mud crab (1 g), *Eurypanopeus depressus*	S, U	Cadmium chloride	25	**4,900**	-	**4,900**	Collier et al. 1973
Pacific sand crab (juvenile), *Emerita analoga*	R, U	Cadmium chloride	28	**2,110**	-	**2,110**	Boese et al. 1997
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	10 (20°C)	32,300	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	20 (20°C)	46,600	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	30 (20°C)	37,000	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	10 (30°C)	6,800	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	20 (30°C)	10,400	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	30 (30°C)	23,300	21,238	21,238	O'Hara 1973a
Fiddler crab (intermolt, males, 24-29 mm carapace), *Uca triangularis*	R, U	Cadmium chloride	25	**7,660**	-	**7,660**	Devi 1987
Common starfish, *Asterias forbesii*	S, U	Cadmium chloride	-	820	-	-	Eisler 1971

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Common starfish, *Asterias forbesii*	S, U	Cadmium chloride	-	7,100	2,413	2,413	Eisler and Hennekey 1977
Green sea urchin (embryo), *Strongylocentrotus droebachiensis*	S, M	Cadmium chloride	30	1,800	1,800	1,800	Dinnel et al. 1989
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M	Cadmium chloride	30	500	-	-	Dinnel et al. 1989
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M	Cadmium chloride	34	**342.3**	500	**413.7**	Phillips et al. 2003
Sand dollar (embryo), *Dendraster excentricus*	S, M	Cadmium chloride	30	7,400	7,400	7,400	Dinnel et al. 1989
Moon jellyfish (ephyra), *Aurelia aurita*	S, U	Cadmium nitrate	37	**61.75**	-	**61.75**	Faimali et al. 2013
Coho salmon (smolt), *Oncorhynchus kisutch*	F, M	Cadmium chloride	28.3	1,500	1,500	1,500	Dinnel et al. 1989
Sheepshead minnow (36 mm, 1.1 g), *Cyprinodon variegatus*	S, U	Cadmium chloride	-	50,000	-	-	Eisler 1971
Sheepshead minnow (25.8 mm, 0.27 g), *Cyprinodon variegatus*	S, M	Cadmium chloride	10	**15,900**	50,000	**28,196**	Roberts et al. 1982
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	49,000[i]	-	-	Eisler 1971
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	114,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	92,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	78,000[i]	-	-	Voyer 1975

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	73,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	73,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	63,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	31,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	30,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	29,000[i]	-	-	Voyer 1975
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	22,000[i]	-	-	Eisler and Hennekey 1977
Mummichog (12-20 mm), *Fundulus heteroclitus*	F, M	Cadmium sulfate	14	18,200	18,200	18,200	Lin and Dunson 1993
Striped killifish (adult), *Fundulus majalis*	S, U	Cadmium chloride	-	21,000	21,000	21,000	Eisler 1971
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M	Cadmium sulfate	14	23,700[c]	-	-	Lin and Dunson 1993
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M	Cadmium sulfate	14	18,500[c]	-	-	Lin and Dunson 1993
Rivulus (adult, 120 d), *Rivulus marmoratus*	S, M	Cadmium chloride	10	32,200[c]	-	-	Park et al. 1994
Rivulus (juvenile, 30 d), *Rivulus marmoratus*	S, M	Cadmium chloride	10	18,800[c]	-	-	Park et al. 1994
Rivulus (larvae, 7 d), *Rivulus marmoratus*	S, M	Cadmium chloride	10	800	800	800	Park et al. 1994
Atlantic silverside (59.4 mm, 2.15 g), *Menidia menidia*	S, M	Cadmium chloride	10	**6,400**[c]	-	-	Roberts et al. 1982
Atlantic silverside (adult), *Menidia menidia*	S, U	Cadmium chloride	30	2,032[c]	-	-	Cardin 1985

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	30	28,532[c]	-	-	Cardin 1985
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	30	13,652[c]	-	-	Cardin 1985
Atlantic silverside (larva, 1d), *Menidia menidia*	S, U	Cadmium chloride	30.4	1,054	779.8	**1,054**	Cardin 1985
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	1	75.0	75.0	75.0	Palawski et al. 1985
Cabezon (larva), *Scorpaenichthys marmoratus*	S, M	Cadmium chloride	27	>200	>200	>200	Dinnel et al. 1989
Pinfish (subadult), *Lagodon rhomboides*	S, U	Cadmium	1	**1,000**	-	**1,000**	Sharp 1988
Shiner perch (adult, 87 mm), *Cymatogaster aggregata*	F, M	Cadmium chloride	30.1	11,000	11,000	11,000	Dinnel et al. 1989
Striped mullet (juvenile, 50 mm), *Mugil cephalus*	S, U	Cadmium chloride	37.3	28,000[c]	-	-	Hilmy et al. 1985
Striped mullet (fry, 10 mm), *Mugil cephalus*	S, U	Cadmium chloride	37.3	7,079	7,079	7,079	Hilmy et al. 1985
White mullet, *Mugil curema*	S, U	Cadmium chloride	36	**12,000**	-	**12,000**	Chung 1978
Mozambique tilapia (27 mm), *Oreochromis mossambicus*	S, U	Cadmium chloride	1	**>80,000**	-	**>80,000**	Chung 1983
Cunner (2-3 yr., 1 cm, 14-29 g), *Tautogolabrus adspersus*	R, U	Cadmium chloride	-	25,900	-	**25,900**	Robohm 1986

Species	**Method**[a]	**Chemical**	**Salinity (g/kg)**	**Acute Value (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	-	14,297	14,297	14,297	Cardin 1985
Scorpionfish (287 g), *Scorpaena guttata*	R, M	Cadmium chloride	-	**62,000**	-	**62,000**	Brown et al. 1984

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured

[c] Data not used to calculate SMAV because more sensitive lifestage available.

[f] Study reported a dissolved value only and this value was converted to total cadmium with a conversion factor of 1.028, 1.059 and 1.093 for total hardness levels of 50, 100 and 200 mg/L, respectively for freshwater species and 1.006 for saltwater species.

[g] Not used to calculate SMAV because either a more definitive value available or value is considered an outlier.

[i] Data not used to calculate SMAV because flow-through measure test(s) available.

Appendix C Acceptable Freshwater Chronic Toxicity Data

Appendix Table C-1. Acceptable Freshwater Chronic Toxicity Data

(Values normalized to total hardness=100 mg/L as CaCO$_3$ using pooled hardness slope of 0.7977 and expressed as total cadmium).
(Underlined values are used in SMCV calculation and values in bold represent new/revised values since 2001 AWQC document).
(Species are organized phylogenetically).

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L CaCO$_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Oligochaete, *Aeolosoma headleyi*	R, M	LC	Cadmium chloride	175 (160-190)	32-50.2	40.08 (growth & reproduction)	57.35 (growth)	**36.70**	34.66	**36.70**	Niederlehner et al. 1984
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	R, M	28 d	-	140	86.9-107.6	96.70 (reproduction)	19.83 (reproduction)	**15.16**	-	-	Straus 2011
Oligochaete (adult), *Lumbriculus variegatus*	R, M	28 d	-	22	2.3->2.3	>2.3 (survival)	-	**>7.695[c]**	-	**15.16**	Straus 2011
Snail (<24 hr, egg masses), *Aplexa hypnorum*	F, M	LC	Cadmium chloride	45.3	4.41-7.63	5.801 (-)	4.002 (reproduction)	7.525	-		Holcombe et al. 1984
Snail (<24 hr, egg masses), *Aplexa hypnorum*	F, M	LC	Cadmium chloride	45.3	2.50-4.79	3.460 (-)	0.8737 (survival)	1.643	8.055	3.516	Holcombe et al. 1984
Pond snail (5 mm), *Lymnaea stagnalis*	R, M	31 d	Cadmium chloride	135 (130-140)	9.43-28.3	16.34 (growth)	1.944 (survival)	**1.530**	-	-	Pais 2012
Pond snail (10 mm), *Lymnaea stagnalis*	R, M	31 d	Cadmium chloride	135 (130-140)	28.3-94.3	51.66 (survival)	35.56 (growth)	**27.99**	-	-	Pais 2012
Pond snail (15 mm), *Lymnaea stagnalis*	R, M	31 d	Cadmium chloride	135 (130-140)	94.3->94.3	>94.3 (growth)	28.68 (growth)	**22.57**	-	-	Pais 2012
Pond snail (5 mm), *Lymnaea stagnalis*	R, M	28 d	Cadmium chloride	90	5.20->5.20	>5.20 (survival & growth)	-	**>5.655[c]**	-	**9.887**	Pais 2012
Mudsnail, *Potamopyrgus antipodarum*	R, M	28 d	Cadmium sulfate	-	0.806-3.44	1.665 (reproduction)	2.641 (reproduction)	-	-	**NA[f]**	Sieratowicz et al. 2011

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L CaCO$_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Fatmucket (juvenile), *Lampsilis siliquoidea*	F, M	28 d	Cadmium nitrate	44 (40-48)	4.4-8.2	6.007 (survival & growth)	5.868 (growth)	**11.29**	-	**11.29**	Wang et al. 2010d
Cladoceran, *Ceriodaphnia dubia*	-	LC	-	100	-	2.20 (-)	-	**2.200**[c]	-	-	Spehar and Fiandt 1986
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	-	20	10-19	13.78 (-)	-	49.75[c]	-	-	Jop et al. 1995
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	5.304-9.934	7.259 (survival & reproduction)	6.129 (reproduction)	**2.775**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	1.073-2.391	1.602 (reproduction)	2.262 (reproduction)	**1.024**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	3.066-4.108	3.549 (reproduction)	3.029 (reproduction)	**1.371**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	5.457-7.174	6.257 (survival & reproduction)	3.376 (reproduction)	**1.528**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	1.748-2.391	2.044 (reproduction)	1.341 (reproduction)	**0.6071**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	-	LC	-	170	1.1-3.4	1.93 (reproduction)	-	**1.264**[c]	45.40	**1.293**	Brooks et al. 2004
Cladoceran, *Ceriodaphnia reticulata*	-	LC	-	44	3.6-7.5	5.20 (-)	-	**10.01**	-	**NA**[g]	Spehar and Carlson 1984a,b
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	53	0.08-0.29	0.1523 (reproduction)	-	0.2527[c]	-	-	Chapman et al. Manuscript, 1980
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	103	0.16-0.28	0.2117 (reproduction)	0.2118 (reproduction)	0.2068	-	-	Chapman et al. Manuscript, 1980

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	209	0.21-0.91	0.4371 (reproduction)	0.3545 (reproduction)	0.1969	-	-	Chapman et al. Manuscript, 1980
Cladoceran, *Daphnia magna*	R, M	LC	-	200	0.37-0.48	0.37 (EC$_{20}$)	0.37 (-)	**0.2128**	-	-	Canton and Slooff 1982
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	150	5.0-10	7.07 (reproduction)	6.166 (survival)	4.461	-	-	Bodar et al. 1988b
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium	130	<1.86-1.86	<1.86 (reproduction)	1.677 (reproduction)	1.360	-	-	Borgmann et al. 1989a; b
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	170	0.6-2.0	1.10 (growth)	-	**0.7203**[c]	-	-	Baird et al. 1990
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	99	1.67-3.43	2.39 (reproduction)	2.496 (reproduction)	**2.516**	-	-	Chadwick Ecological Consultants 2003
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	51	1.97-3.43	2.60 (reproduction)	2.373 (reproduction)	**4.059**	-	-	Chadwick Ecological Consultants 2003
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	-	0.328-0.656	0.46 (reproduction)	1.528 (survival)	**NA**[c]	<0.6340	**0.9150**	Jemec et al. 2008
Cladoceran, *Daphnia pulex*	R, M	LC	Cadmium chloride	65	5.5-10.2	7.49 (survival & reproduction)	6.214 (growth)	8.761	-	-	Niederlehner 1984
Cladoceran (<24 hr), *Daphnia pulex*	R, M	LC	Cadmium chloride	52	14.6->14.6	>14.6 (reproduction)	3.051 (reproduction)	**5.140**	-	-	Chadwick Ecological Consultants 2003
Cladoceran, *Daphnia pulex*	-	LC	-	52	-	-	1.45 (survival)	**2.443**	-	-	Chadwick Ecological Consultants 2004a

Species	Method^a	Test^a	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value^b (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Cladoceran, *Daphnia pulex*	-	LC	-	52	-	-	2.17 (reproduction)	**3.655**	10.30	**4.478**	Chadwick Ecological Consultants 2004a
Amphipod (7-8 d), *Hyalella azteca*	F, M	LC	Cadmium chloride	280	0.51-1.9	0.984 (growth & survival)	1.695 (reproduction)	0.7453	0.4590	0.7453	Ingersoll and Kemble 2001
Midge (larva, <24 hr), *Chironomus dilutus*	F, M	LC	Cadmium chloride	280	5.8-16.4	9.753 (growth)	4.548 (percent hatch)	2.000	4.686	2.000	Ingersoll and Kemble 2001
Rio Grande cutthroat trout (eyed egg), *Oncorhynchus clarkii virginalis*	F, M	ELS	Cadmium sulfate	44.9	1.48-3.37	2.296^e (2.233 dissolved) (survival, growth & biomass)	1.871^e (1.82 dissolved) (survival, growth & biomass)	**3.543**	-	**3.543**	Brinkman 2012
Coho salmon (Lake Superior), *Oncorhynchus kisutch*	-	ELS	Cadmium chloride	44	1.3-3.4	2.102 (-)	-	4.046	-	-	Eaton et al. 1978
Coho salmon (West Coast), *Oncorhynchus kisutch*	-	ELS	Cadmium chloride	44	4.1-12.5	7.159 (-)	-	13.78	7.127	**NA^g**	Eaton et al. 1978
Rainbow trout (adult, female, 270 d), *Oncorhynchus mykiss*	-	LC	-	250	3.39-5.48	4.310 (-)	3.319 (reproduction)	1.598	-	-	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	F, M	PLC	-	46	1.25-1.74	1.47 (lethal to 1%)	2.473 (survival)	**4.593**	-	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	F, M	PLC	-	217	2.55-5.03	3.58 (lethal to 1%)	4.762 (survival)	**2.567**	-	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	F, M	PLC	-	413.8	2.57-5.16	3.64 (lethal to 1%)	3.808 (survival)	**1.226**	-	-	Davies et al. 1993

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium sulfate	301	8.20-14.2	10.8 (survival)	9.508 (survival)	**3.947[d]**	-	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium sulfate	282	1.48-2.24 (aged solution)	1.82 (survival)	-	**0.7962[c]**	-	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium sulfate	29	1.02-1.89	1.39 (survival)	2.604 (survival)	**6.989[d]**	-	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	-	103	1.3-2.7	1.87 (survival)	3.471 (survival)	**3.389[d]**	-	-	Besser et al. 2007
Rainbow trout (4 hr post fert), *Oncorhynchus mykiss*	R, M	ELS	Cadmium chloride	6.8	0.25-2.5	0.79 (delayed hatch & growth)	-	**6.743[c]**	-	-	Lizardo-Daudt and Kennedy 2008
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium chloride	19.7	0.6-1.3	0.905[e] (0.88 dissolved) (survival)	1.312[e] (1.276 dissolved) (survival)	**4.794[d]**	-	-	Mebane et al. 2008
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium chloride	29.4	<0.16-0.16	<0.164[e] (<0.16 dissolved) (growth)	2.386[e] (2.321 dissolved) (survival)	**6.334[d]**	-	**-**	Mebane et al. 2008
Rainbow trout (1 dph), *Oncorhynchus mykiss*	F, M	ELS	Cadmium chloride	100	-	-	5.613[e] (5.3 dissolved) (survival)	**5.612[d]**	2.186	**2.192**	Wang et al. 2014a
Chinook salmon (egg-fry), *Oncorhynchus tshawytscha*	F, M	ELS	Cadmium chloride	25	1.30-1.88	1.563 (survival)	1.465 (growth)	4.426	4.366	4.426	Chapman 1975
Atlantic salmon, *Salmo salar*	-	ELS (5°C)	Cadmium chloride	23.5	90-270	155.9 (survival & hatch)	19.37 (biomass)	61.47[d]	-	-	Rombough and Garside 1982
Atlantic salmon, *Salmo salar*	-	ELS (8.9°C)	Cadmium chloride	24.5	300-800	489.9 (survival)	127.8 (biomass)	**392.5[d]**	-	-	Rombough and Garside 1982

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Atlantic salmon (alevin), *Salmo salar*	-	ELS (9.6°C)	Cadmium chloride	23.5	2.5-8.2	4.53 (survival)	0.7528 (biomass)	2.389	13.24	2.389	Rombough and Garside 1982
Brown trout, *Salmo trutta*	-	ELS	Cadmium chloride	44	3.8-11.7	6.668 (-)	-	12.83[c]	-	-	Eaton et al. 1978
Brown trout (adult, female), *Salmo trutta*	-	LC	Cadmium sulfate	250	9.34-29.1	16.49 (growth)	15.15 (survival)	7.294[d]	-	-	Brown et al. 1994
Brown trout, *Salmo trutta*	F, M	ELS	Cadmium sulfate	36.9	1.11-1.6	1.33 (survival)	1.368 (survival)	**3.030**	-	-	Davies and Brinkman 1994a
Brown trout (fingerling), *Salmo trutta*	F, M	ELS	Cadmium sulfate	37.6	<0.7-0.7	<0.7 (growth & survival)	0.624 (survival)	**1.361**	-	**-**	Davies and Brinkman 1994c
Brown trout (eggs), *Salmo trutta*	F, M	ELS	Cadmium sulfate	149	9.62-19.1	13.56 (survival)	16.02 (biomass)	**11.65**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (eggs), *Salmo trutta*	F, M	ELS	Cadmium sulfate	71.3	4.68-8.64	6.36 (survival)	5.187 (biomass)	**6.793**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (eggs), *Salmo trutta*	F, M	ELS	Cadmium sulfate	30.6	2.54-4.87	3.52 (survival)	2.807 (biomass)	**7.218**	8.360	**4.725**	Brinkman and Hansen 2004a; 2007
Brook trout, *Salvelinus fontinalis*	-	LC	Cadmium chloride	44	1.7-3.4	2.404 (growth of F3 juveniles)	1.224 (reproduction)	2.356	-	-	Benoit et al. 1976
Brook trout, *Salvelinus fontinalis*	-	ELS	Cadmium chloride	37	1-3	1.732 (growth)	2.187 (survival)	4.833[d]	-	-	Sauter et al. 1976
Brook trout, *Salvelinus fontinalis*	-	ELS	Cadmium chloride	188	7-12	9.165 (survival & growth)	9.172 (survival)	**5.543[d]**	-	-	Sauter et al. 1976
Brook trout, *Salvelinus fontinalis*	-	ELS	Cadmium chloride	44	1.1-3.8	2.045 (-)	-	3.935[c]	4.416	2.356	Eaton et al. 1978

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L CaCO$_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Lake trout, *Salvelinus namaycush*	-	ELS	Cadmium chloride	44	4.4-12.3	7.357 (-)	-	14.16	13.51	**NA[g]**	Eaton et al. 1978
Northern pike, *Esox lucius*	-	ELS	Cadmium chloride	44	4.2-12.9	7.361 (-)	-	14.17	13.52	14.17	Eaton et al. 1978
Fathead minnow (0.23 g), *Pimephales promelas*	-	LC	Cadmium sulfate	201	37-57	45.92 (-)	24.71 (reproduction)	14.16	-	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	-	ELS	-	44	9-18	12.73 (-)	-	**24.50[c]**	-	-	Spehar and Carlson 1984a,b
Fathead minnow, *Pimephales promelas*	-	ELS	Cadmium nitrate	44	-	10.0 (-)	-	19.25[c]	27.37	14.16	Spehar and Fiandt 1986
White sucker, *Catostomus commersoni*	-	ELS	Cadmium chloride	44	4.2-12.0	7.099 (-)	-	13.66	13.04	13.66	Eaton et al. 1978
Flagfish, *Jordanella floridae*	-	LC	Cadmium chloride	44	4.1-8.1	5.763 (-)	5.018 (reproduction)	9.659	-	-	Spehar 1976a,b
Flagfish, *Jordanella floridae*	-	LC	Cadmium chloride	47.5	3.0-6.5	4.416 (-)	6.274 (reproduction)	11.36	-	-	Carlson et al. 1982
Flagfish, *Jordanella floridae*	-	LC	Cadmium chloride	47.5	3.4-7.3	4.982 (-)	3.341 (reproduction)	6.050	8.886	8.723	Carlson et al. 1982
Bluegill, *Lepomis macrochirus*	-	LC	Cadmium sulfate	207	31-80	49.80 (-)	29.35 (survival)	16.43	29.05	16.43	Eaton 1974
Smallmouth bass, *Micropterus dolomieui*	-	ELS	Cadmium chloride	44	4.3-12.7	7.390 (-)	-	14.22	13.58	14.22	Eaton et al. 1978
Blue tilapia, *Oreochromis aurea*	-	LC	Cadmium nitrate	145	>52.0	>52.0 (-)	-	>38.66	>39.48	>38.66	Papoutsoglou and Abel 1988
Mottled sculpin, *Cottus bairdi*	F, M	ELS	Cadmium chloride	103	1.4-2.6	1.908 (survival)	1.762 (biomass)	**1.721**	-	-	Besser et al. 2007

NMED Exhibit 70

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Mottled sculpin, *Cottus bairdii*	F, M	ELS	Cadmium chloride	103	0.59-1.3	0.8758 (survival)	1.285 (survival)	**1.255**	-	**1.470**	Besser et al. 2007

[a] R=renewal, F=flow-through, U=unmeasured, M=measured, ELS=early life-cycle test, PLC=partial life-cycle test, LC=life-cycle test.

[b] Freshwater data normalized to a hardness of 100 mg/L using the pooled acute slope of 0.7977.

[c] Not used to calculate SMCV because other normalized data available or normalized EC20 values available.

[d] Not used to calculate SMCV because either a more definitive value available, value is considered an outlier, or preference was given to the more sensitive exposure scenario (LC versus ELS tests).

[e] Study reported a dissolved value only and was converted to total cadmium with a conversion factor of 1.028, 1.059, and 1.093 for hardness of 50, 100, and 200 mg/L, respectively for freshwater species and 1.006 for saltwater species.

[f] Freshwater data not normalized so no SMCV calculated.

[g] No SMCV calculated because normalized EC_{20} data available for the genus.

Appendix Table C-2. Chronic Values used to develop the Chronic Hardness Correction Slope

Species	Hardness (mg/L $CaCO_3$)	Chronic Value (µg/L)	Endpoint	Reference
Daphnia magna	53	0.1523	MATC	Chapman et al. Manuscript, 1980
Daphnia magna	103	0.2117	MATC	Chapman et al. Manuscript, 1980
Daphnia magna	209	0.4371	MATC	Chapman et al. Manuscript, 1980
Oncorhynchus mykiss	250	3.319	EC_{20}	Brown et al. 1994
Oncorhynchus mykiss	301	9.508	EC_{20}	Davies and Brinkman 1994b
Oncorhynchus mykiss	29	2.604	EC_{20}	Davies and Brinkman 1994b
Oncorhynchus mykiss	103	3.471	EC_{20}	Besser et al. 2007
Oncorhynchus mykiss	19.7	1.312	EC_{20}	Mebane et al. 2008
Oncorhynchus mykiss	29.4	2.386	EC_{20}	Mebane et al. 2008
Salmo trutta	250	15.15	EC_{20}	Brown et al. 1994
Salmo trutta	36.9	1.368	EC_{20}	Davies and Brinkman 1994a
Salmo trutta	37.6	0.624	EC_{20}	Davies and Brinkman 1994c
Salmo trutta	149.2	16.02	EC_{20}	Brinkman and Hansen 2004a; 2007
Salmo trutta	71.3	5.187	EC_{20}	Brinkman and Hansen 2004a; 2007
Salmo trutta	30.6	2.807	EC_{20}	Brinkman and Hansen 2004a; 2007
Salvelinus fontinalis	44	1.224	EC_{20}	Benoit et al. 1976
Salvelinus fontinalis	37	2.187	EC_{20}	Sauter et al. 1976
Salvelinus fontinalis	188	9.172	EC_{20}	Sauter et al. 1976

Appendix Table C-3. Chronic Freshwater Total to Dissolved Conversion Factors for Cadmium based on Hardness.

Hardness (mg/L as $CaCO_3$)	Conversion Factor[a]
25	0.9670
50	0.9380
75	0.9210
100	0.9090
150	0.8920
200	0.8800
250	0.8707
300	0.8630
350	0.8566
400	0.8510

a The conversion factor (CF) is calculated as: CF = 1.101672 - (ln (hardness) x 0.041838).

Appendix D Acceptable Estuarine/Marine Chronic Toxicity Data

Appendix Table D-1. Acceptable Estuarine/Marine Chronic Toxicity Data
(Underlined values are used in SMCV calculation and values in bold represent new/revised values since 2001 AWQC document).
(Species are organized phylogenetically).

Species	Method[a]	Test	Chemical	Salinity (g/kg)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Mysid, *Americamysis bahia*	-	LC	Cadmium chloride	15-23	6.4-10.6	8.237	5.605	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	-	LC	Cadmium chloride	30	5.1-10	7.141	10.93	-	-	Gentile et al. 1982; Lussier et al. 1985
Mysid, *Americamysis bahia*	-	LC	Cadmium chloride	30	<4-4	<4[d]	5.833	6.173	6.149	Carr et al. 1985
Mysid, (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	-	LC	Cadmium chloride	-	5.1-10	7.141	11.61	7.141	11.61	Gentile et al. 1982

[a] S=static, R=renewal; F=flow-through, U=unmeasured, M=measured, ELS=early life-cycle test, LC=life-cycle test

NMED Exhibit 70

Appendix E Acceptable Freshwater Plant Toxicity Data

Appendix Table E-1. Acceptable Freshwater Plant Toxicity Data

Species	**Method[a]**	**Chemical**	**Hardness (mg/L as $CaCO_3$)**	**Duration**	**Effect**	**Chronic Limits (µg/L)**	**Concentration (µg/L)**	**Reference**
Alga, *Euglena gracilis*	-	Cadmium chloride	-	-	Morphological abnormalities	-	5,000	Nakano et al. 1980
Alga, *Euglena gracilis anabaena*	-	Cadmium nitrate	-	-	Cell division inhibition	-	20,000	Nakano et al. 1980
Blue-green alga, *Anabaena doliolum*	R, U	-	-	12 d	EC_{50} (lethal)	-	75,000	Kaur et al. 2002
Blue-green alga, *Anabaena doliolum*	R, U	-	-	12 d	Algicidal	-	250,000	Kaur et al. 2002
Blue-green alga, *Anabaena flos-aquae*	-	Cadmium chloride	-	96 hr	EC_{50}	-	120	Rachlin et al. 1984
Blue-green alga (15 d), *Anabaena flos-aquae*	S, U	Cadmium nitrate	-	96 hr	EC_{50}	-	140	Heng et al. 2004
Blue-green alga, *Microcystis aeruginosa*	-	Cadmium nitrate	-	-	Incipient inhibition	-	70	Bringmann 1975
Blue-green alga, *Microcystis aeruginosa*	S, U	Cadmium chloride	-	14 d	Growth	56.21-112.41	79.49	Zhou et al. 2006
Blue-green alga, *Spirulina platensis*	S, U	Cadmium chloride	-	96 hr	EC_{50} (growth)	-	18,350	Rangsayatorn et al. 2002
Diatom, *Asterionella formosa*	-	-	-	-	Factor of 10 growth rate decrease	-	2	Conway 1978
Diatom, *Navicula incerta*	-	Cadmium chloride	-	96 hr	EC_{50}	-	310	Rachlin et al. 1982
Diatom, *Navicula pelliculosa*	S, M	Cadmium chloride	-	96 hr	EC_{50} (mat formation)	-	31	Irving et al. 2009
Diatom, *Nitzschia costerium*	-	Cadmium chloride	-	96 hr	EC_{50}	-	480	Rachlin et al. 1982

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Diatom, *Nitzschia palea*	S, U	Cadmium chloride	-	5 d	EC_{50} (growth)	-	27.6	Branco et al. 2010
Green alga, *Ankistrodesmus falcatus*	-	Cadmium chloride	-	-	58% reduction in growth	-	2,500	Devi Prasad and Devi Prasad 1982
Green alga, *Chara vulgaris*	S, M	Cadmium sulfate	-	7 d	Lethal dose	-	56.2	Heumann 1987
Green alga, *Chara vulgaris*	S, M	Cadmium sulfate	-	14 d	EC_{50} (growth)	-	9.5	Heumann 1987
Green alga, *Chlamydomonas sp.*	S, U	Cadmium chloride	-	12 d	EC_{50} (growth)	-	22,482	Aguilera and Amils 2005
Green alga, *Chlamydomonas moewusii*	S, U	Cadmium chloride	-	96 hr	EC_{50} (growth)	-	4,100	Suarez et al. 2010
Green alga, *Chlamydomonas reinhardii*	F, M	Cadmium chloride	24	96 hr	EC_{50} (cell density)	-	203	Schafer et al. 1993
Green alga, *Chlamydomonas reinhardii*	F, M	Cadmium chloride	24	7 d	EC_{50} (cell density)	-	130	Schafer et al. 1993
Green alga, *Chlamydomonas reinhardii*	F, M	Cadmium chloride	24	10 d	EC_{50} (cell density)	-	99	Schafer et al. 1993
Green alga, *Chlamydomonas reinhardii*	S, U	Cadmium nitrate	-	96 hr	EC_{50} (growth)	-	3,020	Li et al. 2012b
Green alga, *Chlamydomonas reinhardii*	S, U	Cadmium nitrate	-	96 hr	EC_{50} (cell density)	-	2,690	Li et al. 2013
Green alga, *Chlamydomonas reinhardii*	S, U	Cadmium nitrate	-	96 hr	EC_{50} (Chlorophyll a)	-	1,820	Li et al. 2013
Green alga, *Chlorella pyrenoidosa*	-	-	-	-	Reduction in growth	-	250	Hart and Scaife 1977
Green alga, *Chlorella pyrenoidosa*	S, U	Cadmium nitrate	-	96 hr	EC_{50} (growth)	-	5,170	Li et al. 2012b

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Green alga, *Chlorella pyrenoidosa*	S, U	Cadmium chloride	-	96 hr	Reduced O_2 evolution	-	2,810	Wang et al. 2013
Green alga, *Chlorella saccharophila*	-	Cadmium chloride	-	96 hr	EC_{50}	-	105	Rachlin et al. 1984
Green alga, *Chlorella vulgaris*	-	-	-	-	EC_{50} (growth)	-	50	Hutchinson and Stokes 1975
Green alga, *Chlorella vulgaris*	-	Cadmium chloride	-	-	EC_{50} (growth)	-	60	Rosko and Rachlin 1977
Green alga, *Chlorella vulgaris*	-	Cadmium chloride	50	96 hr	EC_{50} (growth)	-	3,700	Canton and Slooff 1982
Green alga, *Chlorella vulgaris*	S, U	Cadmium sulfate	-	15 d	Growth	<17.99-17.99	<17.99	Awasthi and Das 2005
Green alga (South Laguna de Bay strain), *Chlorella vulgaris*	S, U	Cadmium chloride	-	12 d	EC_{50} (growth)	-	1,850	Nacorda et al. 2007
Green alga (West Laguna de Bay strain), *Chlorella vulgaris*	S, U	Cadmium chloride	-	12 d	EC_{50} (growth)	-	2,500	Nacorda et al. 2007
Green alga, *Chlorella vulgaris*	S, U	Cadmium chloride	-	7 d	Stimulated growth	<562.1-562.1	<562.1	Huang et al. 2009
Green alga, *Chlorococcum sp.*	-	Cadmium chloride	-	-	42% reduction in growth	-	2,500	Devi Prasad and Devi Prasad 1982
Green alga, *Chlorococcum sp.*	S, U	Cadmium chloride	-	10 d	Growth	1,000-5,000	2,236	Qiu et al. 2006
Green alga, *Gonium pectorale*	S, U	Cadmium chloride	-	96 hr	EC_{50} (growth)	-	109	Pereira et al. 2005
Green alga, *Parachlorell kessleri*	S, M	-	-	5 d	Growth and chlorophyll a content	2-8	4.000	Ngo et al. 2009

Species	Method[a]	Chemical	Hardness (mg/L as CaCO$_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Green alga, *Pseudokirchneriella subcapitata*	S, U	Cadmium chloride	171	96 hr	EC$_{50}$ (growth)	-	130	Versteeg 1990
Green alga, *Pseudokirchneriella subcapitata*	-	Cadmium chloride	-	-	Reduction in growth	-	50	Bartlett et al. 1974
Green alga, *Pseudokirchneriella subcapitata*	-	Cadmium nitrate	-	-	Reduction in growth	-	255	Slooff et al. 1983a
Green alga, *Pseudokirchneriella subcapitata*	S, U	Cadmium chloride	-	96 hr	EC$_{50}$ (growth)	-	10,500	Bozeman et al. 1989
Green alga, *Pseudokirchneriella subcapitata*	S, U	Cadmium chloride	-	96 hr	EC$_{50}$ (growth)	-	23.2	Thellen et al. 1989
Green alga, *Pseudokirchneriella subcapitata*	S, M	Cadmium nitrate	-	96 hr	IC$_{50}$ (growth rate)	-	67.44	Rodgher et al. 2012
Green alga, *Scenedesmus obliquus*	-	Cadmium chloride	-	-	39% reduction in growth	-	2,500	Devi Prasad and Devi Prasad 1982
Green alga, *Scenedesmus obliquus*	S, U	Cadmium nitrate	-	96 hr	EC$_{50}$ (growth)	-	2,660	Li et al. 2012b
Green alga, *Scenedesmus quadricauda*	-	Cadmium chloride	-	-	Reduction in cell count	-	6.1	Klass et al. 1974
Green alga, *Scenedesmus quadricauda*	-	Cadmium nitrate	-	-	Incipient inhibition	-	310	Bringmann and Kuhn 1977a,c
Green alga, *Scenedesmus quadricauda*	S, U	Cadmium chloride	-	144 hr	Growth rate and chlorophyll a concentration	<50-50	<50	Mohammed and Markert 2006
Green alga, *Spirogyra decimina*	S, U	Cadmium chloride	-	96 hr	Growth	<1,124.1-1,124.1	<1,124.1	Pribyl et al. 2005
Duckweed, *Lemna gibba*	S, M	Cadmium nitrate	-	7 d	EC$_{50}$ (growth)	-	800	Devi et al. 1996

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Duckweed, *Lemna gibba*	S, M	Cadmium chloride	-	96 hr	Growth	<1-1	<1	Megateli et al. 2009
Duckweed, *Lemna gibba*	S, U	Cadmium sulfate	-	96 hr	Total chlorophyll	100-500	223.6	Doganlar 2013
Duckweed, *Lemna gibba*	R, U	Cadmium nitrate	-	7 d	Reduced chlorophyll pigment	-	5,000	Uruc Parlak and Yilmaz 2013
Duckweed, *Lemna minor*	R, M	Cadmium chloride	39	96 hr	Reduced chlorophyll	-	54	Taraldsen and Norberg-King 1990
Duckweed, *Lemna minor*	S, U	-	-	96 hr	EC_{50} (growth)	-	200	Wang 1986
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	9 d	Chlorosis symptoms	<112.41-112.41	<112.41	Paczkowska et al. 2007
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	9 d	Growth	112.41-562.05	251.4	Paczkowska et al. 2007
Duckweed, *Lemna minor*	S, U	Cadmium sulfate	-	7 d	EC_{50} (growth)	-	<2,500	Uysal and Taner 2007
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	7 d	Growth rate, chlorosis	11.24-112.4	35.54	Razinger et al. 2008
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	7 d	EC_{20} (frond abscission)	-	56.0	Henke et al. 2011
Duckweed, *Lemna minor*	R, M	Cadmium chloride	-	7 d	EC_{50} (growth)	-	112.4	Basile et al. 2012
Duckweed, *Lemna minor*	S, U	Cadmium sulfate	-	96 hr	Total chlorophyll	500-1,500	866.0	Doganlar 2013
Duckweed, *Lemna triscula*	S, U	Cadmium sulfate	-	7 d	LOEC (Chl *a* reduction)	-	112.4	Malec et al. 2010
Duckweed, *Lemna valdiviana*	-	Cadmium nitrate	-	-	Reduction in number of fronds	-	10	Hutchinson and Czyrska 1972
Giant duckweed, *Spirodela polyrrhiza*	R, U	Cadmium sulfate	-	28 d	Growth	<7.63-7.63	<7.63	Sajwan and Ornes 1994
Giant duckweed, *Spirodela polyrrhiza*	S, U	Cadmium chloride	-	7 d	Multiplication rate and fresh weight	<1,000-1,000	<1,000	Singh et al. 2011

Species	Method[a]	Chemical	Hardness (mg/L as CaCO$_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Giant duckweed, *Spirodela polyrrhiza*	S, U	Cadmium sulfate	-	96 hr	Total chlorophyll	10-50	22.36	Doganlar 2013
Duckweed, *Wolffia arrhiza*	S, M	Cadmium nitrate	-	7 d	Fresh weight	112.41-1,124.1	355.5	Piotrowska et al. 2010
Duckweed, *Wolffia arrhiza*	S, M	Cadmium nitrate	-	14 d	Fresh weight	<112.41-112.41	<112.41	Piotrowska et al. 2010
Duckweed (3 wk), *Wolffia globosa*	S, U	Cadmium chloride	-	12 d	Algal lethal	-	8,000	Boonyapookana et al. 2002
Duckweed (3 wk), *Wolffia globosa*	S, U	Cadmium chloride	-	9 d	EC$_{50}$ (biomass)	-	1,500	Boonyapookana et al. 2002
Duckweed (3 wk), *Wolffia globosa*	S, U	Cadmium chloride	-	9 d	EC$_{50}$ (total chlorophyll content)	-	500	Boonyapookana et al. 2002
Pondweed, *Elodea canadensis*	R, M	Cadmium chloride	-	7 d	EC$_{50}$ (growth)	-	112.4	Basile et al. 2012
Feathered fern, *Azolla pinnata*	S, U	-	-	96 hr	Decrease chlorophyll	100-500	223.6	Prasad and Singh 2011
Macrophyte, *Bacopa monnieri*	R, M	Cadmium nitrate	-	96 hr	Cysteine content in roots	1,124.1-5,620.5	2,514	Singh et al. 2006
Macrophyte, *Bacopa monnieri*	R, M	Cadmium nitrate	-	96 hr	TBARS content in leaves and roots	1,124.1-5,620.5	2,514	Singh et al. 2006
Macrophyte, *Bacopa monnieri*	R, M	Cadmium nitrate	-	96 hr	Cysteine content in leaves	<1,124.1-1,124.1	<1,124.1	Singh et al. 2006
Water hyacinth (mature), *Eichhornia crassipes*	S, U	Cadmium nitrate	-	16 d	Growth	2,500-4,000	3,162	Hasan et al. 2007
Moss, *Leptodictyum riparium*	R, M	Cadmium chloride	-	7 d	EC$_{50}$ (growth)	-	562.5	Basile et al. 2012

Species	**Method**[a]	**Chemical**	**Hardness (mg/L as $CaCO_3$)**	**Duration**	**Effect**	**Chronic Limits (µg/L)**	**Concentration (µg/L)**	**Reference**
Crome sphagnum (young shorts), *Sphagnum squarrosum*	S, U	Cadmium chloride	-	25 d	LOEC (reduced chlorophyll)	-	1,124	Saxena and Saxena 2012
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	-	32 d	EC_{50} (root weigtht)	-	7,400	Stanley 1974
Water lettuce, *Pistia stratiotes*	R, U	Cadmium chloride	-	21 d	Growth	8.993-17.98	12.72	Wang et al. 2010b
Macrophyte, *Potamogeton crispus*	R, U	Cadmium chloride	-	7 d	Decreased chlorophyll a, b and carotenoid pigments in leaves	<2,248-2,248	<2,248	Xu et al. 2012
Sage pond weed, *Potamogeton pectinatus*	S, M	Cadmium chloride	-	96 hr	Chlorophyll a content	2,810-5,620	3,974	Rai et al. 2003
Aquatic fern, *Salvinia cucullata*	S, U	Cadmium chloride	-	8 d	% biomass, total chlorophyll content	<500-500	<500	Phetsombat et al. 2006
Fern, *Salvina natans*	-	Cadmium nitrate	-	-	Reduction in number of fronds	-	10	Hutchinson and Czyrska 1972
Macrophyte, *Vallisneria spiralis*	S, U	Cadmium chloride	-	14 d	Growth	4.496-8.993	6.359	Wang et al. 2009e

[a] S=static, R=renewal; F=flow-through, U=unmeasured, M=measured

Appendix F Acceptable Estuarine/Marine Plant Toxicity Data

Appendix Table F-1. Acceptable Estuarine/Marine Plant Toxicity Data

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Diatom, *Asterionella japonica*	-	Cadmium chloride	-	72 hr	EC_{50} (growth rate)	-	224.8	Fisher and Jones 1981
Diatom, *Chaetoceros calcitrans*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth)	-	50-70	Ismail et al. 2002
Diatom, *Ditylum brightwellii*	-	Cadmium chloride	-	5 d	EC_{50} (growth)	-	60	Canterford and Canterford 1980
Diatom, *Isochrysis galbana*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-well test)	-	50-70	Ismail et al. 2002
Diatom, *Isochrysis galbana*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-shaken flask)	-	60	Ismail et al. 2002
Diatom, *Phaeodactylum tricornutum*	S, U	Cadmium chloride	35	96 hr	EC_{50} (growth)	-	22,390	Torres et al. 1998
Diatom (3-5 d), *Phaeodactylum tricornutum*	S, U	Cadmium nitrate	-	96 hr	EC_{50} (growth)	-	15,720	Horvatic and Persic 2007
Diatom (3-5 d), *Phaeodactylum tricornutum*	S, U	Cadmium nitrate	-	336 hr	EC_{50} (growth)	-	7,560,000	Horvatic and Persic 2007
Dinoflagellate, *Prorocentrum minimum*	S, U	-	-	96 hr	EC_{50} (growth, nutrient rich medium)	-	674.5	Miao and Wang 2006
Dinoflagellate, *Prorocentrum minimum*	S, U	-	-	96 hr	EC_{50} (growth, P-starved medium)	-	113.5	Miao and Wang 2006
Diatom, *Skeletonema costatum*	-	Cadmium chloride	-	96 hr	EC_{50} (growth rate)	-	175	Gentile and Johnson 1982
Diatom, *Tetraselmis sp.*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-well test)	-	3,900-7,500	Ismail et al. 2002
Diatom, *Tetraselmis sp.*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-shaken flask)	-	5,199	Ismail et al. 2002

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Diatom, *Tetraselmis tetrahele*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-well test)	-	4,500-5,800	Ismail et al. 2002
Diatom, *Tetraselmis tetrahele*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-shaken flask)	-	6,900	Ismail et al. 2002
Diatom, *Thalassiosira nordenskioeldii*	S, U	-	-	15 d	IC_{50} (growth)	-	67.00	Wang and Wang 2011
Diatom, *Thalassiosira pseudonana*	-	Cadmium chloride	-	96 hr	EC_{50} (growth rate)	-	160	Gentile and Johnson 1982
Green alga, *Cladophora rupestris*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009
Green alga, *Dunaliella viridis*	S, U	Cadmium chloride	35	10 d	Chlorophyll production	5-10	7.071	Marcano et al. 2009
Green alga, *Scenedesmus sp.*	S, U	Cadmium chloride	35	10 d	Chlorophyll production	5-10	7.071	Marcano et al. 2009
Green alga, *Ulva intestinalis*	R, U	Cadmium chloride	-	14 d	NOEC (growth)	>1,124.1	>1,124.1	Baumann et al. 2009
Green alga, *Ulva pertusa*	S, U	-	35	5 d	EC_{50} (growth)	-	326	Han and Choi 2005
Green alga, *Ulva pertusa*	S, U	-	35	5 d	Sporulation inhibition	63->63	>63	Han and Choi 2005
Green alga, *Ulva pertusa*	S, U	-	35	96 hr	EC_{50} (spore inhibition)	-	95	Han et al. 2008
Brown alga, *Ascophyllum nodosum*	R, U	Cadmium chloride	-	14 d	NOEC (growth)	>1,124.1	>1,124.1	Baumann et al. 2009
Brown alga, *Fucus vesiculosus*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Kelp, *Laminana saccharina*	-	Cadmium chloride	-	8 d	EC_{50} (growth rate)	-	860	Markham et al. 1980
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporophyte growth	-	24.9	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporangia production	-	>189	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced female growth	-	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Stopped sexual production	-	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	R, U	Cadmium chloride	28-30	14 d	Sexual reproduction	77->77	>77	Thursby and Steele 1986
Red alga, *Chondrus crispus*	R, U	Cadmium chloride	-	14 d	NOEC (growth)	>1,124.1	>1,124.1	Baumann et al. 2009
Red alga, *Gracilaria lemaneiformis*	S, U	-	-	96 hr	Growth	5,620-11,241	7,948	Xia et al. 2004
Red alga, *Hypnea musciformis*	S, U	Cadmium chloride	34	7 d	LOEC (Chl *a*)	-	5,620	Bouzon et al. 2011
Red alga, *Palmaria palmata*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009
Red alga, *Polysiphonia lanosa*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009

[a] S=static, R=renewal; F=flow-through, U=unmeasured, M=measured

Appendix G Acceptable Bioaccumulation Data

Appendix Table G-1. Acceptable Bioaccumulation Data

(Species are organized phylogenetically).

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
FRESHWATER								
Aufwuchs (attached microscopic plants and animals)	Cadmium chloride	-	-	-	-	365	720	Giesy et al. 1979
Aufwuchs (attached microscopic plants and animals)	Cadmium chloride	-	-	-	-	365	580	Giesy et al. 1979
Duckweed, *Lemna valdiviana*	Cadmium nitrate	-	-	Whole plant	-	21	603	Hutchinson and Czyrska 1972
Fern, *Salvinia natans*	Cadmium nitrate	-	-	Whole plant	-	21	960	Hutchinson and Czyrska 1972
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	4.6	140	Whole body	51.3 (dry wt.)	87	2,230	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	32.4	140	Whole body	156.4 (dry wt.)	87	965	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	57.4	140	Whole body	533.1 (dry wt.)	87	1,857	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	86.9	140	Whole body	649.9 (dry wt.)	87	1,496	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	107.6	140	Whole body	739.2 (dry wt.)	87	1,374	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	153	140	Whole body	989.3 (dry wt.)	87	1,293	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	205.3	140	Whole body	1,620.6 (dry wt.)	87	1,579	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	0.3	22	Whole body	15.9 (dry wt.)	28	10,600	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	0.5	22	Whole body	21.6 (dry wt.)	28	8,640	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	1.3	22	Whole body	45.5 (dry wt.)	28	7,000	Straus 2011

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	2.3	22	Whole body	99.4 (dry wt.)	28	8,643	Straus 2011
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	0.35	20.5 (20-21)	Soft tissue	25 (dry wt.)	28 d	14,285	Pais 2012
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	0.53	20.5 (20-21)	Soft tissue	30 (dry wt.)	28 d	11,320	Pais 2012
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	1.41	20.5 (20-21)	Soft tissue	61 (dry wt.)	28 d	8,652	Pais 2012
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	2.51	20.5 (20-21)	Soft tissue	117 (dry wt.)	28 d	9,322	Pais 2012
Snail, *Physa integra*	Cadmium chloride	-	-	Whole body	-	28	1,750	Spehar et al. 1978
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	71	Tessier et al. 1994a
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	74	Tessier et al. 1994a
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	109	Tessier et al. 1994a
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	28	Tessier et al. 1994a
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	42	Tessier et al. 1994a
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	60	Tessier et al. 1994a
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	27	Tessier et al. 1994a
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	42	Tessier et al. 1994a

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	26	Tessier et al. 1994a
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	10	-	Soft tissue	-	60	6,910	Tessier et al. 1994b
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	50	-	Soft tissue	-	60	2,238	Tessier et al. 1994b
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	10	-	Soft tissue	-	60	1,758	Tessier et al. 1994b
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	50	-	Soft tissue	-	60	758	Tessier et al. 1994b
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	10	-	Soft tissue	-	60	1,258	Tessier et al. 1994b
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	50	-	Soft tissue	-	60	617	Tessier et al. 1994b
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	15	Tessier et al. 1994a
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	16	Tessier et al. 1994a
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	28	Tessier et al. 1994a
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	16	Tessier et al. 1994a
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	16	Tessier et al. 1994a
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	14	Tessier et al. 1994a
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	8	Tessier et al. 1994a
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	7	Tessier et al. 1994a
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	8	Tessier et al. 1994a
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	10	-	Soft tissue	-	60	1,256	Tessier et al. 1994b

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	50	-	Soft tissue	-	60	918	Tessier et al. 1994b
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	10	-	Soft tissue	-	60	945	Tessier et al. 1994b
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	50	-	Soft tissue	-	60	613	Tessier et al. 1994b
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	10	-	Soft tissue	-	60	574	Tessier et al. 1994b
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	50	-	Soft tissue	-	60	254	Tessier et al. 1994b
Zebra mussel (19-25 mm), *Dreissena polymorpha*	Cadmium chloride	2.2	-	Whole body	22 (dry wt.)	31	2,000	Voets et al. 2004
Zebra mussel (19-25 mm), *Dreissena polymorpha*	Cadmium chloride	7.3	-	Whole body	42.7 (dry wt.)	31	1,170	Voets et al. 2004
Zebra mussel (19-25 mm), *Dreissena polymorpha*	Cadmium chloride	23.9	-	Whole body	129.3 (dry wt.)	31	1,082	Voets et al. 2004
Asian clam, *Corbicula fluminea*	Cadmium sulfate	-	-	Whole body	-	28	3,770	Graney et al. 1983
Asian clam, *Corbicula fluminea*	Cadmium sulfate	-	-	Whole body	-	28	1,752	Graney et al. 1983
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	3	55.8	Whole body	175 (dry wt.)	28	11,667	Barfield et al. 2001
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	5	55.8	Whole body	227.4 (dry wt.)	28	9,096	Barfield et al. 2001
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	9.2	55.8	Whole body	175 (dry wt.)	28	3,804	Barfield et al. 2001
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	20.2	55.8	Whole body	175 (dry wt.)	28	1,733	Barfield et al. 2001
Cladoceran, *Daphnia magna*	Cadmium sulfate	-	-	Whole body	-	2-4	320	Poldoski 1979
Cladoceran, *Daphnia magna*	Cadmium sulfate	-	-	Whole body	-	7	484	Winner 1984

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Amphipod, *Hyalella azteca*	Cadmium sulfate	0.48	162.7	Whole body	0.59 (wet wt.)	28	1,229	Stanley et al. 2005
Amphipod, *Hyalella azteca*	Cadmium sulfate	5.09	162.7	Whole body	41.18 (wet wt.)	28	8,090	Stanley et al. 2005
Amphipod, *Hyalella azteca*	-	0.3	22	Whole body	98.4 (dry wt.)	28	65,600	Straus 2011
Amphipod, *Hyalella azteca*	-	0.5	22	Whole body	145.0 (dry wt.)	28	58,000	Straus 2011
Amphipod, *Hyalella azteca*	-	1.25	140	Whole body	82.4 (dry wt.)	21	13,184	Straus 2011
Amphipod, *Hyalella azteca*	-	2.5	140	Whole body	128.3 (dry wt.)	21	10,264	Straus 2011
Amphipod, *Hyalella azteca*	-	5	140	Whole body	106.7 (dry wt.)	21	4,268	Straus 2011
Amphipod (2-9 d, neonate), *Hyalella azteca*	Cadmium chloride	0.64	90	Whole body	15 (dry wt.)	28 d	4,688	Pais 2012
Amphipod (2-9 d, neonate), *Hyalella azteca*	Cadmium chloride	1.38	90	Whole body	110 (dry wt.)	28 d	15,942	Pais 2012
Amphipod (2-9 d, neonate), *Hyalella azteca*	Cadmium chloride	2.65	90	Whole body	145 (dry wt.)	28 d	10,943	Pais 2012
Crayfish, *Orconectes propinquus*	-	-	-	Whole body	-	8	184	Gillespie et al. 1977
Mayfly, *Ephemeroptera sp.*	Cadmium chloride	-	-	Whole body	-	365	1,630	Giesy et al. 1979
Mayfly, *Ephemeroptera sp.*	Cadmium chloride	-	-	Whole body	-	365	3,520	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Cadmium chloride	-	-	Whole body	-	365	736	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Cadmium chloride	-	-	Whole body	-	365	3,520	Giesy et al. 1979
Damselfly, *Ischnura sp.*	Cadmium chloride	-	-	Whole body	-	365	1,300	Giesy et al. 1979

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Damselfly, *Ischnura sp.*	Cadmium chloride	-	-	Whole body	-	365	928	Giesy et al. 1979
Stonefly, *Pteronarcys dorsata*	Cadmium chloride	-	-	Whole body	-	28	373	Spehar et al. 1978
Beetle, Dytiscidae	Cadmium chloride	-	-	Whole body	-	365	164	Giesy et al. 1979
Beetle, Dytiscidae	Cadmium chloride	-	-	Whole body	-	365	260	Giesy et al. 1979
Caddisfly, *Hydropsyche sp.*	Cadmium chloride	-	-	Whole body	-	2-8	228.2	Dressing et al. 1982
Caddisfly, *Hydropsyche betteni*	Cadmium chloride	-	-	Whole body	-	28	4,190	Spehar et al. 1978
Biting midge, Ceratopogonidae	Cadmium chloride	-	-	Whole body	-	365	936	Giesy et al. 1979
Biting midge, Ceratopogonidae	Cadmium chloride	-	-	Whole body	-	365	662	Giesy et al. 1979
Midge, Chironomidae	Cadmium chloride	-	-	Whole body	-	365	2,200	Giesy et al. 1979
Midge, Chironomidae	Cadmium chloride	-	-	Whole body	-	365	1,830	Giesy et al. 1979
Midge, *Chironomus riparius*	-	10,000	-	Whole body	-	28	1,370	Timmermans et al. 1992
Lake whitefish, *Coregonus clupeaformis*	Cadmium chloride	2.07	82.5	Whole body	-	72	42	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	-	-	-	Whole body	-	140	540	Kumada et al. 1973

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as CaCO$_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	-	-	Whole body	-	70	33	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	3.39	82.5	Whole body	-	72	55	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	1.8	250	Muscle	-	231	333	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	3.4	250	Muscle	-	231	294	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	5.5	250	Muscle	-	231	509	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	1.8	250	Muscle	-	455	89	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	3.4	250	Muscle	-	455	182	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	5.5	250	Muscle	-	455	127	Brown et al. 1994
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	0.87	- (pH=6.8)	Whole body	-	91	229	Peterson et al. 1985
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	1.74	- (pH=6.8)	Whole body	-	91	176	Peterson et al. 1985
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	1.01	- (pH=4.5)	Whole body	-	91	4	Peterson et al. 1985
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	2.09	- (pH=4.5)	Whole body	-	91	7	Peterson et al. 1985
Brookl trout, *Salvelinus fontinalis*	Cadmium chloride	-	-	Muscle	-	490	3	Benoit et al. 1976
Brook trout, *Salvelinusfontinalis*	Cadmium chloride	-	-	Muscle	-	84	151	Benoit et al. 1976
Bull trout, *Salvelinus confluentus*	Cadmium chloride	-	-	Muscle	-	93	22	Sangalang and Freeman 1979
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.052	30.6	Whole body	0.170 (dry wt.)	55	817	Hansen et al. 2002a

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.089	30.6	Whole body	0.204 (dry wt.)	55	573	Hansen et al. 2002a
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.197	30.6	Whole body	0.379 (dry wt.)	55	481	Hansen et al. 2002a
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.383	30.6	Whole body	0.572 (dry wt.)	55	373	Hansen et al. 2002a
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.786	30.6	Whole body	0.913 (dry wt.)	55	290	Hansen et al. 2002a
Mosquitofish, *Gambusia affinis*	Cadmium chloride	-	-	Whole body (estimated steady state)	-	180	2,213	Giesy et al. 1979
Mosquitofish, *Gambusia affinis*	Cadmium chloride	-	-	Whole body (estimated steady state)	-	180	1,891	Giesy et al. 1979
Guppy, *Poecilia reticulata*	-	-	-	Whole body	-	32	280	Canton and Sloof 1982
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	0.8	134	Whole body	-	28	113	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	1.8	134	Whole body	-	28	78	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	2.2	134	Whole body	-	28	86	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	2.8	134	Whole body	-	28	68	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	3.6	134	Whole body	-	28	67	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	4.4	134	Whole body	-	28	66	Cope et al. 1994

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	5.2	134	Whole body	-	28	69	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	6.2	134	Whole body	-	28	50	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	7.7	134	Whole body	-	28	48	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	8.4	134	Whole body	-	28	62	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	13.2	134	Whole body	-	28	55	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	16.1	134	Whole body	-	28	37	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	19.7	134	Whole body	-	28	34	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	32.3	134	Whole body	-	28	41	Cope et al. 1994
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	6.8	145	Muscle	-	112	17.6	Papoutsoglou and Abel 1988
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	14	145	Muscle	-	112	16.4	Papoutsoglou and Abel 1988
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	28	145	Muscle	-	112	25.7	Papoutsoglou and Abel 1988
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	52	145	Muscle	-	112	17.7	Papoutsoglou and Abel 1988
African clawed frog, *Xenopus laevis*	-	-	-	Whole body	-	100	130	Canton and Sloof 1982
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	0.1	-	Whole body	2.5 (dry wt.)	47	6,250	Sharma and Patino 2008
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	0.8	-	Whole body	6.6 (dry wt.)	47	2,063	Sharma and Patino 2008

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	8	-	Whole body	8.4 (dry wt.)	47	263	Sharma and Patino 2008
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	84	-	Whole body	14 (dry wt.)	47	42	Sharma and Patino 2008
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	855	-	Whole body	100 (dry wt.)	47	29	Sharma and Patino 2008

Species	Chemical	Concentration in water (µg/L)	Salinity	Tissue	Concentration (µg/g)	Duration	BCF or BAF	Reference
ESTUARINE/MARINE WATER								
Polychaete worm, *Ophryotrocha diadema*	Cadmium chloride	-	-	Whole body	-	64	3,160	Klockner 1979
Common bay mussel, *Mytilus edulis*	Cadmium chloride	-	-	Soft parts	-	35	306	Phillips 1976
Common bay mussel, *Mytilus edulis*	Cadmium chloride	-	-	Soft parts	-	28	113	George and Coombs 1977
Common bay mussel (adult, 40-50 mm), *Mytilus edulis*	Cadmium chloride	3.3 (dissolved)	- (6ºC)	Whole body	8 (dry wt.)	28	485	Mubiana and Blust 2007
Common bay mussel (adult, 40-50 mm), *Mytilus edulis*	Cadmium chloride	3.1 (dissolved)	- (16ºC)	Whole body	16 (dry wt.)	28	1,032	Mubiana and Blust 2007
Common bay mussel (adult, 40-50 mm), *Mytilus edulis*	Cadmium chloride	3.2 (dissolved)	- (26ºC)	Whole body	21 (dry wt.)	28	1,313	Mubiana and Blust 2007
Common bay mussel (9.5 g, 43.2 cm), Mytilus edulis	Cadmium chloride	55.9	-	Soft tissue	85 (dry wt.)	14		Amachree et al. 2013

Species	**Chemical**	**Concentration in water (µg/L)**	**Salinity**	**Tissue**	**Concentration (µg/g)**	**Duration**	**BCF or BAF**	**Reference**
Bay scallop, *Argopecten irradians*	Cadmium chloride	-	-	Muscle	-	42	2,040	Pesch and Stewart 1980
Eastern oyster, *Crassostrea virginica*	Cadmium nitrate	-	-	Soft parts	-	98	1,220	Schuster and Pringle 1969
Eastern oyster, *Crassostrea virginica*	Cadmium chloride	-	-	Soft parts	-	280	2,150	Zaroogian and Cheer 1976
Eastern oyster, *Crassostrea virginica*	Cadmium chloride	-	-	Soft parts	-	280	1,830	Zaroogian 1979
Soft-shell clam, *Mya arenaria*	Cadmium nitrate	-	-	Soft parts	-	70	160	Pringle et al. 1968
Pink shrimp, *Penaeus duorarum*	Cadmium chloride	-	-	Whole body	-	30	57	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes pugio*	Cadmium chloride	-	-	Whole body	-	28	203	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes pugio*	Cadmium chloride	-	-	Whole body	-	42	22	Pesch and Stewart 1980
Grass shrimp, *Paleomonetes vulgaris*	Cadmium chloride	-	-	Whole body	-	28	307	Nimmo et al. 1977b
Green crab, *Carcinus maenas*	Cadmium chloride	-	-	Muscle	-	68	5	Wright 1977
Green crab, *Carcinus maenas*	Cadmium chloride	-	-	Muscle	-	40	7	Jennings and Rainbow 1979a

Appendix H Other Freshwater Toxicity Data

Appendix Table H-1. Other Freshwater Toxicity Data
(Species are organized phylogenetically).

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
FRESHWATER							
Mixed natural fungi and bacterial colonies on leaf litter	Cadmium chloride	196 d	10.7	Inhibition of leaf decomposition	5	Giesy 1978	Mixed community exposure
Mixed algal species	Cadmium chloride	-	11.1	Significant reduction in population	5	Giesy et al. 1979	Mixed community exposure
Mixed algal species	Cadmium chloride	10 d	-	Growth inhibition	50	Lasheen et al. 1990	Mixed community exposure
Phytoplankton community	-	7 week	-	Positive biodiversity-production relationship	120,000	Li et al. 2010b	Mixed community exposure
Stream microcosm	Cadmium nitrate	21 d	-	No effect on periphyton structure, but adverse effects on invertebrate grazers and collectors	22	Selby et al. 1985	Mixed community exposure
Mixed zooplankton community	-		14 d	60% reduced biomass	1	Lawrence and Holoka 1987	Mixed community exposure
Mixed macro-invertebrates	Cadmium chloride	52 wk	11.1	Reduced taxa	5	Giesy et al. 1979	Mixed community exposure
Blue-green alga, *Microcystis aeruginosa*	Cadmium chloride	24 hr	-	EC50 (growth)	0.56	Guanzon et al. 1994	Duration
Blue-green alga, *Microcystis aeruginosa*	-	48 hr	-	EC50 (growth, non-toxic strain)	19.78	Zeng et al. 2009	Duration
Blue-green alga, *Microcystis aeruginosa*	-	48 hr	-	EC50 (growth, toxic strain)	11.58	Zeng et al. 2009	Duration
Cyanobacteria, *Anacystis nidulans*	Cadmium chloride	14 d	-	No growth	50,000	Lee et al. 1992	
Cyanobacteria, *Synechococcus sp.*	-		-	EC50	5,400	Satoh et al. 2005	
Cyanobacteria, *Synechococcus sp.*	Cadmium chloride	72 hr	-	Reduced growth	562	Toth et al. 2012	

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Diatom, *Entomoneis* cf *punctulata*	Cadmium sulfate	24 hr	-	EC50 (fluorescence inhibition)	3,700	Adams and Stauber 2004	Duration
Diatom, *Entomoneis* cf *punctulata*	Cadmium sulfate	72 hr	-	EC50 (growth)	2,400	Adams and Stauber 2004	Duration
Green alga, *Acetabularia acetabulum*	Cadmium chloride	3 wk	-	Morphological deformities	100	Karez et al. 1989	
Green alga, *Chlamydomonas acidophila*	Cadmium sulfate	72 hr	-	EC50 (growth)	1,562	Nishikawa and Tominaga 2001	Duration
Green alga, *Chlamydomonas reinhardtii*	Cadmium chloride	72 hr	-	EC50 (growth)	789	Schafer et al. 1994	Duration
Green alga, *Chlamydomonas reinhardtii*	-	24 hr	-	NOEC-LOEC (specific growth rate)	2.248-4.496	Stoiber et al. 2010	Duration
Green alga, *Chlorella pyrenoidosa*	Cadmium chloride	24 hr	-	EC50 (growth-batch test)	170	Lin et al. 2007	Duration
Green alga, *Chlorella pyrenoidosa*	Cadmium chloride	24 hr	-	EC50 (growth-continuous test)	28	Lin et al. 2007	Duration
Green alga, *Chlorella vulgaris*	Cadmium nitrate	72 hr	-	EC50 (growth)	50,000	Wren and McCarroll 1990	Duration
Green alga, *Chlorella vulgaris*	Cadmium chloride	72 hr	-	Reduced progeny formation	100	Wilczok et al. 1994	Duration
Green alga, *Chlorella vulgaris*	Cadmium sulfate	72 hr	-	LOEC (reduced nitrate reductase activity)	17.99	Awasthi and Das 2005	Duration; Atypical endpoint
Green alga, *Chlorococcum sp.*	-	72 hr	-	EC50 (growth)	11,200	Satoh et al. 2005	Duration
Green alga, *Chlorococcum littorale*	-	72 hr	-	EC50 (growth)	9,700	Satoh et al. 2005	Duration
Green alga, *Prasinococcus sp.*	-	72 hr	-	EC50 (growth)	5,900	Satoh et al. 2005	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Cadmium nitrate	5 d	-	LOEC (growth)	30	Thompson and Couture 1991	
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	24.2	EC50 (cell counts)	20.6	Radetski et al. 1995	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	24.2	EC50 (cell counts)	42.7	Radetski et al. 1995	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	72 hr	-	EC50 (cell number)	164	Van der Heever and Grobbelaar 1996	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	72 hr	-	EC50 (chlorophyll)	97	Van der Heever and Grobbelaar 1996	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	3.5	EC50 (growth rate)	31	Kallqvist 2009	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	13.5	EC50 (growth rate)	62	Kallqvist 2009	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	43.5	EC50 (growth rate)	131	Kallqvist 2009	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	24 hr	-	EC50 (growth rate-total cell volume)	82	Chao and Chen 2001	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	24 hr	-	EC50 (growth rate-cell density)	13	Chao and Chen 2001	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	72 hr	-	EC50 (cell division)	15	Franklin et al. 2001	Duration too short; Lack of exposure details
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	24 hr	-	EC50 (growth)	15,370	Bascik-Remisiewicz and Tukaj 2002	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium nitrate	24 hr	-	EC50 (growth)	18,000	Bascik-Remisiewicz and Tukaj 2002	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium sulfate	24 hr	-	EC50 (growth)	16,440	Bascik-Remisiewicz and Tukaj 2002	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	60 min	-	EC50 (photosynthesis inhibition)	200	Koukal et al. 2003	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	48 hr	-	EC50 (growth)	35	Lin et al. 2005	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	48 hr	-	EC50 (cell density)	25	Lin et al. 2005	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	-	48 hr	-	EC50 (D.O. production)	80	Lin et al. 2005	Duration
Green alga, *Scenedesmus dimorphus*	Cadmium nitrate	48 hr	11.3	LC50 (density)	63	Ghosh et al. 1990	Duration
Green alga, *Scenedesmus quadricauda*	Cadmium chloride	96 hr	-	Incipient inhibition (river water)	100	Bringmann and Kuhn 1959a;b	
Green alga, *Scenedesmus quadricauda*	Cadmium chloride	20 d	-	LC50	9	Fargasova 1993	
Green alga, *Scenedesmus quadricauda*	Cadmium chloride	24 hr	-	EC50 (growth)	1.9	Guanzon et al. 1994	Duration
Green alga, *Stichococcus bacillaris*	Cadmium chloride	96 hr	-	Reduced growth	5,000	Skowronski et al. 1985	
Duckweed, *Lemna minor*	-	10 d	-	EC50 (frond production)	191	Smith and Kwan 1989	
Duckweed, *Lemna minor*	Cadmium sulfate	48 hr	-	NOEC-LOEC (relative pigment concentration)	562,050-1,124,100	Prasad et al. 2001	Duration
Duckweed, *Lemna minor*	Cadmium chloride	24 hr	-	EC50 (growth)	57,000	Drinovec et al. 2004	Duration
Duckweed, *Lemna pavcicostata*	Cadmium chloride	48 hr	-	NOEC-LOEC (increase colony break-up)	44.96-89.93	Li and Xiong 2004	Duration
Giant duckweed, *Spirodela polyrrhiza*	-	12 d	-	NOEC-LOEC (inhibit chlorophyll synthesis)	100-500	Rolli et al. 2010	Lack of exposure details
Duckweed, *Spirodela punctata*	-	30 d	-	Reduced growth rate	25	Outridge 1992	
Fungi, *Cylindrotheca sp.*	-	72 hr	-	EC50 (growth)	9,300	Satoh et al. 2005	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Garden cress (seeds), *Lepidium sativum*	Cadmium chloride	72 hr	-	EC50 (growth)	33,723	Gianazza et al. 2007	Duration
Water fern, *Salvinia minima*	-	30 d	-	Reduced growth rate	10	Outridge 1992	
Bacteria, *Escherichia coli*	Cadmium chloride	-	-	Incipient inhibition	150	Bringmann and Kuhn 1959a,b	Bacteria
Bacteria, *Salmonella typhimurium*	Cadmium chloride	8 hr	50	EC50 (growth inhibition)	10,400	Canton and Slooff 1982	Bacteria
Bacteria, *Pseudomonas putida*	Cadmium chloride	16 hr	-	Incipient inhibition	80	Bringmann and Kuhn 1976; 1977a,c; 1979; 1980b	Bacteria
Bacteria, *Vibrio fischeri*	Cadmium chloride	30 min	-	EC50	14,240	Macken et al. 2009	Bacteria
Bacteria (6 species)	Cadmium chloride	18 hr	-	Reduced growth	5,000	Seyfreid and Horgan 1983	Bacteria
Protozoan community	Cadmium chloride	48 hr	70	EC50 (number of species)	4,600	Niederlehner et al. 1985	Protozoan
Protozoan community	Cadmium chloride	28 d	70	EC20 (colonization)	1	Niederlehner et al. 1985	Protozoan
Protozoan community	Cadmium chloride	10 d	-	Reduced biomass	1	Fernandez-Leborans and Novillo-Villajos 1993	Protozoan
Protozoan, *Chilomonas paramecium*	Cadmium nitrate	48 hr	-	Incipient inhibition	160	Bringmann et al. 1980	Protozoan
Ciliate, *Colpidium campylum*	Cadmium sulfate	24 hr	-	EC50 (growth)	75	Dive et al. 1989	Protozoan

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Protozoan, *Colpidium colpoda*	Cadmium chloride	24 hr	103	LC50	890	Madoni and Romeo 2006	Protozoan
Protozoan, *Colpoda steinii*	-	24 hr	-	LC50	500	Martin-Gonzalez et al. 2005	Protozoan
Protozoan, *Cyrtolophosis elongata*	-	24 hr	-	LC50	2,000	Martin-Gonzalez et al. 2005	Protozoan
Protozoan, *Dexiotricha granulosa*	Cadmium chloride	24 hr	103	LC50	300	Madoni and Romeo 2006	Protozoan
Protozoan, *Drepanomonas revoluta*	-	24 hr	-	LC50	2,000	Martin-Gonzalez et al. 2005	Protozoan
Protozoa, *Entosiphon sulcatum*	Cadmium nitrate	72 hr	-	Incipient inhibition	11	Bringmann 1978; Bringmann and Kuhn 1979; 1980b; 1981	Protozoan
Protozoa, *Euglena gracilis*	Cadmium nitrate	24 hr	-	EC50 (motility)	860	Ahmed and Hader 2010	Protozoan
Protozoa, *Euplotes aediculatus*	Cadmium chloride	24 hr	103	LC50	590	Madoni and Romeo 2006	Protozoan
Protozoan, *Halteria grandinella*	Cadmium chloride	24 hr	103	LC50	70	Madoni and Romeo 2006	Protozoan
Protozoan, *Microregma heterostoma*	Cadmium chloride	28 hr	-	Incipient inhibition	100	Brinmgmann and Kuhn 1959b	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium chloride	24 hr	28	LC50	78.1	Nalecz-Jawecki et al. 1993	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium chloride	24 hr	250	LC50	5,270	Nalecz-Jawecki et al. 1993	Protozoan

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	-	LC50	168	Nalecz-Jawecki and Sawicki 1998	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	<10	LC50	160	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	<10	EC50 (deformity)	130	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	200	LC50	3,870	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	200	EC50 (deformity)	3,250	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum teres*	Cadmium chloride	24 hr	-	LC50	1,950	Twagilimana et al. 1998	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	90 min	-	Reduced locomotor rate	750	Bergquist and Bovee 1976	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	60 min	-	Decrease in swimming rate	1,000	Bergquist and Bovee 1976	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	72 hr	-	Growth inhibition	3,372	Krawczynska et al. 1989	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium acetate	30 min	-	Complete mortality	56,205	Larsen and Svensmark 1991	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	96 hr	-	EC50 (growth)	1,045	Schafer et al. 1994	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	9 hr	-	IC50 (growth)	3,000	Sauvant et al. 1995	Protozoan
Protozoan, *Tetrahymena thermophila*	Cadmium chloride	24 hr	-	LC50	195	Gallego et al. 2007	Protozoan
Protozoan, *Tetrahymena thermophila*	Cadmium nitrate	24 hr	<10	EC50 (feeding inhibition)	130	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Tetrahymena thermophila*	Cadmium nitrate	24 hr	200	EC50 (feeding inhibition)	260	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Uronema parduezi*	Cadmium nitrate	20 hr	-	Incipient inhibition	26	Bringmann and Kuhn 1980a; 1981	Protozoan

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Paramecium, *Paramecium caudatum*	Cadmium chloride	5 d	-	IC50 (growth)	94.40	Miyoshi et al. 2003	Protozoan
Paramecium, *Paramecium bursaria*	-	24 hr	-	LC50	640	Wanick et al. 2008	Protozoan
Paramecium, *Paramecium trichium*	Cadmium chloride	5 d	-	IC50 (growth)	11.71	Miyoshi et al. 2003	Protozoan
Heliozoon, *Raphidiophrys contractilis*	Cadmium chloride	20 min	-	LOEC (axopodial degradation)	11.24	Khan et al. 2006a	Protozoan
Hydra, *Hydra littoralis*	Cadmium chloride	12 d	70	Reduced growth	20	Santiago-Fandino 1983	Duration; Exposure methods unknown
Hydra, *Hydra oligactis*	Cadmium nitrate	48 hr	-	LC50	583	Slooff 1983; Slooff et al. 1983a	Duration
Green hydra, *Hydra viridissima*	Cadmium chloride	7 d	19-20	NOEC-LOEC (population growth rate)	0.4-0.8	Holdway et al. 2001	Duration; Unmeasured exposure
Green hydra (symbiotic, with algae), *Hydra viridissima*	Cadmium chloride	48 hr	207	LC50	160	Karntanut and Pascoe 2005	Duration
Green hydra (aposymbiotic, without algae), *Hydra viridissima*	Cadmium chloride	48 hr	207	LC50	140	Karntanut and Pascoe 2005	Duration
Pink hydra, *Hydra vulgaris*	Cadmium chloride	7 d	19-20	LOEC (population growth rate)	12.5	Holdway et al. 2001	Duration; Unmeasured exposure
Planarian, *Dendrocoelum lacteum*	Cadmium chloride	48 hr	122.8	LC50	46,000	Brown and Pascoe 1988	Duration
Planarian, *Dugesia lugubris*	Cadmium nitrate	48 hr	-	LC50	>20,000	Slooff 1983	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	24 hr	80-100	LC50	1,300	Snell et al. 1991a	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	48 hr	80-100	EC50	70	Snell and Moffat 1992	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	48 hr	80-100	Chronic value	60	Snell and Moffat 1992	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium sulfate	24 hr	250	EC50	120	Crisinel et al. 1994	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium chloride	35 min	170	NOEC (ingestion rate)	250.00	Juchelka and Snell 1994	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	72 hr	80-100	Chronic value (asexual reproduction)	20	Snell and Carmona 1995	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	72 hr	80-100	Chronic value (sexual reproduction)	20	Snell and Carmona 1995	Duration
Rotifer (<2 hr), *Brachionus calyciflorus*	Cadmium nitrate	48 hr	80-100	EC50	10	Radix et al. 1999	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium chloride	24 hr	-		180	Sarma et al. 2006	Duration
Rotifer, *Brachionus macracanthus*	Cadmium chloride	24 hr	-	LC50	118.9	Nandini et al. 2007	Duration
Rotifer, *Brachionus macracanthus*	Cadmium chloride	21 d	-	LOEC (population growth)	0.383	Nandini et al. 2007	Unmeasured chronic exposure
Rotifer, *Brachionus rubens*	Cadmium chloride	24 hr	80-100	LC50	810	Snell and Persoone 1989a	Duration
Rotifer, *Brachionus rubens*	Cadmium chloride	24 hr	80-100	NOEC (survival)	280	Snell and Persoone 1989a	Duration
Rotifer, *Philodina acuticornis*	Cadmium chloride	96 hr	Soft water	EC50 (death and immobility)	500	Buikema et al. 1973	Test species fed
Rotifer, *Philodina acuticornis*	Cadmium sulfate	96 hr	Soft water	EC50 (death and immobility)	200	Buikema et al. 1973	Test species fed
Rotifer, *Philodina acuticornis*	Cadmium sulfate	96 hr	Hard water	EC50 (death and immobility)	300	Buikema et al. 1973	Test species fed

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rotifer, *Streptocephalus rubricaudatus*	Cadmium sulfate	24 hr	250	EC50	250	Crisinel et al. 1994	Duration
Rotifer, *Thamnocephalus platyurus*	Cadmium chloride	24 hr	80-100	LC50	400	Centeno et al. 1995	Duration
Parasite (embryo, blastula stage), *Chordodes nobilli*	Cadmium chloride	96 hr	162	Infective capacity of larva	630	Achiorno et al. 2010	Atypical endpoint
Parasite (larva), *Chordodes nobilli*	Cadmium chloride	48 hr	162	Infective capacity of larva	360	Achiorno et al. 2010	Atypical endpoint; Duration
Nematode, *Caenorhabditis elegans*	Cadmium chloride	96 hr	-	LC50	61	Williams and Dusenbery 1990	Test species fed
Nematode (adult), *Caenorhabditis elegans*	-	48 hr	-		2,000	Cressman and Williams 1997	Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	EC50 (growth)	16,524	Anderson et al. 2001	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	EC50 (movement)	18,772	Anderson et al. 2001	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	EC50 (feeding)	14,388	Anderson et al. 2001	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	72 hr	-	EC50 (reproduction)	16,973	Anderson et al. 2001	Test species fed; Duration
Nematode (L1 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	LC50	66,884	Chu and Chow 2002	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	LC50	620,503	Chu and Chow 2002	Test species fed; Duration
Nematode (larva), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	LC50	169,920	Ura et al. 2002	Duration
Nematode (3 d), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	LC50	518,598	Roh et al. 2006	Duration
Nematode (L1-L4 larva), *Caenorhabditis elegans*	Cadmium chloride	4 hr	-	LOEC (reproduction)	11,240	Guo et al. 2009	Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	72 hr	-	LOEC (reproduction)	11,240	Guo et al. 2009	Duration
Nematode (L4 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	EC50 (number of offsprings)	20,906	Boyd et al. 2010	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Nematode (L4 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	EC50 (number of offsprings)	19,784	Boyd et al. 2010	Duration
Nematode (L4 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	EC50 (number of offsprings)	21,583	Boyd et al. 2010	Duration
Polychaete worm (non-reproductive), *Aelosoma headleyi*	Cadmium chloride	48 hr	60-70	LC50	1,200	Niederlehner et al. 1984	Test species fed; Duration
Polychaete worm (non-reproductive), *Aelosoma headleyi*	Cadmium chloride	48 hr	160-190	LC50	4,980	Niederlehner et al. 1984	Test species fed; Duration
Oligochaete, *Aeolosoma headleyi*	Cadmium chloride	10 d	65 (60-70)	NOEC-LOEC (growth and reproduction)	17.2-36.9	Niederlehner et al. 1984	Duration
Oligochaete (adult) worm, *Lumbriculus variegatus*	Cadmium chloride	10 d	44-47	LC50	158	Phipps et al. 1995	Duration
Oligochaete worm, *Lumbriculus variegatus*	Cadmium chloride	48 hr	20	LC50	270	Penttinen et al. 2011	Duration
Oligochaete worm, *Lumbriculus variegatus*	Cadmium chloride	48 hr	50	LC50	410	Penttinen et al. 2011	Duration
Oligochaete worm, *Lumbriculus variegatus*	Cadmium chloride	48 hr	250.25	LC50	2,161	Penttinen et al. 2011	Duration
Oligochaete, *Pristina sp.*	Cadmium chloride	52 week	11.1	Population reduction	5	Giesy et al. 1979	Exposure methods unknown
Oligochate, *Prstina leidyi*	Cadmium chloride	48 hr	95	LC50	215	Smith et al. 1991	Duration
Tubificid worm, *Tubifex tubifex*	Cadmium chloride	48 hr	224	LC50	320,000	Qureshi et al. 1980	Duration
Tubificid worm, *Tubifex tubifex*	Cadmium chloride	96 hr	245	LC50	47,530	Khangarot 1991	
Tubificid worm (adult, 4 cm), *Tubifex tubifex*	Cadmium chloride	24 hr	-	LC50	4,900	Gerhardt 2009	Duration
Tubificid worm (adult, 4 cm), *Tubifex tubifex*	Cadmium chloride	24 hr	-	EC50 (locomotion)	1,100	Gerhardt 2009	Duration

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Spire snail, *Amnicola limosa*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	6,350	Mackie 1989	pH is artificially low as part of study
Spire snail, *Amnicola limosa*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	3,800	Mackie 1989	pH is artificially low as part of study
Spire snail, *Amnicola limosa*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	2,710	Mackie 1989	pH is artificially low as part of study
Snail (egg, strain BS90), *Biomphalaria glabrata*	Cadmium chloride	3 mo	-	LOEC (hatching success)	1.14	Salice and Miller 2003	Unmeasured chronic exposure
Snail (egg, strain NMRI), *Biomphalaria glabrata*	Cadmium chloride	3 mo	-	LOEC (hatching success)	2.81	Salice and Miller 2003	Unmeasured chronic exposure
Pond snail (6-9 mo., 10.32 mm), *Lymnaea palustris*	Cadmium chloride	28 d	-	LC50	>320	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail (6-9 mo., 10.32 mm), *Lymnaea palustris*	Cadmium chloride	28 d	-	EC50 (growth)	58.2	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail (6-9 mo., 10.32 mm), *Lymnaea palustris*	Cadmium chloride	28 d	-	NOEC-LOEC (reproduction)	40-80	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail, *Lymnaea stagnalis*	Cadmium chloride	48 hr	-	LC50	583	Slooff 1983; Slooff et al. 1983a	Duration
Pond snail (6-9 mo., 20.62 mm), *Lymnaea stagnalis*	Cadmium chloride	28 d	-	EC50 (growth)	142.2	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail (5 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	LC50	12.8 (dissolved)	Pais 2012	Duration
Pond snail (10 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	NOEC (length and weight)	94.3	Pais 2012	More sensitive endpoint available for this study
Pond snail (10 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	LC50	49.7 (dissolved)	Pais 2012	Duration
Pond snail (15 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	NOEC (length and weight)	94.3	Pais 2012	More sensitive endpoint available for this study
Pond snail (15 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	LC50	45.7 (dissolved)	Pais 2012	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Pond snail (juvenile, 7 mm), *Lymnaea stagnalis*	Cadmium chloride	28 d	20.5 (20-21)	LC50	7.3 (dissolved)	Pais 2012	Duration; Too few exposure concentrations
Pond snail (juvenile, 7 mm), *Lymnaea stagnalis*	Cadmium chloride	28 d	20.5 (20-21)	NOEC-LOEC (length and weight)	2.47-4.76	Pais 2012	Too few exposure concentrations
Snail, *Physa integra*	Cadmium chloride	28 d	44-58	LC50	10.4	Spehar et al. 1978	Exposure methods unknown; Duration
New Zealand mud snail (clone A, 3-4 mm), *Potamopyrgus antipodarum*	Cadmium chloride	48 hr	197	LC50	1,920	Jensen and Forbes 2001	Duration
New Zealand mud snail (clone B, 3-4 mm), *Potamopyrgus antipodarum*	Cadmium chloride	48 hr	197	LC50	1,290	Jensen and Forbes 2001	Duration
New Zealand mud snail (clone C, 3-4 mm), *Potamopyrgus antipodarum*	Cadmium chloride	48 hr	197	LC50	560	Jensen and Forbes 2001	Duration
New Zealand mudsnail, *Potamopyrgus antipodarum*	Cadmium sulfate	28 d	-	EC50 (reproduction)	11.5	Sieratowicz et al. 2011	Atypical endpoint
Snail, *Viviparus bengalensis*	Cadmium chloride	96 hr	140-190	LC50	1,550	Gadkari and Marathe 1983	
Mussel (glochidia), *Fusconia masoni*	Cadmium chloride	24 hr	88	LC50	168.1	Black 2001	Control mortality was not reported adequately to use for this lifestage
Fatmucket (juvenile), *Lampsilis siliquoidea*	Cadmium nitrate	28 d	40-48	LC50	8.1	Wang et al. 2010d	Atypical endpoint
Mussel, *Utterbackia imbecillis*	Cadmium chloride	48 hr	39	LC50	57	Keller and Zam 1991	Duration
Mussel, *Utterbackia imbecillis*	Cadmium chloride	48 hr	80-100	LC50	137	Keller and Zam 1991	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mussel (glochidia), *Utterbackia imbecillis*	Cadmium chloride	24 hr	88	LC50	56.76	Black 2001	Control mortality was not reported adequately to use for this lifestage
Zebra mussel (3.0-3.5 cm), *Dreissena polymorpha*	Cadmium chloride	8 hr	-	Caused valve closure	200-560	Slooff et al. 1983b	Atypical endpoint; Duration
Zebra mussel, *Dreissena polymorpha*	Cadmium chloride	77 d	268	LOEC (filtration rate)	9	Kraak et al. 1992b	Atypical endpoint
Zebra mussel, *Dreissena polymorpha*	Cadmium chloride	77 d	268	EC50	130	Kraak et al. 1992b	Duration
Zebra mussel, *Dreissena polymorpha*	Cadmium chloride	48 hr	150	EC50	388	Kraak et al. 1994a	Duration
Zebra mussel (18-25 mm), *Dreissena polymorpha*	Cadmium chloride	7 d	290	Increased metallothionein level	10	Ivankovic et al. 2010	Atypical endpoint; Duration
Asian clam (adult, 15-20 mm), *Corbicula fluminea*	Cadmium chloride	30 d	90	LOEC (reduced phagocytosis activity)	3	Champeau et al. 2007	Unmeasured chronic exposure; Atypical endpoint
Asian clam (adult, 15-20 mm), *Corbicula fluminea*	Cadmium chloride	30 d	90	NOEC-LOEC (decrease lysosomal value, surface, size and number)	21.5-46.5	Champeau et al. 2007	Unmeasured chronic exposure; Atypical endpoint
Bivalve, *Pisidium casertanum*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	1,370	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium casertanum*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	480	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium casertanum*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	700	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium compressum*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	2,080	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium compressum*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	700	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium compressum*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	360	Mackie 1989	pH is artificially low as part of study

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Cadmium nitrate	48 hr	100	LC50	27.3	Spehar and Fiandt 1986	High TOC; River dilution water not characterized
Cladoceran, *Ceriodaphnia dubia*	Cadmium sulfate	10 d	90	NOEC (reproduction)	0.5	Winner 1988	Duration; Unmeasured chronic exposure
Cladoceran, *Ceriodaphnia dubia*	Cadmium sulfate	7 d	169	Chronic value (reproduction)	<14	Masters et al. 1991	Duration; Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	-		290		120	Schubauer-Berigan et al. 1993	Test species fed
Cladoceran (<48 hr), *Ceriodaphnia dubia*	Cadmium nitrate	48 hr	280-300	LC50	560	Schubauer-Berigan et al. 1993	Test species fed
Cladoceran, *Ceriodaphnia dubia*	Cadmium chloride	1 hr	80-100	EC50 (feeding inhibition)	54	Bitton et al. 1996	Duration; Atypical endpoint
Cladoceran, *Ceriodaphnia dubia*	Cadmium chloride	1 hr	80-100	EC50 (feeding inhibition)	76.2	Lee et al. 1997	Duration; Atypical endpoint
Cladoceran (≤ 24hr), *Ceriodaphnia dubia*	Cadmium chloride	48 hr	17	LC50	63.1	Suedel et al. 1997	Test species fed
Cladoceran, *Ceriodaphnia dubia*	-	LC	17	NOEC-LOEC	1.0-4.0	Suedel et al. 1997	Static exposure
Cladoceran, *Ceriodaphnia dubia*	Cadmium chloride	7 d	80-100	Chronic value	1.4	Zuiderveen and Birge 1997	Duration; Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Cadmium sulfate	120 min	160-180	Reduced mobility	2,500 (dissolved)	Brent and Herricks 1998	Duration
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Cadmium nitrate	48 hr	80-100	LC50	78.2	Nelson and Roline 1998	Test species fed
Cladoceran (neonate), *Ceriodaphnia dubia*	Cadmium chloride	1.5 hr	-	EC50	34.2	Jun et al. 2006	Duration
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	-	7 d	100	LOEC (reproduction)	5.22	Sofyan et al. 2007a	Duration
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	-	7 d	100	LOEC (reproduction)	5	Sofyan et al. 2007b	Duration; Unmeasured chronic exposure

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	-	7 d	100	NOEC-LOEC (survival)	5-10	Sofyan et al. 2007b	Duration; Unmeasured chronic exposure
Cladoceran, *Ceriodaphnia reticulata*	-	48 hr	45	LC50	66	Mount and Norberg 1984	Test species fed
Cladoceran, *Ceriodaphnia reticulata*	Cadmium chloride	48 hr	55-79	LC50	129	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Cladoceran (< 6hr), *Ceriodaphnia reticulata*	Cadmium chloride	48 hr	200	LC50	79.4	Hall et al. 1986	Well water (not characterized)
Cladoceran, *Daphnia galeata mendotae*	Cadmium chloride	154 d	-	Reduced biomass	4.0	Marshall 1978a	Exposure methods unknown
Cladoceran, *Daphnia galeata mendotae*	Cadmium chloride	15 d	-	Reduced rate of increase	5.0	Marshall 1978b	Exposure methods unknown
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	-	EC50	100	Bringmann and Kuhn 1959a;b	River dilution water not characterized
Cladoceran, *Daphnia magna*	Cadmium chloride	21 d	45	Reproductive impairment	0.17	Biesinger and Christensen 1972	Exposure methods unknown
Cladoceran, *Daphnia magna*	Cadmium chloride	72 hr	163	LC50	15.8	Debelak 1975	Test species fed
Cladoceran, *Daphnia magna*	Cadmium nitrate	24 hr	-	LC50	600	Bringmann and Kuhn 1977b	Duration
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (10ºC)	LC50	224	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (15ºC)	LC50	224	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (25ºC)	LC50	12	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (30ºC)	LC50	0.1	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (10ºC)	LC50	479	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (15ºC)	LC50	187	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (25ºC)	LC50	10.2	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (30ºC)	LC50	2.4	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran, *Daphnia magna*	Cadmium nitrate	24 hr	200	EC50	160	Bellavere and Gorbi 1981	Duration
Cladoceran, *Daphnia magna*	Cadmium chloride	20 d	200	LC50	670	Canton and Sloof 1982	Other endpoints used
Cladoceran, *Daphnia magna*	-	48 hr	45	LC50	118	Mount and Norberg 1984	Test species fed
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	55-79	LC50	166	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	37	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	6.1	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	43	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	31	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	18	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	12	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	24	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	200	LC50	49.0	Hall et al. 1986	Well water (not characterized)
Cladoceran (1 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	64	Nebeker et al. 1986a	Test species fed
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	55	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	306	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	41	LC50	98	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	307	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	37	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	94	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	277	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	71	LC50	135	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	17	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	40	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	41	LC50	30	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	131	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	92	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old; Test species fed
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	25	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	36	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	71	LC50	18	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	34	LC50	33	Nebeker et al. 1986b	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	34	LC50	24	Nebeker et al. 1986b	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	34	LC50	40	Nebeker et al. 1986b	Typically tests with cladocerans are <24 hr old
Cladoceran, *Daphnia magna*	Cadmium sulfate	25 d	100 (20ºC)	NOEC (reproduction)	2.25	Winner and Whitford 1987	Unmeasured chronic exposure
Cladoceran, *Daphnia magna*	Cadmium sulfate	25 d	100 (25ºC)	NOEC (reproduction)	0.75	Winner and Whitford 1987	Unmeasured chronic exposure

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran, *Daphnia magna*	Cadmium chloride	25 d	150	NOEC-LOEC (reproduction)	5.0-10	Bodar et al. 1988b	More sensitive endpoint available from this study
Cladoceran, *Daphnia magna*	Cadmium sulfate	10 d	90	NOEC (reproduction)	2.5	Winner 1988	Duration; Unmeasured chronic exposure
Cladoceran (egg), *Daphnia magna*	Cadmium chloride	46 hr	150	Profound effect on egg development	>1,000	Bodar et al. 1989	Duration
Cladoceran, *Daphnia magna*	Cadmium sulfate	48 hr	240	LC50	1,880	Khangarot and Ray 1989a	Dilution water not fully characterized
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	24 hr	-	EC50	1,900	Kuhn et al. 1989	Duration
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	24 d	-	NOEC (reproduction)	0.6	Kuhn et al. 1989	
Cladoceran (small neonate), *Daphnia magna*	Cadmium chloride	48 hr	250	LC50	98	Enserink et al. 1990	Test species fed
Cladoceran (large neonate), *Daphnia magna*	Cadmium chloride	48 hr	250	LC50	294	Enserink et al. 1990	Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180 (20ºC)	LC50	38	Lewis and Horning 1991	Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180 (26ºC)	LC50	9	Lewis and Horning 1991	Test species fed
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	21 d	225	LOEC (reproduction)	2.3	Enserink et al. 1993	
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	-	LC50	48	Domal-Kwiatkowska et al. 1994	Test species fed
Cladoceran (14 d), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	80	Allen et al. 1995	
Cladoceran, *Daphnia magna*	Cadmium acetate	24 hr	-	EC50	980	Sorvari and Sillanpaa 1996	Duration
Cladoceran (≤ 24 hr) *Daphnia magna*	Cadmium chloride	48 hr	17	LC50	26.4	Suedel et al. 1997	Test species fed
Cladoceran (juvenile, 4-5 d), *Daphnia magna*	Cadmium sulfate	48 hr	160-180	EC50 (death and immobility)	30-219	Barata et al. 2000	Test species fed
Cladoceran (juvenile, 4-5 d), *Daphnia magna*	Cadmium sulfate	48 hr	160-180	EC50 (feeding inhibition)	9-41	Barata et al. 2000	Test species fed; Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (neonate, <48 hr), *Daphnia magna*	Cadmium chloride	17 d	-	NOEC-LOEC (reproduction)	1.7-3.7	Knops et al. 2001	Duration; Unmeasured chronic exposure
Cladoceran (4th instar, 4-5 d), *Daphnia magna*	-	24 hr	-	IC50 (feeding inhibition)	1.31	McWilliam and Baird 2002	Duration; Atypical endpoint; Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	96 hr	50	LC50	>3.43	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	96 hr	100	LC50	>6.85	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (adult, 12-15 d), *Daphnia magna*	Cadmium chloride	3 hr	-	LOEC (reduce phototactic index)	30	Yuan et al. 2003	Duration; Atypical endpoint
Cladoceran (neonate, >14 d, female), *Daphnia magna*	Cadmium nitrate	14 d	-	NOEC-LOEC (Survival-low food ration groups)	2.81-5.62	Smolders et al. 2005	Duration
Cladoceran (neonate, >14 d, female), *Daphnia magna*	Cadmium nitrate	14 d	-	NOEC-LOEC (Survival-high food ration groups)	1.12-2.81	Smolders et al. 2005	Duration
Cladoceran (<24 hr), *Daphnia magna*	Cadmium sulfate	48 hr	-	Reduced feeding and egg production	2.473	Barata et al. 2007	Atypical endpoint
Cladoceran (<24 hr), *Daphnia magna*	Cadmium sulfate	21 d	125-140	EC50 (survival)	0.64	Poynton et al. 2007	Unmeasured chronic exposure
Cladoceran (<24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	125-140	LC50	180	Poynton et al. 2007	Duration
Cladoceran (juvenile, 5 d), *Daphnia magna*	Cadmium chloride	4 hr	240	LOEC (ROS production)	>112.41	Xie et al. 2007	Duration; Atypical endpoint
Cladoceran (4th instar, 4-5 d), *Daphnia magna*	Cadmium chloride	24 hr	160-180	EC50 (feeding inhibition)	35.54	Ferreira et al. 2008a	Duration; Atypical endpoint
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	24 hr	-	50% reduced survival	36.79	Connon et al. 2008	Duration
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	21 d	-	NOEC-LOEC (ChE activities)	0.041-0.082	Jemec et al. 2008	Atypical endpoint
Cladoceran (juvenile, ≤24 hr), *Daphnia magna*	Cadmium chloride	48 hr	250	EC50 (respiration)	160	Zitova et al. 2009	Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	- (20ºC)	EC50 (immobility)	112 (dissolved)	Muyssen et al. 2010	Elevated DOC (3.7-5.74 mg/L) in dilution water
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	- (24ºC)	EC50 (immobility)	64 (dissolved)	Muyssen et al. 2010	Elevated DOC (3.7-5.74 mg/L) in dilution water
Cladoceran (14 d), *Daphnia magna*	Cadmium chloride	24 hr	-	LC50	71	Taylor et al. 2010	Lack of exposure details; Duration
Cladoceran, *Daphnia magna*	Cadmium chloride	24 hr	90 (80-110) (20ºC)	EC50	6.34	Kim et al. 2012a	Duration
Cladoceran, *Daphnia magna*	Cadmium chloride	1 hr	90 (80-110) (36.5ºC)	EC50	26.9	Kim et al. 2012a	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=5.0)	EC50 (immobility)	1,210	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=6.0)	EC50 (immobility)	1,160	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=7.0)	EC50 (immobility)	420	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=8.0)	EC50 (immobility)	390	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=9.0)	EC50 (immobility)	350	Qu et al. 2013	Duration
Cladoceran, *Daphnia pulex*	Cadmium chloride	140 d	57	Reduced reproduction	1	Bertram and Hart 1979	Lack of exposure details
Cladoceran, *Daphnia pulex*	Cadmium chloride	48 hr	57	LC50	104-127	Ingersoll and Winner 1982	Test species fed
Cladoceran, *Daphnia pulex*	Cadmium chloride	58 d	106	NOEC-LOEC	5-10	Ingersoll and Winner 1982	Lack of exposure details
Cladoceran, *Daphnia pulex*	-	48 hr	45	LC50	68	Mount and Nerberg 1984	Test species fed
Cladoceran, *Daphnia pulex*	Cadmium sulfate	72 hr	100	LC50	80-92	Winner 1984	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Test species fed

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	120	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	170	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	190	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	160	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	150	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	150	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	100	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	180	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	200	LC50	100	Hall et al. 1986	Well water (not characterized)
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	58	NOEC (survival)	3.8	Winner 1986	
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	115	NOEC (brood size)	7.5	Winner 1986	
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	230	NOEC (brood size)	7.5	Winner 1986	
Cladoceran (adult), *Daphnia pulex*	Cadmium chloride	48 hr	124-130	LC50	87.9	Jindal and Verma 1990	Pond water (not characterized)
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90 (20ºC)	LC50	42	Lewis and Horning 1991	Test species fed
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90 (26ºC)	LC50	6	Lewis and Horning 1991	Test species fed
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	80-90	NOEC (reproduction)	<0.003	Roux et al. 1993	Static, unmeasured exposure
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	96 hr	50	LC50	>14.6	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	96 hr	100	LC50	>20	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (24 hr), *Macrothrix triserialis*	Cadmium chloride	24 hr	-	LC50	420	Garcia et al. 2004	Duration
Cladoceran, *Moina macrocopa*	Cadmium chloride	20 d	80-84	Reduced survival	0.2	Hatakeyama and Yasuno 1981b	Duration; Unknown exposure methods
Cladoceran, *Moina macrocopa*	Cadmium chloride	10 d	-	Reduced survival	10	Wong and Wong 1990	Duration
Cladoceran (24 hr), *Moina macrocopa*	Cadmium chloride	24 hr	-	LC50	680	Garcia et al. 2004	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran, *Simocephalus serrulatus*	Cadmium chloride	48 hr	55-79	LC50	123	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Cladoceran, *Simocephalus vetulus*	-	48 hr	45	LC50	24	Mount and Norberg 1984	Test species fed
Cladoceran, *Simocephalus vetulus*	Cadmium chloride	48 hr	55-79	LC50	89.3	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Copepod, *Acanthocyclops viridis*	Cadmium sulfate	72 hr	-	LC50	0.5	Braginskly and Shcherban 1978	Duration
Copepod, *Eucyclops agilis*	Cadmium chloride	52 wk	11.1	Population reduction	5	Giesy et al. 1979	Lack of exposure details
Copepod, *Tropocyclops prasinus mexicanus*	Cadmium chloride	48 hr	10	LC50	149	Lalande and Pinel-Alloul 1986	Duration
Aquatic sowbug (3-6 mm, land population), *Asellus aquaticus*	-		176		76	Pascoe and Carroll 2004	Test species fed
Aquatic sowbug (3-6 mm, pond population), *Asellus aquaticus*	-		176		160	Pascoe and Carroll 2004	Test species fed
Aquatic sowbug (3-6 mm, canal population), *Asellus aquaticus*	-		176		233	Pascoe and Carroll 2004	Test species fed
Amphipod, *Diporeia sp.*	Cadmium chloride	96 hr	- (4ºC)	LC50	800	Gossiaux et al. 1992	Dilution water not fully characterized
Amphipod, *Diporeia sp.*	Cadmium chloride	96 hr	- (10ºC)	LC50	280	Gossiaux et al. 1992	Dilution water not fully characterized
Amphipod, *Diporeia sp.*	Cadmium chloride	96 hr	- (15ºC)	LC50	60	Gossiaux et al. 1992	Dilution water not fully characterized

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Amphipod (0-1 wk), *Gammarus fasciatus*	Cadmium	130	1.49-2.23	NOEC - LOEC (survival)	1.49-2.23	Borgmann et al. 1989b	Poor control survival (45%)
Amphipod, *Gammarus pseudolimnaeus*	Cadmium chloride	96 hr	55-79	LC50	54.4	Spehar and Carlson 1984a;b	River dilution water not characterized
Amphipod (adult, 9 mm), *Gammarus tigrinus*	Cadmium chloride	72 hr	116	LC50	146.5	Boets et al. 2012	Duration
Scud, *Gammarus sp.*	Cadmium	S, U	50		70	Rehwoldt et al. 1973	Lack of detail since other acceptable study available with specific species
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	55-79	LC50	285	Spehar and Carlson 1984a,b	High TOC; River dilution water not characterized
Amphipod (0-1 wk), *Hyalella azteca*	Cadmium	LC	130	NOEC-LOEC (survival)	0.57-0.92	Borgmann et al. 1989b	Low control weights and poor (64%) control survival
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	15.3 (pH=5.0)	LC50	12	Mackie 1989	pH is artificially low as part of study
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	15.3 (pH=5.5)	LC50	16	Mackie 1989	pH is artificially low as part of study
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	15.3 (pH=6.0)	LC50	33	Mackie 1989	pH is artificially low as part of study
Amphipod, *Hyalella azteca*	Cadmium nitrate	6 wk	130	EC50 (survival)	0.53	Borgmann et al. 1991	Inadequate control performance
Amphipod, *Hyalella azteca*	Cadmium nitrate	96 hr	280-300	LC50	230	Schubauer-Berigan et al. 1993	Test species fed
Amphipod (0-2 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈13	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (2-4 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈7.5	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Amphipod (4-6 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈9.5	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (10-12 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈7	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (16-18 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈11.5	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (24-26 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈14	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod, *Hyalella azteca*	Cadmium chloride	10 d	44-47	LC50	2.8	Phipps et al. 1995	Duration
Amphipod, *Hyalella azteca*	-	JGS (juvenile growth and survival test	17	Chronic value (growth and survival)	0.16	Suedel et al. 1997	Static exposure
Amphipod (2-3 wk), *Hyalella azteca*	-	96 hr	17	LC50	2.8	Suedel et al. 1997	Did not meet specific acceptability criteria for this species
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50 (starved for 48 hr before test)	99.34	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50 (starved for 72 hr before test)	82.17	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50 (starved for 96 hr before test)	65.00	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50	107.3	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50	75.42	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50	74.20	McNulty et al. 1999	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Amphipod (7-10 d), *Hyalella azteca*	-	96 hr	48	LC50	3.8	Jackson et al. 2000	Did not meet specific acceptability criteria for this species
Amphipod (7-10 d), *Hyalella azteca*	-	96 hr	118	LC50	12.1	Jackson et al. 2000	Did not meet specific acceptability criteria for this species
Amphipod (7-8 d), *Hyalella azteca*	Cadmium chloride	LC	153	NOEC-LOEC (survival)	0.8-1.3	Chadwick Ecological Consultants 2003	Low control weights; does not meet feeding recommendations for chronic test with this species
Amphipod (7-8 d), *Hyalella azteca*	Cadmium chloride	LC	126	NOEC-LOEC (survival)	0.5-1.1	Chadwick Ecological Consultants 2003	Low control weights; does not meet feeding recommendations for chornic test with this species
Amphipod (1-11 d), *Hyalella azteca*	-	7 d	18	LC50	0.15	Borgmann et al. 2005	Duration
Amphipod (1-11 d), *Hyalella azteca*	-	7 d	124	LC50	1.60	Borgmann et al. 2005	Duration
Amphipod, *Hyalella azteca*	Cadmium sulfate	LC	162.7	NOEC-LOEC (survival)	2.49-5.09	Stanley et al. 2005	Low control weights; does not meet feeding recommendations for chornic test with this species
Amphipod, *Hyalella azteca*	-	72 hr	-	LC50	1.9	Gust 2006	Duration
Amphipod (neonate 2-9 d), *Hyalella azteca*	-	21 d	140	NOEC-LOEC (survival)	5-10	Straus 2011	More sensitive endpoint available for this study
Amphipod (neonate 2-9 d), *Hyalella azteca*	-	21 d	140	NOEC-LOEC (growth)	<1.25-1.25	Straus 2011	Does not meet chronic test requirements for this species
Amphipod (neonate 2-9 d), *Hyalella azteca*	-	28 d	22	NOEC-LOEC (survival)	0.5-1.3	Straus 2011	Does not meet chronic test requirements for this species
Amphipod (neonate 2-9 d), *Hyalella azteca*	Cadmium chloride	7 d	90	LC50	4.6 (dissolved)	Pais 2012	Duration

NMED Exhibit 70

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Amphipod (neonate 2-9 d), *Hyalella azteca*	Cadmium chloride	28 d	90	LC50	0.70 (dissolved)	Pais 2012	Duration
Crayfish, *Cambarus latimanus*	Cadmium chloride	50 mo	11.1	Significant mortality	5	Thorp et al. 1979	Lack of exposure details
Crayfish, *Orconectes immunis*	Cadmium chloride	96 hr	50.3	LC50	>10,000	Thorp and Gloss 1986	Effect level based on nominal, but substantial loss per measured levels was observed
Crayfish (juvenile, 2 g), *Orconectes immunis*	Cadmium nitrate	5 d	-	LC50	7,000	Khan et al. 2006b	Duration; Test species fed
Crayfish (juvenile, 2 g), *Orconectes immunis*	Cadmium nitrate	2.51 d	-	LT50=2.51 d	22,000	Khan et al. 2006b	Duration; Test species fed
Fairy shrimp (2nd-3rd instar nauplii), *Streptocephalus proboscideus*	-	24 hr	-	-	460	Centeno et al. 1993	Duration
Fairy shrimp (2nd-3rd instar nauplii), *Streptocephalus proboscideus*	-	24 hr	-	-	510	Centeno et al. 1993	Duration
Fairy shrimp, *Streptocephalus proboscideus*	Cadmium sulfate	24 hr	250	-	250	Crisinel et al. 1994	Duration
Fairy shrimp, *Thamnocephalus platyurus*	Cadmium chloride	24 hr	80-100		400	Centeno et al. 1995	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (10ºC)	LC50	70,600	Braginskly and Shcherban 1978	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (15ºC)	LC50	28,600	Braginskly and Shcherban 1978	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (25ºC)	LC50	6,990	Braginskly and Shcherban 1978	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (30ºC)	LC50	930	Braginskly and Shcherban 1978	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mayfly, *Cleon dipterum*	Cadmium nitrate	48 hr	-	LC50	56,000	Slooff et al. 1983a	Duration
Mayfly, *Ephemerella sp.*	Cadmium chloride	28 d	44-48	LC50	<3.0	Spehar et al. 1978	Lack of exposure details
Mayfly, *Paraleptophlebia praepedita*	Cadmium chloride	96 hr	55-77	LC50	449	Spehar and Carlson 1984a;b	River dilution water not characterized
Mayfly, *Rhithrogena sp.*	Cadmium chloride	96 hr	25	LC50	157 (dissolved)	Mebane et al. 2012	Other data avilable for a specific species in the genus
Mayfly, *Rhithrogena sp.*	Cadmium chloride	96 hr	21	LC50	>50 (dissolved)	Mebane et al. 2012	Other data avilable for a specific species in the genus
Mayfly (nymph), *Rhithrogena hageni*	Cadmium sulfate	10 d	48	NOEC-LOEC (survival)	1,880-3,520	Brinkman and Johnston 2008	Duration
Mosquito, *Aedes aegypti*	Cadmium nitrate	48 hr	-	LC50	4,000	Slooff et al. 1983a	Duration
Mosquito, *Culex pipiens*	Cadmium nitrate	48 hr	-	LC50	765	Slooff et al. 1983a	Duration
Midge (2nd instar), *Chironomus riparius*	Cadmium chloride	96 hr	100-110	LC50	13,000	Williams et al. 1986	Test species fed
Midge (3rd instar), *Chironomus riparius*	Cadmium chloride	96 hr	100-110	LC50	22,000	Williams et al. 1986	Test species fed
Midge (4th instar), *Chironomus riparius*	Cadmium chloride	96 hr	100-110	LC50	54,000	Williams et al. 1986	Test species fed
Midge, *Chironomus riparius*	Cadmium chloride	5 d	98	LOEC (egg viability)	30,000	Williams et al. 1987	Duration; Static, unmeasured exposure
Midge, *Chironomus riparius*	Cadmium chloride	10 d	98	LOEC (number of eggs ovipositioned)	100,000	Williams et al. 1987	Duration; Static, unmeasured exposure

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Midge (1st instar), *Chironomus riparius*	-	17 d	98	LOEC (survival, development and growth)	150	Pascoe et al. 1989	Duration
Midge (1st instar), *Chironomus riparius*	-	1 hr	100	Reduced emergence	2,100	McCahon and Pascoe 1991	Duration
Midge (1st instar), *Chironomus riparius*	-	10 hr	100	Reduced emergence	210	McCahon and Pascoe 1991	Duration
Midge (4th instar), *Chironomus riparius*	-	1 hr	100	Reduced emergence	2,000	McCahon and Pascoe 1991	Duration
Midge (4th instar), *Chironomus riparius*	-	10 hr	100	Reduced emergence	200	McCahon and Pascoe 1991	Duration
Midge (1st instar larva, <24 hr), *Chironomus riparius*	Cadmium nitrate	24 hr	8	LC50	9,380	Bechard et al. 2008	Duration
Midge (4th instar), *Chironomus riparius*	Cadmium chloride	24 hr	-	LC50	212,230	Choi and Ha 2009	Duration
Midge (4th instar), *Chironomus riparius*	Cadmium chloride	72 hr	-	Downregulation of CrSTART1 mRNA	2,000	Nair and Choi 2012	Duration; Atypical endpoint
Midge, *Chironomus dilutus*	Cadmium chloride	48 hr	25	LC50	8,050	Khangarot and Ray 1989b	Dilution water (natural surface water) not characterized
Midge (2nd instar, 10-12 d), *Chironomus dilutus*	Cadmium chloride	96 hr	17	LC50	2,956	Suedel et al. 1997	Test species fed
Midge (4th instar larva), *Chironomus dilutus*	Cadmium chloride	24 hr	-	LOEC (increased HSP gene expression)	200	Lee et al. 2006b	Duration; Atypical endpoint
Midge (4th instar larva), *Chironomus dilutus*	Cadmium chloride	48 hr	-	NOEC (growth)	20,000	Lee et al. 2006b	Duration
Midge (4th instar larva), *Chironomus dilutus*	Cadmium chloride	24 hr	-	LC50	169,500	Ha and Choi 2008	Duration
Midge, *Tanytarsus dissimilis*	Cadmium chloride	10 d	47	LC50	3.8	Anderson et al. 1980	Duration
Damselfly, *Enallagma sp.*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	7,050	Mackie 1989	pH is artificially low as part of study

Species	Chemical	Duration	Hardness (mg/L CaCO$_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Damselfly, *Enallagma sp.*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	8,660	Mackie 1989	pH is artificially low as part of study
Damselfly, *Enallagma sp.*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	10,660	Mackie 1989	pH is artificially low as part of study
Rio Grande cutthroat trout (eyed egg), *Oncorhynchus clarkii virginalis*	Cadmium sulfate	ELS (53 d)	44.9	NOEC (hatch success)	8.03 (dissolved)	Brinkman 2012	More sensitive endpoint available for this study
Pink salmon (alevin), *Oncorhynchus gorbuscha*	Cadmium chloride	7 d	83.1	LC50	3,160	Servizi and Martens 1978	Duration
Pink salmon (fry), *Oncorhynchus gorbuscha*	Cadmium chloride	7 d	83.1	LC50	2,700	Servizi and Martens 1978	Duration
Pink salmon (alevin, newly hatched), *Oncorhynchus gorbuscha*	Cadmium chloride	7 d	83.1	LC50	3,600	Servizi and Martens 1978	Duration
Coho salmon (juvenile), *Oncorhynchus kisutch*	Cadmium chloride	217 hr	22	LC50	2.0	Chapman and Stevens 1978	Duration
Coho salmon (adult), *Oncorhynchus kisutch*	Cadmium chloride	215 hr	22	LC50	3.7	Chapman and Stevens 1978	Duration
Coho salmon (alevin), *Oncorhynchus kisutch*	Cadmium chloride	96 hr	41	LC50	6.0	Buhl and Hamilton 1991	
Rainbow trout, *Oncorhynchus mykiss*	-	7 d	290	LC50	8.944 (8-10)	Ball 1967	Lack of exposure details; Duration; Unmeasured exposure
Rainbow trout, *Oncorhynchus mykiss*	-	24 hr	290	LC50	30,000	Ball 1967	Lack of exposure details; Duration
Rainbow trout, *Oncorhynchus mykiss*	-	10 d	-	LC50	7	Kumada et al. 1973	Duration
Rainbow trout, *Oncorhynchus mykiss*	-	10 d	-	LC50	5	Kumada et al. 1973	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	96 hr	326	LC20	20	Davies 1976b	Atypical endpoint for this duration
Rainbow trout (embryo, larva), *Oncorhynchus mykiss*	Cadmium chloride	28 d	104	EC50 (death and deformity)	140	Birge 1978; Birge et al. 1980	Lack of exposure details

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (alevin), *Oncorhynchus mykiss*	Cadmium chloride	186 hr	23	LC10	>6	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (swim-up fry), *Oncorhynchus mykiss*	Cadmium chloride	200 hr	23	LC10	1.0	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (parr), *Oncorhynchus mykiss*	Cadmium chloride	200 hr	23	LC10	0.7	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (smolt), *Oncorhynchus mykiss*	Cadmium chloride	200 hr	23	LC10	0.8	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (adult), *Oncorhynchus mykiss*	Cadmium chloride	17 d	54	LC50	5.2	Chapman and Stevens 1978	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	243 d	240	Increased gill diffusion	2	Hughes et al. 1979	Lack of exposure details; Atypical endpoint
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	10 d	125 (18ºC)	LC50	10-30	Roch and Maly 1979	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	10 d	125 (12ºC)	LC50	30	Roch and Maly 1979	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	10 d	125 (6ºC)	LC50	10-30	Roch and Maly 1979	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	80 min	112	Significant avoidance	52	Black and Birge 1980	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium stearate	96 hr	-	LC50	6	Kumada et al. 1980	Inappropriate form of toxicant
Rainbow trout, *Oncorhynchus mykiss*	Cadmium acetate	96 hr	-	LC50	6.2	Kumada et al. 1980	Inappropriate form of toxicant
Rainbow trout, *Oncorhynchus mykiss*	-	18 mo	112	Reduced survival	0.2	Birge et al. 1981	Lack of exposure details
Rainbow trout (embryo, larva), *Oncorhynchus mykiss*	Cadmium sulfate	62 d	100	Reduced survival	<5	Dave et al. 1981	Lack of exposure details
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	4 mo	320	Physiological effects	10	Arillo et al. 1982; 1984	Lack of exposure details; Atypical endpoint
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	47 d	98.6	Reduced growth and survival	100	Woodworth and Pascoe 1982	Lack of exposure details
Rainbow trout (larva), *Oncorhynchus mykiss*	Cadmium chloride	7 d	89-107	LC50	700	Birge et al. 1983	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (larva), *Oncorhynchus mykiss*	Cadmium chloride	7 d	89-107	LC50	1,590	Birge et al. 1983	Duration; Acclimated to 5.9 ug/L for 24 days
Rainbow trout, *Oncorhynchus mykiss*	Cadmium nitrate	48 hr	-	LC50	55	Slooff et al. 1983a	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	11 d	82 (10ºC)	LC50	16.0	Majewski and Giles 1984	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	8 d	82 (15ºC)	LC50	16.6	Majewski and Giles 1984	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	178 d	82	Physiological effects	4.8	Majewski and Giles 1984	Atypical endpoint
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	96 hr	55-79	LC50	10.2	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Rainbow trout (egg, 0 hr), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	13,000	Van Leeuwen et al. 1985a	
Rainbow trout (egg, 24 hr), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	13,000	Van Leeuwen et al. 1985a	
Rainbow trout (eyed egg, 14 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	7,500	Van Leeuwen et al. 1985a	
Rainbow trout (eyed egg, 28 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	9,200	Van Leeuwen et al. 1985a	
Rainbow trout (sac fry, 42 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	30	Van Leeuwen et al. 1985a	
Rainbow trout (early fry, 77 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	10	Van Leeuwen et al. 1985a	
Rainbow trout (fry), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	9.2 (pH=4.7)	LC50	28	Cusimano et al. 1986	Exposure at low pH
Rainbow trout (fry), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	9.2 (pH=5.7)	LC50	0.7	Cusimano et al. 1986	Exposure at low pH
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	96 hr	63	LC50	1,300 (dissolved)	Pascoe et al. 1986	Test species fed
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	96 hr	300	LC50	2,600 (dissolved)	Pascoe et al. 1986	Test species fed
Rainbow trout (5 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	>100,000	Shazili and Pascoe 1986	Duration

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Rainbow trout (10 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	3,300	Shazili and Pascoe 1986	Duration
Rainbow trout (15 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	7,200	Shazili and Pascoe 1986	Duration
Rainbow trout (22 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	8,000	Shazili and Pascoe 1986	Duration
Rainbow trout (29 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	12,500	Shazili and Pascoe 1986	Duration
Rainbow trout (36 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	16,500	Shazili and Pascoe 1986	Duration
Rainbow trout (alevin, 2 d post hatch), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	5,800	Shazili and Pascoe 1986	Duration
Rainbow trout (alevin, 7 d post hatch), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	8,300	Shazili and Pascoe 1986	Duration
Rainbow trout (alevin), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	41	LC50	37.9	Buhl and Hamilton 1991	
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Cadmium nitrate	96 hr	140	LC50	280	Hollis et al. 1999	Prior exposed to 3 ug/L for 30 d
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Cadmium nitrate	96 hr	140	LC50	250	Hollis et al. 1999	Prior exposed to 10 ug/L for 30 d
Rainbow trout (33.3 mm, 263 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	30.7	LC50	0.53	Hansen et al. 2002b	Duration
Rainbow trout (33.6 mm, 289 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	89.3	LC50	2.07	Hansen et al. 2002b	Duration
Rainbow trout (34 mm, 299 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	30.0	LC50	0.84	Hansen et al. 2002b	Duration
Rainbow trout (42.6 mm, 659 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	29.3	LC50	0.35	Hansen et al. 2002b	Duration
Rainbow trout (49.4 mm, 1,150 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	31.7	LC50	0.36	Hansen et al. 2002b	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (48.2 mm, 1,030 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	30.2	LC50	0.35	Hansen et al. 2002b	Duration
Rainbow trout (larvae, 1 mo., 1.2-1.5 g), *Oncorhynchus mykiss*	Cadmium chloride	1 hr	210	NOEC (decrease oxygen consumption rates)	200	Jezierska and Sarnowski 2002	Duration; Atypical endpoint
Rainbow trout (swim-up fry, 4-5 wk), *Oncorhynchus mykiss*	-	96 hr	101	LC50	5.4	Besser et al. 2006; 2007	Test species fed
Rainbow trout (1 dph), *Oncorhynchus mykiss*	Cadmium chloride	21 d	100	EC20 (survival)	12	Wang et al. 2014a	Duration too short
Rainbow trout (juvenile, 26 dph), *Oncorhynchus mykiss*	Cadmium chloride	28 d	100	EC20 (biomass)	1.9	Wang et al. 2014a	Exposure started too late for true ELS test
Sockeye salmon (newly hatched alevin), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	4,500	Servizi and Martens 1978	Duration
Sockeye salmon (alevin), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	1,000	Servizi and Martens 1978	Duration
Sockeye salmon (alevin), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	500	Servizi and Martens 1978	Duration
Sockeye salmon (fry), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	30	Servizi and Martens 1978	Duration
Sockeye salmon (fry), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	8	Servizi and Martens 1978	Duration
Sockeye salmon (smolt), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	360	Servizi and Martens 1978	Duration
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	18-26	Chapman 1978	Duration
Chinook salmon (swim-up fry), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	1.2	Chapman 1978	Duration
Chinook salmon (parr), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	1.3	Chapman 1978	Duration
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	1.5	Chapman 1978	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Atlantic salmon (alevin), *Salmo salar*	Cadmium chloride	92 d	28	Net water uptake inhibited	0.78	Rombough and Garside 1982	Atypical endpoint
Atlantic salmon, *Salmo salar*	Cadmium chloride	70 d	13	Reduced growth	2	Peterson et al. 1983	Lack of exposure details
Brown trout, *Salmo trutta*	Cadmium chloride	96 hr	55-79	LC50	15.1	Spehar and Carlson 1984a;b	River dilution water not characterized
Brown trout, *Salmo trutta*	Cadmium sulfate	96 hr	36.9	LC50	1.87	Davies and Brinkman 1994a	Test species fed
Brown trout, *Salmo trutta*	Cadmium sulfate	12 wk	37.6	Chronic value (growth and survival)	0.70	Davies and Brinkman 1994c	Per author chronic values does not have a clear effect level
Brown trout (fry), *Salmo trutta*	Cadmium sulfate	30 d	29.2	NOEC-LOEC (survival)	0.74-1.40	Brinkman and Hansen 2004a; 2007	Duration
Brown trout (fry), *Salmo trutta*	Cadmium sulfate	30 d	67.6	NOEC-LOEC (survival)	1.30-2.58	Brinkman and Hansen 2004a; 2007	Duration
Brown trout (fry), *Salmo trutta*	Cadmium sulfate	30 d	151	NOEC-LOEC (survival)	4.81-8.88	Brinkman and Hansen 2004a; 2007	Duration
Bull trout (juvenile, 30.5 mm, 212 mg), *Salvelinus confluentus*	Cadmium chloride	55 d	30.6	NOEC-LOEC (growth and survival)	0.383-0.786	Hansen et al. 2002a	Duration
Bull trout (23.8 mm, 76.1 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	30.7	LC50	0.83	Hansen et al. 2002b	Duration
Bull trout (23.4 mm, 72.7 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	89.3	LC50	5.23	Hansen et al. 2002b	Duration
Bull trout (26.0 mm, 84.2 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	30.0	LC50	2.41	Hansen et al. 2002b	Duration
Bull trout (30.2 mm, 200 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	29.3	LC50	0.83	Hansen et al. 2002b	Duration
Bull trout (32.0 mm, 221 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	31.7	LC50	0.88	Hansen et al. 2002b	Duration
Bull trout (31.8 mm, 218 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	30.2	LC50	0.83	Hansen et al. 2002b	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Brook trout, *Salvelinus fontinalis*	Cadmium chloride	21 d	10	Testicular damage	10	Sangalang and O'Halloran 1972; 1973	Lack of exposure details; Atypical endpoint
Brook trout (8 mo.), *Salvelinus fontinalis*	-	10 d	20	NOEC-LOEC (survival)	8-18	Jop et al. 1995	Duration
Lake trout, *Salvelinus namaycush*	Cadmium chloride	8-9 mo	90	Decreased thyroid follicle epithelial cell height	5	Scherer et al. 1997	Atypical endpoint
Arctic grayling (alevin), *Thymallus arcticus*	Cadmium chloride	96 hr	41	LC50	6.1	Buhl and Hamilton 1991	Only acclimated to test water for 1 d
Arctic grayling (juvenile), *Thymallus arcticus*	Cadmium chloride	96 hr	41	LC50	4.0	Buhl and Hamilton 1991	Low D.O.
Goldfish, *Carassius auratus*	-	50 d	-	Reduced plasma sodium	44.5	McCarty and Houston 1976	Lack of exposure details; Atypical endpoint
Goldfish (embryo, larva), *Carassius auratus*	Cadmium chloride	7 d	195	EC50 (death and deformity)	170	Birge 1978	Duration
Common carp (embryo), *Cyprinus carpio*	Cadmium sulfate	-	360	EC50 (hatch)	2,094	Kapur and Yadav 1982	Duration unknown
Common carp (embryo, larva), *Cyprinus carpio*	Cadmium chloride	8 d	101.6	LC50	139	Birge et al. 1985	Multiple-species test; Duration
Common carp (fry), *Cyprinus carpio*	-	96 hr	100	LC50	4,260	Suresh et al. 1993a	
Common carp (fingerling), *Cyprinus carpio*	-	96 hr	100	LC50	17,050	Suresh et al. 1993a	
Common carp (30 g), *Cyprinus carpio*	Cadmium chloride	29 d	-	NOEC-LOEC (survival)	449.64-2,248	De Smet and Blust 2001	Duration
Common carp (30 g), *Cyprinus carpio*	Cadmium chloride	29 d	-	NOEC-LOEC (survival)	56.2-280.25	De Smet et al. 2001	Duration
Common carp (larva, 0.9-1.39 g), *Cyprinus carpio*	Cadmium chloride	1 hr	210	LOEC (decrease oxygen consumption rates)	200	Jezierska and Sarnowski 2002	Duration; Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Golden shiner (3 mo, 6.75 g), *Notemigonus crysoleucas*	Cadmium sulfate	96 hr	100-119	Elevated metabolic rate	200	Peles et al. 2012	Atypical endpoint
Common shiner (0.75-3.5 mg), *Notropis cornutus*	Cadmium chloride	7 d	48	67% reduced growth	200 (dissolved)	Borgmann and Ralph 1986	Duration; Atypical endpoint
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	12 d	200	LC50	100	Nguyen and Janssen 2001	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	12 d	200	NOEC-LOEC (survival)	50-150	Nguyen and Janssen 2001	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	48 hr	100	NOEC (enlarged edema)	753.1	Fraysse et al. 2006	Duration; Atypical endpoint
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	80 hr	100	NOEC (hatching time)	<22.48	Fraysse et al. 2006	Duration; Atypical endpoint
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	48 hr	-	EC50	3,372	Lahnsteiner 2008	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	48 hr	-	LC50	24,185	Notch et al. 2011	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	72 hr	250	EC50 (deformation rate)	4,856	Sawle et al. 2010	Duration; Atypical endpoint
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	63	LC50	80.8	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	55	LC50	40.9	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	59	LC50	64.8	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	66	LC50	135	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	65	LC50	120	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	74	LC50	86.3	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	79	LC50	86.6	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	62	LC50	114	Spehar 1982	

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	63	LC50	80.8	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	6.8 hr	103	LT50=6.8 hr	6,000	Birge et al. 1983	Atypical endpoint
Fathead minnow, *Pimephales promelas*	Cadmium chloride	3.7 hr	254-271	LT50=3.7 hr	16,00	Birge et al. 1983	Atypical endpoint
Fathead minnow (larva), *Pimephales promelas*	Cadmium chloride	7 d	89-107	LC50	200	Birge et al. 1983	Duration
Fathead minnow (larva), *Pimephales promelas*	Cadmium chloride	7 d	89-107	LC50	540	Birge et al. 1983	Duration; Acclimated to 5.6 ug/L for 4 d
Fathead minnow, *Pimephales promelas*	Cadmium nitrate	48 hr	-	LC50	2,200	Slooff et al. 1983a	Duration
Fathead minnow, *Pimephales promelas*	Cadmium nitrate	48 hr	209	LC50	802	Slooff et al. 1983a	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	-	Histological effects	12,000	Stromberg et al. 1983	Atypical endpoint
Fathead minnow (30 d), *Pimephales promelas*	Cadmium chloride	96 hr	55-79	LC50	3,390	Spehar and Carlson 1984a;b	River dilution water not characterized
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	55-79	LC50	1,830	Spehar and Carlson 1984a;b	River dilution water not characterized
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (20.1ºC)	LC50	125	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (22.8ºC)	LC50	84	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (25.7ºC)	LC50	76	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (27.9ºC)	LC50	87	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6	LC50	41	Birge et al. 1985	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6	LC50	107	Birge et al. 1985	Duration; Multiple-species test
Fathead minnow (14-30 d), *Pimephales promelas*	Cadmium chloride	96 hr	200	LC50	90	Hall et al. 1986	
Fathead minnow (1-7 d), *Pimephales promelas*	Cadmium chloride	48 hr	70-90	LC50	35.4	Diamond et al. 1997	Duration
Fathead minnow (2-4 d), *Pimephales promelas*	Cadmium chloride	96 hr	17	LC50	4.8	Suedel et al. 1997	Test species fed
Fathead minnow, *Pimephales promelas*	-	juvenile growth & survival test	17	NOEC-LOEC (growth and survival)	1.0-2	Suedel et al. 1997	Static exposure
Fathead minnow, *Pimephales promelas*	-	Juvenile growth & survival test	17	NOEC-LOEC (growth and survival)	2.0-3	Suedel et al. 1997	Static exposure
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	270	NOEC-LOEC (growth and survival)	10.7-21.9	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	261	NOEC-LOEC (growth and survival)	11.5-21.3	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	285	NOEC-LOEC (growth and survival)	8.5-11.3	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	272	NOEC-LOEC (growth and survival)	9.6-12.2	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	292	NOEC-LOEC (growth and survival)	5.3-6.9	Southwest Texas State University 2000	Duration
Fathead minnow (larva, 96-144 hr), *Pimephales promelas*	Cadmium chloride	7 d	-	LC50	15.43	Southwest Texas State University 2000	Duration
Fathead minnow (larva, 96-144 hr), *Pimephales promelas*	Cadmium chloride	7 d	-	LC50	16.99	Southwest Texas State University 2000	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow (adult pairs), *Pimephales promelas*	Cadmium chloride	21 d	169	NOEC-LOEC (spawning frequency)	24.3-39.7	Sellin and Kolok 2006a	Duration; Atypical endpoint
Fathead minnow (larva, 8 d), *Pimephales promelas*	Cadmium chloride	21 d	173	NOEC-LOEC (# of pairs to spawn per day)	25-50	Sellin and Kolok 2006b	Duration
Fathead minnow (larva, 8 d), *Pimephales promelas*	Cadmium chloride	21 d	173	NOEC (hatching success, offspring mortality)	50	Sellin and Kolok 2006b	Duration
Fathead minnow (adult), *Pimephales promelas*	Cadmium sulfate	96 hr	117.9	LOEC (increase metabolic rate)	250	Pistole et al. 2008	Atypical endpoint
Fathead minnow (29-55 mm), *Pimephales promelas*	Cadmium nitrate	96 hr	120	Increase in auditory threshold	2.1-2.9	Low 2009	Atypical endpoint
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Cadmium chloride	48 hr	38-66	LC50	47.7	Robison 2011	Duration
White sucker (larva), *Catostomus commersoni*	Cadmium chloride	7 d	48	46% reduced growth	36 (dissolved)	Borgmann and Ralph 1986	Duration
Walking catfish (12-14 cm, 25 g), *Clarias batrachus*	Cadmium chloride	96 hr	250 (240-260)	LC50	315,000	Banerjee et al. 1978	Lack of exposure details
Walking catfish, *Clarias batrachus*	Cadmium chloride	14 d	-	60% mortality	8,993	Jana and Sahana 1989	Duration; Unmeasured exposure
Stickleback, *Gasterosteus aculeatus*	Cadmium sulfate	18 d	299	Kidney cell tissue breakdown	6,000	Oronsaye 1989	Duration; Atypical endpoint
Stickleback, *Gasterosteus aculeatus*	Cadmium sulfate	30 d	299	NOEC-LOEC (kidney cytological alteration)	4,000-6,000	Oronsaye 2001	Duration; Atypical endpoint
Brown bullhead, *Ictalurus nebulosus*	Cadmium chloride	2 hr	-	Affected gills and kidney	61,300	Blickens 1978; Garofano 1979	Duration; Atypical endpoint
Channel catfish, *Ictalurus punctatus*	Cadmium chloride	-	-	Increased albinism	0.5	Westerman and Birge 1978	Duration unknown; Atypical endpoint
Channel catfish, *Ictalurus punctatus*	Cadmium chloride	96 hr	55-79	LC50	7,940	Spehar and Carlson 1984a;b	River dilution water not characterized

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mosquitofish, *Gambusia affinis*	Cadmium sulfate	48 hr	45	LC50	7,260	Chagnon and Guttman 1989	Duration
Guppy (fry), *Poecilia reticulata*	Cadmium chloride	96 hr	140-190	LC50	2,500	Gadkari and Marathe 1983	
Guppy (male), *Poecilia reticulata*	Cadmium chloride	96 hr	140-190	LC50	12,750	Gadkari and Marathe 1983	
Guppy (female), *Poecilia reticulata*	Cadmium chloride	96 hr	140-190	LC50	16,000	Gadkari and Marathe 1983	
Guppy, *Poecilia reticulata*	Cadmium nitrate	48 hr	209	LC50	41,900	Slooff et al. 1983a	Duration
Striped bass (larva), *Morone saxatilis*	Cadmium chloride	72 hr	34.5	LC50	1	Hughes 1973	Duration
Striped bass (fingerling), *Morone saxatilis*	Cadmium chloride	72 hr	34.5	LC50	2	Hughes 1973	Duration
Bluegill, *Lepomis macrochirus*	Cadmium chloride	80 min	112	Significant avoidance	>41.1	Black and Birge 1980	Duration; Atypical endpoint
Bluegill, *Lepomis macrochirus*	Cadmium chloride	3 d	340-360	Increased cough rate	50	Bishop and McIntosh 1981	Duration; Atypical endpoint
Bluegill, *Lepomis macrochirus*	Cadmium chloride	96 hr	55-79	LC50	8,810	Spehar and Carlson 1984a;b	River dilution water not characterized
Bluegill (juvenile), *Lepomis macrochirus*	Cadmium chloride	32 d	134	NOEC (growth)	>32.3	Cope et al. 1994	
Bluegill (31.1 mm), *Lepomis macrochirus*	Cadmium chloride	22 d	174	LOEC (prey attack rate)	37.3	Bryan et al. 1995	Duration; Atypical endpoint
Largemouth bass (embryo, larva), *Micropterus salmoides*	Cadmium chloride	8 d	99	EC50 (death and deformity)	1,640	Birge et al. 1978	Duration
Largemouth bass, *Micropterus salmoides*	-	24 hr	-	Affected opercular activity	150	Morgan 1979	Duration; Atypical endpoint
Largemouth bass, *Micropterus salmoides*	Cadmium chloride	80 min	112	Significant avoidance	8.83	Black and Birge 1980	Duration; Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Largemouth bass (embryo, larva), *Micropterus salmoides*	Cadmium chloride	8 d	101.6	LC50	244	Birge et al. 1985	Duration; Multiple-species test
Fountain darter (larva, 96-144 hr), *Etheostoma fonticola*	Cadmium chloride	96 hr	254-282	LC50	9.62 (reported-dissolved)	Southwest Texas State University 2000	Test species fed
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	270	NOEC-LOEC (growth and survival)	1.4-2.8	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	261	NOEC-LOEC (growth and survival)	5.5-11.5	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	285	NOEC-LOEC (growth and survival)	5.7-8.5	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	270	NOEC-LOEC (growth and survival)	6.6-9.6	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	292	NOEC-LOEC (growth and survival)	4-5.3	Southwest Texas State University 2000	Duration
Orangethroat darter (embryo), *Etheostoma spectabile*	Cadmium chloride	96 hr	180	LC50	>500	Sharp and Kaszubski 1989	River dilution water not characterized
Nile tilapia (adult, 13.1 cm, 77.2 g), *Oreochromis niloticus*	Cadmium chloride	96 hr	36.17	Reduction in plasma Ca 2+ concentration	5,000	Garcia-Santos et al. 2006	Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	LOEC (increase CAT activity)	562	Atli and Canli 2007	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	LOEC (decrease intestine Na, K-ATPase activity)	562	Atli and Canli 2007	Unmeasured chronic exposure; Duration; Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	NOEC-LOEC (decrease muscle Na, K-ATPase activity)	562-1,124	Atli and Canli 2007	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	NOEC (gill, blood, and muscle and GSH level)	>2,248	Atli and Canli 2008	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	LOEC (increase liver MT level)	562	Atli and Canli 2008	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (fingerling, 4-6 cm), *Oreochromis niloticus*	Cadmium chloride	28 d	-	NOEC (brain and muscle ChE activity)	30	Silva and Pathiratne 2008	Atypical endpoint
Mozambique tilapia (12-14 cm, 25 g), *Oreochromis mossambica*	Cadmium chloride	96 hr	250 (240-260)	LC50	200,000	Banerjee et al. 1978	Lack of exposure details
Mozambique tilapia (larva, <1 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	205	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 1 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	83	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 2 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	33	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 3 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	22	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 7 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	29	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (72 hr), *Oreochromis mossambica*	Cadmium chloride	96 hr	28	LC50	21.4	Chang et al. 1998	
Mummichog, *Fundulus heteroclitus*	Cadmium chloride	96 hr	5	TL50	12.2	Gill and Epple 1992	Atypical endpoint
White sturgeon (embryo), *Acipenser transmontanus*	Cadmium chloride	66 d	70	NOEC-LOEC (mortality)	1.1-8.3	Vardy et al. 2011	No true control group - control water had Cd level similar to lowest exposure group

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
White sturgeon (embryo), *Acipenser transmontanus*	Cadmium chloride	66 d	70	LC20	1.5	Vardy et al. 2011	No true control group
White sturgeon (larva, 2 dph), *Acipenser transmontanus*	Cadmium chloride	14 d	100	EC20 (survival)	>11	Wang et al. 2014a	Duration too short
White sturgeon (juvenile, 28 dph), *Acipenser transmontanus*	Cadmium chloride	28 d	100	EC20 (biomass)	3.2	Wang et al. 2014a	Exposure started too late for true ELS test
Southern gray treefrog (embryo), *Hyla chrysoscelis*	Cadmium chloride	72 hr	90	LC50	49.9	Westerman 1977	Duration
Southern gray treefrog (embryo), *Hyla chrysoscelis*	Cadmium chloride	7 d	90	LC50	40.3	Westerman 1977	Duration
Pipfrog (embryo), *Rana grylio*	Cadmium chloride	6 d	90	LC50	81.8	Westerman 1977	Duration
Pipfrog (embryo), *Rana grylio*	Cadmium chloride	10 d	90	LC50	69.3	Westerman 1977	Duration
River frog (embryo), *Rana heckscheri*	Cadmium chloride	6 d	90	LC50	69.2	Westerman 1977	Duration
River frog (embryo), *Rana heckscheri*	Cadmium chloride	10 d	90	LC50	60.5	Westerman 1977	Duration
Leopard frog (embryo), *Rana pipiens*	Cadmium chloride	6 d	90	LC50	56.1	Westerman 1977	Duration
Leopard frog (embryo), *Rana pipiens*	Cadmium chloride	10 d	90	LC50	50.1	Westerman 1977	Duration
Southern leopard frog (tadpole, GS 25), *Rana sphenocephala*	Cadmium chloride	48 hr	130.8	NOEC-LOEC (decreased tadpole activity)	750-1,200	Moyer 2012	Duration; Atypical endpoint
American toad (tadpoles, Gosner stage 25), *Bufo americanus*	Cadmium chloride	60 d	51.2	LOEC (metamorph wet weight and days to tail resorption)	5	James and Little 2003	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
American toad (tadpoles, Gosner stage 25), *Bufo americanus*	Cadmium chloride	60 d	51.2	NOEC-LOEC (survival)	54-540	James and Little 2003	Duration
Red-spotted toad (embryo), *Bufo punctatus*	Cadmium chloride	72 hr	90	LC50	9,800	Westerman 1977	Duration
Red-spotted toad (embryo), *Bufo punctatus*	Cadmium chloride	7 d	90	LC50	6,781	Westerman 1977	Duration
Narrow-mouthed toad (embryo, larva), *Gastrophyryne carolinensis*	Cadmium chloride	7 d	195	EC50 (death and deformity)	40	Birge 1978	Duration
Narrow-mouthed toad (embryo), *Gastrophyryne carolinensis*	Cadmium chloride	72 hr	90	LC50	47.9	Westerman 1977	Duration
Narrow-mouthed toad (embryo), *Gastrophyryne carolinensis*	Cadmium chloride	7 d	90	LC50	41.5	Westerman 1977	Duration
African clawed frog, *Xenopus laevis*	Cadmium nitrate	48 hr	209	LC50	11,700	Slooff and Baerselman 1980; Slooff et al. 1983a	Duration
African clawed frog, *Xenopus laevis*	Cadmium chloride	48 hr	170	LC50	3,200	Canton and Slooff 1982	Duration
African clawed frog, *Xenopus laevis*	Cadmium chloride	100 d	170	Inhibited development	650	Canton and Slooff 1982	Lack of exposure details
African clawed frog (stage 40), *Xenopus laevis*	Cadmium chloride	24 hr	-	LC50	1,000	Herkovits et al. 1997	Duration
African clawed frog (stage 40), *Xenopus laevis*	Cadmium chloride	72 hr	-	LC50	0.2	Herkovits et al. 1998	Duration
African clawed frog (stage 47), *Xenopus laevis*	Cadmium chloride	72 hr	-	LC50	1.6	Herkovits et al. 1998	Duration
African clawed frog (adult, female), *Xenopus laevis*	Cadmium chloride	30 d	-	NOEC-LOEC (total egg count)	500-1,000	Fort et al. 2001	Duration
African clawed frog (adult, male), *Xenopus laevis*	Cadmium chloride	30 d	-	NOEC-LOEC (total sperm count)	2,500-5,000	Fort et al. 2001	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
African clawed frog (stage 50), *Xenopus laevis*	Cadmium chloride	6 d	-	40% mortality	5,000	Mouchet et al. 2007	Duration; Test species fed
African clawed frog (stage 50), *Xenopus laevis*	Cadmium chloride	6 d	-	60% mortality	10,000	Mouchet et al. 2007	Duration; Test species fed
African clawed frog, *Xenopus laevis*	Cadmium chloride	96 hr	-	Increased toxicity and teratogenicity	562	Boga et al. 2008	Atypical endpoint
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	47 d	-	NOEC-LOEC (delayed development and forelimb emergence)	84-855	Sharma and Patino 2008	Duration
African clawed frog (embryo,<24 hr), *Xenopus laevis*	Cadmium chloride	86 d	-	NOEC-LOEC (survival)	85-860	Sharma and Patino 2009	Duration
African clawed frog (embryo,<24 hr), *Xenopus laevis*	Cadmium chloride	86 d	-	NOEC-LOEC (growth)	8-85	Sharma and Patino 2009	Duration
Marbled salamander (embryo, larva), *Ambystoma gracile*	Cadmium chloride	8 d	99	EC50 (death and deformity)	150	Birge et al. 1978	Duration
Northwestern salamander, *Ambystoma gracile*	Cadmium chloride	10 d	45	LOEC (limb regeneration)	44.6	Nebeker et al. 1994	Duration
Northwestern salamander, *Ambystoma gracile*	Cadmium chloride	10 d	45	LOEC (growth)	227	Nebeker et al. 1995	Duration

Appendix I Other Estuarine/Marine Toxicity Data

Appendix Table I-1. Other Estuarine/Marine Toxicity Data

(Species are organized phylogenetically).

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
				ESTUARINE/MARINE WATER			
Bacterium, *Vibrio fischeri*	Cadmium nitrate	22 hr	35	EC50	214	Radix et al. 1999	Bacteria
Bacteria, *Vibrio fischeri*	Cadmium chloride	15 min	35	EC50 (luminescence)	56,800	Rosen et al. 2008	Bacteria
Phytoplankton population	Cadmium nitrate	4 d	-	Reduced biomass	112	Hollibaugh et al. 1980	Mixed community exposure
Phytoplankton community	-	-	-	LC50	0.23-498.7	Echeveste et al. 2012	Mixed community exposure, exposure duration not well defined
Phytoflagellate, *Olisthodiscus luteus*	Cadmium chloride	192 hr	-	27% biovolume reduction	500	Fernandez-Leborans and Novillo 1996	
Dinoflagellate, *Alexandrium catenella*	Cadmium sulfate	30 d	-	30% decreased growth	5.83	Herzi et al. 2013	Duration
Dinoflagellate, *Ceratocorys horrida*	Cadmium chloride	24 hr	35	EC50 (bioluminescence)	1,710	Rosen et al. 2008	Duration
Dinoflagellate, *Heterocapsa sp.*	-	72 hr	-	EC50 (growth)	13,800	Satoh et al. 2005	Duration
Dinoflagellate, *Lingulodinium polyedrum*	Cadmium chloride	24 hr	35	EC50 (bioluminescence)	843	Rosen et al. 2008	Duration
Dinoflagellate, *Prorocentrum minimum*	Cadmium chloride	2 hr	20	LC50 (growth)	12,000	Roberts et al. 1982	Duration
Dinoflagellate, *Prorocentrum minimum*	-	72 hr	-	IC50 (cell-specific growth rate)	116.9	Wang 2010	Duration

Species	**Chemical**	**Duration**	**Salinity (g/kg)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Dinoflagellate (4 wk), *Pyrocystis lunula*	-	48 hr	35	EC50 (bioluminescence)	750	Heimann et al. 2002	Duration
Dinoflagellate, *Pyrocystis noctiluca*	Cadmium chloride	24 hr	35	EC50 (bioluminescence)	1,130	Rosen et al. 2008	Duration
Haptophyte, *Pseudoisochrysis paradoxa*	Cadmium chloride	2 hr	20	LC50 (growth)	167,000	Roberts et al. 1982	Duration
Diatom, *Chaetoceros gracilis*	Cadmium chloride	72 hr	-	EC50 (growth)	8,500	Koutsaftis and Aoyama 2006	Duration
Diatom, *Isochrysis galbana*	-	72 hr	-	EC50 (growth)	2,900	Satoh et al. 2005	Duration
Diatom, *Minutocellus polymorphus*	Cadmium chloride	48 hr	-	EC50	66	Walsh et al. 1988	Duration
Diatom, *Skeletonema costatum*	Cadmium chloride	2 hr	20	LC50 (growth)	681,000	Roberts et al. 1982	Duration
Diatom, *Skeletonema costatum*	-	10 d	-	EC50 (growth)	450	Govindarajan et al. 1993	
Diatom, *Skeletonema costatum*	Cadmium chloride	72 hr	-	EC50	144	Walsh et al. 1988	Duration
Diatom, *Tetraselmis gracilis*	-	96 hr	-	EC50 (survival)	1,800	Okamoto et al. 1996	
Diatom, *Tetraselmis tetrahele*	-	72 hr	-	EC50 (growth)	9,800	Satoh et al. 2005	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- (18ºC)	EC50 (growth)	291.1	Wang and Wang 2008; Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- (24ºC)	EC50 (growth)	210.2	Wang and Wang 2008; Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- (30.5ºC)	EC50 (growth)	33.72	Wang and Wang 2008; Wang 2010	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- High irradiance	IC50 (cell-specific growth rate)	77.56	Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- Low irradiance	IC50 (cell-specific growth rate)	303.5	Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- Med. irradiance	IC50 (cell-specific growth rate)	236.1	Wang 2010	Duration
Diatom, *Thalassiosira pseudonana*	-	72 hr	-	IC50 (cell-specific growth rate)	7.862	Wang 2010	Duration
Diatom, *Thalassiosira weissflogii*	-	48 hr	-	EC50 (growth-nutrient rich medium)	157.4	Miao and Wang 2006	Duration
Diatom, *Thalassiosira weissflogii*	-	48 hr	-	EC50 (growth-N-starved medium)	22.48	Miao and Wang 2006	Duration
Diatom, *Thalassiosira weissflogii*	-	48 hr	-	EC50 (growth-P-starved medium)	73.07	Miao and Wang 2006	Duration
Green alga, *Acetabularia acetabulum*	Cadmium chloride	3 wk	-	Morphological deformities	100	Karez et al. 1989	
Green alga, *Acetabularia acetabulum*	Cadmium chloride	3 wk	-	Decreased cell elongation	1	Karez et al. 1989	
Green alga, *Chlorella autotrophica*	-	72 hr	-	IC50 (cell-specific growth rate)	1,248	Wang 2010	Duration
Green alga, *Ulva pertusa*	Cadmium chloride	72-120 hr	35	EC50 (reproduction)	217	Han et al. 2007	Duration not specifically identified
Red alga, *Champia parvula*	Cadmium chloride	48 hr	28-30	NOEC (sexual reproduction)	>100	Thursby and Steele 1986	Duration
Hydroid, *Campanularia flexuosa*	-	-	-	Enzyme inhibition	40-75	Moore and Stebbing 1976	Duration not specifically identified

Species	**Chemical**	**Duration**	**Salinity (g/kg)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Hydroid, *Campanularia flexuosa*	-	11 d	-	Growth rate	110-280	Stebbing 1976	
Starlet sea anemone (adult, female), *Nematostella vectensis*	Cadmium chloride	21 d	12	NOEC-LOEC (survival)	50-250	Harter and Matthews 2005	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	15	LC50	54,900	Snell and Personne 1989b	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	30	LC50	56,800	Snell and Personne 1989b	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	15	LC50	>39,000	Snell et al. 1991b	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	-	LC50	490.6	Arulvasu et al. 2010	Duration
Rotifer, *Brachionus plicatilis*	Cadmium nitrate	7 d	-	No survival	429.2	Arulvasu et al. 2010	Unmeasured chronic exposure; Duration
Polychaete, *Capitella capitata*	Cadmium chloride	28 d	-	LC50	630	Reish et al. 1976	Duration
Polychaete, *Capitella capitata*	Cadmium chloride	28 d	-	LC50	700	Reish et al. 1976	Duration
Polychaete, *Neanthes arenaceodentata*	Cadmium chloride	28 d	-	LC50	3,000	Reish et al. 1976	Duration
Polychaete worm, *Nereis virens*	Cadmium chloride	144 hr	-	LC50	170	McLeese and Ray 1986	Duration
Sea squirt (sperm), *Ciona intestinalis*	Cadmium chloride	30 min	33	NOEC-LOEC (% fertilization)	4,096-16,384	Bellas et al. 2001	Duration
Sea squirt (gamete), *Ciona intestinalis*	Cadmium chloride	1 hr	33	LOEC (% fertilization)	>16,384	Bellas et al. 2001	Duration
Sea squirt (embryo), *Ciona intestinalis*	Cadmium chloride	20 hr	33	EC50 (development)	809.4	Bellas et al. 2001	Duration
Sea squirt (larva), *Ciona intestinalis*	Cadmium chloride	48 hr	33	EC50 (attachmnet)	>16,366	Bellas et al. 2001	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Sea squirt (egg/sperm), *Ciona intestinalis*	Cadmium chloride	20 hr	33	EC50 (embryonic development)	721	Bellas et al. 2004	Duration
Sea squirt (egg/sperm), *Ciona intestinalis*	Cadmium chloride	70 hr	33	EC50 (larva attachment)	752	Bellas et al. 2004	Duration
Gastropod (larva), *Crepidula fornicata*	Cadmium chloride	48 hr	-	LOEC (% larval mortality)	2,189	Pechenik et al. 2001	Duration; Test species fed
Mud snail (0.24-1.14 g), *Nassarius obsoletus*	Cadmium chloride	72 hr	25	Increased O_2 consumption	500	MacInnes and Thurberg 1973	Atypical endpoint
Mussel, *Mytilus edulis*	Cadmium chloride	9.5 d	28	LT50 = 9.5 d (anoxic conditions)	47	Veldhuizen-Tsoerkan et al. 1991	Atypical endpoint
Bay scallop, *Argopecten irradians*	Cadmium chloride	42 d	-	EC50 (growth)	78	Pesch and Stewart 1980	
Scallop (juvenile, 3 mm), *Argopecten ventricosus*	Cadmium chloride	30 d	36	LOEC (growth)	10	Sobrino-Figueroa et al. 2007	Unmeasured chronic exposure; Duration
Pacific oyster (larva, 6 d), *Crassostrea gigas*	Cadmium chloride	96 hr	-	EC50 (growth)	75	Watling 1982	Atypical endpoint
Pacific oyster (larva, 16 d), *Crassostrea gigas*	Cadmium chloride	96 hr	-	EC50 (growth)	120	Watling 1982	Atypical endpoint
Pacific oyster, *Crassostrea gigas*	Cadmium chloride	6 d	-	50 % reduction in settlement	20-25	Watling 1983b	Duration
Pacific oyster, *Crassostrea gigas*	Cadmium chloride	14 d	-	Growth reduction	10	Watling 1983b	Duration
Pacific oyster, *Crassostrea gigas*	Cadmium chloride	23 d	-	LC50	50	Watling 1983b	Duration
Pacific oyster (1 yr, 112 mm, 20.3 g), *Crassostrea gigas*	Cadmium chloride	11 d	35	LOEC (increase expression of MT mRNA in digestive gland and gills)	10	Choi et al. 2008	Duration; Unmeasured chronic exposure; Atypical endpoint

Species	**Chemical**	**Duration**	**Salinity (g/kg)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Pacific oyster (1 yr, 112 mm, 20.3 g), *Crassostrea gigas*	Cadmium chloride	11 d	35	LOEC (increase expression of HSP90 mRNA in digestive gland and gills)	10	Choi et al. 2008	Duration; Unmeasured chronic exposure; Atypical endpoint
American or virginia oyster, *Crassostrea virginica*	Cadmium chloride	48 hr	-	Reduction in embryonic development	15	Zaroogian and Morrison 1981	Duration
Brown mussel (20-24 mm), *Perna perna*	Cadmium acetate	96 hr	32	LC50	877.5	Baby and Menon 1987	Inappropriate form of toxicant
Clam, *Macoma balthica*	Cadmium chloride	6 d	-	LC50	1,710	McLeese and Ray 1986	Duration
Hard clam (juvenile), *Mercenaria mercenaria*	Cadmium chloride	7 d	25	EC50 (growth)	86.7	Keppler and Ringwood 2002	Duration; Test species fed
Hard clam (juvenile, 212-350 mm), *Mercenaria mercenaria*	-	24 hr	32	LC50	420	Chung et al. 2007	Duration
Japanese carpet shell (6.7-7.1 mm), *Ruditapes philippinarum*	-	5 d	-	LC50	3,114	Figueira et al. 2012	Duration
Sand gaper, *Mya arenaria*	Cadmium chloride	7 d	-	LC50	150	Eisler 1977	Duration
Sand gaper, *Mya arenaria*	Cadmium chloride	7 d	-	LC50	700	Eisler and Hennekey 1977	Duration
Calanoid copepod (newly hatched nauplii), *Eurytemora affinis*	Cadmium chloride	24 hr	-	Reduction in swimming speed	130	Sullivan et al. 1983	Duration
Calanoid copepod (newly hatched nauplii), *Eurytemora affinis*	Cadmium chloride	48 hr	-	Reduction in development rate	116	Sullivan et al. 1983	Duration
Calanoid copepod, *Eurytemora affinis*	Cadmium chloride	96 hr	5	LC50	51.6	Hall et al. 1995	Test species fed

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Calanoid copepod, *Eurytemora affinis*	Cadmium chloride	96 hr	15	LC50	213	Hall et al. 1995	Test species fed
Harpacticoid copepod, *Nitokra spinipes*	Cadmium sulfate	96 hr	30	NOEC (survival)	500	Ward et al. 2011	Atypical endpoint
Copepod, *Tisbe holothurlae*	Cadmium chloride	48 hr	-	LC50	970	Moraitou-Apostolopoulou and Verriopoulos 1982	Duration
Barnacle (larva, stage 2 nauplii), *Balanus improvisus*	Cadmium chloride	96 hr	15	LC50	>100.5	Lang et al. 1981	According to the author no attempt was made to determine a LC50; Test species fed
Barnacle (larva, stage 2 nauplii), *Balanus improvisus*	Cadmium chloride	96 hr	30	LC50	>201.8	Lang et al. 1981	According to the author no attempt was made to determine a LC50; Test species fed
Mysid, *Americamysis bahia*	Cadmium chloride	17 d	15-23	LC50	11.3	Nimmo et al. 1977a	Duration
Mysid, *Americamysis bahia*	Cadmium chloride	16 d	30	LC50	28	Gentile et al. 1982	Duration
Mysid, *Americamysis bahia*	Cadmium chloride	8 d	-	LC50	60	Gentile et al. 1982	Duration
Mysid, *Americamysis bahia*	-	28 d	13-29	NOEC (survival, growth and reproduction)	4-5	Voyer and McGovern 1991	
Mysid (8 d), *Americamysis bahia*	Cadmium chloride	7 d	25	NOEC (survival and growth)	5	Khan et al. 1992	Duration; Unmeasured exposure
Mysid (8 d), *Americamysis bahia*	Cadmium chloride	96 hr	25	NOEC (survival and growth)	5	Khan et al. 1992	
Mysid, *Americamysis bahia*	-	24 hr	12	Reduced serum osmolality	3.62	De Lisle and Roberts 1994	Duration; Atypical endpoint

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mysid, *Mysidopsis bigelowi*	Cadmium chloride	28 d	-	LC50	18	Gentile et al. 1982	Duration
Mysid, *Mysidopsis bigelowi*	Cadmium chloride	8 d	-	LC50	70	Gentile et al. 1982	Duration
Mysid (adult, 18 mm), *Praunus flexuosus*	Cadmium chloride	6 d	10	LC50	83.11	Roast et al. 2001b	Duration
Isopod, *Idotea baltica*	Cadmium chloride	5 d	3	LC50	10,000	Jones 1975	Duration
Isopod, *Idotea baltica*	Cadmium chloride	3 d	21	LC50	10,000	Jones 1975	Duration
Isopod, *Idotea baltica*	Cadmium chloride	1.5 d	14	LC50	10,000	Jones 1975	Duration
White shrimp (0.02 cm, 0.1 g), *Litopenaeus vannamei*	Cadmium sulfate	28 d	15	LOEC (growth)	100	Wu and Chen 2005a	Unmeasured chronic exposure
White shrimp (0.22 cm, 0.49 g), *Litopenaeus vannamei*	Cadmium sulfate	28 d	15	NOEC-LOEC (food consumption)	100-200	Wu and Chen 2005a	Unmeasured chronic exposure; Atypical endpoint
Pink shrimp, *Penaeus duorarum*	Cadmium chloride	30 d	-	LC50	720	Nimmo et al. 1977b	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	29 d	-	LC50	120	Nimmo et al. 1977b	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	5	LC25	50	Vernberg et al. 1977	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	10	LC10	50	Vernberg et al. 1977	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	20	LC5	50	Vernberg et al. 1977	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	-	BCF = 140	-	Vernberg et al. 1977	Steady state not documented
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	6 d	10	LC75	300	Middaugh and Floyd 1978	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	6 d	15	LC50	300	Middaugh and Floyd 1978	Duration
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	6 d	30	LC25	300	Middaugh and Floyd 1978	Duration
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	42 d	-	LC50	300	Pesch and Stewart 1980	Duration
Daggerblade grass shrimp (juvenile), *Palaemonetes pugio*	Cadmium chloride	48 hr	10	LC50	1,300	Burton and Fisher 1990	Duration too short for juvenile shrimp
Daggerblade grass shrimp (25-35 mg), *Palaemonetes pugio*	Cadmium chloride	8 hr	20	NOEC-LOEC (increase GSH)	562.05-5,620.5	Downs et al. 2001a	Duration; Atypical endpoint
Daggerblade grass shrimp (25-35 mg), *Palaemonetes pugio*	Cadmium chloride	8 hr	20	LOEC (increase LPO and ubiquitin)	112.41	Downs et al. 2001a	Duration; Atypical endpoint
Shrimp, *Palaemon sp.*	-	5 d	-		2,300	Ahsanullah 1976	Duration
Spot shrimp, *Pandalus platyceros*	-	-	-		4,970	Cardwell et al. 1979	Unknown duration
Pink shrimp, *Pandalus montagui*	Cadmium chloride	6 d	-	LC50	1,280	McLeese and Ray 1986	Duration
Common shrimp (post-molt), *Crangon crangon*	-	5.3 d	-		350	Price and Uglow 1979	Duration
Bay shrimp, *Crangon septemspinosa*	Cadmium chloride	6 d	-	LC50	1,160	McLeese and Ray 1986	Duration
American lobster, *Homarus americanus*	Cadmium chloride	21 d	-	BCF = 25	-	Eisler et al. 1972	Steady state not documented
American lobster, *Homarus americanus*	Cadmium chloride	30 d	-	Increase in ATPase activity	6	Tucker 1979	Atypical endpoint

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Longwrist hermit crab, *Pagurus longicarpus*	Cadmium chloride	7 d	-	25% mortality	270	Eisler and Hennekey 1977	Duration
Longwrist hermit crab, *Pagurus longicarpus*	Cadmium chloride	60 d	-	LC56	70	Pesch and Stewart 1980	Lack of exposure details; Atypical endpoint
Yellow crab, *Cancer anthonyi*	Cadmium chloride	7 d	34	28% mortality	1,000	MacDonald et al. 1988	Duration
Rock crab, *Cancer irroratus*	Cadmium chloride	96 hr	-	Enzyme activity	1,000	Gould et al. 1976	Atypical endpoint
Rock crab (larva), *Cancer irroratus*	Cadmium chloride	28 d	-	Delayed development	50	Johns and Miller 1982	Lack of exposure details
Blue crab, *Callinectes sapidus*	Cadmium nitrate	7 d	10	LC50	50	Rosenberg and Costlow 1976	Duration
Blue crab, *Callinectes sapidus*	Cadmium nitrate	7 d	30	LC50	150	Rosenberg and Costlow 1976	Duration
Blue crab, *Callinectes sapidus*	Cadmium chloride	21 d	2.5	LC50	19	Guerin and Stickle 1995	Duration
Blue crab, *Callinectes sapidus*	Cadmium chloride	21 d	25	LC50	186	Guerin and Stickle 1995	Duration
Blue crab, *Callinectes sapidus*	Cadmium chloride	6-8 d	28	EC50 (hatching)	0.25	Lee et al. 1996	Duration
Shore crab (45.6 g), *Carcinus maenas*	Cadmium chloride	10 d	32	NOEC-LOEC (osmotic pressure)	3.4-34	Burke et al. 2003	Duration; Only two exposure concentrations
Shore crab (45.6 g), *Carcinus maenas*	Cadmium chloride	10 d	10.5	LOEC (osmotic pressure)	3.4	Burke et al. 2003	Duration; Only two exposure concentrations
Mud crab (larva), *Eurypanopeus depressus*	Cadmium chloride	8 d	-	LC50	10	Mirkes et al. 1978	Duration; Lack of exposure details
Mud crab (larva), *Eurypanopeus depressus*	Cadmium chloride	44 d	-	Delay in metamorphysis	10	Mirkes et al. 1978	Lack of exposure details

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mud crab, *Rhithropanopeus harrisil*	Cadmium nitrate	11 d	10	LC80	50	Rosenberg and Costlow 1976	Duration; Atypical endpoint
Mud crab, *Rhithropanopeus harrisil*	Cadmium nitrate	11 d	20	LC75	50	Rosenberg and Costlow 1976	Duration; Atypical endpoint
Mud crab, *Rhithropanopeus harrisil*	Cadmium nitrate	11 d	30	LC40	50	Rosenberg and Costlow 1976	Duration; Atypical endpoint
Fiddler crab, *Uca pugilator*	-	10 d	-	LC50	2,900	O'Hara 1973a	Duration
Fiddler crab, *Uca pugilator*	Cadmium chloride	-	-	Effect on respiration	1.0	Vernberg et al. 1974	Duration not provided
Northern Pacific seastar (egg/sperm), *Asterias amurensis*	Cadmium chloride	60 min	32	Fertilization rate	154,000	Lee et al. 2004	Duration
Common starfish, *Asterias forbesii*	Cadmium chloride	7 d	-	25% mortality	270	Eisler and Hennekey 1977	Duration
Sea urchin (sperm cell), *Arbacia punctulata*	Cadmium chloride	1 hr	30	EC50 (sperm cell)	38,000	Nacci et al. 1986	Duration
Sea urchin (embryo), *Arbacia punctulata*	Cadmium chloride	4 hr	30	EC50 (embryo growth)	13,900	Nacci et al. 1986	Duration
Green sea urchin (sperm), *Strongylocentrotus droebachiensis*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	26,000	Dinnel et al. 1989	Duration
Green sea urchin (embryo), *Strongylocentrotus droebachiensis*	Cadmium chloride	120 hr	30	EC50 (development)	1,800	Dinnel et al. 1989	Duration
Red sea urchin (sperm), *Strongylocentrotus franciscanus*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	12,000	Dinnel et al. 1989	Duration
Purple sea urchin (sperm), *Strongylocentrotus purpuratus*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	18,000	Dinnel et al. 1989	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	Cadmium chloride	120 hr	30	EC50 (development)	500	Dinnel et al. 1989	Duration
Purple sea urchin, *Strongylocentrotus purpuratus*	Cadmium chloride	40 min	30	NOEC (sperm fertilization)	>67	Bailey et al. 1995	Duration
Sand dollar (sperm), *Dendraster excentricus*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	8,000	Dinnel et al. 1989	Duration
Sand dollar, *Dendraster excentricus*	Cadmium chloride	40 min	30	NOEC (sperm fertilization)	>67	Bailey et al. 1995	Duration
Herring (larvae), *Clupea harengus*	Cadmium chloride	-	-	100% embryonic survival	5,000	Westernhagen et al. 1979	Duration not provided
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	<24 hr	-	17% reduction in volume	10,000	Alderdice et al. 1979a	Duration; Atypical endpoint
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	96 hr	-	Decrease in capsule strength	1,000	Alderdice et al. 1979b	Atypical endpoint
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	48 hr	-	Reduced osmolality of periviteline fluid	1,000	Alderdice et al. 1979c	Duration; Atypical endpoint
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	34-35	LC50	1,230	Hutchinson et al. 1994	Test species fed
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	7 d	34-35	NOEC (survival and growth)	560	Hutchinson et al. 1994	Duration
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	5	LC50	180 (dissolved)	Hall et al. 1995	Test species fed
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	15	LC50	312 (dissolved)	Hall et al. 1995	Test species fed
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	25	LC50	496 (dissolved)	Hall et al. 1995	Test species fed
Mummichog, *Fundulus heteroclitus*	Cadmium chloride	21 d	-	BCF = 48	-	Eisler et al. 1972	Steady state not documented
Mummichog (adult), *Fundulus heteroclitus*	Cadmium chloride	48 hr	20	LC50	60,000	Middaugh and Dean 1977	Duration
Mummichog (adult), *Fundulus heteroclitus*	Cadmium chloride	48 hr	30	LC50	43,000	Middaugh and Dean 1977	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mummichog (larva), *Fundulus heteroclitus*	Cadmium chloride	48 hr	20	LC50	32,000	Middaugh and Dean 1977	Duration
Mummichog (larva), *Fundulus heteroclitus*	Cadmium chloride	48 hr	30	LC50	7,800	Middaugh and Dean 1977	Duration
Mummichog (<23 d), *Fundulus heteroclitus*	Cadmium chloride	48 hr	10	LC50	44,400	Burton and Fisher 1990	Duration
Atlantic silverside (adult), *Menidia menidia*	Cadmium chloride	48 hr	20	LC50	13,000	Middaugh and Dean 1977	Duration
Atlantic silverside (adult), *Menidia menidia*	Cadmium chloride	48 hr	30	LC50	12,000	Middaugh and Dean 1977	Duration
Atlantic silverside (larva), *Menidia menidia*	Cadmium chloride	48 hr	20	LC50	2,200	Middaugh and Dean 1977	Duration
Atlantic silverside (larva), *Menidia menidia*	Cadmium chloride	48 hr	30	LC50	1,600	Middaugh and Dean 1977	Duration
Atlantic silverside, *Menidia menidia*	Cadmium chloride	19 d	12	LC50	<160	Voyer et al. 1979	Duration
Atlantic silverside, *Menidia menidia*	Cadmium chloride	19 d	20	LC50	540	Voyer et al. 1979	Duration
Atlantic silverside, *Menidia menidia*	Cadmium chloride	19 d	30	LC50	>970	Voyer et al. 1979	Duration
Striped bass (juvenile), *Morone saxatilis*	Cadmium chloride	90 d	-	Significant decrease in enzyme activity	5	Dawson et al. 1977	Atypical endpoint
Striped bass (juvenile), *Morone saxatilis*	Cadmium chloride	30 d	-	NOEC-LOEC (significant decrease in oxygen consumption)	0.5-5	Dawson et al. 1977	Atypical endpoint
Cunner (adult), *Tautogolabrus adspersus*	Cadmium chloride	96 hr	-	Decreased enzyme activity	3,000	Gould and Karolus 1974	Atypical endpoint
Cunner (adult), *Tautogolabrus adspersus*	Cadmium chloride	60 d	-	37.5% mortality	100	MacInnes et al. 1977	Lack of exposure details
Cunner (adult), *Tautogolabrus adspersus*	Cadmium chloride	30 d	-	Depressed gill tissue oxygen consumption	50	MacInnes et al. 1977	Atypical endpoint

Species	**Chemical**	**Duration**	**Salinity (g/kg)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Winter flounder, *Pseodopleuronectes americanus*	Cadmium chloride	60 d	-	Increase gill tissue respiration	5	Calabrese et al. 1975	Atypical endpoint
Winter flounder, *Pseudopleuronectes americanus*	Cadmium chloride	8 d	-	50% viable hatch	300	Voyer et al. 1977	Duration
Winter flounder, *Pseodopleuronectes americanus*	Cadmium chloride	17 d	-	Reduction of viable hatch	586	Voyer et al. 1982	Lack of exposure details
Spot (larva), *Leiostomus xanthurus*	Cadmium chloride	9 d	-	Incipient LC50	200	Middaugh and Dean 1977	Duration

Appendix J Unused Studies

Appendix Table J-1. Unused Studies

Authors	Title	Year	Reason Unused
Abbasi and Soni	An examination of environmentally safe levels of zinc (II), cadmium (II) and lead (II) with reference to impact on channelfish *Nuria denricus*	1986	Not North American species
Abbasi and Soni	Relative toxicity of seven heavy metals with respect to impact towards larvae of amphibian *Rana tigrina*.	1989	The materials, methods or results were insufficiently described
Abdallah	Trace Element Levels in Some Commercially Valuable Fish Species from Coastal Waters of Mediterranean Sea, Egypt	2008	Bioaccumulation: steady state not documented
AbdAllah and Moustafa	Accumulation of lead and cadmium in the marine prosobranch *Nerita saxtilis*, chemical analysis, light and electron microscopy	2002	Non-applicable
Abdel-Baky et al.	Seasonal variations of some heavy metals accumulated in the organs of *Clarias gariepinus* (Burchell, 1822) in Lake Manzala, Egypt	1998	Non-applicable
Abel and Barlocher	Uptake of cadmium by *Gammarus fossarum* (Amphipoda) from food and water.	1988	Not North American species
Abel and Garner	Comparisons of median survival times and median lethal exposure times for *Gammarus pulex* exposed to cadmium, permethrin and cyanide.	1986	Not North American species
Abel and Papoutsoglou	Lethal toxicity of cadmium to *Cyprinus carpio* and *Tilapia aurea*.	1986	Not North American species
Abrahim et al.	Distribution and Assessment of Sediment exposure Toxicity in Tamaki Estuary, Auckland, New Zealand	2007	Sediment exposure
Abtahi et al.	Study of Histopathological Effect of Environmental Factors of Caspian Sea on Sturgeon Fishes	2007	Mixture
Adam et al.	Impact of Cadmium and Zinc Prior Exposure on 110mSilver, 58+60Cobalt and 137Cesium Uptake by Two Freshwater Bivalves During a Brief Field Experiment	2002	Bioaccumulation: steady state not documented
Adami et al.	Levels of cadmium and zinc in hepatopancreas of reared *Mytilus galloprovincialis* from the Gulf of Trieste (Italy)	2002	Non-applicable
Adams et al.	The Impact of an Industrially Contaminated Lake on Heavy Metal Levels in Its Effluent Stream	1980	Bioaccumulation: steady state not documented
Adeyemi and Deaton	The effect of cadmium exposure on digestive enzymes in the Eastern oyster *Crassostrea virginica*	2012	Only two exposure concentrations
Adham et al.	Impaired Functions in Nile Tilapia, *Oreochromis niloticus* (Linnaeus, 1757), from Polluted Waters	2002	Mixture
Adhikari et al.	Effect of calcium hardness on toxicity and accumulation of water-borne lead, cadmium and chromium to *Labeo rohita* (Hamilton)	2007	Bioaccumulation: steady state not documented (only 14 day exposure); not North American speciess
Adhikari et al.	Combined effects of water pH and alkalinity on the accumulation of lead, cadmium and chromium to *Labeo rohita* (Hamilton)	2006	Bioaccumulation: steady state not documented (only 14 day exposure); not North American species

Authors	**Title**	**Year**	**Reason Unused**
Adiele	Involvement of mitochondria in cadmium toxicity in rainbow trout (*Oncorhynchus mykiss*)	2012	Excised tissue/cells
Adiele et al.	Reciprocal Enhancement of Uptake and Toxicity of Cadmium and Calcium in Rainbow Trout (*Oncorhynchus Mykiss*) Liver Mitochondria.	2010	In vitro
Adiele et al.	Cadmium- and calcium-mediated toxicity in rainbow trout (*Oncorhynchus mykiss*) *in vivo*: interactions on fitness and mitochondrial endpoints.	2011	Only two exposure concentrations
Adiele et al.	Differential inhibition of electron transport chain enzyme complexes by cadmium and calcium in isolated rainbow trout (*Oncorhynchus mykiss*) hepatic mitochondria.	2012a	In vitro
Adiele et al.	Features of Cadmium and Calcium Uptake and Toxicity in Rainbow Trout (*Oncorhynchus mykiss*) Mitochondria.	2012b	In vitro
Afonso et al.	Contaminant metals in black scabbard fish (*Aphanopus carbo*) caught off Madeira and the Azores	2007	Bioaccumulation: steady state not documented
Agnello et al.	Cadmium induces an apoptotic response in sea urchin embryos	2007	Not North American species, only one exposure concentration, duration too short
Agrahari and Gopal	Fate and toxicity of cadmium and lead accumulation in different tissues (gills, liver, kidney, brain) of a freshwater fish *Channa punctatus*	2007	Not North American species, lack of exposure details
Ahmad et al.	Effect of cadmium chloride on the histoarchitecture of liver and kidney of a freshwater catfish, *Clarias batrachus*	2011	Only two exposure concentrations
Ahmed et al.	Measurements of genotoxic potential of cadmium in different tissues of fresh water climbing perch Anabas testudineus (Bloch), using the comet assay	2010	Excised tissue/cells
Ahn et al.	The effect of body size on metal accumulations in the bivalve *Laternula elliptica*	2001	Non-applicable
Ahn et al.	Spatial Variations of Heavy Metal Accumulation in Manila Clam *Ruditapes philippinarum* From Some Selected Intertidal Flats of Korea	2006	Bioaccumulation: steady state not documented
Ahsanullah and Arnott	Acute toxicity of copper, cadmium, and zinc to larvae of the crab *Paragrapsus quadridentatus* (H. Milne Edwards), and implications for water quality criteria	1978	Not North American species
Ahsanullah and Williams	Sublethal effects and bioaccumulation of cadmium, chromium, copper and zinc in the marine amphipod *Allorchestes compressa*	1991	Not North American species
Ahsanullah et al.	Toxicity of zinc, cadmium, and copper to the shrimp *Callianassa australiensis*	1981	Not North American species
Ai et al.	Effects of Heavy Metal and Pollutants on the Non-Special Immunity of the Shrimp and Crab.	2008	Non-applicable
Airas et al.	Copper, Zinc, Arsenic, Cadmium, Mercury, and Lead in Blue Mussels (*Mytilus edulis*) in the Bergen Harbor Area, Western Norway	2004	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Akinola and Ekiyoyo	Accumulation of Lead, Cadmium and Chromium in Some Plants Cultivated Along the Bank of River Ribila at Odo-Nla Area of Ikorodu, Lagos State, Nigeria	2006	Bioaccumulation: steady state not documented
Aktac et al.	The effects of short-term exposure to cadmium and copper on sialic acid in carp (*Cyprinus carpio*) tissues	2010	Only three exposure concentrations, too few organisms per concentration; Bioaccumulation: steady state not documented
Albers and Camardese	Effects of Acidification on Metal Accumulation by Aquatic Plants and Invertebrates. 1. Constructed Wetlands	1993a	Bioaccumulation: steady state not documented
Albers and Camardese	Effects of Acidification on Metal Accumulation by Aquatic Plants and Invertebrates. 2. Wetlands, Ponds and Small Lake.	1993b	Bioaccumulation: steady state not documented
Albrecht et al.	Heavy Metal Levels in Ribbon Snakes (*Thamnophis sauritus*) and Anuran Larvae From the Mobile-Tensaw River Delta, Alabama, USA	2007	Bioaccumulation: steady state not documented
Albright et al.	Technique for Measuring Metallic Salt Effects Upon the Indigenous Heterotrophic Microflora of Natural Water.	1972	Bacteria
Alhashemi et al.	Bioaccumulation of trace elements in trophic levels of wetland plants and waterfowl birds.	2011	Bioaccumulation: steady state not documented
Al-Homaidan	Heavy Metal Concentrations in Three Species of Green Algae from the Saudi Coast of the Arabian Gulf	2007	Bioaccumulation: steady state not documented
Allen	Accumulation profiles of lead and the influence of cadmium and mercury in *Oreochromis aureus* (Steindachner) during chronic exposure	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Allen	Soft-tissue accumulation of lead in the blue tilapia, *Oreochromis aureus* (Steindachner), and the modifying effects of cadmium and mercury	1995a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Allen	Accumulation profiles of lead and cadmium in the edible tissues of *Oreochromis aureus* during acute exposure	1995b	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Allen et al.	Development and Application of Long-Term Sublethal Whole Sediment exposure Tests With *Arenicola marina* and *Corophium volutator* Using Ivermectin as the Test Compound	2007	Sediment exposure
Al-Madfa	Metals accumulation in the marine ecosystem around Qatar (Arabian Gulf)	2002	Bioaccumulation: steady state not documented
Almaguer-Cantu et al.	Biosorption of Lead (II) and Cadmium (II) Using *Escherichia coli* Genetically Engineered With Mice Metallothionein I.	2011	Bacteria
Almeida et al.	Environmental cadmium exposure and metabolic responses of the Nile tilapia, *Oreochromis niloticus*	2001	Dilution water not characterized, duration too short, unmeasured chronic exposure
Almli et al.	Hepatic and renal concentrations of 10 trace elements in crocodiles (*Crocodylus niloticus*) in the Kafue and Luangwa rivers in Zambia	2005	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Alonso et al.	Development of a feeding behavioural bioassay using the freshwater amphipod *Gammarus pulex* and the multispecies freshwater biomonitor.	2009	Not North American species, duration too short, a typical endpoint
Alonso et al.	Contrasting sensitivities to toxicants of the freshwater amphipods *Gammarus pulex* and *G. fossarum*	2010a	Not North American species
Alonso et al.	Effects of animal starvation on the sensitivity of the freshwater amphipod *Gammarus pulex* to cadmium	2010b	Not North American species, atypical endpoint
Alquezar et al.	Metal Accumulation in the Smooth Toadfish, *Tetractenos glaber*, in Estuaries Around Sydney, Australia	2006a	Bioaccumulation: steady state not documented
Alquezar et al.	Effects of Metals on Condition and Reproductive Output of the Smooth Toadfish in Sydney Estuaries, South-Eastern Australia	2006b	Non-applicable
Alquezar et al.	Comparative Accumulation of 109Cd and 75Se from Water and Food by an Estuarine Fish (*Tetractenos glaber*)	2008	Bioaccumulation: steady state not documented
Al-Shami et al.	Genotoxicity of heavy metals to the larvae of *Chironomus kiiensis* Tokunaga after short-term exposure	2012	Only three exposure concentrations
Al-Shwafi and Rushdi	Heavy Metal Concentrations in Marine Green, Brown, and Red Seaweeds From Coastal Waters of Yemen, the Gulf of Aden	2008	Bioaccumulation: steady state not documented
AltIndag and Yigit	Assessment of heavy metal concentrations in the food web of lake Beysehir, Turkey	2005	Bioaccumulation: steady state not documented
Alvarado et al.	Cellular biomarkers of exposure and biological effect in hepatocytes of turbot (*Scophthalmus maximus*) exposed to Cd, Cu and Zn and after depuration	2005	Dilution water not characterized, only two exposure concentrations, duration too short, not North American species
Alvarez-Legorreta et al.	Thiol peptides in the seagrass *Thalassia testudinum* (Banks ex Konig) in response to cadmium exposure	2008	Bioaccumulation: steady state not documented
Alves de Oliveira et al.	Sulphate uptake and metabolism in water hyacinth and salvinia during cadmium stress	2009	Only one exposure concentration, duration too short
Amado-Filho et al.	Heavy Metals in Benthic Organisms From Todos Os Santos Bay, Brazil	2008	Bioaccumulation: steady state not documented
Amenu	A comparative study of water quality conditions between heavily urbanized and less urbanized watersheds of Los Angeles Basin	2011	Not applicable (no cadmium toxicity information)
Amiard et al.	Influence of some ecological and biological factors on metal bioaccumulation in young oysters (*Crassostrea gigas* Thunberg) during their spat rearing	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Amiard et al.	Influence of ploidy and metal-metal interactions on the accumulation of Ag, Cd, and Cu in oysters *Crassostrea gigas* Thunberg	2005	Bioaccumulation: steady state not documented (only 15 day exposure)
Amiard et al.	Relationship Between the Liability of Sediment exposure-Bound Metals (Cd, Cu, Zn) and Their Bioaccumulation in Benthic Invertebrates	2007	Sediment exposure

Authors	Title	Year	Reason Unused
Amiard-Triquet et al.	Contribution to the ecotoxicological study of cadmium, copper and zinc in the mussel *Mytilus edulis*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Amiard-Triquet et al.	Etudes *in situ* et experimentales de leotoxicologie de quatre metaux (Cd, Pb, Cu, Zn) chez des algues et des mollusques gasteropodes brouteurs	1987	Not North American species
Amiard-Triquet et al.	Field and experimental study of the bioaccumulation of some trace metals in a coastal food chain: seston, oyster (*Crassostrea gigas*), drill (*Ocenebra erinacea*)	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Amin et al.	Toxicity of cadmium, lead, and zinc to larval stages of *Lithodes santolla* (Decapoda, Anomura)	2003	Dilution water not characterized, not North American species
Amin et al.	Heavy Metal Concentrations in Sediment exposure and Intertidal Gastropod *Nerita lineata* From Two Opposing Sites in the Straits of Malacca	2008	Bioaccumulation: steady state not documented
Amutha and Subramanian	Cadmium alters the reproductive endocrine disruption and enhancement of growth in the early and adult stages of *Oreochromis mossambicus*	2013	Only two exposure concentrations
Amweg and Weston	Whole-Sediment exposure Toxicity Identification Evaluation Tools for Pyrethroid Insecticides: I. Piperonyl Butoxide Addition	2007	Sediment exposure
An et al.	Heavy Metals Contents in Haplocladium and Their Relationships With Shanghai City Environment	2006	Bioaccumulation: steady state not documented
Anadu	Fish acclimation and the development of tolerance to zinc as a modifying factor in toxicity	1983	Mixture, prior exposure to zinc
Anadu et al.	Effect of zinc exposure on subsequent acute tolerance to heavy metals in rainbow trout	1989	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Anajjar et al.	Monitoring of Trace Metal Contamination in the Souss Estuary (South Morocco) Using the Clams *Cerastoderma edule* and *Scrobicularia plana*	2008	Bioaccumulation: steady state not documented
Anan et al.	Subcellular distribution of trace elements in the liver of sea turtles	2002	Bioaccumulation: steady state not documented
Anderson	Concentration of Cadmium, Copper, Lead, and Zinc in Thirty-Five Genera of Freshwater Macroinvertebrates From the Fox River, Illinois and Wisconsin.	1977	Bioaccumulation: steady state not documented
Anderson et al.	The distribution of Cd, Cu, Pb and Zn in the biota of two freshwater sites with different trace metal inputs	1978	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Anderson et al.	A Comparison of in Situ and Laboratory Toxicity Tests With the Estuarine Amphipod *Eohaustorius estuarius*	2004	Non-applicable
Anderson et al.	DNA- and RNA-derived assessments of fungal community composition in soil amended with sewage sludge rich in cadmium, copper and zinc	2008	Sludge

Authors	Title	Year	Reason Unused
Andosch et al.	A freshwater green alga under cadmium stress: Ameliorating calcium effects on ultrastructure and photosynthesis in the unicellular model Micrasterias	2012	No control group, only two exposure concentrations
Andreji et al.	Heavy Metals Content and Microbiological Quality of Carp (*Cyprinus carpio*, L.) Muscle From Two Southwestern Slovak Fish Farms	2006a	Bioaccumulation: steady state not documented
Andreji et al.	Accumulation of Some Metals in Muscles of Five Fish Species from Lower Nitra River	2006b	Bioaccumulation: steady state not documented
Andres et al.	Field transplantation of the freshwater bivalve *Corbicula fluminea* along a polymetallic contamination gradient (River Lot, France): I. Geochemical characteristics of sampling sites and cadmium and zinc bioaccumulation kinetics	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Ankley et al.	Evaluation of the Toxicity of Marine Sediments and Dredge Spoils With the Microtox Bioassay.	1989	Bacteria
Annabi et al.	Cadmium accumulation and histological lesion in mosquitofish (*Gambusia affinis*) tissues following acute and chronic exposure	2011	Bioaccumulation: exposure not measured
Annabi et al.	Influence of cadmium exposure on growth and fecundity of freshwater mosquitofish *Gambusia affinis*: In situ and in vivo studies	2012	Only one exposure concentration
Annune et al.	Acute toxicity of cadmium to juveniles of *Clarias gariepinus* (Teugels) and *Oreochromis niloticus* (Trewavas). J.	1994	Not North American species
Ansaldo et al.	Effect of cadmium, lead and arsenic on the oviposition, hatching and embryonic survival of *Biomphalaria glabrata*	2009	Only two exposure concentration, test species fed, unmeasured chronic exposure
Anu et al.	Monitoring of Heavy Metal Partitioning in Reef Corals of Lakshadweep Archipelago, Indian Ocean	2007	Bioaccumulation: steady state not documented
Anushia et al.	Heavy metal induced enzyme response in *Tilapia mossambicus*	2012	Dilution water not characterized
Apeti et al.	Cadmium Distribution in Coastal Sediment exposures and Mollusks of the US	2009	Bioaccumulation: steady state not documented
Aramphongphan et al.	Snakehead-Fish Cell Line, Ssn-1 (*Ophicephalus striatus*) as a Model for Cadmium Genotoxicity Testing	2009	In vitro
Aravind and Prasad	Zinc Alleviates Cadmium-Induced Oxidative Stress in *Ceratophyllum demersum* L.: A Free Floating Freshwater Macrophyte	2003	Mixture
Aravind and Prasad	Zinc Protects Chloroplasts and Associated Photochemical Functions in Cadmium Exposed *Ceratophyllum demersum* L., a Freshwater Macrophyte	2004	Mixture
Aravind and Prasad	Zinc Mediated Protection to the Conformation of Carbonic Anhydrase in Cadmium Exposed *Ceratophyllum demersum* L.	2005	Mixture
Aravind et al.	Zinc Protects *Ceratophyllum demersum* L. (Free-Floating Hydrophyte) Against Reactive Oxygen Species Induced by Cadmium	2009	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Arias-Almeida and Rico-Martinez	Inhibition of Two Enzyme Systems in Euchlanis dilatata (Rotifera: *Monogononta*) as Biomarker of Effect of Metals and Pesticides.	2011a	In vitro
Arias-Almeida and Rico-Martinez	Toxicity of cadmium, lead, mercury and methyl parathion on *Euchlanis dilatata* Ehrenberg 1832 (Rotifera: *Monogononta*).	2011b	Duration too short, not North American species
Arikpo et al.	Cadmium uptake by the green alga *Chlorella emersonii*	2004	Adsorption not absorption study
Arini et al.	Field Translocation of Diatom Biofilms Impacted by Cd and Zn to Assess Decontamination and Community Restructuring Capacities.	2012	Mixture
Arnac and Lassus	Heavy metal accumulation (Cd, Cu, Pb and Zn) by smelt (*Osmerus mordax*) from the north shore of the St. Lawrence estuary	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Arshaduddin et al.	Effect of two heavy metals (lead and cadmium) on growth in the rotifer *Asplanchna intermedia*	1989	Not North American species
Arts et al.	Sensitivity of submersed freshwater macrophytes and endpoints in laboratory toxicity tests	2008	No cadmium toxicity information
Asagba et al.	Bioaccumulation of cadmium and its biochemical effect on selected tissues of the catfish (*Clarias gariepinus*)	2008	Bioaccumulation: steady state not documented (only 21 day exposure); not North American species
Asagba et al.	Oxidative enzymes in tissues of the catfish (*Clarias gariepinus*) exposed to varying levels of cadmium	2010	Dilution water not characterized, not North American species, only three exposure concentrations
Asato and Reish	The effects of heavy metals on the survival and feeding of *Holmesimysis costata* (Crustacea: Mysidacea)	1988	High control mortality reported
Ashraf	Accumulation of heavy metals in kidney and heart tissues of *Epinephelus microdon* fish from the Arabian Gulf	2005	Bioaccumulation: steady state not documented
Ashraf et al.	Seasonal Variation of Metal Concentration in Barnacles (*Balanus spp*.) Of Cochin Estuary, South West Coast of India	2007	Bioaccumulation: steady state not documented
Askary Sary et al.	Cadmium, Iron, Lead and Mercury Bioaccumulation in Abu mullet, *Liza abu*, Different Tissues From Karoun and Karkheh Rivers, Khozestan, Iran	2012	Bioaccumulation: steady state not documented
Atici et al.	Sensitivity of freshwater microalgal strains (*Chlorella vulgaris* Beijernick and *Scenedesmus obliquus* (Turpin) Kutzing) to heavy metals	2008	Excessive EDTA
Attar and Maly	Acute toxicity of cadmium, zinc, and cadmium-zinc mixtures to *Daphnia magna*	1982	Prior exposure (1.0 ug/L Cd in city water used for culturing organisms)
Au et al.	Reproductive impairment of sea urchins upon chronic exposure to cadmium. Part I: effects on gamete quality	2001a	Dilution water not characterized, only two exposure concentrations, Not North American species
Au et al.	Reproductive impairment of sea urchin upon chronic exposure to cadmium. Part II: effects on sperm development	2001b	Dilution water not characterized, only two exposure concentrations, Not North American species

Authors	Title	Year	Reason Unused
Audet and Couture	Seasonal variations in tissue metabolic capacities of yellow perch (*Perca flavescens*) from clean and metal-contaminated environments	2003	Bioaccumulation: steady state not documented
Augier et al.	Variation of heavy metal contents of the green alga *Caulerpa taxifolia* (Vahl) C. agardh in its area of expansion in the French Mediterranean Sea	1999	Bioaccumulation: steady state not documented
Auslander et al.	Pollution-affected fish hepatic transcriptome and its expression patterns on exposure to cadmium	2008	Dietary and injected exposure; not North American species
Austen and McEvoy	The use of offshore meiobenthic communities in laboratory microcosm experiments: response to heavy metal contamination	1997	Sediment, no species name given, only one exposure concentration
Austin and Deniseger	Periphyton Community Changes Along a Heavy Metals Gradient in a Long Narrow Lake. Environ.	1985	Bioaccumulation: steady state not documented
Avery et al.	The detection of pollutant impact in marine environments: condition index, oxidative DNA damage, and their associations with metal bioaccumulation in the Sydney rock oyster *Saccostrea commercialis*	1996	Not North American species
Awasthi and Rai	Toxicity of Nickel, Zinc, and Cadmium to Nitrate Uptake in Free and Immobilized Cells of *Scenedesmus quadricauda*	2005	Mixture
Awasthi and Rai	Interactions Between Zinc and Cadmium Uptake by Free and Immobilized Cells of *Scenedesmus quadricauda* (Turp.)	2006	Mixture
Ayas et al.	Heavy Metal Accumulation in Water, Sediment exposures and Fishes of Nallihan Bird Paradise, Turkey	2007	Bioaccumulation: steady state not documented
Azeez and Banerjee	Influence of light on chlorophyll, a content of blue-green algae treated with heavy metals	1987	Not North American species
Baas et al.	Modeling the Effects of Binary Mixtures on Survival in Time	2007	Modeling
Babich and Stotzky	Influence of chloride ions on the toxicity of cadmium to fungi	1982	Non-aquatic species, only one exposure concentration
Babich et al.	In Vitro Cytotoxicity of Metals to Bluegill (Bf-2) Cells	1986	In vitro
Backor et al.	Response to Copper and Cadmium Stress in Wild-Type and Copper Tolerant Strains of the Lichen Alga *Trebouxia erici*: Metal Accumulation, Toxicity and Non-Protein Thiols	2007	Mixture
Badr and Fawzy	Bioaccumulation and Biosorption of Heavy Metals and Phosphorous by *Potamogeton pectinatus* L. And *Ceratophyllum demersum* L. In Two Nile Delta Lakes	2008	Bioaccumulation: steady state not documented
Bagwe	Effect of cadmium and seasonality on critical temperatures of aerobic metabolism in eastern oysters, *Crassostrea virginica* Gmelin 1791	2012	Only one exposure concentration, unmeasured chronic exposure
Bagy et al.	Effect of pH and organic matter on the toxicity of heavy metals to growth of some fungi	1991	Only three exposure concentrations
Bah et al.	Comparative proteomic analysis of *Typha angustifolia* leaf under chromium, cadmium and lead stress	2010	Soil exposure
Bai et al.	Effect of H2O2 pretreatment on Cd tolerance of different rice cultivars	2011	Not applicable (non-aquatic plant)

Authors	**Title**	**Year**	**Reason Unused**
Baillieul and Blust	Analysis of the swimming velocity of cadmium-stressed *Daphnia magna*	1999	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Baines and Fisher	Modeling the Effect of Temperature on Bioaccumulation of Metals by a Marine Bioindicator Organism, *Mytilus edulis*	2008	Modeling
Baines et al.	Effects of Temperature on Uptake of Aqueous Metals by Blue Mussels *Mytilus edulis* From Arctic and Temperate Waters	2006	Bioaccumulation: steady state not documented
Baird and Van den Brink	Using Biological Traits to Predict Species Sensitivity to Toxic Substances	2007	Modeling
Bajguz	An enhancing effect of exogenous brassinolide on the growth and antioxidant activity in *Chlorella vulgaris* cultures under heavy metals stress	2010	Only three exposure concentrations
Bajguz	Suppression of *Chlorella vulgaris* growth by cadmium, lead, and copper stress and its restoration by endogenous brassinolide	2011	Mixture
Bakhmet et al.	Effect of copper and cadmium ions on heart function and calpain activity in blue mussel *Mytilus edulis*	2012	Dilution water not characterized
Bako and Daudu	Trace Metal Contents of the Emergent Macrophytes *Polygonum sp*. And *Ludwigia sp*. In Relation to the Sediment exposures of Two Freshwater Lake Ecosystems in the Nigerian Savanna	2007	Bioaccumulation: steady state not documented
Baldisserotto et al.	Effects of Dietary exposure Calcium and Cadmium on Cadmium Accumulation, Calcium and Cadmium Uptake from the Water, and Their Interactions in Juvenile Rainbow Trout	2005	Dietary exposure
Baldisserotto et al.	Acute and waterborne cadmium uptake in rainbow trout is reduced by Dietary exposure calcium carbonate	2004a	Bioaccumulation: steady state not documented (only 3 hour exposure); lack of exposure details
Baldisserotto et al.	A protective effect of Dietary exposure calcium against acute waterborne cadmium uptake in rainbow trout	2004b	Bioaccumulation: steady state not documented; lack of exposure details
Ball	The toxicity of cadmium to rainbow trout (*Salmo gairdnerii* Richardson)	1967	The materials, methods or results were insufficiently described
Ball et al.	Toxicity of a cadmium-contaminated diet to *Hyalella azteca*	2006	Dietary exposure
Balog and Shalanki	Crustacean Zooplankton as Indicators of Lake Balaton Pollution With Heavy Metals (Ispol'zovanie Rachkovogo Zooplanktons (Crustacea) Dlya Otsenki Zagryazneniya Oz. Balaton Tyazhelymi Metallami)	1984	Bioaccumulation: steady state not documented
Balogh and Salanki	The dynamics of mercury and cadmium uptake into different organs of *Anodonta cygnea* L	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bambang et al.	Effect of cadmium on survival and osmoregulation of various developmental stages of the shrimp *Penaeus japonicus* (Crustacea: Decapoda)	1994	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Banni et al.	Mixture toxicity assessment of cadmium and benzo[a]pyrene in the sea worm *Hediste diversicolor*	2009	Mixture
Banni et al.	Mechanisms Underlying the Protective Effect of Zinc and Selenium Against Cadmium-Induced Oxidative Stress in Zebrafish *Danio rerio*	2011	Mixture
Baraj et al.	Assessing the effects of Cu, Cd, and exposure period on metallothionein production in gills of the Brazilian brown mussel *Perna perna* by using factorial design	2011	Bioaccumulation: unmeasured exposure
Barata et al.	Toxicity of Binary Mixtures of Metals and Pyrethroid Insecticides to *Daphnia magna* Straus. Implications for Multi-Substance Risks Assessment	2006	Mixture
Barata et al.	Among- and within-population variability in tolerance to cadmium stress in natural populations of *Daphnia magna*: implications for ecological risk assessment	2002a	Lack of detail
Barata et al.	Genetic variability in sublethal tolerance to mixtures of cadmium and zinc in clones of *Daphnia magna* straus	2002b	Water and dietary exposure simultaneously
Barata et al.	Demographic responses of a tropical cladoceran to cadmium: effects of food supply and density	2002c	Dietary exposure
Barbieri	Use of oxygen consumption and ammonium excretion to evaluate the sublethal toxicity of cadmium and zinc on *Litopenaeus schmitti* (Burkenroad, 1936, Crustacea)	2007	Not North American species, dilution water not characterized
Barbieri	Effects of Zinc and Cadmium on Oxygen Consumption and Ammonium Excretion in Pink Shrimp (*Farfantepenaeus paulensis*, Perez-Farfante, 1967, Crustacea)	2009	Mixture, Not North American species
Bargagli et al.	Elevated cadmium accumulation in marine organisms from Terra Nova Bay (Antarctica)	1996	Bioaccumulation: steady state not documented
Barhoumi et al.	Cadmium Bioaccumulation in Three Benthic Fish Species, *Salaria basilisca*, *Zosterisessor ophiocephalus* and *Solea vulgaris* Collected From the Gulf of Gabes in Tunisia	2009	Bioaccumulation: steady state not documented
Barjaktarovic and Bendell-Young	Accumulation of 109Cd by Second-Generation Chironominae Propagated from Wild Populations Sampled from Low-, Mid-, and high-Saline Environments	2001	Bioaccumulation: steady state not documented
Barjhoux et al.	Effects of Copper and Cadmium Spiked-Sediments on Embryonic Development of Japanese Medaka (*Oryzias latipes*)	2012	Sediment
Barka	Insoluble Detoxification of Trace Metals in a Marine Copepod *Tigriopus brevicornis* Exposed to Copper, Zinc, Nickel, Cadmium, Silver and Mercury	2007	Mixture

Authors	Title	Year	Reason Unused
Barka et al.	Metal distributions in *Tigriopus brevicornis* (Crustacea, Copepoda) exposed to copper, zinc, nickel, cadmium, silver, and mercury, and implication for subsequent transfer in the food web	2010	Bioaccumulation: unmeasured exposure
Barnthouse et al.	Estimating responses of fish populations to toxic contaminants	1987	Review of previously published data
Barrento et al.	Influence of Season and Sex on the Contents of Minerals and Trace Elements in Brown Crab (*Cancer pagurus*, Linnaeus, 1758)	2009	Bioaccumulation: steady state not documented
Barrera-Escorcia and Wong	Lipid Peroxidation and Metallothionein Induction by Chromium and Cadmium in Oyster *Crassostrea virginica* (Gmelin) From Mandinga Lagoon, Veracruz	2010	Bioaccumulation: steady state not documented.
Barrera-Escorcia et al.	Mean Lethal Body Concentration of Cadmium in *Crassostrea virginica* from a Mexican Tropical Coastal Lagoon	2005	Bioaccumulation: steady state not documented
Barrera-Escorcia et al.	Filtration rate, assimilation and assimilation efficiency in *Crassostrea virginica* (Gmelin) fed with *Tetraselmis suecica* under cadmium exposure	2010	Only two exposure concentrations
Bartsch et al.	Effects of cadmium-spiked sediment on cadmium accumulation and bioturbation by nymphs of the burrowing mayfly *Hexagenia bilineata*	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Barwick and Maher	Biotransferance and biomagnification of selenium copper, cadmium, zinc, arsenic and lead in a temperate seagrass ecosystem from Lake Macquarie Estuary, NSW, Australia	2003	Bioaccumulation: steady state not documented
Basha and Rani	Cadmium-induced antioxidant defense mechanism in freshwater teleost *Oreochromis mossambicus* (Tilapia)	2003	Dilution water not characterized, only one exposure concentration, exposure methods unknown
Basic et al.	Cadmium hyperaccumulation and genetic differentiation of *Thlaspi caerulescens* populations	2006	Non-aquatic plant
Batista et al.	Impacts of warming on aquatic decomposers along a gradient of cadmium stress	2012	Dilution water not characterized, unmeasured exposure
Battaglini et al.	The effects of cadmium on the gills of the goldfish *Carassius auratus* L.: metal uptake and histochemical changes	1993	No useable data on cadmium toxicity or bioconcentration
Baudrimont et al.	Bioaccumulation and metallothionein response in the asiatic clam (*Corbicula fluminea*) after experimental exposure to cadmium and inorganic mercury	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Baudrimont et al.	The Key Role of Metallothioneins in the Bivalve *Corbicula fluminea* During the Depuration Phase, After In Situ Exposure to Cd and Zn	2003	Mixture
Baudrimont et al.	Geochemical survey and metal bioaccumulation of three bivalve species (*Crassostrea gigas*, *Cerastoderma edule* and *Ruditapes philippinarum*) in the Nord Medoc salt marshes (Gironde estuary, France)	2005	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Baumann and Fisher	Relating the sediment phase speciation of arsenic, cadmium, and chromium with their bioavailability for the deposit-feeding polychaete *Nereis succinea*	2011a	Mixture
Baumann and Fisher	Modeling metal bioaccumulation in a deposit-feeding polychaete from labile sediment fractions and from pore water	2011b	Dilution water not characterized, mixture, sediment
Baunemann and Hofner	Influence of Cd, Cu, Ni and Zn on the Synthesis of Metalloproteins by *Scenedesmus subspicatus* (Einfluss Von Cd, Cu, Ni and Zn Auf Die Synthese Metallothionein-Ahnlicher Substanzen in Scenedesmus Subspicatus).	1991	Text in foreign language
Bay et al.	Status and applications of echinoid (*Phylum echinodermata*) toxicity test methods	1993	Review of previously published data
Bazzaz and Govindjee	Effects of cadmium nitrate on spectral characteristics and light reactions of chloroplasts	1974	Not applicable
Beattie and Pascoe	Cadmium uptake by rainbow trout, *Salmo gairdneri* eggs and alevins	1978	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Beauvais et al.	Cholinergic and behavioral neurotoxicity of carbaryl and cadmium to larval rainbow trout (*Oncorhynchus mykiss*).	2001	Only two exposure concentrations
Bednarz and Warkowska-Dratnal	Toxicity of zinc, cadmium, lead, copper, and their mixture for *Chlorella pyrenoidosa* Chick	1983/ 1984	Not North American species
Beiras and Albentosa	Inhibition of embryo development of the commercial bivalves *Ruditapes decussatus* and *Mytilus galloprovincialis* by trace metals; implications for the implementation of seawater quality criteria.	2004	Not North American species
Beiras et al.	Effects of storage temperature and duration on toxicity of sediments assessed by *Crassostrea gigas* oyster embryo bioassay	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bektas et al.	Inhibition effect of cadmium on carbonic anhydrase in rainbow trout (*Oncorhynchus mykiss*)	2008	Dietary exposure
Belabed et al.	Toxicity study of some heavy metals with daphnia test	1994	The materials, methods or results were insufficiently described
Beltrame et al.	Cadmium and zinc in Mar Chiquita Coastal Lagoon (Argentina): salinity effects on lethal toxicity in juveniles of the burrowing crab *Chasmagnathus granulatus*	2008	Not North American species
Benaduce et al.	Toxicity of cadmium for silver catfish *Rhamdia quelen* (Heptapteridae) embryos and larvae at different alkalinities	2008	Lack of detail; not North American species
Bendell	Cadmium in Shellfish: the British Columbia, Canada Experience--a Mini-Review	2010	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Bendell and Feng	Spatial and Temporal Variations in Cadmium Concentrations and Burdens in the Pacific Oyster (*Crassostrea gigas*) Sampled From the Pacific North-West. Marine Pollution Bulletin	2009	Bioaccumulation: steady state not documented
Bendell-Young	Comparison of metal concentrations in the fore and hindguts of the crayfish *Cambarus bartoni* and *Orconectes virilis* and implications regarding metal absorption efficiencies	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bendell-Young	Application of a kinetic model of bioaccumulation across a pH and salinity gradient for the prediction of cadmium uptake by the sediment dwelling chironomidae	1999	The materials, methods or results were insufficiently described
Bendell-Young et al.	Accumulation of cadmium by white suckers (*Catostomus commersoni*) in relation to fish growth and lake acidification	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bender	Trace Metal Levels In Beach Dipterans And Amphipods	1975	Bioaccumulation: steady state not documented
Bennett et al.	Pilot Sampling For Heavy Metals In Fish Flesh From Killarney Lake, Coeur D'alene River System, Idaho	1996	Bioaccumulation: steady state not documented
Bentley	Accumulation of cadmium by channel catfish (*Ictalurus punctatus*): Influx from environmental solutions	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bere and Tundisi	Toxicity and sorption kinetics of dissolved cadmium and chromium III on tropical freshwater phytoperiphyton in laboratory mesocosm experiments	2011	Only two exposure concentrations
Bere and Tundisi	Cadmium and lead toxicity on tropical freshwater periphyton communities under laboratory-based mesocosm experiments	2012a	Mixture, Mixed species exposure
Bere and Tundisi	Effects of cadmium stress and sorption kinetics on tropical freshwater periphytic communities in indoor mesocosm experiments	2012b	Dilution water not characterized
Berglind	The effects of cadmium on ala-d activity, growth and haemoglobin content in the water flea, *Daphnia magna*	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Berglind	Combined and separate effects of cadmium, lead and zinc on ala-d activity, growth and hemoglobin content in *Daphnia magna*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bernds	Bioaccumulation of trace metals in polychaetes from the German Wadden Sea: evaluation and verification of toxicokinetic models	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Berntssen and Lundebye	Energetics in Atlantic Salmon (*Salmo salar* L.) Parr fed Elevated Dietary exposure Cadmium	2001	Dietary exposure

Authors	Title	Year	Reason Unused
Berntssen et al.	Tissue Metallothionein, Apoptosis and Cell Proliferation Responses in Atlantic Salmon (*Salmo salar* L.) Parr Fed Elevated Dietary exposure Cadmium	2001	Dietary exposure
Berntssen et al.	Effects of dietary exposure cadmium on calcium homeostasis, Ca mobilization and bone deformities in Atlantic salmon (*Salmo salar* L.) Parr	2003	Dietary exposure
Bervoets et al.	The uptake of cadmium by the midge larvae *Chironomus riparius* as a function of salinity	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bervoets et al.	Effect of temperature on cadmium and zinc uptake by the midge larvae *Chironomus riparius*	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bervoets et al.	Accumulation of Metals in the Tissues of Three Spined Stickelback (*Gasterosteus aculeatus*) From Natural Fresh Waters	2001	Bioaccumulation: steady state not documented
Bervoets et al.	Comparison of Accumulation of Micropollutants Between Indigenous and Transplanted Zebra Mussels (*Dreissena polymorpha*)	2004	Non-applicable
Besser and Rabeni	Bioavailability and toxicity of metals leached from lead-mine tailings to aquatic invertebrates	1987	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Besser et al.	Bioavailability of Metals in Stream Food Webs and Hazards to Brook Trout (*Salvelinus fontinalis*) in the Upper Animas River Watershed, Colorado	2001	Bioaccumulation: steady state not documented
Besser et al.	Ecological Impacts of Lead Mining on Ozark Streams: Toxicity of Sediment and Pore Water	2009	Mixture
Besson et al.	NO contributes to cadmium toxicity in *Arabidopsis thaliana*	2007	Mixture
Besson-Bard and Wendehenne	NO Contributes to Cadmium Toxicity in *Arabidopsis thaliana* by Mediating an Iron Deprivation Response	2009	Mixture
Besson-Bard et al.	Nitric Oxide Contributes to Cadmium Toxicity in Arabidopsis by Promoting Cadmium Accumulation in Roots and by up-Regulating Genes Related to Iron Uptake	2009	Mixture
Beyrem et al.	Individual and combined effects of cadmium and diesel on a nematode community in a laboratory microcosm experiment	2007	Sediment exposure
Bhamre et al.	Effects of cadmium intoxication on the gills of freshwater mussel *Parreysia favidens*	2010	Only one exposure concentration
Bhamre and Desai	Impact of heavy metal compounds on oxygen consumption of freshwater mussel *Lamellidens consobrinus* (Lea)	2012	Only one exposure concentration

Authors	**Title**	**Year**	**Reason Unused**
Bhattacharya et al.	Heavy Metals Accumulation in Water, Sediment exposure and Tissues of Different Edible Fishes in Upper Stretch of Gangetic West Bengal	2008	Bioaccumulation: steady state not documented
Bhilave et al.	Biochemical changes in the fish cirrhinus mrigala after acute and chronic exposure of heavy metals	2008	Dilution water not characterized, lack of exposure details, not North American species
Bicho et al.	Accumulation in Livers and Excretion Through Eggs of Heavy Metals in a Nesting Population of Green Turtles, *Chelonia mydas*, in the NW Indian Ocean	2008	Bioaccumulation: steady state not documented
Biddinger and Gloss	The Importance of Trophic Transfer in the Bioaccumulation of Chemical Contaminants in Aquatic Ecosystems	1984	Review
Biesinger et al.	Effects of metal salt mixtures on *Daphnia magna* reproduction	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bigelow and Lasenby	Particle size selection in cadmium uptake by the opossum shrimp, *Mysis relicta*	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bigot et al.	Early defense responses in the freshwater bivalve *Corbicula fluminea* exposed to copper and cadmium: Transcriptional and histochemical studies	2011	Only three exposure concentrations, dilution water not characterized
Billoir et al.	Integrating the lethal and sublethal effects of toxic compounds into the population dynamics of *Daphnia magna*: a combination of the DEBtox and matrix population models	2007	No original data; modeling
Billoir et al.	Bayesian modeling of daphnid responses to time-varying cadmium exposure in laboratory aquatic microcosms	2011	Mixed species exposure
Billoir et al.	Comparison of bioassays with different exposure time patterns: the added value of dynamic modeling in predictive ecotoxicology	2012	Mixed species exposure
Bird et al.	To What Extent Are Hepatic Concentrations of Heavy Metals in *Anguilla anguilla* at a Site in a Contaminated Estuary Related to Body Size and Age and Reflected in the Metallothionein Concentrations?	2008	Bioaccumulation: steady state not documented
Birge and Black	In Situ Acute/Chronic Toxicological Monitoring of Industrial Effluents for the NPDES Biomonitoring Program Using Fish and Amphibian Embryo-Larval Stages as Test Organisms	1981	Effluent
Birmelin et al.	The mysid *Siriella armata* as a test organisms in toxicology: effects of cadmium	1995	Not North American species
Bisova et al.	Cell growth and division processes are differentially sensitive to cadmium in *Scenedesmus quadricauda*	2003	Excessive EDTA in growth media (18,000 ug/L), duration too short
Biswas and Kaviraj	Size dependent tolerance of indian cat fish *Heteropneustes fossilis* (Bloch) to toxicity of cadmium and composted vegetation	2002	Dilution water not characterized, not North American species
Bitton et al.	Evaluation of a microplate assay specific for heavy metal toxicity	1994	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Bitton et al.	Short-term toxicity assay based on daphnid feeding behavior	1995	The materials, methods or results were insufficiently described
Bjerregaard	Accumulation of cadmium and selenium and their mutual interaction in the shore crab *Carcinus maenas*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bjerregaard	Effect of selenium on cadmium uptake in the shore crab *Carcinus maenas* (L.)	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bjerregaard	Relationship between physiological condition and cadmium accumulation in *Carcinus maenas* (L.)	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bjerregaard and Depledge	Cadmium accumulation in *Littorina littorea*, *Mytilus edulis* and *Carcinus maenas*: the influence of salinity and calcium ion concentrations	1994	The materials, methods or results were insufficiently described
Bjerregaard and Depledge	Trace metal concentrations and contents in the tissues of the shore crab *Carcinus maenas*: effects of size and tissue hydration	2002	Bioaccumulation: steady state not documented
Bjerregaard et al.	Cadmium in the Shore Crab *Carcinus maenas*: Seasonal Variation in Cadmium Content and Uptake and Elimination of Cadmium After Administration via Food	2005	Bioaccumulation: steady state not documented
Blackmore and Wang	Uptake and Efflux of Cd and Zn by the Green Mussel *Perna viridis* After Metal Preexposure	2002	Mixture
Blinova	Use of freshwater algae and duckweeds for phytotoxicity testing	2004	Review
Block and Glynn	Influence of xanthates on the uptake of ^{109}Cd by Eurasian dace (*Phoxinus phoxinus*) and rainbow trout (*Oncorhynchus mykiss*)	1992	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Block and Part	Uptake of ^{109}Cd by cultured gill epithelial cells from rainbow trout (*Oncorhynchus mykiss*)	1992	No interpretable concentration, time, response data or examined only a single exposure concentration
Block et al.	Xanthate effects on cadmium uptake and intracellular distribution in rainbow trout (*Oncorhynchus mykiss*) gills	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Blondin et al.	An in vitro submitochondrial bioassay for predicting acute toxicity in fish	1989	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Bocchetti et al.	Trace Metal Concentrations and Susceptibility to Oxidative Stress in the Polychaete *Sabella spallanzanii* (Gmelin) (Sabellidae): Potential Role of Antioxidants in Revealing Stressful Environmental Conditions in the Mediterranean	2004	Bioaccumulation: steady state not documented
Bochenek et al.	Concentrations of Cd, Pb, Zn, and Cu in Roach, *Rutilus rutilis* (L.) From the Lower Reaches of the Oder River, and Their Correlation With Concentrations of Heavy Metals in Bottom Sediment exposures Collected in the Same Area	2008	Bioaccumulation: steady state not documented
Bodar et al.	Effects of cadmium on consumption, assimilation and biochemical parameters of *Daphnia magna*: possible implications for reproduction	1988a	Organisms were exposed to cadmium in food or by injection or gavage
Bodar et al.	Ecdysteroids in *Daphnia magna*: their role in moulting and reproduction and their levels upon exposure to cadmium	1990a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bodar et al.	Cadmium resistance in *Daphnia magna*	1990b	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Bohn and Mcelroy	Trace metals arsenic cadmium copper iron and zinc in arctic cod *Boreogadus saida* and selected zoo plankton from Strathcona Sound Northern Baffin Island	1976	Bioaccumulation: steady state not documented
Boisson et al.	Comparative radiotracer study of cadmium uptake, storage, detoxification and depuration in the oyster *Crassostrea gigas*: potential adaptive mechanisms	2003	Bioaccumulation: steady state not documented (only 15 day exposure)
Bolanos et al.	Differential toxicological response to cadmium in *Anabaena* strain PCC 7119 grown with NO_3^- or NH_4^+ as nitrogen source	1992	The materials, methods or results were insufficiently described
Bonneris et al.	Sub-cellular Partitioning of Cd, Cu and Zn in Tissues of Indigenous Unionid Bivalves Living Along a Metal Exposure Gradient and Links to Metal-Induced Effects	2005	Bioaccumulation: steady state not documented
Borane et al.	Ascorbate effect on the cadmium induced alterations in the behavior of the fresh water fish *Channa orientalis* (Schneider)	2008	Only one exposure concentration, not North American species
Borchardt	Influence of food quantity on the kinetics of cadmium uptake and loss via food and seawater in *Mytilus edulis*	1983	No useable data on cadmium toxicity or bioconcentration
Borchardt	Biological monitoring in the central and southern north sea heavy metal contamination of mussels *Mytilus edulis*	1988	Bioaccumulation: steady state not documented
Borcherding and Wolf	The influence of suspended particles on the acute toxicity of 2-chloro-4-nitro-aniline, cadmium, and pentachlorophenol on the valve movement response of the zebra mussel (*Dreissena polymorpha*)	2001	Only one exposure concentration, duration too short, concentration decreased over time
Bordajandi et al.	Study on PCBs, PCDD/Fs, organochlorine pesticides, heavy metals and arsenic content in freshwater fish species from the River Turia (Spain)	2003	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Borgmann et al.	Relative Contribution of Food and Water to 27 Metals and Metalloids Accumulated by Caged *Hyalella azteca* in Two Rivers Affected by Metal Mining	2007	Mixture
Boscher et al.	Chemical contaminants in fish species from rivers in the North of Luxembourg: Potential impact on the Eurasian otter (*Lutra lutra*)	2010	Bioaccumulation: steady state not documented
Bouallam and Nejmeddine	Effects of Heavy Metals - Cu, Hg, Cd - on Three Species of Mosquitoes Larvae (Diptera: Culicidae)	2001	Mixture
Boughammoura et al.	Effects of cadmium and high temperature on some parameters of calcium metabolism in the killifish (*Aphanius fasciatus*)	2013	Only one exposure concentration; not North American species
Boullemant et al.	Uptake of lipophilic cadmium complexes by three green algae: influence of humic acid and its pH dependence	2011	Bioaccumulation: steady state not achieved (only 40 minute exposure)
Bouquegneau and Martoja	La teneur en cuivre et son degre de complexation chez quatre gasteropodes marins. Donnees sur le cadmium et zinc	1982	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Bouraoui et al.	Acute effects of cadmium on liver phase I and phase II enzymes and metallothionein accumulation on sea bream *Sparus aurata*	2008	Injected toxicant, not North American species
Bourgeault et al.	Modeling the effect of water chemistry on the bioaccumulation of waterborne cadmium in zebra mussels	2010	Bioaccumulation: steady state not achieved
Bourret et al.	Evolutionary Ecotoxicology of Wild Yellow Perch (*Perca flavescens*) Populations Chronically Exposed to a Polymetallic Gradient	2008	Mixture
Bovee	Effects of certain chemical pollutants on small aquatic plants	1975	Lack of exposure details; cannot determine effect concentration
Bowen and Engel	Effects of protracted cadmium exposure on gametes of the purple sea urchin, *Arbacia punctulata*	1996	No interpretable concentration, time, response data or examined only a single exposure concentration
Bowmer et al.	The Detection of Chronic Biological Effects in the Marine Intertidal Bivalve *Cerastoderma edule*, in Model Ecosystem Studies With Pulverised Fuel Ash: Reproduction and Histopathology	1994	Mixture
Boyden	Effect of size upon metal content of shellfish	1977	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Boyer	Trace Elements In The Water Sediment exposures And Fish Of The Upper Mississippi River Twin Cities Metropolitan Area USA	1984	Bioaccumulation: steady state not documented
Boyle et al.	Natural Arsenic Contaminated Diets Perturb Reproduction in Fish	2008	Dietary exposure
Bozcaarmutlu and Arinc	Effect of Mercury, Cadmium, Nickel, Chromium and Zinc on Kinetic Properties of NADPH-Cytochrome P450 Reductase Purified From Leaping Mullet (*Liza saliens*)	2007	Mixture

Authors	Title	Year	Reason Unused
Bradac et al.	Kinetics of cadmium accumulation in periphyton under freshwater conditions	2009	Mixed species exposure
Bradac et al.	Cadmium Speciation and Accumulation in Periphyton in a Small Stream With Dynamic Concentration Variations	2010	Bioaccumulation: steady state not documented
Brand et al.	Reduction of marine phytoplankton reproduction rates by copper and cadmium.	1986	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Brandao et al.	Correlation between the in vitro cytotoxicity to cultured fathead minnow fish cells and fish lethality data for 50 chemicals	1992	Not applicable per ECOTOX Duluth; in vitro
Brauwers	Algae and Heavy Metal Pollution	1985	Review
Bresler and Yanko	Acute toxicity of heavy metals for benthic epiphytic foraminifera *Pararotalia spinigera* (Le Calvez) and influence of seaweed-derived DOC	1995	Not North American species
Bressan and Brunetti	The effects of nitriloacetic acid, Cd and Hg on the marine algae *Dunaliella tertiolecta* and *Isochrysis galbana*	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Bringmann and Kuhn	Results of toxic action of water pollutants on *Daphnia magna* Straus tested by an improved standardized procedure	1982	Cultured daphnids in one dilution water and tested them in another one
Brinke et al.	Using Meiofauna to Assess Pollutants in Freshwater Sediments: a Microcosm Study With Cadmium	2011	Sediment
Brinkhurst et al.	Comparative study of respiration rates of some aquatic oligochaetes in relation to sublethal stress	1983	Only two exposure concentrations
Brinkman and Vieira	Water pollution studies	2008	Scientific name not given, just common name
Brinza et al.	Cadmium Tolerance and Adsorption by the Marine Brown Alga *Fucus vesiculosus* From the Irish Sea and the Bothnian Sea	2009	Bioaccumulation: steady state not documented
Brix et al.	Effects of Copper, Cadmium, and Zinc on the Hatching Success of Brine Shrimp (*Artemia franciscana*)	2006	Mixture
Brix et al.	The Sensitivity of Aquatic Insects to Divalent Metals: a Comparative Analysis of Laboratory and Field Data	2011	Review
Brkovic-Popovic and Popovic	Effects of heavy metals on survival and respiration rate of tubificid worms: Part I-effects on survival	1977a	The dilution water or medium used was open to questions because of its origin or content
Brkovic-Popovic and Popovic	Effects of heavy metals on survival and respiration rate of tubificid worms: Part II-effects on respiration rate	1977b	The dilution water or medium used was open to questions because of its origin or content
Brooks et al.	Sublethal Effects and Predator-Prey Interactions: Implications for Ecological Risk Assessment	2009	Multiple species exposed
Brooks et al.	A simple indoor artificial stream system designed to study the effects of toxicant pulses on aquatic organisms	1996	Not North American species
Brouwer et al.	In vivo magnetic resonance imaging of the blue crab, *Callinectes sapidus*: effect of cadmium accumulation in tissues on proton relaxation properties	1992	Organisms were exposed to cadmium in food or by injection or gavage
Brown	Effects of Polluting Substances on Enzymes of Aquatic Organisms	1976	In vitro

Authors	Title	Year	Reason Unused
Brown and Ahsanullah	Effect of heavy metals on mortality and growth	1971	Brine shrimp
Brown et al.	A comparison of the differential accumulation of cadmium in the tissues of three species of freshwater fish, *Salmo Gairdneri*, *Rutilus rutilus* and *Noemacheilus barbatulus*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Brucka-Jastrzebska and Protasowicki	Elimination Dynamics of Cadmium, Administered by a Single Intraperitoneal Injection, in Common Carp, *Cyprinus carpio* L	2004	In vitro
Brumbaugh et al.	Concentrations of cadmium, lead, and zinc in fish from mining-influenced waters of northeastern Oklahoma: sampling of blood, carcass, and liver for aquatic biomonitoring	2005	Bioaccumulation: steady state not documented
Brunelli et al.	Ultrastructural and immunohistochemical investigation on the gills of the teleost, *Thalassoma pavo* L., exposed to cadmium	2011	Not North American species
Brunetti et al.	Effects of the chelating agent nitrilotriacetic acid (NTA) on the toxicity of metals (Cd, Cu, Zn and Pb) in the sea urchin *Paracentrotus lividus* LMK	1991	Not North American species
Brunham and Bendell	The effect of temperature on the accumulation of cadmium, copper, zinc, and lead by *Scirpus acutus* and *Typha latifolia*: a comparative analysis	2011	Sediment exposure
Bryan	The effects of heavy metals (other than mercury) on marine and estuarine organisms	1971	Questionable treatment of test organisms or inappropriate test conditions or methodology
Bryan and Langston	Bioavailability, Accumulation and Effects of Heavy Metals in Sediments With Special Reference to United Kingdom Estuaries: a Review.	1992	Review
Bryan et al.	An assessment of the gastropod, *Littorina littorea*, as an indicator of heavy metal contamination in United Kingdom estuaries	1983	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Bryson et al.	Roxboro Steam Electric Plant Preliminary Hyco Bioassay Report for 1983	1984a	Effluent
Bryson et al.	Roxboro Steam Electric Plant 1982 Environmental Monitoring Studies Volume II Hyco Reservoir Bioassay Studies	1984b	Mixture
Buchwalter et al.	Using Biodynamic Models to Reconcile Differences Between Laboratory Toxicity Tests and Field Biomonitoring With Aquatic Insects	2007	Modeling
Buckley et al.	Toxicities of total and chelex-labile cadmium to salmon in solutions of natural water and diluted sewage with potentially different cadmium complexing capacities	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Budambula and Mwachiro	Metal Status of Nairobi River Waters and Their Bioaccumulation in *Labeo cylindricus*	2006	Bioaccumulation: steady state not documented
Buikema et al.	Rotifer sensitivity to combinations of inorganic water pollutants	1977	The 96 hour values reported were subject to error because of possible reproductive interactions
Buikema et al.	Rotifers as monitors of heavy metal pollution in water	1974a	The 96 hour values reported were subject to error because of possible reproductive interactions

Authors	**Title**	**Year**	**Reason Unused**
Buikema et al.	Evaluation of *Philodina acuticornis* (Rotifera) as a bioassay organism for heavy metals	1974b	The 96 hour values reported were subject to error because of possible reproductive interactions
Bulus Rossini and Ronco	Sensitivity of *Cichlasoma facetum* (Cichlidae, Pisces) to metals	2004	Not North American species
Bunluesin et al.	Influences of Cadmium and Zinc Interaction and Humic Acid on Metal Accumulation in *Ceratophyllum demersum*	2007	Mixture
Bu-Olayan and Thomas	Trace metals toxicity and bioaccumulation in mudskipper *Periophthalmus waltoni* Koumans 1941 (Gobiidae: Perciformes)	2008	Dilution water not characterized, not North American species
Bu-Olayan et al.	Trace metals toxicity to the body structures of mullet *Liza klunzingeri* (Mugilidae: Perciformes)	2008	Mixture, dilution water not characterized
Burdin and Bird	Heavy metal accumulation by carrageenan and agar producing algae	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Burger	Assessment and Management of Risk to Wildlife From Cadmium	2008	Review
Burger and Campbell	Species differences in contaminants in fish on and adjacent to the Oak Ridge Reservation, Tennessee	2004	Bioaccumulation: steady state not documented
Burger and Gochfeld	Heavy metals in commercial fish in New Jersey	2005	Bioaccumulation: steady state not documented
Burger et al.	Exposure Assessment for Heavy Metal Ingestion From a Sport Fish in Puerto Rico: Estimating Risk for Local Fishermen.	1992	Bioaccumulation: steady state not documented
Burger et al.	Metal Levels in Fish from the Savannah River: Potential Hazards to Fish and Other Receptors	2002a	Bioaccumulation: steady state not documented
Burger et al.	Metal levels in horseshoe crabs (*Limulus polyphemus*) from Maine to Florida	2002b	Bioaccumulation: steady state not documented
Burger et al.	Metal levels in tissues of Florida gar (*Lepisosteus platyrhincus*) from Lake Okeechobee	2004	Bioaccumulation: steady state not documented
Burger et al.	Metal Levels in Blood, Muscle and Liver of Water Snakes (*Nerodia spp.*) from New Jersey, Tennessee and South Carolina	2007a	Bioaccumulation: steady state not documented
Burger et al.	Metal Levels in Flathead Sole (*Hippoglossoides elassodon*) and Great Sculpin (*Myoxocephalus polyacanthocephalus*) From Adak Island, Alaska: Potential Risk to Predators and Fishermen	2007b	Bioaccumulation: steady state not documented
Burger et al.	Heavy Metals in Pacific Cod (*Gadus macrocephalus*) From the Aleutians: Location, Age, Size, and Risk	2007c	Bioaccumulation: steady state not documented
Burgos and Rainbow	Availability of Cadmium and Zinc from Sewage Sludge to the Flounder, *Platichthys flesus*, via a Marine Food Chain	2001	Sludge
Burnison et al.	Toxicity of cadmium to freshwater algae	1975	The materials, methods or results were insufficiently described
Burnison et al.	Cadmium accumulation in zebrafish (*Danio rerio*) eggs in modulated by dissolved organic matter (DOM)	2006	Bioaccumulation: steady state not documented (only 5 hour exposure)

Authors	Title	Year	Reason Unused
Burrell and Weihs	Uptake of cadmium by marine bacteria and transfer to a deposit feeding clam	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Burt et al.	The Accumulation of Zn, Se, Cd, and Pb and Physiological Condition of *Anadara trapezia* Transplanted to a Contamination Gradient in Lake Macquarie, New South Wales, Australia	2007	Bioaccumulation: steady state not documented
Burton and Pinkney	Yellow Perch Larval Survival in the Zekiah Swamp Watershed (Wicomico River, Maryland) Relative to the Potential Effects of a Coal Ash Storage Facility	1994	Effluent
Busch et al.	Effects of changing salt concentrations and other physical-chemical parameters on bioavailability and bioaccumulation of heavy metals in exposed *Dreissena polymorpha* (Pallas, 1771)	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bustamante et al.	Biokinetics of zinc and cadmium accumulation and depuration at different stages in the life cycle of the cuttlefish *Sepia officinalis*	2002	Mixture; not North American species
Bustamante et al.	Distribution of trace elements in the tissues of benthic and pelagic fish from the Kerguelen Islands	2003	Bioaccumulation: steady state not documented
Byzitter et al.	Acute Combined Exposure to Heavy Metals (Zn, Cd) blocks memory formation in a freshwater snail.	2012	Only one exposure concentration, duration too short
Cadena-Cardenas et al.	Heavy Metal Levels in Marine Mollusks From Areas With, or Without, Mining Activities Along the Gulf of California, Mexico	2009	Bioaccumulation: steady state not documented
Cain et al.	Linking metal bioaccumulation of aquatic insects to their distribution patterns in a mining-impacted river	2004	Bioaccumulation: steady state not documented
Cain et al.	Influence of metal exposure history on the bioaccumulation and subcellular distribution of aqueous cadmium in the insect *Hydropsyche californica*	2006	Bioaccumulation: steady state not documented (only 6 day exposure)
Cain et al.	Bioaccumulation dynamics and exposure routes of Cd and Cu among species of aquatic mayflies	2011	Bioaccumulation: steady state not documented, not renewal or flow-through
Cairns et al.	The effects of temperature upon the toxicity of chemicals to aquatic organisms	1975	Not applicable per ECOTOX Duluth; review
Cairns et al.	A simple, cost-effective multispecies toxicity test using organisms with a cosmopolitan distribution	1986	Review of previously published data
Calabro et al.	Survey on the Presence of Heavy Metals in *Patella caerulea* Specimens Collected Along Coastlines in Messina Province (Italy)	2006	Bioaccumulation: steady state not documented
Calevro et al.	Tests of toxicity and teratogenicity in biphasic vertebrates treated with heavy metals (Cr^{3+}, Al^{3+}, Cd^{2+})	1998a	Not North American species
Calevro et al.	Toxic effects of aluminum, chromium and cadmium in intact and regenerating freshwater planarians	1998b	The materials, methods or results were insufficiently described

Authors	Title	Year	Reason Unused
Caliceti et al.	Heavy metal contamination in the seaweeds of the Venice Lagoon	2002	Bioaccumulation: steady state not documented
Call et al.	Variation of acute toxicity with water source	1983	Report appears to be missing data tables and LC50 values
Cambier et al.	Cadmium-induced genotoxicity in zebrafish at environmentally relevant doses	2010	Only two exposure concentrations
Campbell and Evans	Cadmium concentrations in the freshwater mussel (*Elliptio complanata*) and their relationship to water chemistry	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Campbell et al.	Cadmium-Handling Strategies in Two Chronically Exposed Indigenous Freshwater Organisms-The Yellow Perch (*Perca flavescens*) and the Floater Mollusc (*Pyganodon grandis*)	2005	Non-applicable
Campos	Heavy Metal Concentrations In Some Oyster Species Of The Caribbean Coast Of Columbia	1985	Bioaccumulation: steady state not documented
Camusso et al.	Bioconcentration of trace metals in rainbow trout: a field study	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Canli and Furness	Toxicity of heavy metals dissolved in sea water and influences of sex and size on metal accumulation and tissue distribution in the Norway lobster *Nephrops norvegicus*	1993	Not North American species
Canli and Furness	Mercury and cadmium uptake from seawater and from food by the Norway lobster *Nephrops norvegicus*	1995	Not North American species
Canli and Kargin	A Comparative Study on Heavy Metal (Cd, Cr, Pb and Ni) Accumulation in the Tissue of the Carp *Cyprinus carpio* and the Nile Fish *Tilapia nilotica*	1995	Mixture
Canli et al.	The induction of metallothionein in tissues of the Norway lobster *Nephrops norvegicus* following exposure to cadmium, copper and zinc: the relationships between metallothionein and the metals	1997	Mixture
Canli et al.	Metal (Cd, Pb, Cu, Zn, Fe, Cr, Ni) Concentrations in Tissues of a Fish *Sardina pilchardus* and a Prawn *Penaeus japonicus* from Three Stations on the Mediterranean Sea	2001	Bioaccumulation: steady state not documented
Cannicci et al.	Effects of Urban Wastewater on Crab and Mollusc Assemblages in Equatorial and Subtropical Mangroves of East Africa	2009	Mixture
Canton and Slooff	A proposal to classify compounds and to establish water quality based on laboratory data	1979	The materials, methods or results were insufficiently described
Cao et al.	Cadmium toxicity to embryonic-larval development and survival in red sea bream *Pagrus major*	2009	Not North American species
Cao et al.	Accumulation and oxidative stress biomarkers in japanese flounder larvae and juveniles under chronic cadmium exposure	2010	Not North American species, usually Unused data
Cao et al.	Tissue-specific accumulation of cadmium and its effects on antioxidative responses in japanese flounder juveniles	2012	Not North American species, lack of exposure details

Authors	Title	Year	Reason Unused
Capelli et al.	Distribution of Trace Elements in Organs of Six Species of Cetaceans From the Ligurian Sea (Mediterranean), and the Relationship With Stable Carbon and Nitrogen Ratios	2008	Bioaccumulation: steady state not documented
Caplat et al.	Comparative toxicities of aluminum and zinc from sacrificial anodes or from sulfate salt in sea urchin embryos and sperm	2010	Not applicable, not cadmium toxicity information
Carattino et al.	Effects of Long-Term Exposure to Cu2+ and Cd2+ on the Pentose Phosphate Pathway Dehydrogenase Activities in the Ovary of Adult *Bufo arenarum*: Possible Role as Biomarker for Cu2+ Toxicity	2004	Mixture
Cardwell et al.	Metal accumulation in aquatic macrophytes from southeast Queensland, Australia	2002	Bioaccumulation: steady state not documented
Carline et al.	Long-Term Effects of Treated Domestic Wastewater on Brown Trout	1987	Effluent
Carlisle and Clements	Sensitivity and variability of metrics used in biological assessments of running waters	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Carmichael and Fowler	Cadmium accumulation and toxicity in the kidney of the bay scallop *Argopecten irradians*	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Carpene and Boni	Effects of heavy metals on the algae *Nitzschia closterium* and *Prorocentrum micans*	1992	The materials, methods or results were insufficiently described
Carpene et al.	Cadmium-binding proteins from the mantle of *Mytilus edulis* (L.) after exposure to cadmium	1980	Exposure concentration not measured
Carr and Neff	Biochemical indices of stress in the sandworm *Neanthes virens* (Sars). II. sublethal responses to cadmium	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured, No pertinent adverse effects reported
Carranza-Alvarez et al.	Accumulation and Distribution of Heavy Metals in *Scirpus americanus* and *Typha latifolia* from an Artificial Lagoon in San Luis Potosi, Mexico	2008	Bioaccumulation: steady state not documented
Carriquiriborde and Ronco	Sensitivity of the neotropical teleost *Odonthestes bonariensis* (Pisces, Atherinidae) to chromium(VI), copper(II), and cadmium(II)	2002	Not North American species, duration too short, test species fed
Carriquiriborde and Ronco	Distinctive Accumulation Patterns of Cd(II), Cu(II), and Cr(VI) in Tissue of the South American Teleost, Pejerrey (*Odontesthes bonariensis*)	2008	Bioaccumulation: steady state not documented
Carroll et al.	Influences of hardness constituents on the acute toxicity of cadmium to brook trout (*Salvelinus fontinalis*)	1979	Authors noted that the Cd measured conc in the control water was greater than the LC50 value of 1.5 ug/L and had 100% survival
Casado-Martinez et al.	Biodynamic Modeling and the Prediction of Accumulated Trace Metal Concentrations in the Polychaete *Arenicola marina*	2009	Modeling
Casas et al.	Relation between metal concentration in water and metal content of marine mussels (*Mytilus galloprovincialis*): impact of physiology	2008	Bioaccumulation: steady state not documented; not North American species

Authors	Title	Year	Reason Unused
Casini and Depledge	Influence of copper, zinc, and iron on cadmium accumulation in the Talitrid amphipod, *Platorchestia platensis*	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Casiot et al.	Hydrological and Geochemical Control of Metals and Arsenic in a Mediterranean River Contaminated by Acid Mine Drainage (the Amous River, France) Preliminary Assessment of Impacts on Fish (*Leuciscus cephalus*)	2009	Mixture
Cassini et al.	Cadmium bioaccumulation studies in the freshwater molluscs *Anodonta cygnea* and *Unio elongatulus*	1986	Not North American species
Cassis et al.	The Role of Phytoplankton in the Modulation of Dissolved and Oyster Cadmium Concentrations in Deep Bay, British Columbia, Canada	2011	Bioaccumulation: steady state not documented
Castano et al.	Correlations between the RTG-2 cytotoxicity test EC50 and *in vivo* LC50 rainbow trout bioassay	1996	No interpretable concentration, time, response data or examined only a single exposure concentration
Castille and Lawrence	The effects of EDTA (ethylenedinitrotetraacetic acid) on the survival and development of shrimp nauplii (*Penaeus stylirostris* Stimpson) and the interactions of EDTA and the toxicities of cadmium, calcium, and phenol	1981	Not North American species
Cavas et al.	Induction of micronuclei and binuclei in blood, gill and liver cells of fishes subchronically exposed to cadmium chloride and copper sulphate	2005	Mixture
Cearley and Coleman	Cadmium toxicity and accumulation in southern naiad	1973	The dilution water or medium used was open to questions because of its origin or content
Cearley and Coleman	Cadmium toxicity and bioconcentration in largemouth bass and bluegill	1974	The dilution water or medium used was open to questions because of its origin or content
Cebrian and Uriz	Contrasting effects of heavy metals and hydrocarbons on larval settlement and juvenile survival in sponges	2007	Not North American species, only one exposure concentration, duration too short
Celik et al.	Determination of the lead and cadmium burden in some northeastern Atlantic and Mediterranean fish species by DPSAV	2004	Bioaccumulation: steady state not documented
Cesar et al.	Sensitivity of mediterranean amphipods and sea urchins to reference toxicants	2002	Not North American species, duration too short
Cevik et al.	Assessment of Metal Element Concentrations in Mussel (*M. galloprovincialis*) in Eastern Black Sea, Turkey	2008	Bioaccumulation: steady state not documented
Chadwick Ecological Consultants	U.S. EPA Cadmium water quality criteria document-technical review and criteria update	2004b	Review
Chadwick Ecological Consultants	Addendum to U.S. EPA Cadmium water quality criteria document-technical review and criteria update	2004c	Review
Chaharlang et al.	Assessment of Cadmium, Copper, Lead and Zinc Contamination Using Oysters (*Saccostrea cucullata*) as Biomonitors on the Coast of the Persian Gulf, Iran	2012	Bioaccumulation: steady state not documented
Chan and Cheng	Cadmium-induced ectopic apoptosis in zebrafish embryos	2003	Lack of details

Authors	Title	Year	Reason Unused
Chan et al.	Effects of polyethylene glycol on growth and cadmium accumulation of *Chlorella salina* CU-1	1981	Questionable treatment of test organisms or inappropriate test conditions or methodology
Chan et al.	Uptake of zinc and cadmium by two populations of shore crabs *Carcinus maenas* at different salinities	1992	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chan et al.	The Uptake of Cd, Cr, and Zn by the Macroalga *Enteromorpha crinita* and Subsequent Transfer to the Marine Herbivorous Rabbitfish, *Siganus canaliculatus*	2003	Bioaccumulation: steady state not documented
Chander et al.	Response of *Pithophora oedogonia* to cadmium	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chandini	Changes in food (*Chlorella*) levels and the acute toxicity of cadmium to *Daphnia carinata* (daphnidae) and *Echinisca triserialis* (macrothricidae) (Crustacea: cladocera)	1988a	Not North American species, dilution water not characterized
Chandini	Effects of different food (*Chlorell*a) concentrations on the chronic toxicity of cadmium to survivorship, growth and reproduction of *Echinisca triserialis* (crustacea: cladocera)	1988b	Not North American species
Chandini	Survival, growth and reproduction of *Daphnia carinata* (crustacea: cladocera) exposed to chronic cadmium stress at different food (*Chlorella*) levels	1989	Not North American species
Chandini	Reproductive value and the cost of reproduction in *Daphnia carinata* and *Echinisca triserialis* (crustacea: cladocera) exposed to food and cadmium stress	1991	Not North American species
Chandra and Garg	Absorption and toxicity of chromium and cadmium in *Limnanthemum cristatum* Griseb	1992	Not North American species
Chandra and Khuda-Bukhsh	Genotoxic effects of cadmium chloride and azadirachtin treated singly and in combination in fish	2004	Injected pollutant
Chandrudu and Radhakrishnaiah	Effect of cadmium on the histology of hepatopancreas and foot of the freshwater mussels *Lamellidens marginalis* (Lam.)	2008	Lack of detail, not North American species
Chandrudu et al.	Effect of subacute concentration of cadmium on the energetics of freshwater mussel *Lamellidens marginalis* (Lam.) and fish *Labeo rohita* (Ham.)	2007	Only one exposure concentration, not North American species
Chandurvelan et al.	Impairment of green-lipped mussel (*Perna canaliculus*) physiology by waterborne cadmium: relationship to tissue bioaccumulation and effect of exposure duration	2012	Not North American species
Chandurvelan et al.	Waterborne cadmium impacts immunocytotoxic and cytogenotoxic endpoints in green-lipped mussel, *Perna canaliculus*	2013a	Not North American species; only two exposure concentrations

Authors	**Title**	**Year**	**Reason Unused**
Chandurvelan et al.	Biochemical biomarker responses of green-lipped mussel, *Perna canaliculus*, to acute and subchronic waterborne cadmium toxicity	2013b	Not North American species; only two exposure concentrations
Chang et al.	Element concentrations in shell of *Pinctada margaritifera* from French Polynesia and evaluation for using as a food supplement	2007	Field bioaccumulation: steady state not documented, exposure concentration unknown
Chang et al.	Effects of cadmium on respiratory burst, intracellular Ca2+ and DNA damage in the white shrimp *Litopenaeus vannamei*.	2009	Dilution water not characterized, duration too short
Chang et al.	Influence of Divalent Metal Ions on E2-Induced ER Pathway in Goldfish (*Carassius auratus*) Hepatocytes	2011	In vitro
Chapman et al.	Global Geographic Differences in Marine Metals Toxicity	2006	Non-applicable
Charpentier et al.	Toxicity and bioaccumulation of cadmium in experimental cultures of duckweed, *Lemna polyrrhiza* L.	1987	Not North American species
Chassard-Bouchaud	Ultrastructural Study of Cadmium Concentration by the Digestive Gland of the Crab *Carcinus maenas* (Crustacea Decapoda).	1982	Bioaccumulation: steady state not documented
Chattopadhyay et al.	Bioassay evaluation of acute toxicity levels of mercuric chloride and cadmium chloride on the early growing stages of *Labeo rohita*	1995	Not North American species
Chaumot et al.	Additive vs non-additive genetic components in lethal cadmium tolerance of Gammarus (Crustacea): novel light on the assessment of the potential for adaptation to contamination	2009	Only one exposure concentration, dilution water not characterized, not North American species
Chawla et al.	Effect of pH and temperature on the uptake of cadmium by *Lemna minor* L.	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chelomin et al.	An in vitro study of the effect of reactive oxygen species on subcellular distribution of deposited cadmium in digestive gland of mussel *Crenomytilus grayanus*	2005	In vitro
Chen and Fang	Safety assessment and acute toxicity of copper, zinc and cadmium to the embryo and larval fish of *Tanichthys albonubes*	2011	Not North American species; text in foreign language, abstract only in English
Chen et al.	Comparison of the relative toxicity relationships based on batch and continuous algal toxicity tests	1997	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Chen et al.	Use of Japanese Medaka (*Oryzias latipes*) and Tilapia (*Oreochromis mossambicus*) in Toxicity Tests on Different Industrial Effluents in Taiwan	2001	Effluent
Chen et al.	Expression Pattern of Metallothionein, MTF-1 Nuclear Translocation, and Its DNA-Binding Activity in Zebrafish (Danio rerio) Induced by Zinc and Cadmium	2007	Mixture
Chen et al.	Accumulation and Release Characteristics of Heavy Metals in *Crassostrea rivalaris* Under Mixed Exposure	2008	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Chen et al.	Effects of Cd and Zn on Oxygen Consumption and Ammonia Excretion in Sipuncula (*Phascolosoma esculenta*)	2009	Mixture
Chen et al.	Accumulation and Elimination Characteristics of Heavy Metal Cadmium in *Bullacta exarata* from Intertidal Zone of Tianjin, China.	2010	Bioaccumulation: steady state not documented
Chen et al.	Toxicity Assessment of Simulated Urban Runoff Containing Polycyclic Musks and Cadmium in Carassius auratus Using Oxidative Stress Biomarkers	2012	Mixture
Chen et al.	Assessing abalone growth inhibition risk to cadmium and silver by linking toxicokinetics/toxicodynamics and subcellular partitioning	2011a	Analyzed data from another study
Chen et al.	Molecular cloning, characterization and expression analysis of receptor for activated C kinase 1 (RACK1) from pearl oyster (*Pinctada martensii*) challenged with bacteria and exposed to cadmium	2011b	Mixture
Chen et al.	Differential effect of waterborne cadmium exposure on lipid metabolism in liver and muscle of yellow catfish *Pelteobagrus fulvidraco*	2013	Only two exposure concentrations
Cherkasov et al.	Effects of acclimation temperature and cadmium exposure on cellular energy budgets in the marine mollusk *Crassostrea virginica*: linking cellular and mitochondrial responses	2006	Only one exposure concentration
Cherkasov et al.	Combined effects of temperature and cadmium exposure on haemocyte apoptosis and cadmium accumulation in the eastern oyster *Crassostrea virginica* (Gmelin)	2007	Bioaccumulation: not whole body or muscle content
Cherkasov et al.	Seasonal variation in mitochondrial responses to cadmium and temperature in eastern oysters *Crassostrea virginica* (Gmelin) from different latitudes	2010	Bioaccumulation: not renewal or flow-through; Excised cells
Chernova and Sergeeva	Metal Concentrations in Sargassum Algae From Coastal Waters of Nha Trang Bay (South China Sea)	2008	Bioaccumulation: steady state not documented
Cherry and Guthrie	Toxic Metals in Surface Waters From Coal Ash	1977	Bioaccumulation: steady state not documented
Cherry et al.	Coal Ash Basin Effects (Particulates, Metals, Acidic Ph) Upon Aquatic Biota: an Eight-Year Evaluation	1984	Effluent
Cheung and Lam	Effect of cadmium on the embryos and juveniles of a tropical freshwater snail, *Physa acuta* (Draparnaud, 1805)	1998	Not North American species
Cheung and Wong	Risk Assessment of Heavy Metal Contamination in Shrimp Farming in Mai Po Nature Reserve, Hong Kong	2006	Bioaccumulation: steady state not documented
Cheung et al.	Effects of heavy metals on the survival and feeding behaviour of the sandy shore scavenging gastropod *Nassarius festivus* (Powys)	2002	Not North American species
Cheung et al.	Metal Concentrations of Common Freshwater and Marine Fish From the Pearl River Delta, South China	2008	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Chevreuil et al.	Evaluation of the Pollution by Organochlorinated Compounds (Polychlorobiphenyls and Pesticides) and Metals (Cd, Cr, Cu and Pb) in the Water and in the Zebra Mussel (*Dreissena polymorpha* Pallas) of the River Seine	1996	Bioaccumulation: steady state not documented
Chiarelli et al.	Sea urchin embryos as a model system for studying autophagy induced by cadmium stress	2011	Lack of exposure details
Chiarelli et al.	Sea urchin embryos exposed to cadmium as an experimental model for studying the relationship between autophagy and apoptosis	2013	Only one exposure concentration\
Chigbo et al.	Uptake of Arsenic, Cadmium, Lead and Mercury Form Polluted Waters by the Water Hyacinth *Eichornia crassipes*	1982	Bioaccumulation: steady state not documented
Chiodi Boudet et al.	Lethal and sublethal effects of cadmium in the white shrimp *Palaemonetes argentinus*: A comparison between populations from contaminated and reference sites	2013	Not North American species; dilution water not characterized
Chishty et al.	Evaluation of acute toxicity of zinc, lead and cadmium to zooplanktonic community in upper Berach river system, Rajasthan, India	2012	Mixture (lead, zinc and cadmium)
Chitguppa et al.	Reusability of seaweed biosorbent in multiple cycles of cadmium adsorption and desorption	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Choi et al.	Cadmium bioaccumulation and detoxification in the gill and digestive gland of the Antarctic bivalve *Laternula elliptica*	2007a	Bioaccumulation: steady state not documented; not North American species
Choi et al.	Cadmium affects the expression of metallothionein (MT) and glutathione peroxidase (GPX) mRNA in goldfish, *Carassius auratus*	2007b	Injected pollutant
Choi et al.	Biosorption of heavy metals and uranium by starfish and *Pseudomonas putida*	2009	Bioaccumulation: steady state not documented
Chojnacka et al.	Biosorption of Cr3+, Cd2+ and Cu2+ Ions by Blue-Green Algae *Spirulina sp.*: Kinetics, Equilibrium and the Mechanism of the Process	2005	Mixture
Chora et al.	Effect of cadmium in the clam *Ruditapes decussatus* assessed by proteomic analysis	2009	Bioaccumulation: steady state not documented
Chou and Uthe	Effect of starvation on trace metal levels in blue mussels (*Mytilus edulis*)	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chou et al.	Effect of dietary cadmium on growth, survival, and tissue concentrations of cadmium, zinc, copper, and silver in juvenile american lobster (*Homarus americanus*)	1987	Organisms were exposed to cadmium in food or by injection or gavage

Authors	**Title**	**Year**	**Reason Unused**
Chou et al.	Cadmium, Copper, Manganese, Silver, and Zinc in Rock Crab (*Cancer irroratus*) from Highly Copper Contaminated Sites in the Inner Bay of Fundy, Atlantic Canada	2002	Bioaccumulation: steady state not documented
Chou et al.	Effect of magnesium deficiency on antioxidant status and cadmium toxicity in rice seedlings.	2011	Only one exposure concentration
Chouchene et al.	Cadmium-induced ovarian pathophysiology is mediated by change in gene expression pattern of zinc transporters in zebrafish (*Danio rerio*).	2011	Only one exposure concentrations
Chowdhury et al.	Gastrointestinal Uptake and Fate of Cadmium in Rainbow Trout Acclimated to Sublethal Dietary exposure Cadmium	2004	Dietary exposure
Christoffers and Ernst	The *in-vivo* fluorescence of *Chlorella fusca* as a biological test for the inhibition of photosynthesis	1983	No interpretable concentration, time, response data or examined only a single exposure concentration
Ciardullo et al.	Bioaccumulation Potential of Dietary exposure Arsenic, Cadmium, Lead, Mercury, and Selenium in Organs and Tissues of Rainbow Trout (*Oncorhyncus mykiss*) as a Function of Fish Growth	2008	Dietary exposure
Cicik et al.	Effects of lead and cadmium interactions on the metal accumulation in tissue and organs of the Nile tilapia (*Oreochromis niloticus*)	2004	Bioaccumulation: steady state not documented (only 15 day exposure); not renewal or flow-through exposure
Cid et al.	Determination of trace metals in fish species of the Ria de Aveiro (Portugal) by electrothermal atomic absorption spectrometry	2001	Bioaccumulation: steady state not documented
Ciliberti et al.	The Nile Monitor (*Varanus niloticus*, Squamata: Varanidae) as a Sentinel Species for Lead and Cadmium Contamination in Sub-Saharan Wetlands	2011	Bioaccumulation: steady state not documented
Cincinelli et al.	Organochlorine Pesticide Air-Water Exchange and Bioconcentration in Krill in the Ross Sea	2009	Bioaccumulation: steady state not documented
Ciocan and Rotchell	Cadmium induction of metallothionein isoforms in juvenile and adult mussels (*Mytilus edulis*)	2004	Bioaccumulation: steady state not documented; dilution water not characterized
Cirillo et al.	Cadmium accumulation and antioxidant responses in *Sparus aurata* exposed to waterborne cadmium	2012	Bioaccumulation: steady state not documented (only 11 day exposure)
Ciutat and Boudou	Bioturbation Effects on Cadmium and Zinc Transfers from a Contaminated Sediment exposure and on Metal Bioavailability to Benthic Bivalves	2003	Sediment exposure
Ciutat et al.	Cadmium bioaccumulation in Tubificidae from the overlying water source and effects on bioturbation	2005	Sediment exposure
Clason et al.	Bioaccumulation of Trace Metals in the Antarctic Amphipod *Paramoera walkeri* (Stebbing, 1906): Comparison of Two-Compartment and Hyperbolic Toxicokinetic Models	2003	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Clausen et al.	Passive and active cadmium uptake in the isolated gills of the shore crab, *Carcinus maenas* (L.)	1993	No interpretable concentration, time, response data or examined only a single exposure concentration
Coban et al.	Heavy Metals in Livers, Gills and Muscle of *Dicentrarchus labrax* (Linnaeus, 1758) Fish Species Grown in the Dardanelles	2009	Bioaccumulation: steady state not documented
Cogun et al.	Accumulation of copper and cadmium in small and large Nile tilapia *Oreochromis niloticus*	2003	Bioaccumulation: unmeasured exposure, dilution water not characterized
Cogun et al.	Metal Concentrations in Fish Species from the Northeast Mediterranean Sea	2006	Bioaccumulation: steady state not documented
Cohen et al.	Trace Metals in Fish and Invertebrates of Three California Coastal Wetlands	2001	Bioaccumulation: steady state not documented
Collado et al.	Heavy Metals (Cd, Cu, Pb and Zn) in Two Species of Limpets (*Patella rustica* and *Patella candei crenata*) in the Canary Islands, Spain	2006	Bioaccumulation: steady state not documented
Collard and Matagne	Cd^{2+} resistance in wild-type and mutant strains of *Chlamydomonas reinhardtii*	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Company et al.	Effect of Cadmium, Copper and Mercury on Antioxidant Enzyme Activities and Lipid Peroxidation in the Gills of the Hydrothermal Vent Mussel *Bathymodiolus azoricus*	2004	Mixture
Company et al.	Sub-lethal effects of cadmium on the antioxidant defense system of the hydrothermal vent mussel *Bathymodiolus azoricus*	2010	Bioaccumulation: steady state not documented
Conti and Cecchetti	A biomonitoring study: trace metals in algae and molluscs from Tyrrhenian coastal areas	2003	Bioaccumulation: steady state not documented
Conway	Ecological Impact of Cadmium on Aquatic Organisms	1981	Review
Conway and Williams	Sorption and desorption of cadmium by *Asterionella formosa* and *Fragilaria crotonensis*	1977	Bioaccumulation: steady state not documented
Cooke et al.	Biological Availability of Sediment-Bound Cadmium to the Edible Cockle, *Cerastoderma edule*	1979	Sediment
Cooper and De	Reducing the Toxicity of Cadmium Sulphate to Rainbow Trout (*Salmo gairdneri*) by Preliminary Exposure of Fish to Zinc Sulphate, With and Without Intermittent Exposure to Cadmium	1978	Mixture
Cooper et al.	The Effects of Dietary exposure Iron Concentration on Gastrointestinal and Branchial Assimilation of both Iron and Cadmium in Zebrafish (*Danio rerio*)	2006	Dietary exposure
Cooper et al.	Subcellular partitioning of cadmium in the freshwater bivalve, *Pyganodon grandis*, after separate short-term exposures to waterborne or diet-borne metal	2010a	Bioaccumulation: not renewal or flow-through

NMED Exhibit 70

Authors	Title	Year	Reason Unused
Cooper et al.	Modeling cadmium uptake from water and food by the freshwater bivalve *Pyganodon grandis*	2010b	Bioaccumulation: steady state not documented (only 60 hour exposure)
Cope et al.	Differential exposure, duration, and sensitivity of unionoidean bivalve life stages to environmental contaminants	2008	Dilution water not characterized, lack of details, duration too short
Copes et al.	Uptake of Cadmium From Pacific Oysters (*Crassostrea gigas*) in British Columbia Oyster Growers	2008	Bioaccumulation: steady state not documented
Coppellotti	Effects of cadmium on *Uronema marinum* (Ciliophora, Scuticociliatida) from Antarctica	1994	Not North American species
Corami et al.	Complexation of Cadmium and Copper by Fluvial Humic Matter and Effects on Their Toxicity	2007	Mixture
Cordero et al.	Effect of Heavy Metals on the Growth of the Tropical Microalgae *Tetrasermis chuii* (Prasinophyceae)	2005	Non-applicable
Cornellier	Cinetique De Bioaccumulation Et Distribution Tissulaire Du Cadmium-109 Par La Nourriture Et Par L'eau Chez Le Petoncle Geant (*Placopecten magellanicus*) Et Le Petoncle D'islande (*Chlamys islandica*)	2010	Text in foreign language
Costa et al.	Biochemical Endpoints on Juvenile *Solea senegalensis* Exposed to Estuarine Sediment exposures: the Effect of Contaminant Mixtures on Metallothionein and Cyp1a Induction	2009a	Sediment exposure
Costa et al.	Histological Biomarkers in Liver and Gills of Juvenile *Solea senegalensis* Exposed to Contaminated Estuarine Sediment exposures: a Weighted Indices Approach	2009b	Sediment exposure
Costa et al.	Multi-organ histological observations on juvenile *Senegalese soles* exposed to low concentrations of waterborne cadmium	2013	Not North American species, only three exposure concentrations
Coteur et al.	Alteration of Cellular Immune Responses in the Seastar *Asterias rubens* Following Dietary Exposure to Cadmium	2005	Dietary exposure
Couch	Ultrastructural study of lesions in gills of a marine shrimp exposed to cadmium	1977	Only one exposure concentration
Couillard	Acute toxicity of six metals to the rotifer *Brachionus calyciflorus*, with comparisons to other freshwaer organisms	1989	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Couture and Kumar	Impairment of Metabolic Capacities in Copper and Calcium Contaminated Wild Yellow Perch (*Perca flavescens*)	2003	Mixture
Cox	Interactions of Cadmium, Zinc, and Phosphorus in Marine *Synechococcus*: Field Uptake, Physiological and Proteomic Studies.	2011	Bioaccumulation: steady state not documented
Craig et al.	Effect of exposure regime on the internal distribution of cadmium in *Chironomus staegeri* larvae (insecta, diptera)	1998	No useable data on cadmium toxicity or bioconcentration

Authors	Title	Year	Reason Unused
Craig et al.	Experimental evidence for cadmium uptake via calcium channels in the aquatic insect *Chironomus staegeri*	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Cravo et al.	Metal concentrations in the shell of *Bathymodiolus azoricus* from contrasting hydrothermal vent fields on the mid-Atlantic ridge	2008	Bioaccumulation: steady state not documented
Creighton and Twining	Bioaccumulation from food and water of cadmium, selenium and zinc in an estuarine fish, *Ambassis jacksoniensis*	2010	Bioaccumulation: steady state not documented
Crichton et al.	Assessing Stream Grazer Response to Stress: A Post-Exposure Feeding Bioassay Using the Freshwater Snail *Lymnaea peregra* (Muller)	2004	Dietary exposure
Croisetiere et al.	A Field Experiment to Determine the Relative Importance of Prey and Water as Sources of As, Cd, Co, Cu, Pb, and Zn for the Aquatic Invertebrate *Sialis velata*	2006	Mixture
Croteau and Luoma	A Biodynamic Understanding of Dietborne Metal Uptake by a Freshwater Invertebrate	2008	Dietary exposure
Croteau et al.	Differences in Cd Accumulation Among Species of the Lake-Dwelling Biomonitor Chaoborus	2001	Bioaccumulation: steady state not documented
Cruz et al.	Kinetic modeling and equilibrium studies during cadmium biosorption by dead *Sargassum sp*. biomass	2004	Modeling
Cruz Rodriguez	Heat Shock Protein (HSP70) Response in the Eastern Oyster, *Crassostrea virginica*, Exposed to Various Contaminants (PAHs, PCBs and Cadmium)	2002	Mixture
Cubadda et al.	Size-dependent concentrations of trace metals in four Mediterranean gastropods	2001	Bioaccumulation: steady state not documented
Culshaw et al.	Concentrations of Cd, Zn and Cu in Sediment exposures and brown shrimp (*Crangon crangon* L.) from the Severn Estuary and Bristol Channel, UK	2002	Bioaccumulation: steady state not documented
Cunha et al.	Effects of Copper and Cadmium on Cholinesterase and Glutathione S-Transferase Activities of Two Marine Gastropods (*Monodonta lineata* and *Nucella lapillus*)	2007	Mixture
Cunningham	The effect of cadmium exposure on repeat swimming performance and recovery in rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and lake whitefish (*Coregonus clupeaformis*)	2012	Only one exposure concentration
Currie et al.	Influence of nutrient additions on cadmium bioaccumulation by aquatic invertebrates in littoral enclosures	1998	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Cuthbert et al.	Toxicity of cadmium to *Bullia digitalis* (prosobranchiata: nassaridae)	1976	Not North American species, dilution water not characterized
Cuvin-Aralar	Survival and heavy metal accumulation of two *Oreochromis niloticus* (L.) strains exposed to mixtures of zinc, cadmium and mercury	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Cuvin-Aralar and Aralar	Effects of long-term exposure to a mixture of cadmium, zinc, and inorganic mercurey on two strains of Tilapia *Oreochromis niloticus* (L.)	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Cyrille et al.	Cadmium accumulation in tissues of *Sarotherodon melanotheron* (Ruppel, 1852) from the Aby Lagoon system in Cote d'Ivoire	2012	Bioaccumulation: steady state not documented
D'Agostino and Finney	The effect of copper and cadmium on the development of *Tigriopus japonicas*	1974	Not North American species
D'Aniello et al.	Effect of mercury, cadmium and copper on the development and viability of *Loligo vulgaris* and *Sepia officinalis* embryos	1990	The materials, methods or results were insufficiently described
da Cruz et al.	Estimation of the critical effect level for pollution prevention based on oyster embryonic development toxicity test: The search for reliability	2007	Not North American species, duration too short
da Silva et al.	Relative contribution of food and water to the Cd burden in *Balanus amphitrite* in an urban tidal creek discharging into the Great Barrier Reef lagoon	2004	Bioaccumulation: steady state not documented
da Silva et al.	Can body burden in the barnacle *Balanus amphitrite* indicate seasonal variation in cadmium concentrations?	2005	Bioaccumulation: steady state not documented
Dabas et al.	Assessment of tissue-specific effect of cadmium on antioxidant defense system and lipid peroxidation in freshwater murrel, *Channa punctatus*	2012	Not North American species
Daka and Hawkins	Interactive Effects of Copper, Cadmium and Lead on Zinc Accumulation in the Gastropod Mollusc *Littorina saxatilis*	2006	Mixture
Daka et al.	Tolerance to Heavy Metals in *Littorina saxatilis* from a Metal Contaminated Estuary in the Isle of Man	2004	Bioaccumulation: steady state not documented
Dallinger and Kautzky	The Importance of Contaminated Food for the Uptake of Heavy Metals by Rainbow Trout (*Salmo gairdneri*): a Field Study	1985	Bioaccumulation: steady state not documented
Dallinger et al.	Effects of cadmium on *Murex trunculus* from the Adriatic Sea. I. Accumulation of metal and binding to a metallothionein-like protein	1989	Not North American species
Dallinger et al.	The role of metallothionein in cadmium accumulation of Arctic char (*Salvelinus alpinus*) from high alpine lakes	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Damiens et al.	Metal bioaccumulation and metallothionein concentrations in larvae of *Crassostrea gigas*	2006	Prior exposure, dilution water not characterized
Dang and Wang	Assessment of tissue-specific accumulation and effects of cadmium in a marine fish fed contaminated commercially produced diet	2009	Dietary exposure
Dang et al.	Metallothionein and Cortisol Receptor Expression in Gills of Atlantic Salmon, *Salmo salar*, Exposed to Dietary exposure Cadmium	2001	Dietary exposure
Dangre et al.	Effects of Cadmium on Hypoxia-Induced Expression of Hemoglobin and Erythropoietin in Larval Sheepshead Minnow, *Cyprinodon variegatus*	2010	In vitro
Darmono	Uptake of cadmium and nickel in banana prawn (*Penaeus merguiensis* de Man)	1990	Not North American species

Authors	Title	Year	Reason Unused
Darmono et al.	The pathology of cadmium and nickel toxicity in the banana shrimp (*Penaeus merguiensis* de Man)	1990	Not North American species
Das and Gupta	Effects of cadmium chloride on oxygen consumption and gill morphology of Indian flying barb, *Esomus danricus*	2012	Not North American species, only three exposure concentrations
Das and Khagarot	Bioaccumulation and toxic effects of cadmium on feeding and growth of an Indian pond snail *Lymnaea luteola* L. under laboratory conditions	2010	Dilution water not characterized
Das and Maiti Subodh	Metal Accumulation in *A. baccifera* Growing Naturally on Abandoned Copper Tailings Pond	2007	Bioaccumulation: steady state not documented
Das et al.	The temperature dependence of the acute toxicity of heavy metals (cadmium, copper and mercury) to a freshwater pond snail, *Lymnae aluteola* L	2012	Not North American species
Datta et al.	Estimation of acute toxicity of cadmium, a heavy metal, in a carnivorous freshwater teleost, *Mystus vittatus* (Bloch)	1987	Not North American species
Dautremepuit et al.	Gill and Head Kidney Antioxidant Processes and Innate Immune System Responses of Yellow Perch (*Perca flavescens*) Exposed to Different Contaminants in the St. Lawrence River, Canada	2009	Mixture
Dauvin	Effects of Heavy Metal Contamination on the Macrobenthic Fauna in Estuaries: the Case of the Seine Estuary	2008	Mixture
Daverat et al.	Otolith Microchemistry Interrogation of Comparative Contamination by Cd, Cu and PCBs of Eel and Flounder, in a Large SW France Catchment.	2011	Bioaccumulation: steady state not documented
Davies and Woodling	Importance of laboratory-derived metal toxicity results in predicting in-stream response of resident salmonids	1980	Not applicable per ECOTOX Duluth; effluent, survey
Davies et al.	Field and experimental studies on cadmium in the edible crab *Cancer pagurus*	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Davies et al.	The influence of particle surface characteristics on pollutant metal uptake by cells	1997	Organisms were exposed to cadmium in food or by injection or gavage
Davis et al.	Bioaccumulation of Arsenic, Chromium and Lead in Fish: Constraints Imposed by Sediment Geochemistry	1996	Bioaccumulation: steady state not documented
Davis et al.	Cadmium biosorption by *S. fluitans*: treatment, resilience and uptake relative to other *Saragassum spp*. and brown algae	2004	Lack of details, not renewal or flow-through accumulation study
Dayeh et al.	Cytotoxicity of metals common in mining effluent to rainbow trout cell lines and to the ciliated protozoan, *Tetrahymena thermophila*	2005	Excised tissue/cells
De Boeck et al.	Metal accumulation and metallothionein induction in the spotted dogfish *Scyliorhinus canicula*	2010	Bioaccumulation: steady state not documented (only 7 day exposure)

Authors	Title	Year	Reason Unused
De Coninck et al.	An investigation of the inter-clonal variation of the interactive effects of cadmium and *Microcystis aeruginosa* on the reproductive performance of *Daphnia magna*	2013	Only one exposure concentration
De Conto Cinier et al.	Cadmium bioaccumulation in carp (*Cyprinus carpio*) tissues during long-term high exposure: analysis by inductively coupled plasma-mass spectrometry	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
De Conto Cinier et al.	Cadmium accumulation and metallothionein biosynthesis in *Cyprinus carpio* tissues	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
de March	Acute toxicity of binary mixtures of five cations (Cu^{2+}, Cd^{2+}, Zn^{2+}, Mg^{2+} and K^{+}) to the freshwater amphipod *Gammarus lacustris* (Sars): alternative descriptive models	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
de Mora et al.	Distribution of heavy metals in marine bivalves, fish and coastal Sediment exposures in the Gulf and Gulf of Oman	2004	Bioaccumulation: steady state not documented
De Nicola Guidici and Guarino	Effects of cadmium on survival, bioaccumulation, histopathology, and PGM polymorphism in the marine isopod *Idotea baltica*.	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
De Nicola Guidici and Migliore	Ecotoxicological Assessment of Pollutants by Chemico-Biological Analysis: a Mini review	1996	Review
De Nicola et al	Effects of chronic exposure to cadmium or copper on *Idothea baltica* (crustacea, isopoda)	1989	Not North American species
De Nicola et al	Long term effect of cadmium of copper on *Asellus aquaticus* (L.) (Crustacea, isopoda)	1988	Not North American species
De Vries et al.	Critical Soil Concentrations of Cadmium, Lead, and Mercury in View of Health Effects on Humans and Animals	2007	Review
De Wolf and Rashid	Heavy Metal Accumulation in *Littoraria scabra* Along Polluted and Pristine Mangrove Areas of Tanzania	2008	Bioaccumulation: steady state not documented
De Wolf et al.	Sensitivity to cadmium along a salinity gradient in populations of the periwinkle, *Littorina littorea*, using time-to-death analysis	2004	Prior exposure
Decho and Luoma	Humic and fulvic acids: ink or source in the availability of metals to the marine bivalves *Macoma balthica* and *Potamocorbula amurensis*?	1994	Organisms were exposed to cadmium in food or by injection or gavage
DeFilippis et al.	The effects of sublethal concentrations of zinc, cadmium and mercury on *Euglena*. II. Respiration, photosynthesis and photochemical activities	1981	No pertinent adverse effects reported
Defo et al.	Evidence for Metabolic Imbalance of Vitamin A2 in Wild Fish Chronically Exposed to Metals	2012	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Dekker et al.	Life History Changes in the Benthic Cladoceran *Chydorus piger* Induced by Low Concentrations of Sediment exposure-Bound Cadmium	2002	Bioaccumulation: steady state not documented
Dekker et al.	Development and Application of a Sediment exposure Toxicity Test Using the Benthic Cladoceran *Chydorus sphaericus*	2006	Sediment exposure
Del Castillo Arias and Robinson	Nuclear and Cytosolic Distribution of Metallothionein in the Edible Blue Mussel, *Mytilus edulis* Linnaeus Exposed to Cadmium and Benzo[a]Pyrene and in Gill Tissue from Three Natural Populations Along the Massachusetts Coast	2009	Bioaccumulation: steady state not documented
Delmail et al.	Physiological, anatomical and phenotypical effects of a cadmium stress in different-aged chlorophyllian organs of *Myriophyllum alterniflorum* DC (Haloragaceae)	2011	Only one exposure concentration
Delmotte et al.	Cadmium Transport in Sediment exposures by Tubificid Bioturbation: an Assessment of Model Complexity	2007	Modeling
Delval et al.	Responses of a Flat Fish, the Flounder (*Platichtys flesus* L.) To Metal Pollutions by Elaborating Metallothioneins. Competition Between Zinc, Copper (Responses D'un Poisson Plat: Le Flet (Platichtys Flesus L.) Aux Pollutions Metalliques Par Elaboration De Metallothioneines: Competition Entre Zinc, Cuivre Et Cadmium)	1988	Text in foreign language
Demirak et al.	Heavy Metals in Water, Sediment exposure and Tissues of *Leuciscus cephalus* From a Stream in Southwestern Turkey	2006	Bioaccumulation: steady state not documented
Demon et al.	The influence of pre-treatment, temperature and calcium ions on trace element uptake by an alga (*Scenedesmus pannonicus* subsp. Berlin) and fungus (*Aureobasidium pullulans*)	1989	Not North American species
Den Besten et al.	Effects of cadmium and PCBs on reproduction of the sea star *Asterias rubens*: aberrations in the early development	1989	Not North American species
Den Besten et al.	Effects of cadmium on gametogenesis in the sea star *Asterias rubens* L	1991	Not North American species
Deng et al.	Trace Metal Concentration in Great Tit (*Parus major*) and Greenfinch (*Carduelis sinica*) at the Western Mountains of Beijing, China	2007	Bioaccumulation: steady state not documented
Deniseger et al.	Periphyton Communities in a Pristine Mountain Stream Above and Below Heavy Metal Mining Operations	1986	Effluent
Denton and Burdon-Jones	Influence of temperature and salinity on the uptake, distribution, and depuration of mercury, cadmium, and lead by the black-lip oyster *Saccostrea echinata*	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Denton and Burdon-Jones	Trace Metals In Corals From The Great Barrier Reef	1986a	Bioaccumulation: steady state not documented
Denton and Burdon-Jones	Environmental effects on toxicity of heavy metals to two species of tropical marine fish from northern Australia.	1986b	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Department of the Environment		1973	The materials, methods or results were insufficiently described
Desouky	Metallothionein is up-regulated in molluscan responses to cadmium, but not aluminum, exposure.	2012	Only one exposure concentration
Desouky et al.	Effect of orthosilic acid on the accumulation of trace metals by the pond snail *Lymnaea stagnalis*	2003	Bioaccumulation: not whole body or muscle content
Desrosiers et al.	Relationships Among Total Recoverable and Reactive Metals and Metalloid in St. Lawrence River Sediment exposure: Bioaccumulation by Chironomids and Implications for Ecological Risk Assessment	2008	Bioaccumulation: steady state not documented
Dethlefsen	Uptake, retention and loss of cadmium by brown shrimp (*Crangon crangon*)	1978	Dilution water not characterized
Deveau	Use of the Edible Seaweed Taqq'astan (*Porphyra abbottiae* Krishnamurthy: Bangiaceae) and Metal Bioaccumulation at Traditional Harvesting Sites in Queen Charlotte Strait and Broughton Strait	2011	Bioaccumulation: steady state not documented
Devi	Bioaccumulation and metabolic effects of cadmium on marine fouling dressinid bivalve, *Mytilopsis sallei* (Recluz)	1996	Not North American species; prior exposure (collected from a polluted harbor)
Devi and Kumaraguru	Toxicity of Heavy Metals Copper and Cadmium on the Brown Macroalgal Species of Pudumadam Coast, Gulf of Mannar	2008	Mixture
Devi and Rao	Cadmium accumulation in fiddler crabs *Uca annulipes* latelle and *Uca triangularis* (Milne Edwards)	1989	Not North American species
Devier et al.	One-Year Monitoring Survey of Organic Compounds (PAHs, PCBs, TBT), Heavy Metals and Biomarkers in Blue Mussels from the Arcachon Bay, France	2005	Bioaccumulation: steady state not documented
Devineau and Triquet	Patterns of bioaccumulation of an essential trace element (zinc) and a pollutant metal (cadmium) in larvae of the prawn *Palaemon serratus*	1985	Not North American species
Dhamotharan et al.	Bioremediation of Tannery Effluent Using Cyanobacterium	2009	Effluent
Diamond et al.	Effects of pulsed contaminant exposures on early life stages of the fathead minnow	2005	Pulsed exposure
Dickson et al.	The effect of chronic cadmium exposure on phosphoadenylate concentrations and adenylate energy charge of gills and dorsal muscle tissue of crayfish	1982	No pertinent adverse effects reported
Dierickx and Bredael-Rozen	Correlation between the *in vitro* cytotoxicity of inorganic metal compounds to cultured fathead minnow fish cells and the toxicity to *Daphnia magna*	1996	Review of previously published data
Dierking et al.	Spatial patterns in PCBs, pesticides, mercury and cadmium in the common sole in the NW Mediterranean Sea, and a novel use of contaminants as biomarkers	2009	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Dietrich et al.	Exposure of rainbow trout milt to mercury and cadmium alters sperm motility parameters and reproductive success	2010	In vitro
Dietrich et al.	Carp transferrin can protect spermatozoa against toxic effects of cadmium ions	2011	Only one exposure concentration, dilution water not characterized
Dixon et al.	Cadmium Uptake by Marine Micro-Organisms in the English Channel and Celtic Sea	2006	Bioaccumulation: steady state not documented
Dobrovoljc et al.	Uptake and elimination of cadmium in *Rana dalmatina* (Anura, amphibia) tadpoles	2003	Bioaccumulation: steady state not documented; dilution water not characterized; not North American species
Dong et al.	Concentrations of Heavy Metals and Safe Assessments of Fishes in Main Lakes From Wuhan City	2006	Bioaccumulation: steady state not documented
Dorfman	Tolerance of *Fundulus heteroclitus* to different metals in salt waters	1977	Questionable treatment of test organisms or inappropriate test conditions or methodology
Dorgelo et al.	Effects of diet and heavy metals on growth rate and fertility in the deposit-feeding snail *Potamopyrgus jenkinsi* (Smith) (Gastropoda: Hydrobiidae)	1995	Not North American species
Dorts et al.	Sub-lethal cadmium toxicity in bullhead *Cottus gobio*. Biochemical and proteomic approaches	2009	Lack of detail
Dorts et al.	Proteomic response to sublethal cadmium exposure in a sentinel fish species, *Cottus gobio*	2011	Not North American species
Dorts et al.	Proteasome and antioxidant responses in *Cottus gobio* during a combined exposure to heat stress and cadmium	2012	Not North American species, only two exposure concentrations
Douben	Uptake and elimination of waterborne cadmium by the fish *Noemacheilus barbatulus* L. (stone loach)	1989	Not North American species
Dovzhenko et al.	Cadmium-induced oxidative stress in the bivalve mollusk *Modiolus modiolus*	2005	Bioaccumulation: steady state not documented
Downs et al.	A molecular biomarker system for assessing the health of gastropods (*Ilyanassa obsoleta*) exposed to natural and anthropogenic stressors	2001b	Duration too short, only two exposure concentrations
Dragun et al.	The Influence of the Season and the Biotic Factors on the Cytosolic Metal Concentrations in the Gills of the European Chub (*Leuciscus cephalus* L.)	2007	Bioaccumulation: steady state not documented
Dragun et al.	Assessment of low-level metal contamination using the Mediterranean mussel gills as the indicator tissue	2010	Bioaccumulation: steady state not documented
Drastichova et al.	Effect of cadmium on hematological indices of common carp (*Cyprinus carpio* L.)	2004a	Dilution water not characterized, not definitive value, usually Unused data
Drastichova et al.	Effect of cadmium on blood plasma biochemistry in carp (*Cyprinus carpio* L.)	2004b	Dilution water not characterized, only one exposure concentration
Drava et al.	Trace elements in the muscle of red shrimp *Aristeus antennatus* (Risso, 1816) (Crustacea, Decapoda) from Ligurian sea (NW Mediterranean): variations related to the reproductive cycle	2004	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Drazkiewicz and Baszynaski	Calcium Protection of Ps2 Complex of *Phaseolus coccineus* From Cadmium Toxicity: in Vitro Study	2008	In vitro
Drbal et al.	Toxicity and accumulation of copper and cadmium in the alga *Scenedesmus obliquus* LH.	1985	Not North American species
Dressing	The effect of chemical speciation on the equilibrium, whole-body cadmium content of larvae of the caddisfly, *Hydropsyche sp.*	1980	Chelator present in test media (NTA (nitrilotriacetic acid))
Drost et al.	Heavy metal toxicity to *Lemna minor*: Studies on the time dependence of growth inhibition and the recovery after exposure	2007	Excessive EDTA in the medium (1,177 ug/L)
Du Laing et al.	Factors Affecting Metal Concentrations in Reed Plants (*Phragmites australis*) of Intertidal Marshes in the Scheldt Estuary	2009	Bioaccumulation: steady state not documented
Duan et al.	Differential survivorship among allozyme genotypes of *Hyalella azteca* exposed to cadmium, zinc or low pH	2001	Only one exposure concentration, duration too short
Dugmonits et al.	Major distinctions in the antioxidant responses in liver and kidney of Cd^{2+}-treated common carp (*Cyprinus carpio*)	2013	Only one exposure concentration
Dulymamode et al.	Evaluation of *Padina boergesenii* (Phaeophyceae) as a bioindicator of heavy metals: some preliminary results from Mauritius	2001	Bioaccumulation: not renewal or flow-through
Duman et al.	Bioaccumulation of nickel, copper, and cadmium by *Spirodela polyrhiza* and *Lemna gibba*	2009	Bioaccumulation: steady state not documented (only 10 day duration); unmeasured exposure
Duman and Kar	Temporal variation of metals in water, sediment and tissues of the European chup (*Squalius cephalus* L.)	2012	Field survey
Duman et al.	Seasonal Changes of Metal Accumulation and Distribution in Common Club Rush (*Schoenoplectus lacustris*) and Common Reed (*Phragmites australis*)	2007	Bioaccumulation: steady state not documented
Duman et al.	Effects of exogenous glycinebetaine and trehalose on cadmium accumulation and biological responses of an aquatic plant (*Lemna gibba* L.)	2011	No control group; only three exposure concentrations
Duong et al.	Seasonal Effects of Cadmium Accumulation in Periphytic Diatom Communities of Freshwater Biofilms	2008	Bioaccumulation: steady state not documented
Duong et al.	Experimental toxicity and bioaccumulation of cadmium in freshwater periphytic diatoms in relation with biofilm maturity	2010	Only one exposure concentration, mixed species exposure
Duquesne and Coll	Metal accumulation in the clam *Tridacna crocea* under natural and experimental conditions	1995	Not North American species
Duquesne et al.	Sub-lethal effects of metal exposure: physiological and behavioural responses of the estuarine bivalve *Macoma balthica*	2004	Lack of details, not North American species
Dural et al.	Bioaccumulation of some heavy metals in different tissues of *Dicentrarchus labrax* L, 1758, *Sparus aurata* L, 1758 and *Mugil cephalus* L, 1758 from the Camlik Lagoon of the eastern coast of Mediterranean (Turkey)	2006	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Dutta and Kaviraj	Acute Toxicity of Cadmium to Fish *Labeo rohita* and Copepod *Diaptomus forbesi* Pre-Exposed to CaO and KMnO4	2001	Mixture
Dutton and Fisher	Salinity effects on the bioavailability of aqueous metals for the estuarine killifish *Fundulus heteroclitus*	2011a	Bioaccumulation: not renewal or flow-through
Dutton and Fisher	Bioaccumulation of As, Cd, Cr, Hg(II), and MeHg in killifish (*Fundulus heteroclitus*) from amphipod and worm prey	2011b	Dietary exposure
Dutton and Fisher	Influence of humic acid on the uptake of aqueous metals by the killifish *Fundulus heteroclitus*	2012	Bioaccumualtion: steady state not documented
Dyer et al.	An initial evaluation of the use of Euro/North American fish species for tropical effects assessments	1997	Review of previously published data
Eaton	Chronic Toxicity Of A Copper, Cadmium And Zinc Mixture To The Fathead Minnow (*Pimephales promelas* Rafinesque)	1973	Non-applicable
Ebau et al.	Toxicity of cadmium and lead on tropical midge larvae, *Chironomus kiiensis* Tokunaga and *Chironomus javanus* Kieffer (Diptera: Chironomidae)	2012	Not North American species; test species fed
Ebrahimi	Using Computer Assisted Sperm Analysis (CASA) to Monitoring the Effects of Zinc and Cadmium Pollution on Fish Sperm	2005	Mixture
Ebrahimi	Effects of in Vivo and in Vitro Zinc and Cadmium Treatment on Sperm Steroidogenesis of the African Catfish *Clarias gairepinus*	2007	Mixture
Ebrahimi and Taherianfard	Concentration of Four Heavy Metals (Cadmium, Lead, Mercury, and Arsenic) in Organs of Two Cyprinid Fish (*Cyprinus carpio* and *Capoeta sp.*) From the Kor River (Iran)	2010	Bioaccumulation: steady state not documented
Ebrahimpour and Mushrifah	Heavy Metal Concentrations (Cd, Cu and Pb) in Five Aquatic Plant Species in Tasik Chini, Malaysia	2008	Bioaccumulation: steady state not documented
Ebrahimpour and Mushrifah	Seasonal Variation of Cadmium, Copper, and Lead Concentrations in Fish From a Freshwater Lake	2010	Bioaccumulation: steady state not documented
Edema and Egborge	Heavy metal content of crabs from Warri River, Nigeria	2001	Bioaccumulation: steady state not documented
Edge et al.	Indicators of environmental stress: cellular biomarkers and reproductive responses in the Sydney rock oyster (*Saccostrea glomerata*)	2012	Mixture
EIFAC Working Party on Water Quality Criteria for European Freshwater Fish	Report on cadmium and freshwater fish	1978	Review
Eimers et al.	Cadmium accumulation in the freshwater isopod *Asellus racovitzai*: the relative importance of solute and particulate sources at trace concentrations	2001	Sediment exposure
Eisler	Radio cadmium exchange with seawater by *Fundulus heteroclitus* (L.) (Pisces: Cyprinodontidae)	1974	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination

Authors	Title	Year	Reason Unused
Eisler	Trace metal concentrations in marine organisms	1981	Review of previously published data
Eisler and Gardner	Acute toxicology to an estuarine teleost of mixtures of cadmium, copper, and zinc salts	1973	Questionable treatment of test organisms or inappropriate test conditions or methodology
Eisler et al.	Metal Survey of the Marine Clam *Pitar morrhauna* Collected Near a Rhode Island (USA) Electroplating Plant	1978	Bioaccumulation: steady state not documented
Eissa et al.	Behavioral alterations in juvenile *Cyprinus carpio* (Linnaeus, 1758) exposed to sublethal waterborne cadmium	2006	Only two exposure concentrations, test species fed, usually Unused data
Eissa et al.	Quantitative behavioral parameters as toxicity biomarkers: fish responses to waterborne cadmium	2010	Dilution water not characterized
Elder and Mattraw	Accumulation of Trace Elements, Pesticides, and Polychlorinated Biphenyls in Sediments and the Clam *Corbicula manilensis* of the Apalachicola River, Florida.	1984	Sediment
Eletta et al.	Determination of concentration of heavy metals in two common fish species from Asa River, Ilorin, Nigeria	2004	Bioaccumulation: steady state not documented
Elliott et al.	The influence of cyclic exposure on the accumulation of heavy metals by *Mytilus edulis planulatus* (Lamarck)	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Elliott et al.	Metal interaction during accumulation by the mussel *Mytilus edulis planulatus*	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Engel	Accumulation and cytosolic partitioning of metals in the american oyster *Crassostrea virginica*	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Engel and Fowler	Copper and cadmium induced changes in the metabolism and structure of molluscan gill tissue	1979	Excised tissue/cells
Enserink et al.	Combined effects of metals; an ecotoxicological evaluation	1991	Review of previously published data
Erdogrul and Ates	Determination of Cadmium and Copper in Fish Samples From Sir and Menzelet Dam Lake Kahramanmaras, Turkey	2006	Bioaccumulation: steady state not documented
Erickson et al.	Effects of copper, cadmium, lead, and arsenic in a live diet on juvenile fish growth	2010	Dietary exposure
Errecalde et al.	Influence of a low molecular weight metabolite (citrate) on the toxicity of cadmium and zinc to the unicellular green alga *Selenastrum capricornutum*: and exception to the free-ion model	1998	The materials, methods or results were insufficiently described
Escobedo-Fregoso et al.	Assessment of Metallothioneins in Tissues of the Clam *Megapitaria squalida* as Biomarkers for Environmental Cadmium Pollution From Areas Enriched in Phosphorite	2010	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Eslami et al.	Trace element level in different tissues of *Rutilus frisii* kutum collected from Tajan River, Iran	2011	Bioaccumulation: steady state not documented
Espana et al.	Manganese, nickel, selenium and cadmium in molluscs from the Magellan Strait, Chile	2004	Bioaccumulation: steady state not documented
Espinoza et al.	Effect of cadmium on glutathione s-transferase and metallothionein gene expression in coho salmon liver, gill and olfactory tissues	2012	Only two exposure concentrations
Esposito et al.	Effects of heavy metals on ultrastructure and HSP70s induction in the aquatic moss *Leptodictyum riparium* Hedw	2012	Lack of exposure details (duration), effect concentration not clear
Essumang	Analysis and Human Health Risk Assessment of Arsenic, Cadmium, and Mercury in *Manta birostris* (Manta Ray) Caught Along the Ghanaian Coastline	2009	Bioaccumulation: steady state not documented
Estabrook et al.	Comparison of Heavy Metals in Aquatic Plants on Charity Island, Saginaw Bay, Lake Huron, USA, With Plants Along the Shoreline of Saginaw Bay	1985	Bioaccumulation: steady state not documented
Esvelt et al.	Toxicity Removal From Municipal Wastewaters. Volume IV of a Study of Toxicity and Biostimulation in San Francisco Bay-Delta Waters	1971	Effluent
Etnier et al.	Update of Acute and Chronic Aquatic Toxicity Data for Heavy Metals and Organic Chemicals Found at Hazardous Waste Sites	1987	Review
Eustace	Zinc, cadmium, copper and manganese in species of finfish and shellfish caught in the Derwent estuary, Tashmania	1974	Bioaccumulation: steady state not documented
Evans et al.	Simultaneous measurements of uptake and elimination of cadmium by caddisfly (Trichoptera: hydropsychidae) larvae using stable isotope tracers	2002	Dilution water not characterized
Everaarts	Uptake and release of cadmium in various organs of the common mussel, *Mytilus edulis* (L.)	1990	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Everaarts and Fischer	Micro Contaminants In Surface Sediment exposures And Macrobenthic Invertebrates Of The North Sea	1991	Bioaccumulation: steady state not documented
Everard and Swain	Isolation, charaterization and induction of metallothionein in the stonefly *Eusthenia spectabilis* following exposure to cadmium	1983	Not North American species, dilution water not characterized
EVS Environment Consultants	Site-Specfic Toxicity Testing Methods for the South Fork Coeur D'Alene River-Results and Recommendations	1996	Dilution water not characterized
Evtushenko et al.	Cadmium accumulation in organs of the scallop *Mizuhopecten yessoensis* - I. activities of phosphatases and composition and amount of lipids	1986	Not North American species
Evtushenko et al.	Cadmium bioaccumulation in organs of the scallop *Mizuhopecten yessoensis*	1990	Not North American species
Ezemonye and Enuneku	Evaluation of acute toxicity of cadmium and lead to amphibian tadpoles (toad: *Bufo Maculatus* and frog: *Ptychadena Birroni*)	2005	Lack of exposure details, not North American species

Authors	**Title**	**Year**	**Reason Unused**
Fabacher	Hepatic Microsomes From Freshwater Fish - I. In Vitro Cytochrome P-450 Chemical Interactions	1982	In vitro
Fabris et al.	Trace Metal Concentrations in Edible Tissue of Snapper, Flathead, Lobster, and Abalone from Coastal Waters of Victoria, Australia	2006	Bioaccumulation: steady state not documented
Fair and Sick	Accumulations of naphthalene and cadmium after simultaneous ingestion by the Black Sea Bass, *Centropristis striata*	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Falfushynska et al.	Population-related molecular responses on the effect of pesticides in *Carassius auratus gibelio*	2012	Mixture
Fan et al.	Metal accumulation and biomarker responses in *Daphnia magna* following cadmium and zinc exposure	2009	Mixture
Fang	Comparative studies on uptake pathway of cadmium by *Perna viridis*	2006	Bioaccumulation: steady state not documented
Fang et al.	Heavy Metals in Oysters, Mussels and Clams Collected From Coastal Sites Along the Pearl River Delta, South China	2003	Bioaccumulation: steady state not documented
Fang et al.	Trace Metals in Seawater and Copepods in the Ocean Outfall Area off the Northern Taiwan Coast	2006	Bioaccumulation: steady state not documented
Fang et al.	Metal Concentrations in Green-Lipped Mussels (*Perna viridis*) and Rabbitfish (*Siganus oramin*) From Victoria Harbour, Hong Kong After Pollution Abatement	2008	Bioaccumulation: steady state not documented
Fang et al.	Metallothionein and superoxide dismutase responses to sublethal cadmium exposure in the clam *Mactra veneriformis*.	2010	Not North American species, only three exposure concentrations
Farag et al.	Physiological changes and tissue metal accumulation in rainbow trout exposed to foodborne and waterborne metals	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Farag et al.	Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River basin, Idaho	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Farag et al.	Characterizing Aquatic Health Using Salmonid Mortality, Physiology, and Biomass Estimates in Streams with Elevated Concentrations of Arsenic, Cadmium, Copper, Lead, and Zinc in the Boulder River Watershed, Montana	2003	Mixture
Farag et al.	Concentrations of Metals in Water, Sediment exposure, Biofilm, Benthic Macroinvertebrates, and Fish in the Boulder River Watershed, Montana, and the Role of Colloids in Metal Uptake	2007	Bioaccumulation: steady state not documented
Fargasova	Comparative toxicity of five metals on various biological subjects	1994b	No interpretable concentration, time, response data or examined only a single exposure concentration

NMED Exhibit 70

Authors	Title	Year	Reason Unused
Faria et al.	In situ and laboratory bioassays with *Chironomus riparius* larvae to assess toxicity of metal contamination in rivers: the relative toxic effect of sediment versus water contamination	2007	Mixture
Faria et al.	Contaminant accumulation and multi-biomarker responses in field collected zebra mussels (*Dreissena polymorpha*) and crayfish (*Procambarus clarkii*), to evaluate toxicological effects of industrial hazardous dumps in the Ebro river (NE Spain).	2010	Bioaccumulation: steady state not documented
Farkas et al.	Age- and size-specific patterns of heavy metals in the organs of freshwater fish *Abramis brama* L. populating a low-contaminated site	2003	Bioaccumulation: steady state not documented
Fattorini et al.	Seasonal, Spatial and Inter-Annual Variations of Trace Metals in Mussels From the Adriatic Sea: a Regional Gradient for Arsenic and Implications for Monitoring the Impact of Off-Shore Activities	2008	Bioaccumulation: steady state not documented
Faucher et al.	Impact of acute cadmium exposure on the trunk lateral line neuromasts and consequences on the "C-Start" response behaviour of the sea bass (*Dicentrarchus labrax* L.; Teleostei, Moronidae).	2006	Dilution water not characterized, not North American species, duration too short
Faucher et al.	Impact of cadmium exposure at environmental dose on escape behaviour in sea bass (*Dicentrarchus labrax* L.; Teleostei, Moronidae)	2008	Pulsed exposure, not North American species
Faupel and Traunspurger	Secondary Production of a Zoobenthic Community Under Metal Stress	2012	Mixture
Faupel et al.	The functional response of a freshwater benthic community to cadmium pollution	2012	Sediment; only two exposure concentrations
Fava et al.	Comparative Toxicity of Whole and Liquid Phase Sewage Sludges to Marine Organisms	1985	Sludge
Favorito et al.	Bioaccumulation of cadmium and its cytotoxic effect on zebrafish brain	2011	Bioaccumulation: steady state not documented
Fayed and Abdel-Shafy	Accumulation of Cu, Cd, and Pb by algae	1986	Bioaccumulation: unmeasured exposure
Fdil et al.	Valve movement response of the mussel *Mytilus galloprovincialis* to metals (Cu, Hg, Cd and Zn) and phosphate industry effluents from moroccan Atlantic coast	2006	Duration unknown, dilution water not characterized, not North American species
Felten et al.	Physiological and behavioural responses of *Gammarus pulex* (Crustacea: Amphipoda) exposed to cadmium	2008	Not North American species, test species fed, usually Unused data
Feng et al.	Exploring spatial and temporal variations of cadmium concentrations in Pacific oysters from British Columbia	2011	Bioaccumulation: steady state not documented
Feng et al.	Indication function of aquatic algae for environment	2012	Review of previously published data
Fennikoh et al.	Cadmium toxicity in planktonic organisms of a freshwater food web	1978	The materials, methods or results were insufficiently described
Fernandez and Beiras	Combined Toxicity of Dissolved Mercury with Copper, Lead and Cadmium on Embryogenesis and Early Larval Growth of the Paracentrotus lividus Sea-Urchin	2001	Mixture

Authors	Title	Year	Reason Unused
Fernandez et al.	Assessment of the mechanisms of detoxification of chemical compounds and antioxidant enzymes in the digestive gland of mussels, *Mytilus galloprovincialis*, from Mediterranean coastal sites.	2012	Bioaccumulation: steady state not documented
Fernandez Severini et al.	Spatial and temporal distribution of cadmium and copper in water and zooplankton in the Bahia Blanca estuary, Argentina	2009	Bioaccumulation: steady state not documented
Fernandez-Leborans and Antonio-Garcia	Effects of lead and cadmium in a community of protozoans	1988	The materials, methods or results were insufficiently described
Fernandez-Pinas et al.	Cadmium toxicity in *Nostoc* UAM208: protection by calcium	1995	No interpretable concentration, time, response data or examined only a single exposure concentration
Ferrari et al.	Selective protection of temperature against cadmium acute toxicity to *Bufo arenarum* tadpoles	1993	Not North American species
Ferrari et al.	Energy balance of juvenile *Cyprinus carpio* after a short-term exposure to sublethal water-borne cadmium	2011	Only one exposure concentration
Ferreira da Silva et al.	Heavy Metal Pollution Downstream the Abandoned Coval Da Mo Mine (Portugal) and Associated Effects on Epilithic Diatom Communities	2009	Mixture
Ferreira et al.	Metal Accumulation and Oxidative Stress Responses in, Cultured and Wild, White Seabream from Northwest Atlantic	2008b	Bioaccumulation: steady state not documented
Ferrer et al.	Acute toxicities of four metals on the early life stages of the crab *Chasmagnathus granulata* from Bahia Blanca Estuary, Argentina	2006	Not North American species
Fialkowski et al.	Seasonal variation in trace metal concentrations in three talitrid amphipods from the Gulf of Gdansk, Poland	2003	Bioaccumulation: steady state not documented
Filazi et al.	Metal concentrations in tissues of the Black Sea fish Mugil auratus from Sinop-Icliman, Turkey	2003	Bioaccumulation: steady state not documented
Filosto et al.	Environmentally relevant cadmium concentrations affect development and induce apoptosis of *Paracentrotus lividus* larvae cultured *in vitro*	2008	Not North American species, unmeasured chronic exposure
Finger and Bulak	Toxicity of Water From Three South Carolina Rivers to Larval Striped Bass	1988	Mixture
Finlayson et al.	Toxicity of metal-contaminated Sediment exposures from Keswick Reservoir, California, USA	2000	Sediment exposure
Firat and Kargin	Biochemical alterations induced by Zn and Cd individually or in combination in the serum of *Oreochromis niloticus*	2010a	Only one exposure concentration
Firat and Kargin	Effects of zinc and cadmium on erythrocyte antioxidant systems of a freshwater fish *Oreochromis niloticus*	2010b	Only one exposure concentration
Firat and Kargin	Individual and combined effects of heavy metals on serum biochemistry of Nile *Tilapia oreochromis* Niloticus	2010c	Only one exposure concentration

Authors	Title	Year	Reason Unused
Firat and Kargin	Protein intensity changes in the hemoglobin and plasma electrophoretic patterns of *Oreochromis niloticus* in response to single and combined Zn and Cd exposure	2010d	Only two exposure concentrations
Fisher and Fabris	Complexation of Cu, Zn and Cd by metabolites excreted from marine diatoms	1982	No pertinent adverse effects reported
Fisher et al.	Accumulation and retention of metals in mussels from food and water: a comparison under field and laboratory conditions	1996	Not North American species
Fitzsimons et al.	Occurrence of a Swim-up Syndrome in Lake Ontario Lake Trout in Relation to Contaminants and Cultural Practices	1995	Bioaccumulation: steady state not documented
Flament et al.	Effect of cadmium on gonadogenesis and metamorphosis in *Pleurodeles waltl* (Urodele Amphibian)	2003	Not North American species, duration too short
Fleeger et al.	Does Bioturbation by a Benthic Fish Modify the Effects of Sediment exposure Contamination on Saltmarsh Benthic Microalgae and Meiofauna?	2006	Sediment exposure
Flegal	Trace Element Concentrations of the Rough Limpet, *Acmaea scabra*, in California	1978	Bioaccumulation: steady state not documented
Florence et al.	Determination of trace element speciation and the role of speciation in aquatic toxicity	1992	Review of previously published data
Food and Agriculture Organization of the United Nations	Report on Cadmium and Freshwater Fish	1977	Review
Foran et al.	Influence of parental and developmental cadmium exposure on endocrine and reproductive function in Japanese medaka (*Oryzias latipes*)	2002	Prior exposure, not North American species
Foran et al.	A survey of metals in tissues of farmed Atlantic and wild Pacific salmon	2004	Bioaccumulation: steady state not documented
Forbes	Response of *Hydrobia ventrosa* (Montagu) to environmental stress: Effects of salinity fluctuations and cadmium exposure on growth	1991	Not North American species
Forget et al.	Joint action of pollutant combinations (pesticides and metals) on survival (LC50 values) and acetylcholinesterase activity of *Tigriopus brevicornis* (Copepoda, Harpacticoida)	1999	Mixture
Formicki et al.	Combined effects of cadmium and ultraviolet radiation on mortality and mineral content in common frog (*Rana temporaria*) larvae	2008	Not North American species, duration too short
Formicki et al.	Cadmium Availability to Freshwater Mussel (*Unio tumidus*) in the Presence of Organic Matter and UV Radiation	2009	Mixture
Foster	Metal resistances of chlorophyta from rivers polluted by heavy metals	1982	Organisms were not exposed to cadmium in water
Fowler et al.	Levels of Toxic Metals in Marine Organisms Collected From Southern California Coastal Waters	1975	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Fracacio et al.	In situ and laboratory evaluation of toxicity with *Danio rerio* Buchanan (1822) and *Poecilia reticulata* Peters (1859)	2009	Mixture
France	Calcium and Trace Metal Composition of Crayfish (*Orconectes virilis*) in Relation to Experimental Lake Acidification	1987	Bioaccumulation: steady state not documented
Francesconi	Distribution of cadmium in the pearl oyster, *Pinctada albina albina* (Lamarck), following exposure to cadmium in seawater	1989	Not North American species
Francesconi et al.	Cadmium uptake from seawater and food by the western rock lobster *Panulirus Cygnus*	1994	Not North American species
Francesconi et al.	Cadmium in the saucer scallop, *Amusium balloti*, from Western Australian waters: Concentrations in adductor muscle and redistribution following frozen storage	1993	Bioaccumulation: steady state not documented
Franchi et al.	Bioconcentration of Cd and Pb by the river crab *Trichodactylus fluviatilis* (Crustacea: Decapoda)	2011	Dilution water not characterized
Frankenne et al.	Isolation and characterization of metallothioneins from cadmium-loaded mussel *Mytilus edulis*	1980	Dilution water not characterized
Franklin et al.	Toxicity of Metal Mixtures to a Tropical Freshwater Alga (*Chlorella sp.*): The Effect of Interactions Between Copper, Cadmium, and Zinc on Metal Cell Binding and Uptake	2002	Mixture
Franzellitti et al.	Heavy metals in tissues of loggerhead turtles (*Caretta caretta*) from the northwestern Adriatic Sea	2004	Bioaccumulation: steady state not documented
Franzin and McFarlane	An Analysis of the Aquatic Macrophyte, *Myriophyllum exalbescens*, as an Indicator of Metal Contamination of Aquatic Ecosystems Near a Base Metal Smelter	1980	Bioaccumulation: steady state not documented
Fraser et al.	Spatial and Temporal Distribution of Heavy Metal Concentrations in Mussels (*Mytilus edulis*) From the Baie Des Chaleurs, New Brunswick, Canada	2011	Bioaccumulation: steady state not documented
Frazier	Bioaccumulation of cadmium in marine organisms	1979	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Frazier and George	Cadmium kinetics in oyster - a comparative study of *Crassostrea gigas* and *Ostrea edulis*	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Freeman	Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress	1978	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	Title	Year	Reason Unused
Freeman	Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress	1980	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Freitas and Rocha	Acute toxicity tests with the tropical cladoceran *Pseudosida ramosa*: The importance of using native species as test organisms	2011	Not North American species
Frias-Espericueta et al.	Heavy Metals in the Tissues of the Sea Turtle *Lepidochelys olivacea* From a Nesting Site of the Northwest Coast of Mexico	2006	Bioaccumulation: steady state not documented
Frias-Espericueta et al.	Metal Content of the Gulf of California Blue Shrimp *Litopenaeus stylirostris* (Stimpson)	2007	Bioaccumulation: steady state not documented
Frias-Espericueta et al.	Histological effects of a combination of heavy metals on Pacific white shrimp *Litopenaeus vannamei*	2008a	Mixture
Frias-Espericueta et al.	The Metal Content of Bivalve Molluscs of a Coastal Lagoon of NW Mexico	2008b	Bioaccumulation: steady state not documented
Frias-Espericueta et al.	Cadmium, copper, lead, and zinc in Mugil cephalus from seven coastal lagoons of NW Mexico	2011	Bioaccumulation: steady state not documented
Fridman et al.	Estradiol uptake, toxicity, metabolism, and adverse effects on cadmium-treated amphibian embryos	2004	Mixture, not North American species
Friedrich and Halden	Determining exposure history of northern pike and walleye to tailings effluence using trace metal uptake in otoliths	2010	Bioaccumulation: steady state not documented
Fritioff and Greger	Uptake and distribution of Zn, Cu, Cd, and Pb in an aquatic plant, *Potamogeton natans*	2006	Bioaccumulation: steady state not documented (only 5 day exposure); unmeasured exposure
Fritioff et al.	Influence of Temperature and Salinity on Heavy Metal Uptake by Submersed Plants	2005	Non-applicable
Fujii and Sugiyama	Toxic effect of cadmium to early life stages of fishes and a simple method for toxicity evaluation of environmental pollutants	1983	Not applicable per ECOTOX Duluth; text in foreign language
Fulladosa et al.	Study on the Toxicity of Binary Equitoxic Mixtures of Metals Using the Luminescent Bacteria *Vibrio fischeri* as a Biological Target	2005	Mixture
Fulladosa et al.	Stress proteins induced by exposure to sublethal levels of heavy metals in sea bream (*Sparus sarba*) blood levels	2006	Excised tissue/cells
Gaal et al.	The Heavy Metal Content Of Fish In Lake Balaton The Danube And The Tisza From 1979-1982	1984	Bioaccumulation: steady state not documented
Gachter	Heavy Metal Toxicity and Synergism to Natural Phytoplankton (Untersuchungen Uber Die Beeinflussung Der Planktischen Photosynthese Durch Anorganische Metallsalze Im Eutrophen Alpnachersee Und Der Mesotrophen Horwer Bucht)	1976	Text in foreign language
Gachter and Geiger	Melimex, an Experimental Heavy Metal Pollution Study: Behaviour of Heavy Metals in an Aquatic Food Chain	1979	Mixture

Authors	Title	Year	Reason Unused
Gachter and Mares	Melimex, an Experimental Heavy Metal Pollution Study: Effects of Increased Heavy Metal Loads on Phytoplankton Communities	1979	Mixture
Gaete and Paredes	Toxicity of chemical pollutant mixtures towards *Daphnia magna*	1996	Non-applicable
Gagnaire et al.	In vitro effects of cadmium and mercury on Pacific oyster, *Crassostrea gigas* (Thunberg), haemocytes	2004	In vitro
Gagne et al.	Biomarker study of a municipal effluent dispersion plume in two species of freshwater mussels	2002	Effluent
Gagne et al.	Immunocompetence and Alterations in Hepatic Gene Expression in Rainbow Trout Exposed to Cds/Cdte Quantum Dots.	2010	Inappropriate toxicant
Gagnon et al.	Exposure of Caged Mussels to Metals in a Primary-Treated Municipal Wastewater Plume	2006	Effluent
Gale et al.	Aquatic Organisms and Heavy Metals in Missouri's New Lead Belt.	1973	Bioaccumulation: steady state not documented
Gale et al.	Lead, Zinc, Copper, and Cadmium in Fish and Sediment exposures from the Big River and Flat River Creek of Missouri's Old Lead Belt	2004	Bioaccumulation: steady state not documented
Gale et al.	Chronic Sublethal Sediment exposure Toxicity Testing Using the Estuarine Amphipod, *Melita plumulosa* (Zeidler): Evaluation Using Metal-Spiked and Field-Contaminated Sediment exposures	2006	Sediment exposure
Galic et al	Toxicity of cadmium and nitrilotriacetic acid in sea water to the photobacteria *Vibrio fisheri*	1987	The materials, methods or results were insufficiently described
Gallo et al.	The impact of metals on the reproductive mechanisms of the ascidian *Ciona intestinalis*	2011	Excised tissue/cells
Galvao et al.	Sudden Cadmium Increases in the Digestive Gland of Scallop, *Nodipecten nodosus* L., Farmed in the Tropics	2010	Bioaccumulation: steady state not documented
Gama-Flores et al.	Exposure time-dependent cadmium toxicity to *Moina macrocopa* (Cladocera): a life table demographic study	2007a	Pulsed exposure
Gama-Flores et al.	Effect of Pulsed Exposure to Heavy Metals (Copper and Cadmium) on Some Population Variables of *Brachionus calyciflorus* Pallas (Rotifera: Brachionidae: Monogononta)	2007b	Pulsed exposure
Gama-Flores et al.	Prey (*Brachionus calyciflorus* and *Brachionus havanaensis*) Exposed to Heavy Metals (Cu and Cd) for Different Durations and Concentrations Affect Predator's (*Asplanchna brightwellii*) Population Growth	2007c	Pulsed exposure
Gao et al.	Expression of metallothionein cDNA in a freshwater crab, *Sinopotamon yangtsekiense*, exposed to cadmium	2012	Dilution water not characterized
Garceau et al.	Inhibition of Goldfish Mitochondrial Metabolism by in Vitro Exposure to Cd, Cu and Ni	2010	In vitro
Garcia et al.	Comparative sensitivity of a tropical mysid metamysidopsis insularis and the temperate species *Americamysis bahia* to six toxicants	2008	Not North American species

Authors	Title	Year	Reason Unused
Garcia et al.	Age-related differential sensitivity to cadmium in *Hyalella curvispina* (Amphipoda) and implications in ecotoxicity studies	2010	Not North American species; test species fed
Garcia et al.	Age differential response of *Hyalella curvispina* to a cadmium pulse: Influence of sediment particle size	2012	Pulsed exposures; sediment present in test chambers
Garcia-Fernandez et al.	Heavy Metals in Tissues From Loggerhead Turtles (*Caretta caretta*) From the Southwestern Mediterranean (Spain)	2009	Bioaccumulation: steady state not documented
Garcia-Hernandez et al.	Concentrations of heavy metals in Sediment exposure and organisms during a harmful algal bloom (HAB) at Kun Kaak Bay, Sonora, Mexico	2005	Bioaccumulation: steady state not documented
Garcia-Santos et al.	Metabolic and osmoregulatory alterations and cell proliferation in gilthead seam bream (*Sparus aurata*) exposed to cadmium	2008	Injected toxicant
Garg and Chandra	The duckweed *Wolffia globosa* as an indicator of heavy metal pollution: sensitivity to Cr and Cd	1994	Excessive EDTA (>200 ug/L FeEDTA)
Garg et al.	Sublethal effects of heavy metals on biochemical composition and their recovery in Indian major carps	2009	Not North American species, unmeasured chronic exposure
Gargiulo et al.	Action of cadmium on the gills of *Carassius auratus* L. in the presence of catabolic NH_3	1996	No useable data on cadmium toxicity or bioconcentration
Gauley and Heikkila	Examination of the expression of the heat shock protein gene, hsp110, in *Xenopus laevis* cultured cells and embryos	2006	Cannot determine effect concentration, lack of details
Gaur et al.	Relationship between heavy metal accumulation and toxicity in *Spirodela polyrhiza* (L.) Schleid. and *Azolla pinnata* R	1994	Not North American species
Gauthier et al.	Metal effects on fathead minnows (*Pimephales promelas*) under field and laboratory conditions	2006	Mixture
Gauthier et al.	Condition and Pyloric Caeca as Indicators of Food Web Effects in Fish Living in Metal-Contaminated Lakes	2009	Bioaccumulation: steady state not documented
Geffard et al.	Relationships between metal bioaccumulation and metallothionein levels in larvae of *Mytilus galloprovincialis* exposed to contaminated estuarine Sediment exposure elutriate	2002	Sediment exposure
Geffard et al.	Bioaccumulation of Metals in Sediment exposure Elutriates and Their Effects on Growth, Condition Index, and Metallothionein Contents in Oyster Larvae	2007	Mixture
Geffard et al.	Effects of chronic dietary and waterborne cadmium exposures on the contamination level and reproduction of *Daphnia magna*	2008	Cannot determine effect concentration, lack of details
Geffard et al.	Ovarian cycle and embryonic development in *Gammarus fossarum*: Application for reproductive toxicity assessment	2010	Not North American species, only three exposure concentrations
George et al.	Effects of cadmium exposure on metal-containing amoebocytes of the oyster *Ostrea edulis*	1983	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Geret and Cosson	Induction of specific isoforms of metallothionein in mussel tissues after exposure to cadmium and mercury	2002	Bioaccumulation: steady state not documented; dilution water not characterized
Geret et al.	Effect of cadmium on antioxidant enzyme activities and lipid peroxidation in the gills of the clam *Ruditapes decussatus*	2002a	Dilution water not characterized, not North American species
Geret et al.	Influence of metal exposure on metallothionein synthesis and lipid peroxidation in two bivalve mollusks: The oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*)	2002b	Dilution water not characterized, only one exposure concentration
Gerhardt	Effects of subacute doses of cadmium on pH-stressed *Leptophlebia marginata* (L.) And *Baetis rhodani* Pictet (Insecta: Ephemeroptera)	1990	Dilution water not characterized, mixture, sediment
Gerhardt	Acute toxicity of Cd in stream invertebrates in relation to pH and test design	1992	Not North American species
Gerhardt	Review of Impact of Heavy Metals on Stream Invertebrates With Special Emphasis on Acid Conditions	1993	Review
Gerhardt	Joint and single toxicity of Cd and Fe related to metal uptake in the mayfly *Leptophlebia marginata* (L.) (Insecta)	1995	Not North American species
Gharbi-Bouraoui et al.	Field Study of Metal Concentrations and Biomarker Responses in the Neogastropod, *Murex trunculus*, From Bizerta Lagoon (Tunisia)	2008	Bioaccumulation: steady state not documented
Ghedira et al.	Metallothionein and metal levels in liver, gills and kidney of *Sparus aurata* exposed to sublethal doses of cadmium and copper	2010	Injected toxicant
Ghiasi et al.	Effects of low concentration of cadmium on the level of lysozyme in serum, leukocyte count and phagocytic index in *Cyprinus carpio* under the wintering conditions	2010	Only one exposure concentration
Ghidini et al.	Cd, Hg and As Concentrations in Fish Caught in the North Adriatic Sea	2003	Bioaccumulation: steady state not documented
Ghnaya et al.	Cd-induced growth reduction in the halophyte *Sesuvium portulacastrum* is significantly improved by NaCl	2007	Lack of details
Ghosh and Chakrabarti	Toxicity of arsenic and cadmium to a freshwater fish	1990	Not North American species
Giarratano et al.	Heavy metal toxicity in *Exosphaeroma gigas* (Crustacea, Isopoda) from the coastal zone of beagle channel	2007	Not North American species
Giesy and Wiener	Frequency Distributions of Trace Metal Concentrations in Five Freshwater Fishes	1977	Bioaccumulation: steady state not documented
Giguere et al.	Influence of lake chemistry and fish age on cadmium, copper, and zinc concentrations in various organs of indigenous yellow perch (*Perca flavescens*)	2004	Bioaccumulation: steady state not documented
Giguere et al.	Metal bioaccumulation and oxidative stress in yellow perch (*Perca flavescens*) collected from eight lakes along a metal contamination gradient (Cd, Cu, Zn, Ni)	2005	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Gil et al.	Heavy metal concentrations in the general population of Andalusia, South of Spain: A comparison with the population within the area of influence of Aznalcóllar mine spill (SW Spain)	2006	Bioaccumulation: steady state not documented
Giles	Accumulation of cadmium by rainbow trout, *Salmo gairdneri*, during extended exposure	1988	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Gillis et al.	Cadmium-Induced Production of a Metallothioneinlike Protein in *Tubifex tubifex* (Oligochaeta) and *Chironomus riparius* (Diptera): Correlation with Reproduction and Growth	2002	Non-applicable
Gillis et al.	Uptake and Depuration of Cadmium, Nickel, and Lead in Laboratory-Exposed *Tubefix tubifex* and Corresponding Changes in the Concentration of a Metallothionein-Like Protein	2004	Non-applicable
Gillis et al.	Metallothionein-Like Protein and Tissue Metal Concentrations in Invertebrates (Oligochaetes and Chironomids) Collected From Reference and Metal Contaminated Field Sediment exposures	2006a	Bioaccumulation: steady state not documented
Gillis et al.	Bioavailability of Sediment exposure-Associated Cu and Zn to *Daphnia magna*	2006b	Sediment exposure
Gingrich et al.	Zinc and cadmium metabolism in *Euglena gracilis*: metal distribution in normal and zinc-deficient cells	1984	No control group; only one exposure concentration
Gismondi et al.	Microsporidia parasites disrupt the responses to cadmium exposure in a gammarid	2012a	Multiple stressors (Cd and parasite)
Gismondi et al.	Acanthocephalan parasites: Help or burden in gammarid amphipods exposed to cadmium?	2012b	Not North American species
Gismondi et al.	Do male and female gammarids defend themselves differently during chemical stress?	2013	Not North American species, only two exposure concentrations
Giusto et al.	Cadmium toxicity assessment in juveniles of the Austral South America amphipod *Hyalella curvispina*.	2012	Not North American species; only 3 exposure concentrations, duration too long
Glubokov	Growth of three species of fish during early ontogeny under normal and toxic conditions	1990	The materials, methods or results were insufficiently described
Glynn	The concentration dependency of branchial intracellular cadmium distribution and influx in the zebrafish (*Brachydanio rerio*)	1996	Not North American species
Glynn	The Influence of Zinc on Apical Uptake of Cadmium in the Gills and Cadmium Influx to the Circulatory System in Zebrafish (*Danio rerio*)	2001	Mixture
Glynn et al.	Chronic toxicity and metabolism of Cd and Zn in juvenile minnows (*Phoxinus phoxinus*) exposed to a Cd and Zn mixture.	1992	Not North American species
Glynn et al.	Differences in uptake of inorganic mercury and cadmium in the gills of the zebrafish, *Brachydanio rerio*	1994	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Gnandi et al.	The Impact of Phosphate Mine Tailings on the Bioaccumulation of Heavy Metals in Marine Fish and Crustaceans from the Coastal Zone of Togo	2006	Bioaccumulation: steady state not documented
Goatcher et al.	Evaluation and Refinement of the Spirillum volutans Test for Use in Toxicity Screening	1984	Bacteria
Gold et al.	Effects of cadmium stress on periphytic diatom communities in indoor artificial streams	2003	No specific species
Golding et al.	Cadmium bioavailability to *Hyalella azteca* from a periphyton diet compared to an artificial diet and application of a biokinetic model	2013	Dietary exposure
Golding et al.	Validation of a chronic dietary cadmium bioaccumulation and toxicity model for *Hyalella azteca* exposed to field-contaminated periphyton and lake water	2011a	Prior exposure
Golding et al.	Modeling chronic dietary cadmium bioaccumulation and toxicity from periphyton to *Hyalella azteca*	2011b	Water and dietary exposure simultaneously
Gomez-Mendikute and Cajaraville	Comparative Effects of Cadmium, Copper, Paraquat and Benzo[a]pyrene on the Actin Cytoskeleton and Production of Reactive Oxygen Species (ROS) in Mussel Haemocytes	2003	In vitro
Gomot	Toxic effects of cadmium on reproduction, development, and hatching in the freshwater snail *Lymnaea stagnalis* for water quality monitoring	1998	No useable data on cadmium toxicity or bioconcentration
Gonzalez et al.	Comparative effects of direct cadmium contamination on gene expression in gills, liver, skeletal muscles and brain of zebrafish (*Danio rerio*)	2006	Bioaccumulation: steady state not documented
Gopal and Devi	Influence of nutritional status on the median tolerance limits (LC50) of *Ophiocephalus striatus* for certain heavy metal and pesticide toxicants	1991	Not North American species
Gopalakrishnan et al.	Comparison of heavy metal toxicity in life stages (spermiotoxicity, egg toxicity, embryotoxicity and larval toxicity) of *Hydroides elegans*	2008	Not North American species
Gordon et al.	*Mytilus californianus* as a bioindicator of trace metal pollution: Variability and statistical considerations	1980	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Gorman and Skogerboe	Speciation of cadmium in natural waters and their effect on rainbow trout	1987	The materials, methods or results were insufficiently described
Gorski and Nugegoda	Sublethal toxicity of trace metals to larvae of the blacklip abalone, *Haliotis rubra*.	2006a	Dilution water not characterized, high control mortality (<13%), not North American species
Gorski and Nugegoda	Toxicity of trace metals to juvenile abalone, *Haliotis rubra* following short-term exposure	2006b	Dilution water not characterized, not North American species
Gosselin and Hare	Effect of Sedimentary exposure Cadmium on the Behavior of a Burrowing Mayfly (Ephemeroptera, Hexagenia limbata)	2004	Sediment exposure
Goto and Wallace	Interaction of Cd and Zn During Uptake and Loss in the Polychaete *Capitella capitata*: Whole Body and Subcellular Perspectives	2007	Mixture

Authors	Title	Year	Reason Unused
Goto and Wallace	Relevance of intracellular partitioning of metals in prey to differential metal bioaccumulation among populations of mummichogs (*Fundulus heteroclitus*)	2009a	Bioaccumulation: steady state not documented
Goto and Wallace	Influences of prey- and predator-dependent processes on cadmium and methylmercury trophic transfer to mummichogs (*Fundulus heteroclitus*)	2009b	Dietary exposure
Gottofrey and Tjalve	Axonal transport of cadmium in the olfactory nerve of the pike	1991	Organisms were exposed to cadmium in food or by injection or gavage
Gottofrey et al.	Effect of sodium isopropylxanthate, potassium amylxanthate and sodium diethyldithiocarbamate or the uptake and distribution of cadmium in the brown trout (*Salmo trutta*)	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Goulet et al.	Dynamic multipathway modeling of Cd bioaccumulation in *Daphnia magna* using waterborne and dietary exposures	2007	Dietary exposure
Grabowski and Trybus	Some Results on Toxicity of Heavy Metals, Fly Ash and Chemical Solvents as Measured by the Method of a Substrate (FDA) With Fluorogenic Product (Badania Toksycznosci Metali Ciezkich, Pylu Lotnego I Rozpuszczalnikow Chemicznych Metoda Substratu Z Fluorogennym Produktem)	2001	Text in foreign language
Grajeda Y Ortega et al.	Cadmium, iron, and zinc uptake individually and as a mixture by *Limnodrillus hoffmeisteri* and impact on adenosine triphosphate content	2008	Sediment exposure
Graney et al.	The influence of substrate, pH, diet and temperature upon cadmium accumulation in the asiatic clam (*Corbicula fluminea*) in laboratory artificial streams	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Green and Williams	A continuous flow toxicity testing apparatus for macroinvertebrates	1983	Cannot determine effect concentration; testing methodology; no cadmium toxicity information
Green et al.	The acute and chronic toxicity of cadmium to different life history stages of the freshwater crustacean *Asellus aquaticus* (L)	1986	Not North American species
Greenwood and Fielder	Acute toxicity of zinc and cadmium to zoeae of three species of portnid crabs (Crustacea: Brachyura)	1983	Not North American species
Greichus et al.	Insecticides, Polychlorinated Biphenyls and Metals in African Lake Ecosystems. II. Lake Mcilwaine, Rhodesia	1978	Bioaccumulation: steady state not documented
Greig	Trace metal uptake by three species of mollusks	1979	Questionable treatment of test organisms or inappropriate test conditions or methodology
Greig and Wenzloff	Metal accumulation and depuration by the american oyster, *Crassostrea virginica*	1978	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water

Authors	**Title**	**Year**	**Reason Unused**
Griscom and Fisher	Uptake of Dissolved Ag, Cd, and Co by the Clam, *Macoma balthica*: Relative Importance of Overlying Water, Oxic Pore Water, and Burrow Water	2002	Mixture
Griscom et al.	Effects of Gut Chemistry in Marine Bivalves on the Assimilation of Metals from Ingested Sediment exposure Particles	2002a	Sediment exposure
Griscom et al.	Kinetic modeling of Ag, Cd and Co bioaccumulation in the clam *Macoma balthica*: quantifying Dietary exposure and dissolved sources	2002b	Modeling
Gross et al.	Lethal and sublethal effects of chronic cadmium exposure on northern leopard frog (*Rana pipiens*) tadpoles	2007	High control mortality (60%)
Gross et al.	Critical period of sensitivity for effects of cadmium on frog growth and development	2009	Only two exposure concentrations
Gstoettner and Fisher	Accumulation of cadmium, chromium, and zinc by the moss *Sphagnum papillosum* Lindle	1997	Bioaccumulation: not renewal or flow-through
Gu et al.	The toxic effect of Hg2+ and Cd2+ combined pollution on *Myriophyllum verticillatum* Linn	2001	Text in foreign language
Guan and Wang	Multipahse biokinetic modeling of cadmium accumulation in *Daphnia magna* from dietary and aqueous sources	2006c	Bioaccumulation: steady state not documented, dietary exposure
Guan and Wang	Cd and Zn uptake kinetics in *Daphnia magna* to Cd exposure history	2004a	Dietary exposure and prior exposure
Guan and Wang	Dietary assimilation and elimination of Cd, Se, and Zn by *Daphnia magna* at different metal concentrations	2004b	Dietary exposure
Guan and Wang	Multigenerational cadmium acclimation and biokinetics in *Daphnia magna*	2006a	Dietary exposure
Guan and Wang	Comparison between two clones of *Daphnia magna*: effects of multigenerational cadmium exposure on toxicity, individual fitness, and biokinetics	2006b	Lack of detail
Guardiola et al.	Accumulation, histopathology and immunotoxicological effects of waterborne cadmium on gilthead seabream (*Sparus aurata*)	2013	Only two exposure concentrations
Gueguen et al.	Competition Between Alga (*Pseudokirchneriella subcapitata*), Humic Substances and EDTA for Cd and Zn Control in the Algal Assay Procedure (AAP) Medium	2003	Mixture
Guerin et al.	Effects of cadmium on survival, osmoregulatory ability and bioenergetics of juvenile blue crabs *Callinectes sapidus* at different salinities.	1994	The materials, methods or results were insufficiently described
Guilhermino et al.	Inhibition of acetylcholinesterase activity as effect criterion in acute tests with juvenile *Daphnia magna*.	1997	Review of previously published data
Gul et al.	Investigation of Zinc, Copper, Lead and Cadmium Accumulation in the Tissues of *Sander lucioperca* (L., 1758) Living in Hirfanli Dam Lake, Turkey.	2011	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Gully and Mason	Cytosolic redistribution and enhanced accumulation of Cu in gill tissue of *Littorina littorea* as a result of Cd exposure	1993	Mixture (Cu and Cd), Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Guner	Effects of Copper and Cadmium Interaction on Total Protein Levels in Liver of *Carassius carassius*	2008	Mixture
Gunkel et al.	A Fish Test on the Basic of the Avoidance Reaction (Die Fluchtreaktion Von Fischen Als Grundlage Eines Fischtests).	1983	Text in foreign language
Guo et al.	Effect of dissolved organic matter on the uptake of trace metals by American oysters	2001	Mixture
Guo et al.	Levels and Bioaccumulation of Organochlorine Pesticides (OCPS) and Polybrominated Diphenyl Ethers (PBDES) in Fishes From the Pearl River Estuary and Daya Bay, South China	2008	Bioaccumulation: steady state not documented
Gupta and Devi	Uptake and toxicity of cadmium in aquatic ferns	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Gupta and Rajbanshi	Toxicity of copper and cadmium to *Heteropneustes fossilis* (Bloch)	1991	Not North American species
Gupta et al.	Effects of long-term low-dose exposure to cadmium during the entire life cycle of *Ceratopteris thalictroides*, a water fern	1992	Not North American species
Gupta et al.	Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad	2009	Bioaccumulation: steady state not documented
Gust and Fleeger	Exposure-related effects on Cd bioaccumulation explain toxicity of Cd-phenanthrene mixtures in *Hyalella azteca*	2005	Bioaccumulation: steady state not documented (only 96 hour exposure)
Gust and Fleeger	Exposure to Cadmium-Phenanthrene Mixtures Elicits Complex Toxic Responses in the Freshwater Tubificid Oligochaete, *Ilyodrilus templetoni*	2006	Non-applicable
Guthrie and Cherry	Trophic Level Accumulation of Heavy Metals in a Coal Ash Basin Drainage System	1979	Bioaccumulation: steady state not documented
Guven and De Pomerai	Differential Expression of Hsp70 Proteins in Response to Heat and Cadmium in *Caenorhabditis elegans*	1995	Mixture
Guven et al.	Heavy Metals Concentrations in Marine Algae From the Turkish Coast of the Black Sea	2007	Bioaccumulation: steady state not documented
Guzman-Garcia et al.	Effects of heavy metals on the oyster (*Crassostrea virginica*) at Mandinga Lagoon, Veracruz, Mexico.	2009	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Hackstein	Changes in the Population Dynamics of *Gammarus tigrinus* Sexton (Crustacea: Amphipoda) as Expression of Sublethal Effects by Reciprocal Interactions of Temperature and Cadmium Enriched Food (Die Veranderung Populations Dynamischer Parameter Bei Gammarus Tigrinus Sexton (Crustacea: Amphipoda) Ala Ausdruck Subletaler Effekte Durch Die Wechselwirkung Von Temperatur Und Cadmium Kontaminiertem Futter)	1988	Text in foreign language
Hader et al.	The Erlanger flagellate test (EFT): photosynthetic flagellates in biological dosimeters	1997	Not North American species
Hadjispyrou et al.	Toxicity, Bioaccumulation, and Interactive Effects of Organotin, Cadmium, and Chromium on Artemia franciscana	2001	Mixture
Haines and Brumbaugh	Metal concentration in the gill, gastrointestinal tract, and carcass of white suckers (*Catostomus commersoni*) in relation to lake acidity	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hakanson	Metals in Fish and Sediments From the River Kolbacksan Water System, Sweden	1984	Sediment
Hall	Studies of Striped Bass in Three Chesapeake Bay Spawning Habitats	1988	Mixture
Hall and Brown	Copper and Manganese Influence the Uptake of Cadmium in Marine Macroalgae	2002	Mixture
Hall et al.	Effects of organic and inorganic chemical contaminants on fertilization, hatching success, and prolarval survival of striped bass	1984	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hall et al.	Survival of Striped Bass Larvae and Yearlings in Relation to Contaminants and Water Quality in the Upper Chesapeake Bay	1987a	Mixture
Hall et al.	*In situ* striped bass (*Morone saxatilis*) contaminant and water quality studies in the Potomac River	1987b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hall et al.	Concurrent mobile on-site and *in situ* striped bass contaminant and water quality studies in the Choptank River and upper Chesapeake Bay	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hall et al.	Ambient Toxicity Testing in the Chesapeake Bay Watershed Using Freshwater and Estuarine Water Column Tests	1992	Mixture
Hall et al.	A ten-year summary of concurrent ambient water column and Sediment exposure toxicity tests in the Chesapeake Bay watershed: 1990-1999	2002	Review
Hamed and Emara	Marine Molluscs as Biomonitors for Heavy Metal Levels in the Gulf of Suez, Red Sea	2006	Bioaccumulation: steady state not documented
Hameed and Muthukumaravel	Impact of cadmium on the biochemical constituents of fresh water fish *Oreochromis mossambicus*.	2006	Lack of exposure details, dilution water not characterized
Hammock et al.	The effect of humic acid on the uptake of mercury(II), cadmium(II), and zinc(II) by Chinook salmon (*Oncorhynchus tshawytscha*) eggs	2003	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Hanafy and Soltan	Comparative changes in absorption, distribution and toxicity of copper and cadmium chloride in toads during the hibernation and the role of vitamin C against their toxicity	2007	Dietary exposure, not North American species
Handy	The effect of acute exposure to dietary Cd and Cu organ toxicant concentrations in rainbow trout, *Oncorhynchus mykiss*	1993	Organisms were exposed to cadmium in food or by injection or gavage
Handy	Dietary Exposure to Toxic Metals in Fish	1996	Review
Hannam et al.	Immune Modulation in the Blue Mussel *Mytilus edulis* Exposed to North Sea Produced Water	2009	Mixture
Hannas et al.	Regulation and Dysregulation of Vitellogenin MRNA Accumulation in Daphnids (*Daphnia magna*).	2011	In vitro
Hansen et al.	Accumulation of copper, zinc, cadmium and chromium by the marine sponge *Halichondria panicea* Pallas and the implications for biomonitoring	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hansen et al.	Behavioral Avoidance: Possible Mechanism for Explaining Abundance and Distribution of Trout Species in a Metal-Impacted River	1999	Mixture
Hansen et al.	Gill Metal Binding and Stress Gene Transcription in Brown Trout (*Salmo trutta*) Exposed to Metal Environments: the Effect of Pre-Exposure in Natural Populations	2007a	Pre-exposure
Hansen et al.	Induction and activity of oxidative stress-related proteins during waterborne Cd/Zn exposure in brown trout (*Salmo trutta*)	2007b	Mixture
Hanson and Evans	Metal Contaminant Assessment For The Southeast Atlantic And Gulf Of Mexico Coasts: Results Of The National Benthic Surveillance Project Over The First Four Years 1984-87	1992	Review
Hansten et al.	Viability of glochidia of *Anodonta anatina* (Unionidae) exposed to selected metals and chelating agents	1996	Not North American species
Harada et al.	Shortened Lifespan of Nematode *Caenorhabditis elegans* After Prolonged Exposure to Heavy Metals and Detergents	2007	Mixture
Hardy and O'Keeffe	Cadmium uptake by the water hyacinth: Effects of root mass, solution volume, complexers and other metal ions	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hardy and Raber	Zinc uptake by the water hyacinth: Effect of solution factors	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hare	Aquatic insects and trace metals: bioavailability, bioaccumulation, and toxicity	1992	Review of previously published data
Hare et al.	Trace Element Distributions in Aquatic Insects: Variations Among Genera, Elements, and Lakes	1991a	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Hare et al.	Dynamics of cadmium, lead, and zinc exchange between nymphs of the burrowing mayfly *Hexagenia rigida* (Ephemeroptera) and the environment	1991b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hare et al.	A field study of metal toxicity and accumulation by benthic invertebrates; implications for the acid-volatile sulfide (AVS) model	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hare et al.	Cadmium Accumulation by Invertebrates Living at the Sediment exposure-Water Interface	2001	Sediment exposure
Haritonidis et al.	Trace metal interactions in the macroalga *Enteromorpha prolifera* (O.F. Muller) grown in water of the Scheldt estuary (Belgium and SW Netherlands), in response to cadmium exposure	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Harper et al.	Effects of Acclimation on the Toxicity of Stream Water Contaminated with Zinc and Cadmium to Juvenile Cutthroat Trout	2008	Mixture
Harper et al.	Trout Density and Health in a Stream With Variable Water Temperatures and Trace Element Concentrations: Does a Cold-Water Source Attract Trout to Increased Metal Exposure?	2009	Mixture
Hartmann	Synergistic Effects of Heavy Metal Ions on the Activity of Bacteria and Other Aquatic Microorganisms	1980	Bacteria
Hartmann et al.	Algal Testing of Titanium Dioxide Nanoparticles - Testing Considerations, Inhibitory Effects and Modification of Cadmium Bioavailability	2010	Mixture
Hartmann et al.	The Potential of Tio2 Nanoparticles as Carriers for Cadmium Uptake in *Lumbriculus variegatus* and *Daphnia magna*	2012	Mixture
Hartwell	Demonstration of a toxicological risk ranking method to correlate measures of ambient toxicity and fish community diversity	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hartwell et al.	Avoidance Responses of Schooling Fathead Minnows (Pimephales Promelas) to a Blend of Metals During a 9-Month Exposure.	1987	Mixture
Hartwell et al.	Fish Behavioral Assessment of Pollutants.	1988	Mixture
Harvey and Luoma	Separation of solute and particulate vectors of heavy metal uptake in controlled suspension-feeding experiments with *Macoma balthica*	1985a	No useable data on cadmium toxicity or bioconcentration
Harvey et al.	Contaminant Concentrations in Whole-Body Fish and Shellfish From US Estuaries	2008	Bioaccumulation: steady state not documented
Hashemi et al.	Copper resistance in *Anabaena variabilis*: effects of phosphate nutrition and polyphosphate bodies	1994	Not applicable; No cadmium toxicity information
Hashim and Chu	Biosorption by brown, green, and red seaweeds	2004	Not in vivo study
Hashim et al.	Adsorption equilibria of cadmium on algal biomass	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	Title	Year	Reason Unused
Has-Schon et al.	Heavy Metal Profile in Five Fish Species Included in Human Diet, Domiciled in the End Flow of River Neretva (Croatia)	2006	Bioaccumulation: steady state not documented
Has-Schon et al.	Heavy Metal Concentration in Fish Tissues Inhabiting Waters of "Busko Blato" Reservoir (Bosnia and Herzegovina)	2008a	Bioaccumulation: steady state not documented
Has-Schon et al.	Heavy Metal Distribution in Tissues of Six Fish Species Included in Human Diet, Inhabiting Freshwaters of the Nature Park (Bosnia and Herzegovina)	2008b	Bioaccumulation: steady state not documented
Hatakeyama	Chronic effects of Cd on reproduction of *Polypedilum nubifer* (Chironomidae) through water and food	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hatakeyama and Yasuno	The effects of cadmium-accumulated *Chlorella* on the reproduction of *Moina macrocopa* (Cladocera)	1981a	Organisms were not exposed to cadmium in water
Hatakeyama et al.	Flora and Fauna in Heavy Metal Polluted Rivers. I. Density of *Epeorus latifolium* (Ephemeroptera) and Heavy Metal Concentrations of *Baetis spp*. (Ephemeroptera) Relating to Cd, Cu and Zn Concentrations.	1986	Text in foreign language
Hatano and Shoji	Toxicity of Copper and Cadmium in Combinations to Duckweed Analyzed by the Biotic Ligand Model	2008	Mixture
Hattink et al.	The toxicokinetics of cadmium in carp under normoxic and hypoxic conditions	2005	Species tested is a hybrid of wild and domestic populations
Haye et al.	Protective Role of Alginic Acid Against Metal Uptake by American Oyster (*Crassostrea virginica*)	2006	Mixture
Haynes et al.	Gender-dependent problems in toxicity tests with *Ceriodaphnia dubia*	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hazen and Kneip	Biogeochemical cycling of cadmium in a marsh ecosystem	1980	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Hedouin et al.	Allometric Relationships in the Bioconcentration of Heavy Metals by the Edible Tropical Clam *Gafrarium tumidum*	2006	Bioaccumulation: steady state not documented
Hedouin et al.	Trends in Concentrations of Selected Metalloid and Metals in Two Bivalves From the Coral Reefs in the SW Lagoon of New Caledonia	2009	Bioaccumulation: steady state not documented
Heininger et al.	Nematode Communities in Contaminated River Sediment exposures	2006	Sediment exposure
Heinis et al.	Short-term sublethal effects of cadmium on the filter feeding chironomid larva *Glyptotendipes pallens* (Meigen) (Diptera)	1990	Not North American species
Heit and Klusek	Trace Element Concentrations in the Dorsal Muscle of White Suckers and Brown Bullheads From Two Acidic Adirondack Lakes	1985	Bioaccumulation: steady state not documented
Heit et al.	Trace Element, Radionuclide, and Polynuclear Aromatic Hydrocarbon Concentrations in Unionidae Mussels From Northern Lake George.	1980	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Hendriks	Modelling equilibrium concentrations of microcontaminants in organisms of the Rhine delta: Can average field residues in the aquatic food chain be predicted from laboratory accumulation?	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hendrix et al.	Microcosms as test systems for the ecological effects of toxic substances: an appraisal with cadmium	1981	Mixed species exposure, only three exposure concentrations
Henebry and Ross	Use of Protozoan Communities to Assess the Ecotoxicological Hazard of Contaminated Sediments.	1989	Mixture
Henry et al.	Contamination accidentelle par le cadmium d'un mollusque *Rudifapes decussatus*: bioaccumulation et toxicite	1984	Not North American species
Henry et al.	Heavy metals in four fish species from the French coast of the Eastern English Channel and Southern Bight of the North Sea	2004	Bioaccumulation: steady state not documented
Herkovits and Perez-Coll	Stage -dependent susceptibility of *Bufo arenarum* embryos to cadmium	1993	Not North American species
Herkovits and Perez-Coll	Zinc protection against delayed development produced by cadmium	1990	Not North American species, only one exposure concentration
Herkovits and Perez-Coll	Increased resistance against cadmium toxicity by means of pretreatment with low cadmium-zinc concentrations in *Bufo arenarum* embryos	1995	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Hermesz et al.	Tissue-specific expression of two metallothionein genes in common carp during cadmium exposure and temperature shock	2001	No control exposure, dilution water not characterized
Hernandez et al.	Accumulation of toxic metals (Pb and Cd) in the sea urchin *Diadema aff. antillarum* Philippi, 1845, in an oceanic island (Tenerife, Canary Islands)	2010	Bioaccumulation: steady state not documented
Herve-Fernandez et al.	Cadmium bioaccumulation and retention kinetics in the Chilean blue mussel *Mytilus chilensis*: seawater and food exposure pathways	2010	Not North American species
Herwig et al.	Bioaccumulation and histochemical localization of cadmium in *Dreissena polymorpha* exposed to cadmium chloride	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Heugens et al.	Population growth of *Daphnia magna* under multiple stress conditions: joint effects of temperature, food, and cadmium	2006	Excessive EDTA (testing used Elendt M7 medium which complexes the metal)
Heugens et al.	Temperature-dependent effects of cadmium on *Daphnia magna*: accumulation versus sensitivity	2003	Excessive EDTA (testing used Elendt M7 medium which complexes the metal)
Hewitt et al.	Influence of water quality and associated contaminants on survival and growth of the endangered Cape Fear shiner (*Notropis mekistocholas*)	2006	Mixture
Heydari et al.	Cadmium and Lead Concentrations in Muscles and Livers of Stellate Sturgeon (*Acipenser stellatus*) From Several Sampling Stations in the Southern Caspian Sea.	2011	Bioaccumulation: steady state not documented
Hickey and Clements	Effects of heavy metals on benthic macroinvertebrate communities in New Zealand streams	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Hickey and Martin	Relative sensitivity of five benthic invertebrate species to reference toxicants and resin-acid contaminated sediments	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hickey and Roper	Acute toxicity of cadmium to two species of infaunal marine amphipods (tube-dwelling and burrowing) from New Zealand	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hildebrand et al.	The Potential Toxicity and Bioaccumulation in Aquatic Systems of Trace Elements Present in Aqueous Coal Conversion Effluents	1976	Effluent
Hinck et al.	Chemical Contaminants, Health Indicators, and Reproductive Biomarker Responses in Fish From the Colorado River and Its Tributaries	2007	Bioaccumulation: steady state not documented
Hinrichsen and Tran	A Circadian Clock Regulates Sensitivity to Cadmium in *Paramecium tetraurelia*	2010	Bacteria
Hiraoka	Reduction of Heavy Metal Content in Hiroshima Bay Oysters (*Crassostrea gigas*) by Purification	1991	Bioaccumulation: steady state not documented
Hiraoka et al.	Acute toxicity of 14 different kinds of metals affecting medaka (*Oryzias latipes*) fry	1985	Not North American species
Hoang and Klaine	Influence of organism age on metal toxicity to *Daphnia magna*	2007	No cadmium toxicity information
Hockett and Mount	Use of metal chelating agents to differentiate among sources of acute aquatic toxicity	1996	Only 5 organisms per concentration and excessive chelant used
Hockner et al.	Coping with cadmium exposure in various ways: the two helicid snails *Helix pomatia* and *Cantareus aspersus* share the metal transcription factor-2, but differ in promoter organization and transcription of their Cd-metallothionein genes	2009	Dietary exposure
Hofer et al.	Organochlorine and Metal Accumulation in Fish (*Phoxinus phoxinus*) Along a North-South Transect in the Alps	2001	Bioaccumulation: steady state not documented
Hofslagare et al.	Cadmium effects on photosynthesis and nitrate assimilation in *Scenedesmus obliquus*. A potentiometric study in an open CO_2-system	1985	The materials, methods or results were insufficiently described
Hogstrand et al.	The importance of metallothionein for the accumulation of copper, zinc and cadmium in environmentally exposed perch, *Perca fluviatilis*	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hollis et al.	Does the age of metal-dissolved organic carbon complexes influence binding of metals to fish gills?	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hollis et al.	Influence of dissolved organic matter on copper binding, and calcium on cadmium binding by gills of rainbow trout	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hollis et al.	Tissue-specific cadmium accumulation, metallothionein induction, and tissue zinc and copper levels during chronic sublethal cadmium exposure in juvenile rainbow trout	2001	Dietary exposure
Hollis et al.	Protective Effects of Calcium Against Chronic Waterborne Cadmium Exposure to Juvenile Rainbow Trout	2000b	Prior exposure

Authors	Title	Year	Reason Unused
Holmes et al.	Trace-Metal Content in Antipatharian Corals From the Jacksonville Lithoherm, Florida	2006	Bioaccumulation: steady state not documented
Hongve et al.	Effect of heavy metals in combination with NTA, humic acid, and suspended sediment on natural phytoplankton photosynthesis	1980	Lack of exposure details; mixed species exposure
Hook and Fisher	Reproductive toxicity of metals in calanoid copepods	2001	Dietary exposure
Hook and Fisher	Relating the Reproductive Toxicity of Five Ingested Metals in Calanoid Copepods with Sulfur Affinity	2002	Dietary exposure
Hook and Lee	Interactive Effects of UV, Benzo(a)Pyrene, and Cadmium on DNA Damage and Repair in Embryos of the Grass Shrimp *Paleomonetes pugio*	2004	Mixture
Hooten and Carr	Development and application of a marine sediment pore-water toxicity test using *Ulva fasciata* zoospores	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hopkins et al.	Responses of benthic fish exposed to contaminants in outdoor microcosms--examining the ecological relevance of previous laboratory toxicity tests	2004	Non-applicable
Horike et al.	Usefulness of flagellar regeneration in *Dunaliella sp*. as an endpoint for the bioassay of seawater pollution	2002	Text in foreign language
Horng et al.	Effects of Sediment exposure-Bound Cd, Pb, and Ni on the Growth, Feeding, and Survival of *Capitella sp*.	2009	Sediment exposure
Hornstrom	Toxicity test with algae - a discussion on the batch method	1990	Review of previously published data
Hoss et al.	Toxicity of cadmium to *Caenorhabditis elegans* (nematoda) in whole sediment and pore water-the ambiguous role of organic matter	2001	Sediment exposure
Hsiao et al.	The Bioconcentration of Trace Metals in Dominant Copepod Species Off the Northern Taiwan Coast	2006	Bioaccumulation: steady state not documented
Hsu et al.	Sublethal levels of cadmium down-regulate the gene expression of DNA mismatch recognition protein MutS homolog 6 (MSH6) in zebrafish (*Danio rerio*) embryos	2010	Dilution water not characterized
Hu et al.	Cadmium accumulation by several seaweeds	1996	Not North American species
Hu et al.	Bioaccumulation and chemical forms of cadmium, copper and lead in aquatic plants	2010	Bioaccumulation: steady state not documented
Hu et al.	Combined Effects of Titanium Dioxide and Humic Acid on the Bioaccumulation of Cadmium in Zebrafish	2011a	Mixture
Hu et al.	Root-induced changes to cadmium speciation in the rhizosphere of two rice (*Oryza sativa* L.) genotypes	2011b	Sediment (soil) exposure
Huang et al.	Bioaccumulation of silver, cadmium and mercury in the abalone Haliotis diversicolor from water and food sources	2008	Bioaccumulation: steady state not documented (only 7 day exposure)
Huang et al.	Cadmium and copper accumulation and toxicity in the macroalga *Gracilaria tenuistipitata*	2010a	Bioaccumulation: unmeasured exposure

Authors	Title	Year	Reason Unused
Huang et al.	Responses of abalone *Haliotis diversicolor* to sublethal exposure of waterborne and dietary silver and cadmium	2010b	Not North American species, dilution water not characterized, only one exposure concentration
Huang et al.	Differential protein expression of kidney tissue in the scallop *Patinopecten yessoensis* under acute cadmium stress	2011a	Dilution water not characterized; Not North American species
Huang et al.	Alteration of heart tissue protein profiles in acute cadmium-treated scallops *Patinopecten yessoensis*	2011b	Dilution water not characterized; Not North American species
Huebert and Shay	The effect of cadmium and its interaction with external calcium in the submerged aquatic macrophyte *Lemna trisulca* L.	1991	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebert and Shay	Zinc toxicity and its interaction with cadmium in the submerged aquatic macrophyte *Lemna trisulca* L.	1992	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebert and Shay	The response of *Lemna trisulca* L. to cadmium	1993	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebert et al.	The effect of EDTA on the assessment of Cu toxicity in the submerged aquatic macrophyte, *Lemna trisulca* L	1993	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebner and Pynnonen	Viability of glochidia of two species of *Anodonta* exposed to low pH and selected metals	1992	Not North American species
Huelya	Seasonal Variations of Heavy Metals in Water, Sediment exposures, Pondweed (P. Pectinatus L.) And Freshwater Fish (C. C. Umbla) of Lake Hazar (Elazig-Turkey)	2009	Bioaccumulation: steady state not documented
Huiskes and Nieuwenhuize	Uptake Of Heavy Metals From Contaminated Sediment exposures By Salt-Marsh Plants	1990	Sediment exposure
Hung	Effects of temperature and chelating agents on cadmium uptake in the American oyster	1982	Questionable treatment of test organisms or inappropriate test conditions or methodology
Hung et al.	Trace metals in different species of mollusca, water and Sediment exposures from Taiwan coastal area	2001	Bioaccumulation: steady state not documented
Hungspreugs et al.	Heavy Metals and Polycyclic Hydrocarbon Compounds in Benthic Organisms of the Upper Gulf of Thailand.	1984	Bioaccumulation: steady state not documented
Husaini et al.	Cadmium toxicity to photosynthesis and associated electron transport system of *Nostoc linckia*	1991	Not North American species
Hutcheson	The effects of temperature and salinity on cadmium uptake by the blue crab, *Callinectes sapidus*	1975	Questionable treatment of test organisms or inappropriate test conditions or methodology
Hutchins et al.	Transcriptomic Signatures in *Chlamydomonas reinhardtii* as Cd Biomarkers in Metal Mixtures	2010	Mixture
Hutchinson and Collins	Effect of H+ Ion Activity and Ca2+ on the Toxicity of Metals in the Environment	1978	Review
Hylland et al.	Interactions between eutrophication and contaminants. IV. Effects on sediment-dwelling organisms	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Iannacone and Alvarino	Acute ecotoxicity of heavy metals using juveniles of freshwater snail *Physa venustula* (Gould, 1847)	1999	Not applicable per ECOTOX Duluth; text in foreign language
Idardare et al.	Metal Concentrations in Sediment exposure and *Nereis diversicolor* in Two Moroccan Lagoons: Khnifiss and Oualidia	2008	Bioaccumulation: steady state not documented
Ieradi et al.	Mutagenicity test and heavy metals in teleost fish from Tiber River (Rome, Italy)	1996	Bioaccumulation: steady state not documented
Iftode et al.	Action of a heavy ion, Cd^{2+}, and the antagonistic effect of Ca^{2+}, on two ciliates *Tetrahymena pyriformis* and *Euplotes vannus*.	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Ikemoto et al.	Biomagnification of Trace Elements in the Aquatic Food Web in the Mekong Delta, South Vietnam Using Stable Carbon and Nitrogen Isotope Analysis	2008	Bioaccumulation: steady state not documented
Ikuta	A Comparison On Heavy Metal Contents Between *Batillus cornutus* And *Babylonia japonica*	1985a	Bioaccumulation: steady state not documented
Ikuta	Distribution And Localization Of Some Heavy Metals In Female And Male Of A Herbivorous Gastropod *Haliotis discus*	1985b	Bioaccumulation: steady state not documented
Ikuta	Distribution Of Heavy Metals In Female And Male Of A Herbivorous Gastropod *Batillus cornutus*	1985c	Bioaccumulation: steady state not documented
Ikuta	Distribution Of Heavy Metals In Female And Male Of A Scallop *Patinopecten yessoensis*	1985d	Bioaccumulation: steady state not documented
Ikuta	Cadmium accumulation by a top shell *Batillus cornutus*	1987	Not North American species
Ilangovan et al.	Effect of cadmium and zinc on respiration and photosynthesis in suspended and immobilized cultures of *Chlorella vulgaris* and *Scenedesmus acutus*	1998	No interpretable concentration, time, response data or examined only a single exposure concentration
Iliopoulou-Georgudaki and Kotsanis	Toxic effects of cadmium and mercury in rainbow trout (*Oncorhynchus mykiss*): a short-term bioassay	2001	Injected pollutant
Illuminati et al.	Cadmium bioaccumulation and metallothionein induction in the liver of the Antarctic teleost *Trematomus bernacchii* during an on-site short-term exposure to the metal via seawater	2010	Bioaccumulation: steady state not documented
Ingersoll et al.	Toxicity of Sediment exposure Cores Collected From the Ashtabula River in Northeastern Ohio, USA, to the Amphipod *Hyalella azteca*	2009	Sediment exposure
Inza et al.	Dynamics of cadmium and mercury compounds (inorganic mercury or methylmercury): uptake and depuration in *Corbicula fluminea*. Effects of temperature and pH	1998	Sediment; mixture (Hg and Cd)
Ip et al.	Heavy metal and Pb isotopic compositions of aquatic organisms in the Pearl River Estuary, South China	2005	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Irato and Piccinni	Effects of cadmium and copper on *Astasia longa*: Metal uptake and glutathione levels	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Irving et al.	Ecotoxicological responses of the mayfly *Baetis tricaudatus* to dietary and waterborne cadmium: Implications for toxicity testing	2003	High control mortality (19%)
Isani et al.	Cadmium accumulation and biochemical responses in *Sparus aurata* following sub-lethal Cd exposure	2009	Bioaccumulation: steady state not documented; not North American species
Ismail and Yusof	Effect of mercury and cadmium on early life stages of java medaka (*Oryzias javanicus*): A potential tropical test fish	2011	Not North American species, unmeasured chronic exposure
Issa et al.	Abolition of heavy metal toxicity on *Kirchneriella lunaris* (Chlorophyta) by calcium	1995	No interpretable concentration, time, response data or examined only a single exposure concentration
Issartel et al.	Cellular and molecular osmoregulatory responses to cadmium exposure in *Gammarus fossarum* (Crustacea, Amphipoda)	2010	Not North American species, only one exposure concentration
Ivanina and Sokolova	Effects of cadmium exposure on expression and activity of p-glycoprotein in eastern oysters, *Crassostrea virginica* Gmelin	2008	Unmeasured, non-renewal or flow-through chronic exposure, only one exposure concentration
Ivanina et al.	Interactive effects of cadmium and hypoxia on metabolic responses and bacterial loads of eastern oysters *Crassostrea virginica* Gmelin	2011	Mixture (Cd and hypoxia)
Ivanina et al.	Effects of cadmium on anaerobic energy metabolism and mrna expression during air exposure and recovery of an intertidal mollusk *Crassostrea virginica*	2010a	Only one exposure concentration
Ivanina et al.	Effects of cadmium exposure and intermittent anoxia on nitric oxide metabolism in eastern oysters, *Crassostrea virginica*	2010b	Only one exposure concentration
Ivanina and Sokolova	Interactive effects of pH and metals on mitochondrial functions of intertidal bivalves *Crassostrea virginica* and *Mercenaria mercenaria*	2013	Only one exposure concentration
Ivorra et al.	Metal-induced tolerance in the freshwater microbenthic diatom Gomphonema parvulum	2002a	No cadmium toxicity information
Ivorra et al.	Responses of Biofilms to Combined Nutrient and Metal Exposure	2002b	Mixture
Iwasaki and Ormerod	Estimating safe concentrations of trace metals from inter-continental field data on river macroinvertebrates.	2012	Bioaccumulation: steady state not documented
Jaafarzadeh et al.	Cadmium Determination in Two Flat Fishes From Two Fishery Regions in North of the Persian Gulf.	2011	Bioaccumulation: steady state not documented
Jak et al.	Evaluation of laboratory derived toxic effect concentrations of a mixture of metals by testing freshwater plankton communities in enclosure	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Jamers et al.	An omics based assessment of cadmium toxicity in the green alga *Chlamydomonas reinhardtii*	2012	Only two exposure concentrations

Authors	**Title**	**Year**	**Reason Unused**
James et al.	Metamorphosis of two amphibian species after chronic cadmium exposure in outdoor aquatic mesocosms	2005	Duration too short, non-renewal or flow-through chronic exposure
Jana and Sahana	Effects of copper, cadmium and chromium cations on the freshwater fish *Clarias batrachus* L.	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Janati-Idrissi et al.	Effect of cadmium on reproduction of daphnids in a small aquatic microcosm	2001	Dietary exposure, lack of details
Jankovska et al.	Concentrations of Zn, Mn, Cu and Cd in different tissues of perch (*Perca fluviatilis*) and in perch intestinal parasite (*Acanthocephalus lucii*) from the stream near Prague (Czech Republic).	2012	Bioaccumulation: steady state not documented
Janssen and Persoone	Rapid toxicity screening tests for aquatic biota. I. Methodology and experiments with *Daphnia magna*	1993	The materials, methods or results were insufficiently described
Janssens de Bisthoven et al.	The concentration of cadmium, lead, copper and zinc in *Chironomus thummi* larvae (Diptera, Chironomidae) with deformed versus normal menta	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Janssens De Bisthoven et al.	Morphological deformities in Chironomus riparius meigen larvae after exposure to cadmium over several generations	2001	Dietary exposure
Jara-Marini et al.	Trophic Relationships and Transference of Cadmium, Copper, Lead and Zinc in a Subtropical Coastal Lagoon Food Web From SE Gulf of California	2009	Bioaccumulation: steady state not documented
Javanshir et al.	Impact of water hardness on cadmium absorption by four freshwater mollusks *Physa fontinalis, Anodonta cygnea, Corbicula fluminea* and *Dreissena polymorpha* from south Caspian Sea region	2011	Mixture, only one exposure concentration
Javed and Greger	Cadmium triggers *Elodea canadensis* to change the surrounding water pH and thereby Cd uptake	2011	Sediment exposure
Jaworska et al.	Effect of metal ions on the entomopathogenic nematode *Heterorhabditis bacteriophora poinar* (Nematoda: Heterohabditidae) under laboratory conditions	1997	The materials, methods or results were insufficiently described
Jay and Muncy	Toxicity to Channel Catfish of Wastewater From an Iowa Coal Beneficiation Plant	1979	Mixture
Jebali et al.	Effects of malathion and cadmium on acetylcholinesterase activity and metallothionein levels in the fish *Seriola dumerilli*	2006	Injected toxicant
Jeitner and Burger	Metal Concentrations (Arsenic, Cadmium, Chromium, Lead, Mercury and Selenium) in Dolly Varden (*Salvelinus malma*) From the Aleutian Islands, Alaska	2009	Bioaccumulation: steady state not documented
Jenkins and Mason	Relationships between subcellular distributions of cadmium and perturbations in reproduction in the polychaete *Neanthes arenaceodentata*	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies

Authors	**Title**	**Year**	**Reason Unused**
Jenkins and Sanders	Relationships between free cadmium ion activity in seawater, cadmium accumulation and subcellular distibution, and growth in polychaetes	1986	Not North American species, Inappropriate medium of medium contained too much of a complexing agent for algal studies
Jenner and Bowmer	The Accumulation of Metals and Their Toxicity in the Marine Intertidal Invertebrates *Cerastoderma edule*, *Macoma balthica*, and *Arenicola marina* Exposed to Pulverized Fuel Ash in Mesocosms.	1990	Mixture
Jenner and Janssen-Mommen	Phytomonitoring of Pulverized Fuel Ash Leachates by the Duckweed (*Lemna minor*)	1989	Mixture
Jenner and Janssen-Mommen	Duckweed *Lemna minor* as a tool for testing toxicity of coal residues and polluted sediments	1993	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Jennett et al.	Some Effects of Century Old Abandoned Lead Mining Operations on Streams in Missouri, USA	1981	Bioaccumulation: steady state not documented
Jennings and Rainbow	Accumulation of cadmium by *Dunaliella tertiolecta* Butcher	1979b	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
Jensen et al.	Variation in cadmium uptake, feeding rate, and life-history effects in the gastropod Potamopyrgus antipodarum: linking toxicant effects on individuals to the population level	2001	Sediment exposure
Jerez et al.	Accumulation and tissue distribution of heavy metals and essential elements in loggerhead turtles (*Caretta caretta*) from Spanish Mediterranean coastline of Murcia	2010	Bioaccumulation: steady state not documented
Jezierska et al.	The effect of temperature and heavy metals on heart rate changes in common carp *Cyprinus carpio* L. and grass carp *Ctenopharyngodon idella* (Val.) during embryonic development	2002	Duration too short, only one exposure concentration
Jia et al.	Low Levels of Cadmium Exposure Induce DNA Damage and Oxidative Stress in the Liver of Oujiang Colored Common Carp *Cyprinus carpio* var. color	2011	In vitro
Jiang et al.	Heavy Metal Exposure Reduces Hatching Success of *Acartia pacifica* Resting Eggs in the Sediment exposure	2007	Sediment exposure
Jing et al.	Acute effect of copper and cadmium exposure on the expression of heat shock protein 70 in the Cyprinidae fish *Tanichthys albonubes*	2013	Excised tissue/cells
Jiraungkoorskul et al.	Micronucleus test: the effect of ascorbic acid on cadmium exposure in fish (*Puntius altus*)	2007a	Lack of detail, Mixture
Jiraungkoorskul et al.	The effect of ascorbic acid on cadmium exposure in the gills of *Puntius altus*	2007b	Not North American species, only one exposure concentration
Jiraungkoorskul et al.	Micronucleus Test: the Effect of Ascorbic Acid on Cadmium Exposure in Fish (*Puntius altus*)	2010	Mixture

Authors	Title	Year	Reason Unused
Jofre et al.	Lead and Cadmium Accumulation in Anuran Amphibians of a Permanent Water Body in Arid Midwestern Argentina	2011	Bioaccumulation: steady state not documented
John et al.	Influence of aquatic humus and pH on the uptake and depuration of cadmium by the Atlantic salmon (*Salmo salar* L.)	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured, Bioaccumulation: not renewal or flow-through
Johns	Spatial Distribution of Total Cadmium, Copper, and Zinc in the Zebra Mussel (*Dreissena polymorpha*) Along the Upper St. Lawrence River	2001	Bioaccumulation: steady state not documented
Johns	Trends of Total Cadmium, Copper, and Zinc in the Zebra Mussel (*Dreissena Polymorpha*) Along the Upper Reach of the St. Lawrence River: 1994-2005.	2012	Bioaccumulation: steady state not documented
Johnson et al.	The Use of Periphyton as a Monitor of Trace Metals in Two Contaminated Indiana Lakes	1978	Bioaccumulation: steady state not documented
Jones et al.	Silver and Other Metals in Some Aquatic Bryophytes From Streams in the Lead Mining District of Mid-Wales, Great Britain	1985	Bioaccumulation: steady state not documented
Jones et al.	Cadmium delays growth hormone expression during rainbow trout development	2001	Bioaccumulation: steady state not documented (duration unknown)
Jonker et al.	Toxicity of Binary Mixtures of Cadmium-Copper and Carbendazim-Copper to the Nematode *Caenorhabditis elegans*	2004	Mixture
Jonnalagadda and Rao	Toxicity, bioavailability and metal speciation	1993	Review of previously published data
Jop	Concentration of metals in various larval stages of four *Ephemeroptera* species	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Jop et al.	Analysis of Metals in Blue Crabs, *Callinectes sapidus*, From Two Connecticut Estuaries	1997	Bioaccumulation: steady state not documented
Jost and Zauke	Trace Metal Concentrations in Antarctic Sea Spiders (*Pycnogonida*, *Pantopoda*)	2008	Bioaccumulation: steady state not documented
Juarez-Franco et al.	Effect of cadmium and zinc on the population growth *of Brachionus havanaensis* (Rotifera: Brachionidae)	2007	Not North American species, duration too short
Juhasza et al.	Comparative Study on the Expression of Glutathione Peroxidase, Glutathione Reductase, Glutathione Synthetase and Metallothionein Genes in Common Carp During Cadmium Exposure	2012	Abstract only
Julshamn et al.	Trace Elements Intake in the Faroe Islands. I. Element Levels in Edible Parts of Pilot Whales (*Globicephalus meleanus*)	1987	Bioaccumulation: steady state not documented
Julshamn et al.	Cadmium, lead, copper and zinc in blue mussels (*Mytilus edulis*) sampled in the Hardangerfjord, Norway	2001	Bioaccumulation: steady state not documented
Julshamn et al.	Concentrations of mercury and other toxic elements in orange roughy, *Hoplostethus atlanticus*, from the Mid-Atlantic Ridge.	2011	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Jung and Zauke	Bioaccumulation of Trace Metals in the Brown Shrimp *Crangon crangon* (Linnaeus, 1758) from the German Wadden Sea	2008	Bioaccumulation: steady state not documented
Jung et al.	Spatial Distribution of Heavy Metal Concentrations and Biomass Indices in *Cerastoderma edule* Linnaeus (1758) From the German Wadden Sea: an Integrated Biomonitoring Approach	2006	Bioaccumulation: steady state not documented
Jurewa and Blanuwa	Mercury, arsenic, lead and cadmium in fish and shellfish from the Adriatic Sea	2003	Bioaccumulation: steady state not documented
Kadioglu and Ozbay	Effects of heavy metals on chlorophyll content and cell colony number in *Chlamydomonas reinhardii*	1995	Lack of exposure details; cannot determine effect concentration
Kahle	Bioaccumulation of trace metals in the copepod *Calanoides acutus* from the Weddell Sea (Antarctica): comparison of two-compartment and hyperbolic toxicokinetic models	2002	Bioaccumulation: steady state not documented
Kahle and Zauke	Bioaccumulation of trace metals in the calanoid copepod *Metridia gerlachei* from the Weddell Sea (Antarctica)	2002	Bioaccumulation: steady state not documented
Kahle and Zauke	Bioaccumulation of Trace Metals in the Antarctic Amphipod *Orchomene plebs*: Evaluation of Toxicokinetic Models	2003a	Bioaccumulation: steady state not documented
Kahle and Zauke	Trace metals in Antarctic copepods from the Weddell Sea (Antarctica)	2003b	Bioaccumulation: steady state not documented
Kaitala et al.	The Effect of Copper, Cadmium, Zinc and Pentachlorophenolate on Heterotrophic Activity and Primary Production	1983	Abstract only
Kalafatic et al.	The impairments of neoblast division in regenerating planarian *Polycelis felina* (Daly.) caused by in vitro treatment with cadmium sulfate	2004	In vitro
Kalman et al.	Comparative Toxicity of Cadmium in the Commercial Fish Species *Sparus aurata* and *Solea senegalensis*	2010a	Injected toxicant
Kalman et al.	Biodynamic Modelling of the Accumulation of Ag, Cd and Zn by the Deposit-Feeding Polychaete *Nereis diversicolor*: Inter-Population Variability and a Generalised Predictive Model	2010b	Modeling
Kamala-Kannan et al.	Assessment of Heavy Metals (Cd, Cr and Pb) in Water, Sediment exposure and Seaweed (*Ulva lactuca*) in the Pulicat Lake, South East India	2008	Bioaccumulation: steady state not documented
Kamunde	Early subcellular partitioning of cadmium in gill and liver of rainbow trout (*Oncorhynchus mykiss*) following low-to-near-lethal waterborne cadmium exposure	2009	Bioaccumulation: steady state not documented
Kamunde and MacPhail	Subcellular interactions of dietary cadmium, copper and zinc in rainbow trout (*Oncorhynchus mykiss*)	2011a	Dietary exposure
Kamunde and MacPhail	Metal-metal interactions of dietary cadmium, copper and zinc in rainbow trout, *Oncorhynchus mykiss*	2011b	Dietary exposure
Kamunde et al	Effect of humic acid during concurrent chronic waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium and zinc	2011	Mixture

Authors	Title	Year	Reason Unused
Kangwe et al.	Heavy metal inhibition of calcification and photosynthetic rates of the geniculate calcareous alga *Amphiroa tribulus*	2001	Lack of details
Kaonga et al.	Accumulation of Lead, Cadmium, Manganese, Copper and Zinc by Sludge Worms *Tubifex tubifex* in Sewage Sludge	2010	Effluent
Kaoud and Rezk	Effect of exposure to cadmium on the tropical freshwater prawn *Macrobrachium rosenbergii*	2011	Dilution water not characterized
Kapauan et al.	Cadmium, Lead, Copper And Zinc In Philippine Aquatic Life	1982	Bioaccumulation: steady state not documented
Kaplan et al.	Cadmium toxicity and resistance in *Chlorella sp*	1995	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Kar and Aditya	Impact of heavy metal and pesticide on total protein content in intact and regenerating *Hydra*	2010	Only one exposure concentration
Kara	Physiological and toxicological effects of lead plus cadmium mixtures on rainbow trout (*Oncorhynchus mykiss*) in soft acidic water	2010	Only two exposure concentrations; dilution water not characterized
Kara and Zeytunluoglu	Bioaccumulation of Toxic Metals (Cd and Cu) by *Groenlandia densa* (L.) Fourr	2007	Non-applicable
Karadede-Akin and Unlu	Heavy Metal Concentrations in Water, Sediment exposure, Fish and Some Benthic Organisms from Tigris River, Turkey	2007	Bioaccumulation: steady state not documented
Karasov et al.	Field Exposure of Frog Embryos and Tadpoles Along a Pollution Gradient in the Fox River and Green Bay Ecosystem in Wisconsin, USA	2005	Mixture
Karayakar et al.	Seasonal Variation in Copper, Zinc, Chromium, Lead and Cadmium Levels in Hepatopancreas, Gill and Muscle Tissues of the Mussel (*Ibrachidontes pharaonis*) Fischer, Collected Along the Mersin Coast, Turkey	2007	Bioaccumulation: steady state not documented
Kargin et al.	Distribution of Heavy Metals in Different Tissues of the Shrimp *Penaeus semiculatus* and *Metapenaeus monocerus* from the Iskenderun Gulf, Turkey: Seasonal Variations	2001	Bioaccumulation: steady state not documented
Karlsson-Norrgren and Runn	Cadmium dynamics in fish: Pulse studies with ^{109}Cd in female zebrafish, *Brachydanio rerio*	1985	Not North American species
Karouna-Renier et al.	Accumulation of Organic and Inorganic Contaminants in Shellfish Collected in Estuarine Waters Near Pensacola, Florida: Contamination Profiles and Risks to Human Consumers	2007	Bioaccumulation: steady state not documented
Karthik et al.	Synergistic effect of cadmium in combination with UV-B radiations in PS II photochemistry of the cyanobacterium *Spirulina platensis*	2011	Only three exposure concentrations
Karuppasamy et al.	Haematological responses to exposure to sublethal concentration of cadmium in air breathing fish, *Channa punctatus* (Bloch)	2005	Dilution water not characterized, only one exposure concentration, not North American species

Authors	Title	Year	Reason Unused
Kasherwani et al.	Cadmium induced skeletal deformities in freshwater catfish, *Heteropneustes fossilis* (Bloch)	2007	Unmeasured chronic exposure, not North American species, only one exposure concentration
Kasherwani et al.	Cadmium toxicity to freshwater catfish, *Heteropneustes fossilis* (Bloch)	2009	Not North American species
Kaska and Furness	Heavy metals in marine turtle eggs and hatchlings in the Mediterranean	2001	Bioaccumulation: steady state not documented
Kasuga	Sexual differences of medaka, *Oryzias latipes* in the acute toxicity test of cadmium	1980	Not North American species
Kato	Studies on Toxicity of Chemical Substances (Heavy Metals Etc.) To Fish and Animal	1973	Text in foreign language
Katsikatsou et al.	Field studies on the relation between the accumulation of heavy metals and metabolic and HSR in the bearded horse mussel *Modiolus barbatus*	2011	Bioaccumulation: steady state not documented
Katsumiti et al.	An Assessment of Acute Biomarker Responses in the Demersal Catfish *Cathorops spixii* After the Vicuna Oil Spill in a Harbour Estuarine Area in Southern Brazil	2009	Mixture
Katti and Sathyanesan	Chronic effects of lead and cadmium on the testis of the catfish *Clarias batrachus*	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kavun	Content of Microelements in the Grass Shrimp *Pandalus kessleri* (Decapoda: Pandalidae) From Coastal Waters of the Lesser Kurilskaya Ridge	2008	Bioaccumulation: steady state not documented
Kavun et al.	Metal accumulation in mussels of the Kuril Islands, North-west Pacific Ocean	2002	Bioaccumulation: steady state not documented
Kawamata et al.	Contents of Heavy Metals in Fishes in Nagano Prefecture	1983	Bioaccumulation: steady state not documented
Kay et al.	Cadmium accumulation and protein binding patterns in tissues of the rainbow trout, *Salmo gairdneri*	1986	The materials, methods or results were insufficiently described
Kayhan et al.	Cadmium (Cd) and Lead (Pb) Levels of Mediterranean Mussel (*Mytilus galloprovincialis* Lamarck, 1819) From Bosphorus, Istanbul, Turkey	2007	Bioaccumulation: steady state not documented
Kayser	Cadmium effects in food chain experiments with marine plankton algae (Dinophyta) and benthic filter-feeders (Tunicata)	1982	Lack of exposure details; dilution water not characterized
Ke and Wang	Trace Metal Ingestion and Assimilation by the Green Mussel *Perna viridis* in a Phytoplankton and Sediment exposure Mixture	2002	Sediment exposure
Ke and Wang	Bioaccumulation of Cd, Se, and Zn in an estuarine oyster (*Crassostrea rivularis*) and a coastal oyster (*Saccostrea glomerata*)	2001	Bioaccumulation: steady state not documented (only 2 hour exposure); not renewal of flow-through exposure; not North American species
Keduo et al.	Effects os six heavy metals on hatching eggs and survival of larval of marine fish	1987	Not North American species

Authors	Title	Year	Reason Unused
Keenan and Alikhan	Comparative study of cadmium and lead accumulations in *Cambarus bartoni* (Fab.) (Decapoda, Crustacea) from an acidic and a neutral lake	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Keil et al.	Significance and Interspecific Variability of Accumulated Trace Metal Concentrations in Antarctic Benthic Crustaceans	2008	Bioaccumulation: steady state not documented
Kelly and Whitton	Interspecific differences in Zn, Cd and Pb accumulation by freshwater algae and bryophytes	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kemble et al.	Toxicity of Metal-Contaminated Sediments From the Upper Clark Fork River, Montana, to Aquatic Invertebrates and Fish in Laboratory Exposures	1994	Mixture
Kennedy and Benson	Report Of Heavy Metal Analysis Conducted On Mussel *Mytilus edulis* Samples Collected At 55 Sites In Newfoundland	1994	Bioaccumulation: steady state not documented
Kennedy and Farrell	Immunological Alterations in Juvenile Pacific Herring, *Clupea pallasi*, Exposed to Aqueous Hydrocarbons Derived From Crude Oil	2008	Mixture
Kerfoot and Jacobs	Cadmium accrual in combined waste-treatment aquaculture system	1976	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Keskin et al.	Cadmium, Lead, Mercury and Copper in Fish From the Marmara Sea, Turkey	2007	Bioaccumulation: steady state not documented
Kessler	An extremely cadmium-sensitive strain of *Chlorella*	1985	The materials, methods or results were insufficiently described
Kessler	Limits of growth of five *Chlorella* species in the presence of toxic heavy metals	1986	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Keteles and Fleeger	The Contribution of Ecdysis to the Fate of Copper, Zinc and Cadmium in Grass Shrimp, *Palaemonetes pugio* Holthius	2001	Non-applicable
Kettle and deNoyelles	Effects of cadmium stress on the plankton communities of experimental ponds	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Khaled	Trace Metals in Fish of Economic Interest From the West of Alexandria, Egypt	2009	Bioaccumulation: steady state not documented
Khaleghzadeh-Ahangar et al.	The parasitic nematodes *Hysterothylacium sp*. type MB larvae as bioindicators of lead and cadmium: a comparative study of parasite and host tissues	2011	Bioaccumulation: steady state not documented
Khalil et al.	Effect of tapeworm parasitisation on cadmium toxicity in the bioindicator copepod, *Cyclops strenuous*	2014	Only one exposure concentration
Khan and Nugegoda	Sensitivity of juvenile freshwater crayfish *Cherax destructor* (Decapoda: Parastacidae) to trace metals	2007	Not North American species
Khan and Weis	Bioaccumulation of heavy metals in two populations of mummichog (*Fundulus heteroclitus*)	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Khan et al.	Bioaccumulation of four heavy metals in tow populations of grass shrimp, *Palaemonetes pugio*	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Khan et al.	Cadmium bound to metal rich granules and exoskeleton from *Gammarus pulex* causes increased gut lipid peroxidation in zebrafish following single dietary exposure	2010	Bioaccumulation: not renewal or flow-through; fed toxicant
Khangarot and Ray	Correlation between heavy metal acute toxicity values in *Daphnia magna* and fish	1987a	Review of previously published data
Khangarot and Ray	Sensitivity of toad tadpoles, *Bufo melanostictus* (Schneider), to heavy metals	1987b	Not North American species
Khangarot et al.	*Daphnia magna* as a model to assess heavy metal toxicity: Comparative assessment with mouse system	1987	The materials, methods or results were insufficiently described
Khoshmanesh et al.	Cadmium uptake by unicellular green microalgae	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Khoshmanesh et al.	Cell surface area as a major parameter in the uptake of cadmium by unicellular green microalgae	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Khosravi et al.	Toxic Effect of Pb, Cd, Ni and Zn on *Azolla filiculoides* in the International Anzali Wetland	2005	Mixture
Khoury et al.	Relating disparity in competitive foraging behavior between two populations of fiddler crabs to the subcellular partitioning of metals	2009	Mixture
Khristoforova et al.	Effect of cadmium on gametogenesis and offspring of the sea urchin *Strongylocentrotus intermedius*	1984	Not North American species
Khristoforova et al.	Heavy Metals in Mass Species of Bivalves in Ha Long Bay (South China Sea, Vietnam)	2007	Bioaccumulation: steady state not documented
Kiffney and Clements	Effects of Heavy Metals on a Macroinvertebrate Assemblage From a Rocky Mountain Stream in Experimental Microcosms.	1994	Mixture
Kiffney and Clements	Effects of heavy metals on a macroinvertebrate assemblage from a rocky mountain stream in experimental microcosms	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kilemade et al.	Genotoxicity of Field-Collected Inter-tidal Sediment exposures from Cork Harbor, Ireland, to Juvenile Turbot (*Scophthalmus maximus* L.) as Measured by the Comet Assay	2004	Sediment exposure
Kim et al.	The Geographic Distribution of Population Health and Contaminant Body Burden in Gulf of Mexico Oysters	2001	Bioaccumulation: steady state not documented
Kim et al.	Effect of Dietary exposure Cadmium on Growth and Haematological Parameters of Juvenile Rockfish, *Sebastes schlegeli* (Hilgendorf)	2004a	Dietary exposure

Authors	**Title**	**Year**	**Reason Unused**
Kim et al.	Cadmium accumulation and elimination in tissues of juvenile olive flounder, *Paralichthys olivaceus* after sub-chronic cadmium exposure	2004b	Dilution water not characterized; Bioaccumulation: unmeasured exposure; not North American species
Kim et al.	Kinetics of Cd Accumulation and Elimination in Tissues of Juvenile Rockfish (*Sebastes schlegeli*) Exposed to Dietary exposure Cd	2006	Dietary exposure
Kim et al.	Molecular Cloning of *Daphnia magna* Catalase and Its Biomarker Potential Against Oxidative Stresses	2010a	In vitro
Kim et al.	Expression Profiles of Seven Glutathione S-Transferase (GST) Genes in Cadmium-Exposed River Pufferfish (*Takifugu obscurus*)	2010b	In vitro
Kim et al.	Effects of Montmorillonite on Alleviating Dietary Cd-Induced Oxidative Damage in Carp (*Carassius auratus*)	2011a	Fed toxicant
Kim et al.	Perfluorooctane sulfonic acid exposure increases cadmium toxicity in early life stage of zebrafish, *Danio rerio*	2011b	Mixture
Kim et al.	8-Oxoguanine DNA Glycosylase 1 (Ogg1) From the Copepod *Tigriopus japonicus*: Molecular Characterization and Its Expression in Response to UV-B and Heavy Metals	2012b	Mixture
Kim et al.	Effect of cadmium exposure on expression of antioxidant gene transcripts in the river pufferfish, *Takifugu obscurus* (Tetraodontiformes)	2010c	Dilution water not characterized
King and Riddle	Effects of metal contaminants on the development of the common antarctic sea urchin *Sterechinus neumayeri* and comparisons of sensitivity with tropical and temperate echinoids	2001	Not North American species, duration too long
King et al.	Short-term accumulation of Cd and Cu from water, sediment and algae by the amphipod Melita plumulosa and the bivalve *Tellina deltoidalis*	2005	Sediment exposure; not North American species
King et al.	Acute toxicity and bioaccumulation of aqueous and sediment-bound metals in the estuarine amphipod *Melita plumulosa*	2006	Not North American species, control mortality (≥75%)
King et al.	Toxicity of metals to the bivalve *Tellina deltoidalis* and relationships between metal bioaccumulation and metal partitioning between seawater and marine sediments	2010	Not North American species; sediment
Kir et al.	Heavy Metal Concentrations in Organs of Rudd, *Scardinus erythrophthalmus* L.,1758 Populating Lake Karatas-Turkey	2006	Bioaccumulation: steady state not documented
Kiran et al.	Trace Metal Levels in the Organs of Finfish *Oreochromis mossambicus* (Peter) and Relevant Water of Jannapura Lake, India	2006	Bioaccumulation: steady state not documented
Kirby et al.	Changes in Selenium, Copper, Cadmium, and Zinc Concentrations in Mullet (*Mugil cephalus*) from the Southern Basin of Lake Macquarie, Australia, in Response to Alteration of Coal-Fired Power Station Fly Ash Handling Procedures	2001a	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Kirby et al.	Selenium, Cadmium, Copper, and Zinc Concentrations in Sediment exposures and Mullet (*Mugil cephalus*) from the Southern Basin of Lake Macquarie, NSW, Australia	2001b	Bioaccumulation: steady state not documented
Kiser et al.	Impacts and pathways of mine contaminants to bull trout (*Salvelinus confluentus*) in an Idaho watershed.	2010	Bioaccumulation: steady state not documented
Klaverkamp and Duncan	Acclimation to cadmium toxicity by white suckers: Cadmium binding capacity and metal distribution in gill and liver cytosol	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kleinert et al.	Concentration of Metals in Fish	1974	Bioaccumulation: steady state not documented
Klerks et al.	Effects of Ghost Shrimp on Zinc and Cadmium in Sediment exposures From Tampa Bay, Fl	2007	Sediment exposure
Klerks and Bartholomew	Cadmium accumulation and detoxification in a Cd-resistant population of the oligochaete *Limnodrilus hoffmeisteri*	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Klinck et al.	Branchial cadmium and copper binding and intestinal cadmium uptake in wild yellow perch (*Perca flavescens*) from clean and metal-contaminated lakes	2007	Prior exposure
Klinck et al.	Cadmium Accumulation and In Vitro Analysis of Calcium and Cadmium Transport Functions in the Gastro-intestinal Tract of Trout Following Chronic Dietary exposure Cadmium and Calcium Feeding	2009	Dietary exposure
Klinck et al.	In Vitro Characterization of Cadmium Transport Along the Gastro-Intestinal Tract of Freshwater Rainbow Trout (*Oncorhynchus mykiss*)	2011	In vitro
Kline et al.	Effects of Pollution on Freshwater Organisms	1987	Review
Kljakovic-Gaspic et al.	A. Distribution of cadmium and lead in *Posidonia oceanica* (L.) delile from the middle Adriatic sea	2004	Bioaccumulation: steady state not documented
Kljakovic-Gaspic et al.	Biomonitoring of Trace Metals (Cu, Cd, Cr, Hg, Pb, Zn) in the Eastern Adriatic Using the Mediterranean Blue Mussel (2001-2005)	2006	Bioaccumulation: steady state not documented
Klochenko et al.	Some Peculiarities of Accumulation of Heavy Metals by Macrophytes and Epiphyton Algae in Water Bodies of Urban Territories	2007	Bioaccumulation: steady state not documented
Kluttgen and Ratte	Effects of different food doses on cadmium toxicity to *Daphnia magna*	1994	Organisms were exposed to cadmium in food or by injection or gavage
Kluytmand et al.	Effects of cadmium on the reproduction of *Mytilus edulis* L.	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Knauer and Martin	Seasonal Variations of Cadmium, Copper, Manganese, Lead and Zinc and in Water and Phytoplankton in Monterey Bay, California	1973	Bioaccumulation: steady state not documented
Kneip	Effects of Cadmium in an Aquatic Environment	1978	Review

Authors	**Title**	**Year**	**Reason Unused**
Kneip and Hazen	Deposit and mobility of cadmium in marsh-cove ecosystem and the relation to cadmium concentration in biota	1979	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Kobayashi	Fertilized sea urchin eggs as an indicator material for marine pollution bioassay, preliminary experiments	1971	Not North American species
Kobayashi and Okamura	Effects of heavy metals on sea urchin embryo development. Part 2. Interactive toxic effects of heavy metals in synthetic mine effluents	2005	Effluent
Koca et al.	Genotoxic and Histopathological Effects of Water Pollution on Two Fish Species, *Barbus capito pectoralis* and *Chondrostoma nasus* in the Menderes River, Turkey	2008	Mixture
Kock et al.	Accumulation of trace metals (Cd, Pb, Cu, Zn) in Arctic char (*Salvelinus alpinus*) from oligotrophic alpine lakes: Relation to alkalinity	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kock et al.	Seasonal Patterns of Metal Accumulation in Arctic Char (*Salvelinus alpinus*) From an Oligotrophic Alpine Lake Related to Temperature	1996	Bioaccumulation: steady state not documented
Koelmans et al.	Influence of salinity and mineralization on trace metal sorption to cyanobacteria in natural waters	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kogan et al.	Effect of cadmium ions on *Chlorella* II: modification of the UV irridation effect	1975	Text in foreign language
Kohler and Riisgard	Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilus edulis*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Koivisto et al.	Does cadmium pollution change trophic interactions in rockpool food webs?	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kojadinovic et al.	Bioaccumulation of Trace Elements in Pelagic Fish From the Western Indian Ocean	2007	Bioaccumulation: steady state not documented
Kola and Wilkinson	Cadmium Uptake by a Green Alga can be Predicted by Equilibrium Modelling	2005	Modeling
Kolok et al.	Individual variation in the swimming performance of fishes: An overlooked source of variation in toxicity studies	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kolyuchkina and Ismailov	Morpho-functional characteristics of bivalve mollusks under the experimental environmental pollution by heavy metals	2011	Only two exposure concentrations
Komjarova and Blust	Multi-Metal Interactions Between Cd, Cu, Ni, Pb and Zn in Water Flea *Daphnia magna*, a Stable Isotope Experiment	2008	Mixture
Komjarova and Blust	Effect of Na, Ca and Ph on Simultaneous Uptake of Cd, Cu, Ni, Pb, and Zn in the Water Flea *Daphnia magna* Measured Using Stable Isotopes	2009	Mixture

Authors	Title	Year	Reason Unused
Kondera and Witeska	Cadmium-induced alterations in heady kidney hematopoietic tissue of common carp	2012	Only one exposure concentration
Kooijman and Bedaux	Analysis of toxicity tests on *Daphnia* survival and reproduction	1996	Review of previously published data
Koop	Untersuchungen Ueber Die Schwermetallanreicherung In Fischen Aus Schwermetallbelasteten Gewaessern Im Hinblick Auf Deren Fischereiliche Nutzung. (Studies On Heavy Metal Enrichment In Fish From Waters Polluted By Heavy Metals With Reference To Their Use By The Fishing Industry)	1991	Mixture
Kopecka-Pilarczyk	The effect of pesticides and metals on acetylcholinesterase (AChE) in various tissues of blue mussel (*Mytilus trossulus* L.) in short-term in vivo exposures at different temperatures	2010	Mixture
Kopfler and Mayer	Concentrations of Five Trace Metals in the Waters and Oysters (*Crassostrea virginica*) of Mobile Bay, Alabama	1973	Bioaccumulation: steady state not documented
Korda et al.	Trace Elements in Samples of Fish, Sediment and Taconite From Lake Superior	1977	Bioaccumulation: steady state not documented
Kosakowska et al.	Effect of amino acids on the toxicity of heavy metals to phytoplankton	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Kosanovic et al.	Influence of Urbanization of the Western Coast of the United Arab Emirates on Trace Metal Content in Muscle and Liver of Wild Red-Spot Emperor (*Lethrinus lentjan*)	2007	Bioaccumulation: steady state not documented
Koskinen et al.	Response of rainbow trout transcriptome to model chemical contaminants	2004	Dilution water not characterized, only two exposure concentrations, duration too short
Kostaropoulos et al.	Effects of Exposure to a Mixture of Cadmium and Chromium on Detoxification Enzyme (GST, P450-MO) Activities in the Frog *Rana ridibunda*	2005	Mixture
Kovacik et al.	Comparison of methyl jasmonate and cadmium effect on selected physiological parameters in *Scenedesmus quadricauda* (Chlorophyta, Chlorophyceae)	2011	Dilution water not characterized
Kovarova et al.	Effect of metals, with special attention of Cd, content of the Svitava and Svratka rivers on levels of thiol compounds in fish liver and their use as biochemical markers	2009	Bioaccumulation: steady state not documented
Koyama et al.	The seawater fish for evaluation of the toxicity of pollutants	1992	The materials, methods or results were insufficiently described
Kraak et al.	Chronic ecotoxicity of mixtures of Cu, Zn, and Cd to the zebra mussel *Dreissena polymorpha*	1993a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Kraak et al.	Toxicity of heavy metals to the zebra mussel (*Dreissena polymorpha*)	1993b	No interpretable concentration, time, response data or examined only a single exposure concentration
Kraak et al.	Ecotoxicity of mixtures of metals to the zebra mussel *Dreissena polymorpha*	1994b	Review of previously published data
Kraal et al.	Uptake and tissue distribution of dietary and aqueous cadmium by carp (*Cyprinus carpio*)	1995	No useable data on cadmium toxicity or bioconcentration
Kraemer et al.	Dynamics of Cd, Cu and Zn accumulation in organs and sub-cellular fractions in field transplanted juvenile yellow perch (*Perca flavescens*)	2005	Mixture
Kraemer et al.	Modeling Cadmium Accumulation in Indigenous Yellow Perch (*Perca flavescens*)	2008	Modeling
Krantzberg	Accumulation of essential and nonessential metals by chironomid larvae in relation to physical and chemical properties of the elements	1989a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krantzberg	Metal accumulation by chironomid larvae: the effects of age and body weight on metal body burdens	1989b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krantzberg and Stokes	The importance of surface adsorption and pH in metal accumulation by chironomids	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krantzberg and Stokes	Metal regulation, tolerance, and body burdens in the larvae of the genus *Chironomus*	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krasnov et al.	Hepatic responses of gene expression in juvenile brown trout (*Salmo trutta lacustris*) exposed to three model contaminants applied singly and in combination	2007	Not North American species
Krassoi and Julli	Chemical batch as a factor affecting the acute toxicity of the reference toxicant potassium dichromate to the cladoceran *Moina australiensis* (Sars)	1994	Not North American species
Kraus	Accumulation and Excretion of Five Heavy Metals by the Saltmarsh Cordgrass *Spartina alteriflora*	1988	Bioaccumulation: steady state not documented
Kremling et al.	Studies on the pathways and effects of cadmium in controlled ecosystem enclosures	1978	Mixture; field study
Krishna Kumari et al.	Bio-accumulation of some trace metals in the short-neck clam *Paphia malabarica* from Mandovi estuary, Goa	2006	Bioaccumulation: steady state not documented
Krishnaja et al.	effects of certain heavy metals (Hg, Cd, Pb, As and Se) on the intertidal crab *Scylla serrata*	1987	Not North American species
Kruatrachue et al.	Histopathological Changes in the Gastrointestinal Tract of Fish, *Puntius gonionotus*, fed on Dietary exposure Cadmium	2003	Dietary exposure
Krumschnabel et al.	Apoptosis and Necroptosis Are Induced in Rainbow Trout Cell Lines Exposed to Cadmium	2010	In vitro

Authors	Title	Year	Reason Unused
Krywult et al.	Metal Concentrations in Chub *Leuciscus cephalus* From a Submontane River (Poland)	2008	Bioaccumulation: steady state not documented
Kucuksezgin et al.	Trace metal and organochlorine residue levels in red mullet (*Mullus barbatus*) from the eastern Aegean, Turkey	2001	Bioaccumulation: steady state not documented
Kuehl and Haebler	Organochlorine, Organobromine, Metal, and Selenium Residues in Bottlenose Dolphins (*Tursiops truncatus*) Collected During an Unusual Mortality Event in the Gulf of Mexico, 1990	1995	Bioaccumulation: steady state not documented
Kuehl et al.	Coplanar PCB and Metal Residues in Dolphins From the U.S. Atlantic Coast Including Atlantic Bottlenose Obtained During the 1987/88 Mass Mortality	1994	Bioaccumulation: steady state not documented
Kuhn and Pattard	Results of the harmful effects of water pollutants to green algae (*Scenedesmus subspicatus*) in the cell multiplication inhibition test	1990	Not North American species
Kumar	Accumulation of Pb, Cd, and Zn in aquatic snails from four freshwater sites in Steuben County, Indiana	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kumar and Achyuthan	Heavy Metal Accumulation in Certain Marine Animals Along the East Coast of Chennai, Tamil Nadu, India	2007	Bioaccumulation: steady state not documented
Kumar et al.	Selected Heavy Metals in the Sediment exposure and Macrobenthos of the Coastal Waters Off Mangalore	2003	Bioaccumulation: steady state not documented
Kumar et al.	Levels of Cadmium and Lead in Tissues of Freshwater Fish (*Clarias batrachus* L.) And Chicken in Western up (India)	2007	Bioaccumulation: steady state not documented
Kumar et al.	Selenium and spermine alleviate cadmium induced toxicity in the red seaweed *Gracilaria dura* by regulating antioxidants and DNA methylation	2012	Lack of exposure details
Kumarasamy et al.	Effect of some heavy metals on the filtration rate of an estuarine clam, *Meretrix casta* (Chemnitz)	2006	Effect level cannot be determined, dilution water not characterized, not North American species
Kumari et al.	Bio-Accumulation of Some Trace Metals in the Short-Neck Clam *Paphia malabarica* From Mandovi Estuary, Goa	2006	Bioaccumulation: steady state not documented
Kurochkin et al.	Cadmium affects metabolic responses to prolonged anoxia and reoxygenation in eastern oysters (*Crassostrea virginica*)	2009	Mixture
Kurochkin et al.	Top-Down Control Analysis of the Cadmium Effects on Molluscan Mitochondria and the Mechanisms of Cadmium-Induced Mitochondrial Dysfunction	2011	In vitro
Kuroshima	Cadmium accumulation and it effect on calcium metabolism in the girella *Girella punctata* during a long term exposure	1987	Not North American species
Kuroshima	Cadmium accumulation in the mummichog, *Fundulus heteroclitus*, adapted to various salinities	1992	Organisms were exposed to cadmium in food or by injection or gavage
Kuroshima and Kimura	Changes in toxicity of Cd and its accumulation in girella and goby with their growth	1990	Not North American species

Authors	Title	Year	Reason Unused
Kuroshima et al.	Kinetic analysis of cadmium toxicity to red sea bream, *Pagrus major*	1993	Not North American species
Kurun et al.	Accumulations of Total Metal in Dominant Shrimp Species (*Palaemon adspersus*, *Palaemon serratus*, *Parapenaeus longirostris*) and Bottom Surface Sediment exposures Obtained From the Northern Inner Shelf of the Sea of Marmara	2007	Bioaccumulation: steady state not documented
Kurun et al.	Total metal levels in crayfish *Astacus leptodactylus* (Eschscholtz, 1823), and surface sediments in Lake Terkos, Turkey	2010	Bioaccumulation: steady state not documented
Kusch et al.	Chronic exposure to low concentrations of water-borne cadmium during embryonic and larval development results in the long-term hindrance of anti-predator behavior in zebrafish	2007	Duration too short, high control mortality (85%)
Kwan and Smith	Some aspects of the kinetics of cadmium and thallium uptake by fronds of *Lemna minor* L.	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kwong and Niyogi	The interactions of iron with other divalent metals in the intestinal tract of a freshwater teleost, rainbow trout (*Oncorhynchus mykiss*)	2009	Mixture
Kwong et al.	Molecular Evidence and Physiological Characterization of Iron Absorption in Isolated Enterocytes of Rainbow Trout (*Oncorhynchus mykiss*): Implications for Dietary Cadmium and Lead Absorption	2010	In vitro
Kwong et al.	Effects of Dietary Cadmium Exposure on Tissue-Specific Cadmium Accumulation, Iron Status and Expression of Iron-Handling and Stress-Inducible Genes in Rainbow Trout: Influence of Elevated Dietary Iron	2011	Fed toxicant
Kwong and Niyogi	Cadmium Transport in Isolated Enterocytes of Freshwater Rainbow Trout: Interactions With Zinc and Iron, Effects of Complexation With Cysteine, and an ATPase-Coupled Efflux.	2012	In vitro
La Touche and Mix	Seasonal Variations of Arsenic and Other Trace Elements in Bay Mussels (*Mytilus edulis*)	1982	Bioaccumulation: steady state not documented
Labonne et al.	Use of non-radioactive, mono-isotopic metal tracer for studying metal (Zn, Cd, Pb) accumulation in the mussel *Mytilus galloprovincialis*	2002	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Lacoue-Labarthe et al.	Acid phosphatase and cathepsin activity in cuttlefish (*Sepia officinalis*) eggs: The effects of Ag, Cd, and Cu exposure	2010	Not North American species
Lacroix and Hontela	A Comparative Assessment of the Adrenotoxic Effects of Cadmium in Two Teleost Species, Rainbow Trout, *Oncorhynchus mykiss*, and Yellow Perch, *Perca flavescens*	2004	Non-applicable
Laegreild et al.	Seasonal variation of cadmium toxicity toward the alga *Selenastrum capricornutum* Printz in two lakes with different humus content	1983	Results were only presented graphically

Authors	Title	Year	Reason Unused
Lahsteiner et al.	The sensitivity and reproducibility of the zebrafish (*Danio Rerio*) embryo test for the screening of waste water quality and for testing the toxicity of chemicals	2004	Duration too short, only one exposure concentration, some species are Not North American
Lake and Thorp	The Gill Lamellae of the Shrimp *Paratya tasmaniensis* (Atyidae: Crustacea). Normal Ultrastructure and Changes With Low Levels of Cadmium	1974	Abstract only
Lakshmi and Rao	Evaluation of cadmium toxicity on survival, accumulation and depuration in an intertidal gastropod, *Turbo intercostalis*	2002	Not North American species
Lam	Effects of cadmium on the consumption and absorption rates of a tropical freshwater snail, *Radix plicatulus*	1996a	Not North American species
Lam	Interpopulation differences in acute response of *Brotia hainanensis* (Gastropoda, Prosobranchia) to cadmium: genetic or environmental variance?	1996b	Not North American species
Lam et al.	Cadmium uptake and depuration in the soft tissues of *Brotia hainanensis* (Gastropoda: Prosobranchia: Thiaridae): A dynamic model	1997	Not North American species
Lamelas and Slaveykova	Comparison of Cd(II), Cu(II), and Pb(II) Biouptake by Green Algae in the Presence of Humic Acid	2007	Mixture
Lamelas et al.	Effect of Humic Acid on Cd(II), Cu(II), and Pb(II) Uptake by Freshwater Algae: Kinetic and Cell Wall Speciation Considerations	2009	Mixture
Lanceleur et al.	Long-Term Records of Cadmium and Silver Contamination in Sediments and Oysters From the Gironde Fluvial-Estuarine Continuum - Evidence of Changing Silver Sources	2011	Bioaccumulation: steady state not documented
Landner and Jernelov	Cadmium in aquatic systems	1969	The materials, methods or results were insufficiently described
Lane et al.	The interaction between inorganic iron and cadmium uptake in the marine diatom *Thalassiosira oceanica*	2008	Mixture
Lang and Lang-Dobler	The Chemical Environment of Tubificid and Lumbriculid Worms According to the Pollution Level of the Sediment	1979	Bioaccumulation: steady state not documented
Lange et al.	Alterations of tissue glutathione levels and metallothionein mRNA in rainbow trout during single and combined exposure to cadmium and zinc	2002	Bioaccumulation: not whole body or muscle content
Langston and Zhou	Cadmium accumulation, distribution and metabolism in the gastropod *Littorina littorea*: The role of metal-binding proteins	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Lannig et al.	Cadmium-dependent oxygen limitation affects temperature tolerance in eastern oysters (*Crassostrea virginica* Gmelin)	2008	Only one exposure concentration, unmeasured chronic exposure
Lannig et al.	Temperature-dependent effects of cadmium on mitochondrial and whole-organism bioenergetics of oysters (*Crassostrea virginica*)	2006a	Only one exposure concentration, lack of details

Authors	Title	Year	Reason Unused
Lannig et al.	Temperature-dependent stress response in oysters, Crassostrea virginica: pollution reduces temperature tolerance in oysters	2006b	Bioaccumulation: not whole body or muscle content
LaPoint et al.	Relationships among observed metal concentrations, criteria, and benthic community structural responses in 15 streams	1984	Not applicable per ECOTOX Duluth; survey
Lapota et al.	The use of bioluminescent dinoflagellates as an environmental risk assessment tool	2007	No cadmium toxicity information
Lares et al.	Mercury and cadmium concentrations in farmed bluefin tuna (*Thunnus orientalis*) and the suitability of using the caudal peduncle muscle tissue as a monitoring tool.	2012	Bioaccumulation: steady state not documented
Larsson	Some experimentally induced biochemical effects of cadmium on fish from the Baltic Sea	1977	Dilution water not characterized
Lasenby and Van Duyn	and cadmium accumulation by the opossum shrimp *Mysis relicta*	1992	Organisms were exposed to cadmium in food or by injection or gavage
Latif et al.	Effect of cadmium chloride and ascorbic acid exposure on the vital organs of freshwater Cyprinid, *Labeo rohita*	2012	Not North American species, dilution water not characterized
Latire et al.	Responses of Primary Cultured Haemocytes From the Marine Gastropod *Haliotis tuberculata* Under 10-Day Exposure to Cadmium Chloride	2012	In vitro
Laube	Strategies of response to copper, cadmium, and lead by a blue-green and a green alga	1980	Results were only presented graphically
Laurent et al.	Cadmium Biosorption by Ozonized Activated Sludge: the Role of Bacterial Flocs Surface Properties and Mixed Liquor Composition	2010	Bacteria
Lavoie et al.	Influence of essential elements on cadmium uptake and toxicity in a unicellular green alga: The protective effect of trace zinc and cobalt concentrations	2012	Excessive EDTA/NTA in growth media
Lawrence and Holoka	Response of crustacean zooplankton impounded *in situ* to cadmium at low environmental concentrations	1991	Organisms were exposed to cadmium in food or by injection or gavage
LeBlanc	Interspecies relationships in acute toxicity of chemicals to aquatic organisms	1984	Review of previously published data
Leblebici et al.	Influence of nutrient addition on growth and accumulation of cadmium and copper in *Lemna gibba*	2010	Dilution water not characterized
Lee	Occurrence of Heavy Metals and Antibiotic Resistance in Bacteria From Internal Organs of American Bullfrog (*Rana catesbeiana*) Raised in Malaysia	2009	Bioaccumulation: steady state not documented
Lee and Lee	Influence of acid volatile sulfides and simultaneously extracted metals on the bioavailability and toxicity of a mixture of Sediment exposure-associated Cd, Ni, and Zn to polychaetes *Neanthes arenaceodentata*	2005	Sediment exposure
Lee and Luoma	Influence of microalgal biomass on absorption efficiency of Cd, Cr, and Zn by two bivalves from San Francisco Bay	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Lee and Noone	Effect of reproductive toxicants on lipovitellin in female blue crabs, *Callinectes sapidus*	1995	Fed toxicant
Lee and Oshima	Effects of selected pesticides, metals and organometallics on development of blue crab (*Callinectes sapidus*) embryos	1998	The materials, methods or results were insufficiently described
Lee and Wang	Metal Accumulation in the Green Macroalga *Ulva fasciata*: Effects of Nitrate, Ammonium and Phosphate	2001	Non-applicable
Lee and Xu	Differential response of marine organisms to certain metal and agrichemical pollutants	1984	Not North American species
Lee et al.	Influence of Reactive Sulfide (AVS) and Supplementary Food on Ag, Cd and Zn Bioaccumulation in the Marine Polychaete *Neanthes arenaceodentata*	2001	Mixture
Lee et al.	Acute toxicities of trace metals and common xenobiotics to the marine copepod *Tigriopus japonicus*: Evaluation of its use as a benchmark species for routine ecotoxicity tests in western Pacific coastal regions	2007	Not North American species
Lee et al.	Acute toxicity of two CdSe/ZnSe quantum dots with different surface coating in *Daphnia magna* under various light conditions	2010	Mixture
Lee et al.	Binding Strength-Associated Toxicity Reduction by Birnessite and Hydroxyapatite in Pb and Cd Contaminated Sediments	2011	Sediment
Lefcort et al.	Aquatic Snails from Mining Sites have Evolved to Detect and Avoid Heavy Metals	2004	Mixture
Lefevre et al.	Chloride salinity reduces cadmium accumulation by the Mediterranean halophyte species *Atriplex halimus* L.	2009	Non-aquatic plant
Legeay et al.	Impact of cadmium contamination and oxygenation levels on biochemical responses in the Asiatic clam *Cobicula fluminea*	2005	Bioaccumulation: steady state not documented (only 13-14 day exposure), static exposure
Lehtonen et al.	Biomarkers of Pollution Effects in the Bivalves *Mytilus edulis* and *Macoma balthica* Collected From the Southern Coast of Finland (Baltic Sea)	2006	Bioaccumulation: steady state not documented
Lei et al.	Effect of cadmium on cytochrome C oxidase isozyme in the hepatopancreas, gill and heart of freshwater crab *Sinopotamon yangtsekiense*	2011a	Dilution water not characterized; Not North American species
Lei et al.	Histopathological and biochemical alternations of the heart induced by acute cadmium exposure in the freshwater crab *Sinopotamon yangtsekiense*	2011b	Dilution water not characterized; Not North American species
Lei et al.	Arsenic, cadmium, and lead pollution and uptake by rice (*Oryza sativa* L.)	2011c	Sediment exposure
Lekhi et al.	Role of dissolved and particulate cadmium in the accumulation of cadmium in cultured oysters (*Crassostrea gigas*)	2008	Mixture
Lera et al.	Variations in sensitivity of two populations of *Corophium orientale* (Crustacea: Amphipoda) towards cadmium and sodium laurylsulphate	2008	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Les	Cadmium uptake and depuration by the pleurocerid gastropod, *Leptoxis carinata* (Bruguiere), and its potential use as an indicator species	2008	Bioaccumulation: steady state not documented (only 21 day exposure)
Les and Walter	Toxicity and binding of copper, zinc and cadmium by the blue-green alga, *Chroococcus paris*	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Lesage et al.	Accumulation of Metals in the Sediment exposure and Reed Biomass of a Combined Constructed Wetland Treating Domestic Wastewater	2007a	Bioaccumulation: steady state not documented
Lesage et al.	Accumulation of Metals in a Horizontal Subsurface Flow Constructed Wetland Treating Domestic Wastewater in Flanders, Belgium	2007b	Bioaccumulation: steady state not documented
Leung et al.	Influence of static and fluctuating salinity on cadmium uptake and metallothionein expression by the dogwhelk *Nucella lapillus* (L.)	2002	Only one exposure concentration, unmeasured chronic exposure
Leung and Furness	Metallothionein induction and condition index of dogwhelks *Nucella lapillus* (L.) exposed to cadmium and hydrogen peroxide	2001a	Only one exposure concentration, unmeasured chronic exposure
Leung and Furness	Survival, growth, metallothionein and glycogen levels of *Nucella lapillus* (L.) exposed to sub-chronic cadmium stress: the influence of nutritional state and prey type	2001b	Only one exposure concentration, unmeasured chronic exposure
Leung et al.	Concentrations of metallothionein-like proteins and heavy metals in the freshwater snail *Lymnaea stagnalis* exposed to different levels of waterborne cadmium	2003	Duration too short, unmeasured chronic exposure, only two exposure concentrations
Leung et al.	Differential proteomic responses in hepatopancreas and adductor muscles of the green-lipped mussel *Perna viridis* to stresses induced by cadmium and hydrogen peroxide	2011	Only one exposure concentration
Lewis	Selected Heavy Metals in Sediments and Biota From Desert Streams of the Gila River Drainage (Arizona).	1980	Bioaccumulation: steady state not documented
Li	Cellular accumulation and distribution of cadmium in *Isochrysis galbana* during growth inhibition and recovery	1980	Bioaccumulation: not renewal or flow-through; Toxicity: only two exposure concentrations
Li	Cadmium toxicity and random motility studies using marine dinoflagellates	2001	Only two exposure concentrations
Li and Lin	Acute Toxicity of Cadmium to *Argopecten irradiams*	2006	Non-applicable
Li et al.	Metal uptake in zebrafish embryo-larvae exposed to metal-contaminated Sediment exposures	2004	Sediment exposure
Li et al.	Trace Metal Concentrations in Suspended Particles, Sediment exposures and Clams (*Ruditapes philippinarum*) From Jiaozhou Bay of China	2006	Bioaccumulation: steady state not documented
Li et al.	Bioaccumulation of Heavy Metals Along Food Chain in the Water of Zhalong Wetland	2007	Bioaccumulation: steady state not documented
Li et al.	Absorption and Accumulation of Heavy Metals by Plants in Poyang Lake Wetland	2008	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Li et al.	Effects of dietary squid viscera meal on growth and cadmium accumulation in tissues of large yellow croaker, *Pseudosciaena crocea* R.	2009	Dietary exposure
Li et al.	Kinetic study of the bioaccumulation of heavy metals (Cu, Pb, and Cd) in Chinese domestic oyster *Ostrea plicatula*	2010a	Dilution water not characterized; Not North American species
Li et al.	Influence of environmental related concentrations of heavy metals on motility parameters and antioxidant responses in sturgeon sperm	2010c	Dilution water not characterized; only two exposure concentrations
Li et al.	Evaluating the function of calcium antagonist on the Cd-induced stress in sperm of Russian sturgeon, *Acipenser gueldenstaedtii*. Aquat. Toxicol	2010d	Not North American species, only two exposure concentrations, duration too short
Li et al.	Low-molecular-weight-chitosan ameliorates cadmium-induced toxicity in the freshwater crab, *Sinopotamon yangtsekiense*	2011b	Not North American species, only two exposure concentrations
Li et al.	Protective roles of calcium channel blocker against cadmium-induced physiological stress in freshwater teleost *Oncorhynchus mykiss*	2011c	Dilution water not characterized; only two exposure concentrations
Li et al.	Uptake pathways and subcellular fractionation of Cd in the polychaete *Nereis diversicolor*	2012a	Bioaccumulation: steady state not documented, unmeasured exposure
Li et al.	Photosynthetic activity and antioidative response of seagrass *Thalassia hemprichii* to trace metal stress	2012c	Only three exposure concentrations
Liao and Hsieh	Toxicity of three heavy metals to *Macrobrachium rosenbergii*	1990	The materials, methods or results were insufficiently described
Liao et al.	Subcellular Partitioning Links BLM-Based Toxicokinetics for Assessing Cadmium Toxicity to Rainbow Trout	2011a	Modeling
Liao et al.	Assessing the impact of waterborne and dietborne cadmium toxicity on susceptibility risk for rainbow trout	2011b	Review
Lieb and Carline	Effects of Urban Runoff From a Detention Pond on Water Quality, Temperature and Caged *Gammarus minus* (Say) (Amphipoda) in a Headwater Stream	2000	Mixture
Lin et al.	Changes of glycogen metabolism in the gills and hepatic tissue of tilapia (*Oreochromis mossambicus*) during short-term Cd exposure	2011	Only one exposure concentration, duration too short
Lin et al.	Selenium reduces cadmium uptake and mitigates cadmium toxicity in rice	2012	Not applicable
Lira et al.	Effects of barium and cadmium on the population development of the marine nematode *Rhabditis* (*Pellioditis*) *marina*	2011	Non-aquatic exposure; not North American species
Lithner et al.	Bioconcentration factors for metals in humic waters at different pH in the Ronnskar area (N. Sweden)	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Liu and Deng	Accumulation of cadmium, copper, lead and zinc in the Pacific oyster, *Crassostrea gigas*, collected from the Pearl River Estuary, southern China	2007	Bioaccumulation: steady state not documented
Liu and Wang	Metallothionein-Like Proteins Turnover, Cd and Zn Biokinetics in the Dietary Cd-Exposed Scallop *Chlamys nobilis*	2011a	Fed toxicant
Liu and Wang	Differential Roles of Metallothionein-Like Proteins in Cadmium Uptake and Elimination by the Scallop *Chlamys nobilis*	2011b	In vitro

Authors	Title	Year	Reason Unused
Liu et al.	Complex toxicity of triadimefon and Cd towards aquatic organisms	2005	Text in foreign language
Liu et al.	Residual Concentrations of Micropollutants in Benthic Mussels in the Coastal Areas of Bohai Sea, North China	2007	Bioaccumulation: steady state not documented
Liu et al.	Distribution of Persistent Toxic Substances in Benthic Bivalves from the Inshore Areas of the Yellow Sea	2008	Bioaccumulation: steady state not documented
Liu et al.	Mitochondrial pathway of apoptosis in the hepatopancreas of the freshwater crab *Sinopotamon yangtsekiense* exposed to cadmium	2011a	Dilution water not characterized
Liu et al.	Toxicity of copper, lead, and cadmium on the motility of two marine microalgae *Isochrysis galbana* and *Tetraselmis chui*	2011b	Dilution water not characterized
Liu et al.	Antioxidant responses, hepatic intermediary metabolism, histology and ultrastructure in *Synechogobius hasta* exposed to waterborne cadmium	2011c	Not North American species
Liu et al.	Metabolic Profiling of Cadmium-Induced Effects in One Pioneer Intertidal Halophyte *Suaeda salsa* by NMR-Based Metabolomics	2011d	In vitro
Liu et al.	Metal accumulation in the tissues of grass carps (*Ctenopharyngodon idellus*) from fresh water around a copper mine in Southeast China	2012a	Bioaccumulation: steady state not documented
Liu et al.	Cadmium-induced changes in trace element bioaccumulation and proteomics perspective in four marine bivalves	2012b	Only two exposure concentrations
Liu et al.	Cloning and Characterization of the HSP90 Beta Gene from *Tanichthys albonubes* Lin (Cyprinidae): Effect of Copper and Cadmium Exposure	2012c	Mixture
Liu et al.	Effect of ambient cadmium with calcium on mRNA expressions of calcium uptake related transporters in zebrafish (*Danio rerio*) larvae	2012d	Only one exposure concentration
Liu et al.	Cadmium induces ultrastructural changes in the hepatopancreas of the freshwater crab *Sinopotamon henanense*	2013	Dilution water not characterized
Loayza-Muro and Elias-Letts	Responses of the mussel *Anodontites trapesialis* (Unionidae) to environmental stressors: Effect of pH, temperature and metals on filtration rate	2007	Not North American species, duration too short
Lobato et al.	The role of lipoic acid in the protection against of metallic pollutant effects in the shrimp *Litopenaeus vannamei* (Crustacea, Decapoda)	2013	Only one exposure concentration
Loehle and Paller	Heavy Metals In Fish From Streams Near F-Area And H-Area Seepage Basins	1991	Bioaccumulation: steady state not documented
Lokeshwari and Chandrappa	Heavy Metals Content in Water, Water Hyacinth and Sediment exposures of Lalbagh Tank, Bangalore (India)	2006	Bioaccumulation: steady state not documented
Lomagin and Ul'yanova	A new bioassay on water pollution using duckweed *Lemna minor* L	1993	Organisms were exposed to cadmium in food or by injection or gavage
Lombardi et al.	Trace metal levels in *Prochilodus lineatus* collected from the La Plata River, Argentina	2010	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Long and Wang	Metallothionein induction and bioaccumulation kinetics of Cd and Ag in the marine fish *Terapon jarbua* challenged with dietary or waterborne Ag and Cu	2005	Mixture
Long et al.	Short-term metal accumulation and MTLP induction in the digestive glands of *Perna virdis* exposed to Zn and Cd	2010	Bioaccumulation: steady state not documented
Lopez and Thompson	An Assessment of Heavy Metal Pollution in Egg Yolks of Olive Ridley Turtles of the Tropical Eastern Pacific	2009	Bioaccumulation: steady state not documented
Lopez Greco et al.	Toxicity of cadmium and copper on larval and juvenile stages of the estuarine crab *Chasmagnathus granulata* (Brachyura, Grapsidae)	2001	Not North American species, Duration too short
Lorenzon et al.	Heavy metals affect the circulating haemocyte number in the shrimp *Palaemon elegans*	2001	Not North American species, atypical endpoint
Loumbourdis	Hepatotoxic and nephrotoxic effects of cadmium in the frog *Rana ridibunda*	2005	Only one exposure concentration, not North American species, duration too short
Loumbourdis et al.	Effects of cadmium exposure on bioaccumulation and larval growth in the frog *Rana ridibunda*	1999	Not North American species
Loumbourdis et al.	Heavy metal accumulation and metallothionein concentration in the frog *Rana ridibunda* after exposure to chromium or a mixture of chromium and cadmium	2007	Mixture
Loureiro et al.	Assessing joint toxicity of chemicals in *Enchytraeus albidus* (Enchytraeidae) and *Porcellionides pruinosus* (Isopoda) using avoidance behaviour as an endpoint	2009	Sediment exposure
Lovett et al.	A Survey of the Total Cadmium Content of 406 Fish From 49 New York State Fresh Waters	1972	Bioaccumulation: steady state not documented
Lozano et al.	Lead and cadmium levels in coastal benthic algae (seaweeds) of Tenerife, Canary Islands	2003	Bioaccumulation: steady state not documented
Lozano et al.	Content of lead and cadmium in barred hogfish, *Bodianus scrofa*, island grouper, *Mycteroperca fusca*, and Portuguese dogfish, *Centroscymnus coelolepis*, from Canary Islands, Spain.	2009	Bioaccumulation: steady state not documented
Lu and Wu	Recolonization and succession of subtidal macrobenthic infauna in sediment exposures contaminated with cadmium	2003	Sediment exposure
Lu and Xu	Effects of cadmium on antioxidant enzyme activity and DNA damage in *Sinonovacula constricta*	2011	Text in foreign language
Lu et al.	Importance of waterborne cadmium and zinc accumulation in the suspension-feeding amphioxus *Branchiostoma belcheri*	2012a	Bioaccumulation: steady state not documented
Lu et al.	Effects of cadmium, 17β-estradiol and their interaction in the male Chinese loach (*Misgurnus anguillicaudatus*)	2012b	Only two exposure concentrations
Lucas et al.	Concentrations of Trace Elements in Great Lakes Fishes	1970	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Lucia et al.	Effect of Dietary Cadmium on Lipid Metabolism and Storage of Aquatic Bird *Cairina moschata*	2010	Fed toxicant
Lucker et al.	Experiments to determine the impact of salinity on the heavy metal accumulation of *Dreissena polymorpha* (Pallas 1771)	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Lue-Kim et al.	Cadmium toxicity on synchronous populations of *Chlorella ellipsoidea*	1980	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Lugowska	The effect of cadmium and cadmium/copper mixture during the embryonic development on deformed common carp larvae	2007	Species name not given
Luis et al.	Impact of Acid Mine Drainage (AMD) on Water Quality, Stream Sediment exposures and Periphytic Diatom Communities in the Surrounding Streams of Aljustrel Mining Area (Portugal)	2009	Mixture
Lukashev	Peculiarities of Seasonal Dynamics of Manganese, Cobalt and Chromium Accumulation by the Mollusks Dreissena Bugensis (Andr.) Nearby City of Kyiv	2008	Bioaccumulation: steady state not documented
Lussier et al.	Comparison of dissolved and total metals concentrations from acute tests with saltwater organisms	1999	No interpretable concentration, time, response data or examined only a single exposure concentration
Lytle and Lytle	Heavy Metals in Oysters and Clams of St. Louis Bay, Mississippi	1982	Bioaccumulation: steady state not documented
Lyubenova et al.	Direct effect of Cd on glutathione s-transferase and glutathione reductase from *Calystegia sepium*	2007	Non-aquatic plant
Ma et al.	Acute toxicity bioassay using the freshwater luminescent bacterium *Vibrio-qinghaiensis sp.* Nov.-Q67	1999	Not North American species
Ma et al.	Tissue-specific cadmium and metallothionein levels in freshwater crab *Sinopotamon henanense* during acute exposure to waterborne cadmium	2008	Deionized water without proper salts, duration too long, not North American species
Ma et al.	Oxidative damages and ultrastructural changes in the sperm of freshwater crab *Sinopotamon henanense* exposed to cadmium	2013	Dilution water not characterized, not North American species
Maanan	Biomonitoring of Heavy Metals Using *Mytilus galloprovincialis* in Safi Coastal Waters, Morocco	2007	Bioaccumulation: steady state not documented
Maanan	Heavy Metal Concentrations in Marine Molluscs From the Moroccan Coastal Region	2008	Bioaccumulation: steady state not documented
Maas	A field study of the relationship between heavy metal concentrations in stream water and selected benthic macroinvertebrate species	1978	The materials, methods or results were insufficiently described
MacDonald	Assessing the Toxicity of Aquatic Sediments Using Japanese Medaka (*Oryzias latipes*) Embryolarval Bioassays	2010	Sediment
Macdonald and Sprague	Cadmium in marine invertebrates and Arctic cod in the Canadian Arctic. Distibution and ecological implications	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Maceda-Veiga et al.	Metal bioaccumulation in the Mediterranean barbel (*Barbus meridionalis*) in a Mediterranean river receiving effluents from urban and industrial wastewater treatment plants	2012	Bioaccumulation: steady state not documented
Macek and Sleight III	Utility of Toxicity Tests With Embryos and Fry of Fish in Evaluating Hazards Associated With the Chronic Toxicity of Chemicals to Fishes	1977	Review
MacFarlane et al.	Effects of Five Metals on Susceptibility of Striped Bass to *Flexibacter columnaris*	1986	Mixture
Macfie et al.	Effects of cadmium, cobalt, copper, and nickel on growth of the green alga *Chlamydomonas reinhardtii*: The influences of the cell wall and pH	1994	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Machreki-Ajmi and Hamza-Chaffai	Accumulation of Cadmium and Lead in *Cerastoderma glaucum* Originating From the Gulf of Gabes, Tunisia	2006	Bioaccumulation: steady state not documented
Machreki-Ajmi and Hamza-Chaffai	Assessment of Sediment exposure/Water Contamination by in Vivo Transplantation of the Cockles *Cerastoderma glaucum* From a Non Contaminated to a Contaminated Area by Cadmium	2008	Mixture
Macka et al.	Uptake of $^{203}Hg^{++}$ and $^{115}Cd^{++}$ by *Chlamydomonas reinhardi* under various conditions	1979	Bioaccumulation: not renewal or flow-through
Mackey et al.	Bioaccumulation of Vanadium and Other Trace Metals in Livers of Alaskan Cetceans and Pinnipeds.	1996	Bioaccumulation: steady state not documented
Madhusudan et al.	Bioaccumulation of zinc and cadmium in freshwater fishes	2003	Dilution water not characterized, not North American species
Madkour and Ali	Heavy Metals in the Benthic Foraminifera From the Coastal Lagoons, Red Sea, Egypt: Indicators of Anthropogenic Impact on Environment (Case Study)	2009	Bioaccumulation: steady state not documented
Madoni et al.	Acute toxicity of lead, chromium, and other heavy metals to ciliates from activated sludge plants	1994	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Maeda et al.	A bioaccumulation of zinc and cadmium in freshwater alga, *Chlorella vulgaris*. Part II. Association mode of the metals and cell tissue	1990	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Maes et al.	Spatial Variations and Temporal Trends Between 1994 and 2005 in Polychlorinated Biphenyls, Organochlorine Pesticides and Heavy Metals in European Eel (*Anguilla anguilla* L.) In Flanders, Belgium	2008	Bioaccumulation: steady state not documented
Maffucci et al.	Trace element (Cd, Cu, Hg, Se, Zn) accumulation and tissue distribution in loggerhead turtles (*Caretta caretta*) from the Western Mediterranean Sea (southern Italy)	2005	Bioaccumulation: steady state not documented
Mahmoud et al.	Acute toxicities of cadmium and permethrin on the pre-spawning and post-spawning phases of *Hexaplex trunculus* from Bizerta Lagoon, Tunisia	2012	Only three exposure concentrations

Authors	Title	Year	Reason Unused
Mahon and Carman	The Influence of Salinity on the Uptake, Distribution, and Excretion of Metals by the Smooth Cordgrass, *Spartina alterniflora* (Loisel.), Grown in Sediment exposure Contaminated by Multiple Metals	2008	Sediment exposure
Mai et al.	Embryotoxic and genotoxic effects of heavy metals and pesticides on early life stages of Pacific oyster (*Crassostrea gigas*)	2012	Only three exposure concentrations
Maine et al.	Cadmium uptake by floating macrophytes	2001	No cadmium toxicity information; treatment study
Malea	Uptake of cadmium and the effect on viability of leaf cells in the seagrass *Halophila stipulacea* (Forsk.) Aschers	1994	Not North American species
Malea et al.	Metal content of some green and brown seaweeds from Antikyra Gulf (Greece)	1995	Bioaccumulation: steady state not documented
Malea et al.	Iron, Zinc, Copper, Lead and Cadmium Contents in *Ruppia maritima* From a Mediterranean Coastal Lagoon: Monthly Variation and Distribution in Different Plant Fractions	2008	Bioaccumulation: steady state not documented
Malea et al.	Kinetics of cadmium accumulation and its effects on microtubule integrity and cell viability in the seagrass *Cymodocea nodosa*	2013	Not North American species, Bioaccumualtion: steady state not documented
Malekpouri and Moshtaghie	Novel Observation in Cadmium-Zinc Interaction on Parameters Related to Bone Metabolism in Common Carp (*Cyprinus carpio* L.)	2011	Abstract only
Malekpouri et al.	Protective effect of zinc on related parameters to bone metabolism in common carp fish (*Cyprinus carpio* L.) intoxified with cadmium	2011	Dilution water not characterized
Maleva et al.	The response of hydrophytes to environmental pollution with heavy metals	2004	Bioaccumulation: steady state not documented; unmeasured exposure
Maleva et al.	Effect of heavy metals on photosynthetic apparatus and antioxidant status of *Elodea*	2012	Only one exposure concentration, mixture
Malley and Chang	Early observations on the zooplankton community of a precambrian shield lake receiving experimental additions of cadmium	1991	Organisms were exposed to cadmium in food or by injection or gavage
Malley et al.	Whole lake addition of cadmium-109: radiotracer accumulation in the mussel population in the first season	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mallick and Mohn	Use of chlorophyll fluorescence in metal-stress research: A case study with the green microalga *Scenedesmus*	2003	Excessive EDTA in growth media (10 g/L), duration too short
Malone-Oliver et al.	Metallothionein and cadmium toxicity in developing zebrafish	2011	Lack of exposure details, abstract only
Maloney	Influence of organic enrichment on the partitioning and bioavailability of cadmium in a microcosm study	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Mandal et al.	Experiences with some toxic and relatively accessible heavy metals on the survival and biomass production of *Amphora costata* W. Smith	2006	Lack of details, no statistical analysis

Authors	Title	Year	Reason Unused
Manga	Trace Metals In The Common Mussel *Mytilus edulis* From Belfast Lough Northern Ireland UK	1980	Bioaccumulation: steady state not documented
Mann and Fyfe	Algal Uptake of U and Some Other Metals: Implications for Global Geochemical Cycling	1985	Bioaccumulation: steady state not documented
Mann et al.	The Chemical Content of Algae and Waters: Bioconcentration	1988	Bioaccumulation: steady state not documented
Mansour	Effects on fish of cadmium concentrations in water	1993	The materials, methods or results were insufficiently described
Manyin and Rowe	Bioenergetic effects of aqueous copper and cadmium on the grass shrimp, *Palaemonetes pugio*	2009	Mixture
Manz et al.	*In situ* characterization of the microbial consortia active in two wastewater treatment plants	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Manzl et al.	Acute toxicity of cadmium and copper in hepatopancreas cells from the Roman snail (*Helix pomatia*)	2004	Excised tissue/cells
Manzo et al.	Cadmium, lead and their mixtures with copper: *Paracentrotus lividus* embryotoxicity assessment, prediction, and offspring quality evaluation	2010	Not North American species
Mao et al.	Expression and function analysis of metallothionein in the testis of stone crab *Charybdis japonica* exposed to cadmium	2012	Dilution water not characterized; Not North American species
Maranhao et al.	Zinc and cadmium concentrations in soft tissues of the red swamp crayfish *Procambarus clarkii* (Girard, 1852) after exposure to zinc and cadmium	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Marcussen et al.	Food Safety Aspects of Toxic Element Accumulation in Fish From Wastewater-Fed Ponds in Hanoi, Vietnam	2007	Mixture
Marie et al.	Metallothionein response to cadmium and zinc exposures compared in two freshwater bivalves, *Dreissena polymorpha* and *Corbicula fluminea*	2006b	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Marie et al.	Cadmium and Zinc Bioaccumulation and Metallothionein Response in Two Freshwater Bivalves (*Corbicula fluminea* and *Dreissena polymorpha*) Transplanted Along a Polymetallic Gradient	2006a	Mixture
Marigomez et al.	Lysosomal enlargement in digestive cells of mussels exposed to cadmium, benzo(a)pyrene and their combination	2005	Not North American species, only one exposure concentration
Marion and Denizeau	Rainbow Trout and Human Cells in Culture for the Evaluation of the Toxicity of Aquatic Pollutants: a Study With Cadmium	1983	In vitro
Mark and Solbe	Analysis of the ecetoc aquatic toxicity (EAT) database V: The relevance of *Daphnia magna* as a representative test species	1998	Review of previously published data
Markich and Jeffree	Absorption of divalent trace metals as analogues of calcium by Australian freshwater bivalves: An explanation of how water hardness reduces metal toxicity	1994	Not North American species

Authors	Title	Year	Reason Unused
Markich et al.	The effects of pH and dissolved organic carbon on the toxicity of cadmium and copper to a freshwater bivalve: Further support for the extended free ion activity model	2003	Not North American species, duration too short
Marr et al.	Differences in relative sensitivity of naive and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana	1995a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Marr et al.	Relative sensitivity of brown and rainbow trout to pulsed exposures of an acutely lethal mixture of metals typical of the Clark Fork River, Montana	1995b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Martignago et al.	Cadmium, lead and metallothionein contents in tissues of the sea bream *Sparus aurata* from three different fish farming systems	2009	Bioaccumulation: steady state not documented
Martin-Diaz et al.	Bioaccumulation and Toxicity of Dissolved Heavy Metals from the Guadalquivir Estuary After the Aznalcollar Mining Spill Using *Ruditapes philippinarum*	2005a	Mixture
Martin-Diaz et al.	Effects of cadmium and zinc on *Procambarus clarkii*: Simulation of the Aznalcollar mining Spill	2005b	Surgically altered (chelipeds removed), only two exposure concentrations
Martinez et al.	Cadmium toxicity, accumulation and metallothionein induction in *Echinogammarus echinosetosus*	1996	Not North American species
Martinez et al.	Morphological Abnormalities in Chironomus tentans Exposed to Cadmium- and Copper-Spiked Sediment exposures	2003	Sediment exposure
Martinez-Guitarte et al.	Overexpression of Long Non-Coding RNAs Following Exposure to Xenobiotics in the Aquatic Midge *Chironomus riparius*	2012	Mixture
Masoudzadeh et al.	Biosorption of Cadmium by *Brevundimonas sp*. Zf12 Strain, a Novel Biosorbent Isolated From Hot-Spring Waters in High Background Radiation Areas	2011	Bacteria
Masson et al.	Responses of Two Sentinel Species (*Hexagenia limbata*--Mayfly *Pyganodon grandis*--Bivalve) Along Spatial Cadmium Gradients in Lakes and Rivers in Northwestern Quebec.	2010	Bioaccumulation: steady state not documented
Mastrangelo et al.	Cadmium toxicity in tadpoles of *Rhinella arenarum* in relation to calcium and humic acids	2011	Not North American species
Mateo et al.	O_2-induced inactivation of nitrogenase as a mechanism for the toxic action of Cd^{2+} on *Nostoc* UAM 208	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Mathad et al.	Short and long term effects of exposure of microalgae to heavy metal stress	2004	Lack of details, no statistical analysis
Mathew and Menon	Toxic responses of bivalves to metal mixtures	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Mathew and Menon	Filtration Rates and Heavy Metal Toxicity in *Donax incarnatus*	2004	Non-applicable

Authors	Title	Year	Reason Unused
Mathew and Menon	Histological aberrations accompanying chronic metal toxicity in the mussel *Perna indica*	2005	Only one exposure concentration, unmeasured chronic exposure
Mathews et al.	Metal Concentrations in Mediterranean Fish Tissues: Exploring Biomagnification Patterns. Monaco	2007	Bioaccumulation: steady state not documented
Mathews et al.	Assimilation and Retention of Metals in Teleost and Elasmobranch Fishes Following Dietary Exposure	2008	Dietary exposure
Mathis and Cummings	Selected Metals in Sediments, Water, and Biota in the Illinois River	1973	Bioaccumulation: steady state not documented
Matozzo et al.	Effects of copper and cadmium exposure on functional responses of hemocytes in the clam, *Tapes philippinarum*	2001	Dilution water not characterized, duration too short, not North American species
Matsuo and Val	Dietary exposure Tissue Cadmium Accumulation in an Amazonian Teleost (Tambaqui, *Colossoma macropomum* Cuvier, 1818)	2007	Dietary exposure
Matz and Krone	Cell death, stress-responsive transgene activation, and deficits in the olfactory system of larval zebrafish following cadmium exposure	2007	No scientific name given, atypical endpoint
Matz et al.	Accumulation and elimination of cadmium in larval stage zebrafish following acute exposure	2007	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Maunder et al.	Uptake, tissue distribution and excretion of Dietary exposure cadmium and copper in discus fish *Symphysodon spp*.	2009	Dietary exposure
Maunder et al.	Accumulation of dietary and aqueous cadmium into the epidermal mucus of the discus fish *Symphysodon sp*	2011	Not North American species, only one exposure concentration
Mayrand and Dutil	Physiological responses of rock crab *Cancer irroratus* exposed to waterborne pollutants	2008	Mixture
Mazen and El Maghraby	Accumulation of Cadmium, Lead and Strontium, and a Role of Calcium Oxalate in Water Hyacinth Tolerance	1997	Mixture
Mazet et al.	Concentrations of PCBs, organochlorine pesticides and heavy metals (lead, cadmium, and copper) in fish from the Drome river: Potential effects on otters (*Lutra lutra*)	2005	Bioaccumulation: steady state not documented
McCahon and Pascoe	Cadmium toxicity to the freshwater amphipod *Gammarus pulex* (L.) during the molt cycle	1988a	Not North American species
McCahon and Pascoe	Increased sensitivity to cadmium of the freshwater amphipod *Gammarus pulex* (L.) during the reproductive period	1988b	Not North American species
McCahon and Pascoe	Use of *Gammarus pulex* (L.) in safety evaluation tests: Culture and selection of a sensitive life stage	1988c	Not North American species
McCahon et al.	The effect of the acanthocephalan *Pomphorhynchus laevis* (Muller 1776) on the acute toxicity of cadmium to its intermediate host, the amphipod *Gammarus pulex* (L.)	1988	Not North American species
McCahon et al.	The toxicity of cadmium to different larval instars of the trichopteran larvae *Agapetus fuscipes* Curtis and the importance of life cycle information to the design of toxicity tests	1989	Not North American species

Authors	Title	Year	Reason Unused
McClain et al.	Laboratory and field validation of multiple molecular biomarkers of contaminant exposure in rainbow trout (*Oncorhynchus mykiss*)	2003	Surgically altered test species
McClosky and Newman	Sediment Preference in the Asiatic Clam (*Corbicula fluminea*) and Viviparid Snail (*Campeloma decisum*) as a Response to Low-Level Metal and Metalloid Contamination	1995	Sediment
McClurg	Effects of fluoride, cadmium and mercury on the estuarine prawn *Penaeus indicus*	1984	Not North American species
McDonald et al.	Incorporation of 28-d *Leptocheirus plumulosus* toxicity data in a sediment weight-of-evidence framework	2010	Sediment exposure
McFarlane and Franzin	Effects of Elevated Heavy Metals on a Natural Population of White Suckers, *Catostomus commersoni*, in Hamell Lake, Saskatchewan: Near a Base Metal Smelter at Flin Flon, Manitoba.	1977	Bioaccumulation: steady state not documented
McFarlane and Franzin	Elevated Heavy Metals: a Stress on a Population of White Suckers, *Catostomus Commersoni*, in Hamell Lake, Saskatchewan.	1978	Bioaccumulation: steady state not documented
McGeer et al.	Influence of acclimation and cross-acclimation of metals on acute Cd toxicity and Cd uptake and distribution in rainbow trout (*Oncorhynchus mykiss*)	2007	Mixture
McGeer et al.	Cadmium	2011	Review
McHardy and George	The Uptake of Selected Heavy Metals by the Green Alga *Cladophora glomerata*	1985	Bioaccumulation: steady state not documented
Mckee et al.	Contaminant Levels in Rainbow Trout, *Oncorhynchus mykiss*, and Their Diets From Missouri Coldwater Hatcheries	2008	Bioaccumulation: steady state not documented
McLean and Williamson	Cadmium accumulation by marine red alga *Porphyra umbilicalis*	1977	Bioaccumulation: steady state not documented
McLeese	Cadmium and marine invertebrates	1981	Lack of exposure details
McLeese and Ray	Toxicity of $CdCl_2$, CdEDTA, $CuCl_2$, and CuEDTA to marine invertebrates	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
McLeese et al.	Lack of excretion of cadmium from lobsters	1981	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
McNicol and Scherer	Influence of cadmium pre-exposure on the preference-avoidance responses of lake whitefish (*Coregonus clupeaformis*) to cadmium	1993	Organisms were selected, adapted or acclimated for increased resistance to cadmium
McPherson and Brown	The Bioaccumulation of Cadmium by the Blue Swimmer Crab *Portunus pelagicus* L	2001	Non-applicable
Meador et al.	A comparison of the non-essential elements cadmium, mercury, and lead found in fish and sediment exposure from Alaska and California	2005	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Mebane	Development of site-specific water quality criteria for the segment of the South Fork Coeur d'Alene River from Daisy Gulch to Wallace, Idaho: Comparison of cadmium criteria to the results toxicity testing with species resident to the South Fork Coeur d'Alene River	2003	Review
Mebane	Cadmium risks to freshwater life: derivation and validation of low-effect criteria values using laboratory and field studies	2006b	Review
Mebane	Relevance of Risk Predictions Derived From a Chronic Species Sensitivity Distribution With Cadmium to Aquatic Populations and Ecosystems	2010	Review
Mebane et al.	Incubating rainbow trout in soft water increased their later sensitivity to cadmium and zinc	2010	Mixture
Medina et al.	Histopathological and biological studies of the effect of cadmium on *Rhinella arenarum* gonads	2012	Not North American species; injected toxicant
Meinelt et al.	Interaction of cadmium toxicity in embryos and larvae of zebrafish (*Danio rerio*) with calcium and humic substances	2001	Lack of detail
Mekkawy et al.	Effects of cadmium on some haematological and biochemical characteristics of *Oreochromis niloticus* (Linnaeus, 1758) dietary supplemented with tomato paste and vitamin E	2011	Dilution water not characterized
Melgar et al.	Accumulation profiles in rainbow trout (*Oncorhynchus mykiss*) after short-term exposure to cadmium	1997	Organisms were exposed to cadmium in food or by injection or gavage
Mellinger	The comparative metabolism of cadmium, mercury and zinc as environmental contaminants in the freshwater mussel, *Margaritifera margaritifera*	1972	Only one exposure concentration; median survival time
Menchaca et al.	Sensitivity comparison of laboratory-cultured and field-collected amphipod *Corophium multisetosum* in toxicity tests	2010	Duration too short, Not North American species
Mendez and Baird	Effects of Cadmium on Sediment exposure Processing on Members of the *Capitella* Species-Complex	2002	Sediment exposure
Mendez and Green-Ruiz	Preliminary observations of cadmium and copper effects on juveniles of the polychaete *Capitella sp*. Y (Annelida: Polychaeta) from Estero del Yugo, Mazatlan, Mexico	2005	Lack of detail, dilution water not characterized
Mendez and Green-Ruiz	Cadmium and copper effects on larval development and mortality of the polychaete *Capitella sp.* Y from Estero del Yugo, Mazatlan, Mexico	2006	Duration too long, dilution water not characterized
Mendoza-Cozatl et al.	Cadmium accumulation in the chloroplast of *Euglena gracilis*	2002	Bioaccumulation: steady state not documented (only 8 day exposure)
Merivirta et al.	Cadmium, mercury and lead content of river lamprey caught in Finnish rivers	2001	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Mersch et al.	Laboratory accumulation and depuration of copper and cadmium in the freshwater mussel *Dreissena polymorpha* and the aquatic moss *Rhynchostegium riparioides*	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mersch et al.	Copper in indigenous and transplanted zebra mussels in relation to changing water concentrations and body weight	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Messaoudi et al.	Study on the sensitivity to cadmium of marine fish *Salaria basilisca* (Pisces: Blennidae)	2009	Not North American species; only one exposure concentration; dilution water not characterized
Messiaen et al.	The micro-evolutionary potential of *Daphnia magna* population exposed to temperature and cadmium stress	2010	Only one exposure concentration
Messiaen et al.	The potential for adaptation in a natural *Daphnia magna* population: broad and narrow-sense heritability of net reproductive rate under Cd stress at two temperatures	2012	Only one exposure concentration
Metayer et al.	Accumulation of some trace metals (cadmium, lead, copper and zinc) in sole (*Solea solea*) and flounder (*Platichthus flesus*): Changes as a function of age and organotropism	1982	Not North American species
Metayer et al.	Evolution Of The Bioaccumulation Of Some Trace Elements In Elvers And Eels *Anguilla anguilla* Of 3 Estuaries Of The Atlantic Ocean	1984	Bioaccumulation: steady state not documented
Metcalfe-Smith	Influence of Species and Sex on Metal Residues in Freshwater Mussels (Family Unionidae) From the St. Lawrence River, With Implications for Biomonitoring Programs	1994	Bioaccumulation: steady state not documented
Metcalfe-Smith et al.	Influence of Biological Factors on Concentrations of Metals in the Tissues of Freshwater Mussels (*Elliptio complanata* and *Lampsilis radiata radiata*) From the St. Lawrence River	1996	Bioaccumulation: steady state not documented
Meteyer et al.	Effect of cadmium on early developmental stages of the sheepshead minnow (*Cyprinodon variegatus*)	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Metian et al.	Interspecific comparison of Cd bioaccumulation in European pectinidae (*Chlamys varia* and *Pecten maximus*)	2007	Bioaccumulation: steady state not documented (only 7 day exposure); dilution water not characterized; not North American species
Metian et al.	Accumulation of nine metals and one metalloid in the tropical scallop *Comptopallium radula* from coral reefs in New Caledonia	2008	Mixture, not North American species
Meyer	A mechanistic explanation for the ln(LC50) vs 1n(hardness) adjustment equation for metals	1999	Review of previously published data
Meyer et al.	Sensitivity analysis of population growth rates estimated from cladoceran chronic toxicity tests	1987	Review
Meyer et al.	Effects of water chemistry on bioavailability and toxicity of waterborne cadmium, copper, nickel, lead, and zinc on freshwater organisms	2007	Not applicable per ECOTOX Duluth; review

Authors	**Title**	**Year**	**Reason Unused**
Mhadhbi et al.	A standard ecotoxicological bioassay using early life stages of the marine fish *Psetta maxima*	2010	Not North American species
Miao et al.	Comparison of Cd, Cu, and Zn toxic effects on four marine phytoplankton by pulse-amplitude-modulated fluorometry	2005	Mixture
Michibata et al.	Effects of calcium and magnesium ions on the toxicity of cadmium to the egg of the teleost, *Oryzias latipes*	1986	Not North American species
Michibata et al.	Stage sensitivity of eggs of the teleost *Oryzias latipes* to cadmium exposure	1987	Not North American species
Migliarini et al.	Effects of cadmium exposure on testis apoptosis in the marine teleost *Gobius niger*	2005	Duration too short, dilution water not characterized, not North American species, only two exposure concentrations
Migliore and De Nicola Giudici	Effect of heavy metals (Hg, Cd, Cu and Fe) on two species of crustacean isopods, *Asellus aquaticus* (L.) and *Proasellus coxalis*	1988	Not North American species
Milani et al.	The Relative Sensitivity of Four Benthic Invertebrates to Metals in Spiked-Sediment exposure Exposures and Application to Contaminated Field Sediment exposure	2003	Sediment exposure
Mills et al.	Contaminant and Nutrient Element Levels in Soft Tissues of Zebra and Quagga Mussels From Waters of Southern Lake Ontario	1993	Bioaccumulation: steady state not documented
Millward et al.	Mixtures of Metals and Hydrocarbons Elicit Complex Responses by a Benthic Invertebrate Community	2004	Mixtures
Milne	The dynamics of chronically bioaccumulated Cd in rainbow trout (*Oncorhynchus mykiss*) during both moderately hard and soft waterborne exposures	2010	Bioaccumulation: not whole body or muscle
Ministry of Technology	-	1967	The materials, methods or results were insufficiently described
Mishra et al.	Accumulation of cadmium and copper from aqueous solutions using Indian lotus (*Nelumbo nucifera*)	2009	No cadmium toxicity information; treatment study
Misitano and Schiewe	Effect of Chemically Contaminated Marine Sediment on Naupliar Production of the Marine Harpacticoid Copepod, *Tigriopus californicus*	1990	Sediment
Mitchell et al.	Acute Toxicity of Mine Tailings to Four Marine Species	1985	Mixture
Mitchelmore et al.	Differential accumulation of heavy metals in the sea anemone *Anthopleura elegantissima* as a function of symbiotic state	2003	Bioaccumulation: unmeasured exposure; dilution water not characterized
Mitchelmore et al.	Uptake and partitioning of copper and cadmium in the coral *Pocillopora damicornis*	2007	Bioaccumulation: steady state not documented; dilution water not characterized; unmeasured exposure

Authors	Title	Year	Reason Unused
Mizutani et al.	Uptake of lead, cadmium and zinc by the fairy shrimp, *Branchinecta longiantenna* (Crustacea: Anostraca)	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mohammed and Agard	Comparative sensitivity of three tropical cladoceran species (*Diaphanosoma brachyurum*, *Ceriodaphnia rigaudii* and *Moinodaphnia macleayi*) to six chemicals	2006	Not North American species
Moller et al.	Influence of acclimation and exposure temperature on the acute toxicity of cadmium to the freshwater snail *Potamopyrgus antipodarum* (Hydrobiidae)	1994	Not North American species
Mondal	Pesticides and Heavy Metals Influence Steroidogenic Activity in Fish Gonad and Interrenal.	1997	In vitro
Mondon et al.	Histological, Growth and 7-Ethoxyresorufin O-Deethylase (EROD) Activity Responses of Greenback Flounder *Rhombosolea tapirina* to Contaminated Marine Sediment exposure and Diet	2001	Sediment exposure
Monteiro-Neto et al.	Concentrations of heavy metals in *Sotalia fluviatilis* (Cetacea: Delphinidae) off the coast of Ceara, northeast Brazil	2003	Bioaccumulation: steady state not documented
Moolman et al.	Comparative studies on the uptake and effects of cadmium and zinc on the cellular energy allocation of two freshwater gastropods	2007	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure
Moraitou-Apostolopoulou et al.	Effects of sublethal concentrations of cadmium pollution for two populations of *Acartis clausi* (Copepoda) living at two differently polluted areas	1979	Questionable treatment of test organisms or inappropriate test conditions or methodology
Morales-Hernandez et al.	Heavy Metals in Sediment exposures and Lobster (*Panulirus gracilis*) from the Discharge Area of the Submarine Sewage Outfall in Mazatlan Bay (SE Gulf of California)	2004	Effluent
Moreno et al.	Inhibition of molting by cadmium in the crab *Chasmagnathus granulata* (Decapoda Brachyura)	2003	Surgically altered species, not North American species
Mori and Wakabayashi	Cells in culture for the evaluation of the toxicity of chemicals. 1. Cytotoxicity of cadmium and copper to CHSE-214 cells derived from Chinook salmon	1996	In vitro
Mori and Wakabayashi	Cells in culture for the evaluation of the toxicity of chemicals. 2. Cytotoxicity of metals toward cultured fish cells and effect of exposure temperature on cytotoxicity	1997	In vitro
Morillo-Velarde et al.	Effects of cadmium on locomotor activity rhythms of the amphipod *Gammarus aequicauda*	2011	Not North American species, short duration
Morin et al.	Detection of DNA damage in yolk-sac larvae of the Japanese medaka, *Oryzias latipes*, by the comet assay	2011	Not North American species, duration too short

Authors	Title	Year	Reason Unused
Morley et al.	Toxicity of Cadmium and Zinc Mixtures *to Diplostomum spathaceum* (Trematoda: Diplostomidae) Cercarial Survival	2002	Mixtures
Morley et al.	Toxicity of Cadmium and Zinc Mixtures to Cercarial Tail Loss in *Diplostomum spathaceum* (Trematoda: Diplostomidae)	2005	Mixtures
Mormede and Davies	Heavy metal concentrations in commercial deep-sea fish from the Rockall Trough	2001	Bioaccumulation: steady state not documented
Morris	Toxicity of Cyanide, Chromium, Cadmium, Copper, Lead, Nickel, and Zinc. Summary Report	1973	Review
Morrison et al.	Proximate Composition and Organochlorine and Heavy Metal Contamination of Eggs From Lake Ontario, Lake Erie and Lake Michigan Coho Salmon (*Oncorhynchus kisutch* Walbaum) in Relation to Egg Survival	1985	Bioaccumulation: steady state not documented
Mostafa and Khalil	Uptake, release and incorporation of radio active cadmium and mercury by the fresh water alga *Phormidium fragile*	1986	Not North American species
Motohashi and Tsuchida	Uptake of cadmium by pure cultured diatom, *Skeletonema costatum*	1974	Bioaccumulation: not renewal or flow-through
Mouneyrac et al.	Comparison of metallothionein concentrations and tissue distribution of trace metals in crabs (*Pachygrapsus marmoratus*) from a metal-rich estuary, in and out of the reproductive season	2001	Bioaccumulation: steady state not documented
Mount et al.	Dietary and waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium, lead and zinc using a live diet	1994	Organisms were exposed to cadmium in food or by injection or gavage
Moureaux et al.	Effects of field contamination by metals (Cd, Cu, Pb, Zn) on biometry and mechanics of echinoderm ossicles	2011	Bioaccumulation: steady state not documented
Moza et al.	Effect of sub-lethal concentrations of cadmium on food intake, growth and digestibility in the gold fish, *Carassius auratus* L	1995	The materials, methods or results were insufficiently described
Mueller and Prosi	Distribution Of Zinc, Copper, And Cadmium In Various Organs Of Roaches (*Rutilus rutilus* L.) From The Neckar And Elsenz Rivers	1978	Bioaccumulation: steady state not documented
Muino et al.	Protective action of ions against cadmium toxicity to young *Bufo arenarum* tadpoles	1990	Not North American species
Mullaugh and Luther III	Formation and Persistence of Cadmium Sulfide Nanoparticle in Aqueous Solution	2009	Inappropriate form of toxicant
Muller and Payer	The influence of pH on the cadmium-repressed growth of the alga *Coelostrum proboscideum*	1979	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Munawar and Legner	Detection of Metal Toxicity Using Natural Phytoplankton as Test Organisms in the Great Lakes.	1993	Mixture
Muncke	Molecular Scale Ecotoxicological Testing in Developing Zebrafish (*Danio rerio*)	2006	In vitro

Authors	Title	Year	Reason Unused
Munger and Hare	Relative importance of water and food as cadmium sources to an aquatic insect (*Chaoborus punctipennis*): Implications for predicting Cd bioaccumulation in nature	1997	Organisms were exposed to cadmium in food or by injection or gavage
Munger et al.	Influence of exposure time on the distribution of cadmium within the cladoceran *Ceriodaphnia dubia*	1999	The materials, methods or results were insufficiently described
Muramoto	Decrease in cadmium concentration in a Cd-contaminated fish by short-term exposure to EDTA	1980	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Musko et al.	The impact of Cd and different pH on the amphipod *Gammarus fossarum* Koch (Crustacea: amphipoda)	1990	Not North American species
Musthafa et al.	Bioaccumulation of cadmium in selected tissues of *Oreochromis mossambicus* exposed to sublethal concentrations of cadmium chloride	2009	Lack of exposure details
Muyssen and Janssen	Multi-generation cadmium accumulation and tolerance in *Daphnia magna* Straus	2004	Excessive EDTA (testing used Elendt M4 medium which complexes the metal)
Mwangi and Alikhan	Cadmium and nickel uptake by tissues of *Cambarus bartoni* (Astacidae, Decapoda, Crustacea): Effects on copper and zinc stores	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mwashote	Levels of Cadmium and Lead in Water, Sediment exposures and Selected Fish Species in Mombasa, Kenya	2003	Bioaccumulation: steady state not documented
Nagel and Voigt	Impaired photosynthesis in a cadmium-tolerant *Chlamydomonas* mutant strain	1995	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Nair and Choi	Identification, Characterization and Expression Profiles of *Chironomus riparius* Glutathione S-Transferase (GST) Genes in Response to Cadmium and Silver Nanoparticles Exposure	2011	Inappropriate form of toxicant
Nair et al.	Expression of catalase and glutathione S-transferase genes in *Chironomus riparius* on exposure to cadmium and nonylphenol	2011	Dilution water not characterized; only three exposure concentrations
Najeeb et al.	Insights into cadmium induced physiological and ultra-structural disorders in *Juncus effusus* L. and its remediation through exogenous citric acid	2011	Excessive EDTA
Nakagawa and Ishio	Aspects of accumulation of cadmium ion in the egg of medaka *Oryzias latipes*	1988	Not North American species
Nakagawa and Ishio	Effects of water hardness on the toxicity and accumulation of cadmium in eggs and larvae of medaka *Oryzias latipes*	1989	Not North American species
Nakamoto and Hassler	Selenium and Other Trace Elements in Bluegills From Agricultural Return Flows in the San Joaquin Valley, California.	1992	Bioaccumulation: steady state not documented
Nakamura	Experimental studies on the accumulation of cadmium in the fish body	1974	Text in foreign language

Authors	Title	Year	Reason Unused
Nakhle et al.	Cadmium and Mercury in Seine Estuary Flounders and Mussels: the Results of Two Decades of Monitoring	2007	Bioaccumulation: steady state not documented
Nalewajko	Effects of cadmium and metal-contaminated sediments on photosynthesis heterotrophy, and phosphate uptake in Mackenzie River delta phytoplankton	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Narayanan et al.	Pattern of depuration of accumulated heavy metals in the mud crab, *Scylla serrata* (Forskal)	1999	Not North American species
Narvaez et al.	Uptake, depuration and effect of cadmium on the green mussel *Perna viridis* (L. 1758) (Mollusca: Bivalvia)	2005	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure; dilution water not characterized
Nassiri et al.	Cadmium bioaccumulation in *Tetraselmis suecica* and electron energy loss spectroscopy (EELS) study	1997	Not North American species
Nasu et al.	Comparative studies on the absorption of cadmium and copper in *Lemna paucicostata*	1983	The dilution water or medium used was open to questions because of its origin or content
Nasu et al.	The toxicity of some water pollutants for Lemnaceae (duckweed) plant	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Naumann et al.	Growth rate based dose-response relationships and EC-values of ten heavy metals using the duckweed growth inhibition test (ISO 20079) with *Lemna minor* L. Clone St.	2007	Excessive EDTA in the medium (>200 ug/L)
Nawaz et al.	In vitro toxicity of copper, cadmium, and chromium to isolated hepatocytes from carp, *Cyprinus carpio* L.	2005	In vitro
Nawaz et al.	Determination of heavy metals in fresh water fish species of the River Ravi, Pakistan compared to farmed fish varieties.	2010	Bioaccumulation: steady state not documented
Naylor et al.	Effect of differing maternal food ration on susceptibility of *Daphnia magna* Straus neonates to toxic substances	1992	The materials, methods or results were insufficiently described
Negilski	Acute toxicity of zinc, cadmium and chromium to the marine fishes, yellow-eye mullet (*Aldrichetta forsteri* C. and V.) and smallmouth hardy head (*Atherinasoma microstoma* Whitley)	1976	Not North American species
Negri et al.	Contamination in Sediment exposures, Bivalves and Sponges of McMurdo Sound, Antarctica	2006	Bioaccumulation: steady state not documented
Nelson	Observed field tolerance of caddisfly larvae (*Hesperophylax sp.*) to fish metal concentrations and low pH	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Nendza et al.	Potential for secondary poisoning and biomagnification in marine organisms	1997	Review of previously published data
Nessim et al.	Biosorption of lead and cadmium using marine algae	2011	Homogenized algal material
Nesto et al.	Bioaccumulation and Biomarker Responses of Trace Metals and Micro-Organic Pollutants in Mussels and Fish from the Lagoon of Venice, Italy	2007	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Neuberger-Cywiak et al.	Effects of zinc and cadmium on the burrowing behavior, LC50, and LT50 on *Donax trunculus* Linnaeus (Bivalvia-Donacidae)	2003	Dilution water not characterized, not North American species
Neuberger-Cywiak et al.	Sublethal effects of Zn++ and Cd++ on respiration rate, ammonia excretion, and O:N ratio of *Donax trunculus* (Bivalvia; Donacidae)	2007	Mixture
Neumann and Leimkuhler	Heavy Metal Ions Inhibit Molybdoenzyme Activity by Binding to the Dithiolene Moiety of Molybdopterin in *Escherichia coli*	2008	Mixture
Ney and Martin	Influence of Prefreezing on Heavy Metal Concentrations in Bluegill Sunfish	1985	Bioaccumulation: steady state not documented
Ng and Wang	Detoxification and Effects of Ag, Cd, and Zn Pre-Exposure on Metal Uptake Kinetics in the Clam *Ruditapes philippinarum*	2004	Prior exposure
Ng and Wang	Modeling of cadmium bioaccumulation in two populations of the green mussel *Perna viridis*	2005	Modeling
Ng and Wang	Interactions of silver, cadmium, and copper accumulation in green mussels (*Perna viridis*)	2007	Bioaccumulation: steady state not documented; unmeasured exposure
Ng and Wood	Trophic Transfer and Dietary exposure Toxicity of Cd from the Oligochaete to the Rainbow Trout	2008	Dietary exposure
Ng et al.	Does Dietary exposure Ca Protect Against Toxicity of a Low Dietborne Cd Exposure to the Rainbow Trout?	2009	Dietary exposure
Ng et al.	Cadmium Accumulation and Loss in the Pacific Oyster *Crassostrea gigas* Along the West Coast of the USA.	2010	Bioaccumulation: steady state not documented
Nguyen and Janssen	Embryo-larval toxicity tests with the African catfish (*Clarias gariepinus*): Comparative sensitivity of endpoints	2002	Duration too long, not North American species
Ni et al.	Influences of salinity on the biokinetics of Cd, Se, and Zn in the intertidal mudskipper *Periophthalmus cantonensis*	2005	Mixture
Nimick et al.	Influence of in-stream diel concentration cycles of dissolved trace metals on acute toxicity to one-year-old cutthroat trout (*Oncorhynchus clarki lewisi*)	2007	Mixture
Nimmo et al.	Three Studies Using *Ceriodaphnia* to Detect Nonpoint Sources of Metals From Mine Drainage.	1990	Mixture
Nimmo et al.	Cadmium and Zinc Accumulation in Aquatic Bryophytes Immersed in the Arkansas River, Colorado: Comparison of Fall Versus Spring	2006	Bioaccumulation: steady state not documented
Nir et al.	Cadmium uptake and toxicity to water hyacinth: Effect of repeated exposures under controlled conditions	1990	Not North American species
Niyogi and Wood	Effects of chronic waterborne and dietary metal exposures on gill metal-binding: implications for the biotic ligand model	2003	Review

Authors	Title	Year	Reason Unused
Niyogi et al.	Kinetic Analyses of Waterborne Ca and Cd Transport and Their Interactions in the Gills of Rainbow Trout (*Oncorhynchus mykiss*) and Yellow Perch (*Perca flavescens*), Two Species Differing Greatly in Acute Waterborne Cd Sensitivity	2004a	Mixture
Noel-Lambot et al.	Distribution of Cd, Zn and Cu in liver and gills of the eel *Anguilla anguilla* with special reference to metallothioneins	1978	Bioaccumulation: unmeasured exposure; not North American species
Noel-Lambot et al.	Cadmium, zinc, and copper accumulation in limpets (*Patella vulgata*) from the British channel and special reference to metallothioneins	1980	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Nolan and Duke	Cadmium accumulation and toxicity in *Mytilus edulis*: Involvement of metallothioneins and heavy molecular weight protein	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Noraho and Gaur	Effect of cations, including heavy metals, on cadmium uptake by *Lemna polyrhiza* L.	1995	Not North American species
Norberg-King et al.	Interlaboratory evaluation of *Hyalella azteca* and *Chironomus tentans* short-term and long-term sediment toxicity tests	2006	Non-applicable
Nordberg	Historical perspectives on cadmium toxicology	2009	Review
Nordberg et al.	Cadmium: Handbook on the Toxicology of Metals (Third Edition)	2007	Review
Norey et al.	Induction of metallothionein gene expression by cadmium and the retention of the toxic metal in the tissues of rainbow Trout (*Salmo gairdneri*)	1990c	Injected toxicant
Norey et al.	A comparison of the accumulation, tissue distribution and secretion of cadmium in different species of freshwater fish	1990a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Norris and Lake	Trace Metal Concentrations in Fish From the South Esk River, Northeastern Tasmania, Australia.	1984	Bioaccumulation: steady state not documented
Norum et al.	Trace element distribution during the reproductive cycle of female and male spiny and Pacific scallops, with implications for biomonitoring	2005	Bioaccumulation: steady state not documented
Norwood et al.	Interactive effects of metals in mixtures on bioaccumulation in the amphipod *Hyalella azteca*	2007	Mixture
Notenboom et al.	Effect of ambient oxygen concentration upon the acute toxicity of chlorophenols and heavy metals to the groundwater copepod *Parastenocaris germanica* (crustacea)	1992	Not North American species
Nott and Nicolaidou	Variable transfer of detoxified metals from snails to hermit crabs in marine food chains	1994	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Novais et al.	Reproduction and biochemical responses in *Enchytraeus albidus* (Oligochaeta) to zinc or cadmium exposures	2011	Sediment exposure
Novais et al.	Exposure of *Enchytraeus albidus* to Cd and Zn - Changes in cellular energy allocation (CEA) and linkage to transcriptional, enzymatic and reproductive effects	2013	Soil exposure
Novakova et al.	Zinc and cadmium toxicity using a biotest with *Artemia franciscana*	2007	Brine shrimp
Novelli et al.	Toxicity of heavy metals using sperm cell and embryo toxicity bioassays with *Paracentrotus lividus* (Echinodermata: Echinoidea): Comparisons with exposure concentrations in the Lagoon of Venice, Italy	2003	Not North American species
Nowak et al.	Consequences of inbreeding and reduced genetic variation on tolerance to cadmium stress in the midge *Chironomus riparius*	2007	Sediment exposure
Nowak et al.	Variation in sensitivity to cadmium among genetically characterized laboratory strains of the midge *Chironomus riparius*	2008	Sediment exposure
Nowierski et al.	Effects of water chemistry on the bioavailability of metals in sediment to *Hyalella azteca*: Implications for sediment quality guidelines	2005	Sediment exposure
Nowierski et al.	Lac Dufault Sediment exposure core trace metal distribution, bioavailability and toxicity to *Hyalella azteca*	2006	Sediment exposure
Nugegoda and Rainbow	The uptake of dissolved zinc and cadmium by the decapod crustacean *Palaemon elegans*	1995	Not North American species
Nunez-Nogueira and Rainbow	Cadmium uptake and accumulation by the decapod crustacean *Penaeus indicus*	2005	Bioaccumulation: steady state not documented; not North American species
Nusetti et al.	Pyruvate kinase, phosphoenolpyruvate carboxykinase, cytochrome c oxidase and catalase activities in cadmium exposed *Perna viridis* subjected to anoxic and aerobic conditions	2010	Too few exposure concentrations, atypical endpoint
Nyholm and Kallqvist	Methods for Growth Inhibition Toxicity Tests With Freshwater Algae	1989	Review
Nyman et al.	Current levels of DDT, PCB and trace elements in the Baltic ringed seals (*Phoca hispida baltica*) and grey seals (*Halichoerus grypus*)	2002	Bioaccumulation: steady state not documented
Nyquist and Greger	Response of two wetland plant species to Cd exposure at low and neutral pH	2009	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure; dilution water not characterized
O'Hara	Cadmium uptake by fiddler crabs exposed to temperature and salinity stress	1973b	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
O'Neill	Effects of intraperitoneal lead and cadmium on the humoral immune response of *Salmo trutta*	1981	Organisms were not exposed to cadmium in water

Authors	Title	Year	Reason Unused
Oakley et al.	Accumulation of cadmium by *Abarenicola pacifica*	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Obande et al.	Trace metal analysis of the prawn (*Atya gabonesis*), water and bottom sediments of Lower River Benue	2006	Bioaccumulation: steady state not documented
Occhiogrosso et al.	Effects of heavy metals on benthic macroinvertebrate densities in foundry cove on the Hudson River	1979	Bioaccumulation: steady state not documented
O'Connor and Lauenstein	Trends in chemical concentrations in mussels and oysters collected along the US Coast: Update to 2003	2006	Bioaccumulation: steady state not documented
Odin et al.	Temperature and pH effects on cadmium and methylmercury bioaccumulation by nymphs of the burrowing mayfly *Hexagenia rigida*, from water column or sediment source	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Odin et al.	Depuration processes after exposure of burrowing mayfly nymphs (*Hexagenia rigida*) to methylmercury and cadmium from water column or sediment: Effects of temperature and pH	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Offermann et al.	Assessing the importance of dietborne cadmium and particle characteristics on bioavailability and bioaccumulation in the nematode *Caenorhabditis elegans*	2009	Dietary exposure
Oguma and Klerks	The role of native salinity regime on grass shrimp (*Palaemonetes pugio*) sensitivity to cadmium	2013	Only one exposure concentration
Ogwok et al.	Pesticide residues and heavy metals in Lake Victoria Nile perch, *Lates niloticus*, belly flap oil	2009	Bioaccumulation: steady state not documented
Oikari et al.	Acute toxicity of chemicals to *Daphnia magna* in humic water	1992	Review of previously published data
Ojaveer et al.	On the effect of copper, cadmium and zinc on the embryonic development of Baltic spring spawning herring	1980	Not North American species
Olesen and Weeks	Accumulation of Cd by the marine sponge *Halichondria panicea* Pallas: Effects upon filtration rate and its relevance for biomonitoring	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Olgunoglu and Polat	Trace metals in marine macroalgae samples from the Iskenderun Bay, Turkey	2008	Bioaccumulation: steady state not documented
Oliveira et al.	Hepatic metallothionein concentrations in the golden grey mullet (*Liza aurata*) relationship with environmental metal concentrations in a metal-contaminated coastal system in Portugal	2010	Bioaccumulation: steady state not documented
Ololade et al.	Influence of diffuse and chronic metal pollution in water and sediments on edible seafoods within Ondo oil-polluted coastal region, Nigeria.	2011	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Olson and Christensen	Effects of water pollutants and other chemicals on fish acetylcholinesterase (in vitro)	1980	In vitro
Olsvik et al.	Metal accumulation and metallothionein in brown trout, Salmo trutta, from two Norwegian rivers differently contaminated with Cd, Cu and Zn	2001	Bioaccumulation: steady state not documented
Olsvik et al.	Effects of combined gamma-irradiation and metal (Al+Cd) exposures in Atlantic salmon (*Salmo salar* L.).	2010	Mixture (Al and Cd)
Olusegun et al.	Heavy metal distribution in crab (*Callinectes amnicola*) living on the shores of Ojo Rivers, Lagos, Nigeria	2009	Bioaccumulation: steady state not documented
Omoregie et al.	Metal concentrations in water column, benthic macroinvertebrates and tilapia from Delimi River, Nigeria	2002	Bioaccumulation: steady state not documented
Oner et al.	Changes in serum biochemical parameters of freshwater fish *Oreochromis niloticus* following prolonged metal (Ag, Cd, Cr, Cu, Zn) exposures	2008	Unmeasured chronic exposure, only one exposure concentration
Ong and Din	Cadmium, copper, and zinc toxicity to the clam, *Donax faba* C., and the blood cockle, *Anadara granosa* L	2001	Not North American species
Ongeri et al.	Seasonal variability in cadmium, lead, copper, zinc and iron concentrations in the three major fish species, *Oreochromis niloticus*, *Lates niloticus* and *Rastrineobola argentea* in Winam Gulf, Lake Victoria: Impact of wash-off into the lake	2012	Bioaccumulation: steady state not documented
Onuoha et al.	Comparative toxicity of cadmium to crustacean zooplankton (copepods and ostracods)	1996	The materials, methods or results were insufficiently described
Opuene and Agbozu	Relationships between heavy metals in shrimp (*Macrobrachium felicinum*) and metal levels in the water column and sediments of Taylor Creek	2008	Bioaccumulation: steady state not documented
Orchard et al.	A rapid response toxicity test based on the feeding rate of the tropical cladoceran *Moinodaphnia macleayi*	2002	Duration too short, not North American species
Oronsaye et al.	The toxicity of zinc and cadmium to *Clarias subnaginatus*	2003	Mixture, not North American species
Orun and Tolas	Antioxidative role of sodium selenite against the toxic effect of heavy metals (Cd+2, Cr+3) on some biochemical and hematological parameters in the blood of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792)	2008	Mixture
Osuna-Martinez et al.	Cadmium, copper, lead and zinc in cultured oysters under two contrasting climatic conditions in coastal lagoons from SE Gulf of California, Mexico	2011	Bioaccumulation: steady state not documented
Othman et al.	Cadmium accumulation in two populations of rice frogs (*Fejervarya limnocharis*) naturally exposed to different environmental cadmium levels	2009	Bioaccumulation: steady state not documented
Otitoloju and Don-Pedro	Integrated laboratory and field assessments of heavy metals accumulation in edible periwinkle, *Tympanotonus fuscatus var radula* (L.)	2004	No cadmium toxicity information
Otitoloju and Don-Pedro	Determination of types of interactions exhibited by binary mixtures of heavy metals tested against the hermit crab, *Clibanarius africanus*	2006	Sediment substrate in exposure water, not North American species

Authors	Title	Year	Reason Unused
Outridge et al.	Changes in mercury and cadmium concentrations and the feeding behaviour of beluga (*Delphinapterus leucas*) near Somerset Island, Canada, during the 20th century	2005	Bioaccumulation: steady state not documented
Packer et al.	Cadmium copper lead zinc and manganese in the polychaete *Arenicola marina* from Sediment exposures around the coast of Wales UK	1980	Bioaccumulation: steady state not documented
Pajevic et al.	The content of some macronutrients and heavy metals in aquatic macrophytes of three ecosystems connected to the Danube in Yugoslavia	2002	Bioaccumulation: steady state not documented
Pajevic et al.	Heavy metal accumulation of Danube River aquatic plants -- indication of chemical contamination	2008	Bioaccumulation: steady state not documented
Palackova et al.	Sublethal effects of cadmium on carp (*Cyprinus carpio*) fingerlings	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Palm and Wikberger	Tungmetallanalyser av mossor och baeckvattenvaexter i norra Estland. (Heavy metals in mosses and aquatic plants in northern Estonia)	1995	Bioaccumulation: steady state not documented
Pan	Application of biokinetic model in studying the bioaccumulation of cadmium, zinc, and copper in the scallop *Chlamys nobilis*	2009	Bioaccumulation: not renewal or flow-through exposure; not North American species
Pan and Wang	Influences of dissolved and colloidal organic carbon on the uptake of Ag, Cd, and Cr by the marine mussel *Perna viridis*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Pan and Wang	The subcellular fate of cadmium and zinc in the scallop *Chlamys nobilis* during waterborne and dietary exposure	2008	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Pan and Zhang	Metallothionein, antioxidant enzymes and DNA strand breaks as biomarkers of Cd exposure in a marine crab, *Charybdis japonica*	2006	Dilution water not characterized, duration too short, not North American species
Pan et al.	Effects of heavy metal ions (Cu2+, Pb2+ and Cd2+) on DNA damage of the gills, hemocytes and hepatopancreas of marine crab, *Charybdis japonica*	2011	Only three exposure concentrations
Pandeswara and Yallapragada	Tolerance, accumulation and depuration in an intertidal gastropod, *Turbo intercostalis*, exposed to cadmium	2000	Not North American species, abstract only
Pandey et al.	Effects of exposure to multiple trace metals on biochemical, histological and ultrastructural features of gills of a freshwater fish, *Channa punctata* Bloch	2008	Mixture
Pantani et al.	Comparative acute toxicity of some pesticides, metals, and surfactants to *Gammarus italicus* Goedm. and *Echinogammarus tibaldii* Pink. and stock (Crustacea: Amphipoda)	1997	Not North American species
Papa et al.	Determination of heavy metal in seawater and macroalgae of shorelines of Naples and Ischia Island, Italy	2008	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Papathanassiou	Cadmium accumulation and ultrastructural alterations in oogenesis of the prawn *Palaemon serratus* (Pennant)	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Papathanassiou	Effects of cadmium and mercury ions on respiration and survival of the common prawn *Palaemon serratus* (Pennant)	1983	Not North American species
Papoutsoglou and Abel	Studies on the lethal and sublethal effects of cadmium on some commercially cultured species of the Mediterranean	1993	Review of previously published data
Park and Kim	Bioassays on marine organisms: Acute toxicity test of mercury, cadmium and copper to arkshell, *Anadara broughtonii*, from Jin-Dong Bay, and to oyster, *Crassostrea gigas*, from Kwang-Do Bay, south coast of Korea	1978	Not North American species
Park and Kim	Bioassays on marine organisms. II. Acute toxicity test of mercury, copper and cadmium to clam, *Meretrix lusoria*	1979	Not North American species
Park and Presley	Trace metal contamination of sediments and organisms from the Swan Lake Area of Galveston Bay	1997	Bioaccumulation: steady state not documented
Parker	The effects of selected chemicals and water quality on the marine polychaete *Ophryotrocha diadema*	1984	Questionable treatment of test organisms or inappropriate test conditions or methodology
Part and Svanberg	Uptake of cadmium in perfused rainbow trout (*Salmo gairdneri*) gills	1981	In vitro
Parveen and Shadab	Cytogenetic evaluation of cadmium chloride on *Channa punctatus*	2012	Dilution water not characterized, not North American species
Parvin et al.	Preliminary acute toxicity bioassays of lead and cadmium on fresh water climbing perch, *Anabas testudineus* (Bloch)	2011	Dilution water not characterized
Pascal et al.	The toxicological interaction between ocean acidity and metals in coastal meiobenthic copepods	2010	Bioaccumulation: steady state not documented
Pascoe and Shazili	Episodic pollution - a comparison of brief and continuous exposure of rainbow trout to cadmium	1986	The materials, methods or results were insufficiently described
Pastorinho et al.	Amphipod susceptibility to metals: cautionary tales	2009	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Patel et al.	Sponge 'sentinel' of heavy metals	1985	Bioaccumulation: steady state not documented
Patthebahadur and Bais	Studies on some physiological aspects in fresh water fish *Ophiocephalus striatus* (Channa) in relation to heavy metal cadmium (Cd) toxicity	2008	Duration too short, test species fed, not North American species
Pauli and Berger	Toxicological comparisons of *Tetrahymena* species, end points and growth media: Supplementary investigations to the pilot ring test	1997	The materials, methods or results were insufficiently described
Paul-Pont et al.	Short-term metallothionein inductions in the edible cockle *Cerastoderma edule* after cadmium or mercury exposure: Discrepancy between MRNA and protein responses	2010a	In vitro

Authors	**Title**	**Year**	**Reason Unused**
Paul-Pont et al.	How life history contributes to stress response in the manila clam *Ruditapes philippinarum*	2010b	Only one exposure concentration
Paul-Pont et al.	Cloning, characterization and gene expression of a metallothionein isoform in the edible cockle *Cerastoderma edule* after cadmium or mercury exposure	2012	Not North American species, only one exposure concentration
Pavicic	Combined cadmium-zinc toxicity on embryonic development of *Mytilus galloprovincialis* LMK. (Mollusca, Mytilidae)	1977	Abstract only
Pavicic and Jarvenpaa	Cadmium toxicity in adults and early larval stages of the mussel *Mytilus galloprovincialis* Lam.	1974	Not North American species
Pavicic et al.	Embryo-larval tolerance of *Mytilus galloprovincialis*, exposed to the elevated sea water metal concentrations - I. Toxic effects of Cd, Zn and Hg in relation to the metallothionein level	1994	Not North American species
Pawlik and Skowronski	Transport and toxicity of cadmium: Its regulation in the cyanobacterium *Synechocystis aquatilis*	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pawlik et al.	pH-dependent cadmium transport inhibits photosynthesis in the cyanobacterium *Synechocystis aquatilis*	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pecon and Powell	Effect of the amino acid histidine on the uptake of cadmium from the digestive system of the blue crab, *Callinectes sapidus*	1981	Questionable treatment of test organisms or inappropriate test conditions or methodology
Pedersen and Petersen	Variability of species sensitivity to complex mixtures	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Pedro et al.	The influence of cadmium contamination and salinity on the survival, growth and phytoremediation capacity of the saltmarsh plant *Salicornia ramosissima*	2013	Soil exposure
Pelgrom et al.	Interactions between copper and cadmium during single and combined exposure in juvenile tilapia *Oreochromis mossambicus*: Influence of feeding condition on whole body metal accumulation and the effect of the metals on tissue water and ion content	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pelgrom et al.	Calcium fluxes in juvenile tilapia, *Oreochromis mossambicus*, exposed to sublethal waterborne Cd, Cu or mixtures of these metals	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pellegrini et al.	Interactions between the toxicity of the heavy metals cadmium, copper, zinc in combinations and the detoxifying role of calcium in the brown alga *Cystoseira barbata*	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Pellet et al.	Model predicting waterborne cadmium bioaccumulation in *Gammarus pulex*: the effects of dissolved organic ligands, calcium, and temperature	2009	Not North American species
Peltier et al.	Accumulation of trace elements and growth responses in *Corbicula fluminea* downstream of a coal-fired power plant	2009	Bioaccumulation: steady state not documented
Pempkowiak et al.	Toxicants accumulation rates and effects in *Mytilus trossulus* and *Nereis diversicolor* exposed separately or together to cadmium and PAHs	2006a	Non-applicable
Pempkowiak et al.	Heavy metals in zooplankton from the southern Baltic	2006b	Bioaccumulation: steady state not documented
Peng et al.	Trace metals in *Iaustinogebia edulis* (Ngoc-Ho & Chan, 1992) (Decapoda, Thalassinidea, Upogebiidae) and its habitat sediment from the central western Taiwan coast	2006	Bioaccumulation: steady state not documented
Peng et al.	Bioaccumulation of heavy metals by the aquatic plants *Potamogeton pectinatus* L. and *Potamogeton malaianus* Miq. and their potential use for contamination indicators in wastewater treatment	2008	No cadmium toxicity information
Pennington et al.	Contaminant levels in fishes from Brown's Lake, Mississippi	1982	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Penttinen et al.	The kinetics of cadmium in *Daphnia magna* as affected by humic substances and water hardness	1995	No useable data on cadmium toxicity or bioconcentration
Penttinen et al.	Combined effects of dissolved organic material and water hardness on toxicity of cadmium to *Daphnia magna*	1998	The materials, methods or results were insufficiently described
Perceval et al.	Long-term trends in accumulated metals (Cd, Cu and Zn) and metallothionein in bivalves from lakes within a smelter-impacted region	2006	Bioaccumulation: steady state not documented
Percy	Heavy metal and sulphur concentrations in *Sphagnum magellanicum* Brid. in the maritime provinces, Canada	1983	Bioaccumulation: steady state not documented
Pereira et al.	Effect of cadmium accumulation on serum vitellogenin levels and hepatosomatic and gonadosomatic indices of winter flounder (*Pleuronectes americanus*)	1993	No interpretable concentration, time, response data or examined only a single exposure concentration
Perez-Coll and Herkovits	Stage-dependent uptake of cadmium by *Bufo arenarum* embryos	1996	Not North American species
Perez-Coll et al.	Teratogenic effects of cadmium on *Bufo arenarum* during gastrulation	1986	Not North American species; too few exposure concentrations; no statistical analysis
Perez-Legaspi and Rico-Martinez	Acute toxicity tests on three species of the genus *Lecane* (Rotifera: Monogononta)	2001	Duration too short, not North American species
Perez-Legaspi and Rico-Martinez	Phospholipase A2 activity in three species of littoral freshwater rotifers exposed to several toxicants	2003	Duration too short, not North American species
Perez-Legaspi et al.	Toxicity testing using esterase inhibition as a biomarker in three species of the genus *Lecane* (Rotifera)	2002	Duration too short, not North American species
Perkins et al.	The potential of screening for agents of toxicity using gene expression fingerprinting in *Chironomus tentans*	2004	Exposure in distilled water without the addition of proper salts

Authors	Title	Year	Reason Unused
Pernice et al.	Comparative Bioaccumulation of Trace Elements Between *Nautilus pompilius* and *Nautilus macromphalus* (Cephalopoda: Nautiloidea) from Vanuatu and New Caledonia	2009	Bioaccumulation: steady state not documented
Pery et al.	Assessing the risk of metal mixtures in contaminated sediments on *Chironomus riparius* based on cytosolic accumulation	2008	Sediment exposure
Pesonen and Andersson	Fish primary hepatocyte culture; and important model for xenobiotic metabolism and toxicity studies	1997	Review of previously published data
Pestana et al.	Effects of cadmium and zinc on the feeding behaviour of two freshwater crustaceans: *Atyaephyra desmarestii* (Decapoda) and *Echinogammarus meridionalis* (Amphipoda)	2007	Not North American species
Peterson	Toxicity testing using a chemostat-grown green alga, *Selenastrum capricornutum*	1991	The materials, methods or results were insufficiently described
Peterson et al.	Metal toxicity to algae: A highly pH dependent phenomenon	1984	The materials, methods or results were insufficiently described
Phelps	Cadmium sorption in estuarine mud-type sediment and the accumulation of cadmium in the soft-shell clam, *Mya arenaria*	1979	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
Phillips	The common mussel *Mytilus edulis* as an indicator of trace metals in Scandinavian waters. I. Zinc and cadmium	1977	Bioaccumulation: steady state not documented
Phillips	Trace metals in the common mussel, *Mytilus edulis* (L.), and in the alga *Fucus vesiculosus* (L.) from the region of the Sound (Oresund)	1979	Bioaccumulation: steady state not documented
Phillips	Toxicity and accumulation of cadmium in marine and estuarine biota. Part 1. Ecological cycling	1980	Review
Phillips and Russo	Metal bioaccumulation in fishes and aquatic invertebrates: A literature review	1978	Review of previously published data
Philp	Effects of experimental manipulation of pH and salinity on Cd2+ uptake by the sponge *Microciona prolifera* and on sponge cell aggregation induced by Ca2+ and Cd2+	2001	Excised tissue/cells
Phipps et al.	Effects of pollution on freshwater organisms.	1984	Review
Pierron et al.	Impairment of lipid storage by cadmium in the European eel (*Anguilla anguilla*)	2007a	Only one exposure concentration, not North American species
Pierron et al.	Effects of salinity and hypoxia on cadmium bioaccumulation in the shrimp *Palaemon longirostris*	2007b	Bioaccumulation: steady state not documented; not North American species
Pierron et al.	Transcriptional responses to environmental metal exposure in wild yellow perch (*Perca flavescens*) collected in lakes with differing environmental metal concentrations (Cd, Cu, Ni)	2009a	Bioaccumulation: steady state not documented
Pierron et al.	Ovarian gene transcription and effect of cadmium pre-exposure during artificial sexual maturation of the European eel (*Anguilla anguilla*)	2009b	Only one exposure concentration, not North American species

Authors	Title	Year	Reason Unused
Pierron et al.	Effects of chronic metal exposure on wild fish populations revealed by high-throughput cDNA sequencing	2011	Bioaccumulation: steady state not documented
Pinkina	Effect of the ionic form of cadmium on reproduction and development of *Lymnaea stagnalis* L.	2006	Dilution water not characterized, unmeasured chronic exposure
Pinto et al.	Influence of organic matter on the uptake of cadmium, zinc, copper and iron by sorghum plants	2004	Non-aquatic plants
Pip and Mesa	Cadmium, copper, and lead in two species of *Artemisia* (compositae) in southern Manitoba, Canada	2002	Bioaccumulation: steady state not documented
Piyatiratitivorakul and Boonchamoi	Comparative toxicity of mercury and cadmium to the juvenile freshwater snail, *Filopaludina martensi martensi*	2008	Not North American species, dilution water not characterized
Piyatiratitivorakul et al.	Comparative toxicity of heavy metal compounds to the juvenile golden apple snail, *Pomacea sp*.	2006	Dilution water not characterized
Planello et al.	Effect of acute exposure to cadmium on the expression of heat-shock and hormone-nuclear receptor genes in the aquatic midge *Chironomus riparius*	2010	Only one exposure concentration; duration too short; mixture
Playle	Physiological and toxicological effects of metals at gills of freshwater fish	1997	Review
Playle et al.	Copper and cadmium binding to fish gills: Estimates of metal-gill stability constants and modelling of metal accumulation	1993a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Playle et al.	Copper and cadmium binding to fish gills: Modification by dissolved organic carbon and synthetic ligands	1993b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Ploetz et al.	Differential accumulation of heavy metals in muscle and liver of a marine fish, (king mackerel, *Scomberomorus cavalla cuvier*) from the northern Gulf of Mexico, USA	2007	Bioaccumulation: steady state not documented
Podgurskaya and Kavun	Cadmium concentration and subcellular distribution in organs of the mussel *Crenomytilus grayanus* from upwelling regions of Okhotsk Sea and Sea of Japan	2006	Bioaccumulation: steady state not documented
Pohl	Wechselbeziehungen zwischen spurenmetallkonzentrationen (Cd, Cu, Pb, Zn) im meerwasser und in zooplanktonorganismen (Copepoda) der arktis und des atlantiks. (Correlations between trace metal concentrations (Cd, Cu, Pb, Zn) in seawater and zooplankton organisms (Copepoda) of the Arctic and Atlantic	1993	Bioaccumulation: steady state not documented
Pokora and Tukaj	The combined effect of anthracene and cadmium on photosynthetic activity of three desmodesmus (Chlorophyta) species	2010	Only one exposure concentration
Polak-Juszczak	Temporal trends in the bioaccumulation of trace metals in herring, sprat, and cod from the southern Baltic Sea in the 1994-2003 period	2009	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Polar and Kucukcezzar	Influence of some metal chelators and light regimes on bioaccumulation and toxicity of Cd2+ in duckweed (*Lemna gibba*)	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Portmann and Wilson	The toxicity of 140 substances to the brown shrimp and other marine animals	1971	Not North American species
Postma and Davids	Tolerance induction and life cycle changes in cadmium-exposed *Chironomus riparius* (Diptera) during consecutive generation	1995	Organisms were exposed to cadmium in food or by injection or gavage
Postma et al.	Chronic toxicity of cadmium to *Chironomus reparius* (Diptera: Chironomidae) at different food levels	1994	Organisms were exposed to cadmium in food or by injection or gavage
Postma et al.	Increased cadmium excretion in metal-adapted populations of the midge *Chironomus riparius* (Diptera)	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Poteat et al.	Divalent metal (Ca, Cd, Mn, Zn) uptake and interactions in the aquatic insect *Hydropsyche sparna*	2012	Bioaccumulation: steady state not reached (only 9 hour exposure)
Poulsen et al.	Accumulation of cadmium and bioenergetics in the mussel *Mytilus edulis*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Poulton et al.	Relations between benthic community structure and metals concentrations in aquatic macroinvertebrates: Clark Fork River, Montana	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Pourang and Dennis	Distribution of trace elements in tissues of two shrimp species from the Persian Gulf and roles of metallothionein in their redistribution	2005	Bioaccumulation: steady state not documented
Powell and Powell	Trace Elements in Fish Overlying Subaqueous Tailings in the Tropical West Pacific	2001	Bioaccumulation: steady state not documented
Powell et al.	Use of *Azolla* to assess toxicity and accumulation of metals from artificial and natural Sediment exposures containing cadmium, copper, and zinc	1998	Sediment exposure
Prafulla et al.	Concentrations of trace metals in the squids, *Loligo duvauceli* and *Doryteuthis sibogae* caught from the southwest coast of India	2001	Bioaccumulation: steady state not documented
Prasad et al.	Toxicity of cadmium and copper in *Chlamydomonas reinhardtii* wild-type (WT2137) and cell wall deficient mutant strain (CW15)	1998	No interpretable concentration, time, response data or examined only a single exposure concentration
Pratap and Wendelaar	Mineral composition and cadmium accumulation in Oreochromis mossambicus exposed to waterborne cadmium	2004	Bioaccumulation: not whole body or muscle content
Prato and Biandolino	Combined toxicity of mercury, copper and cadmium on embryogenesis and early larval stages of the *Mytlius galloprovincialis*	2007	Not North American species, duration too short
Prato et al.	Effects of temperature on the sensitivity of *Gammarus aequicauda* (Martynov, 1931) to cadmium	2009	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Presing et al.	Cadmium uptake and depuration in different organs of *Lymnaea stagnalis* L. and the effect of cadmium on the natural zinc level	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pretto et al.	Acetylcholinesterase activity, lipid peroxidation, and bioaccumulation in silver catfish (*Rhamdia quelen*) exposed to cadmium	2010	Dilution water not characterized, not North American species
Pretto et al.	Effects of water cadmium concentrations on bioaccumulation and various oxidative stress parameters in *Rhamdia quelen*	2011	In vitro
Prevot and Soyer-Gobillard	Combined action of cadmium and selenium on two marine dinoflagellates in culture, *Prorocentrum micans* Ehrbg. and *Crypthecodinium cohnii* Biecheler	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Price and Knight	Mercury cadmium lead and arsenic in sediment exposures plankton and clams from Lake Washington and Sardis reservoir Mississippi October 1975-may 1976	1978	Bioaccumulation: steady state not documented
Prowe et al.	Heavy metals in crustaceans from the Iberian Deep Sea Plain	2006	Bioaccumulation: steady state not documented
Pundir and Malhotra	Haematological alterations induced by heavy metal cadmium toxicity in *Clarias batrachus*	2011	Only one exposure concentration
Pundir et al.	Toxicopathological changes in liver of *Clarias batrachus* due to cadmium sulphate toxicity	2012	Dilution water not characterized
Puvaneswari and Karuppasamy	Accumulation of cadmium and its effects on the survival and growth of larvae of *Heteropneustes fossilis* (Bloch, 1794)	2007	Unmeasured chronic exposure, duration too short, not North American species
Pynnonen	Effect of pH, hardness and maternal pre-exposure on the toxicity of Cd, Cu and Zn to the glochidial larvae of a freshwater clam *Anodonta cygnea*	1995	Not North American species
Pytharopoulou et al.	Translational responses and oxidative stress of mussels experimentally exposed to Hg, Cu and Cd: One pattern does not fit at all	2011	Mixture
Qian et al.	Combined effect of copper and cadmium on *Chlorella vulgaris* growth and photosynthesis-related gene transcription	2009	Mixture
Qian et al.	Photoperiod and temperature influence cadmium's effects on photosynthesis-related gene transcription in *Chlorella vulgaris*	2010	Mixture
Qian et al.	Combined effect of copper and cadmium on heavy metal ion bioaccumulation and antioxidant enzymes induction in *Chlorella vulgaris*	2011	Mixture
Qichen et al.	A comprehensive investigation of the toxic effects of heavy metals on fish	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Qin et al.	Effect of nanometer selenium on nonspecific immunity and antioxidase of gift stressed by cadmium	2011	Mixture
Qin et al.	Immune responses and ultrastructural changes of hemocytes in freshwater crab *Sinopotamon henanense* exposed to elevated cadmium	2012	In vitro

Authors	**Title**	**Year**	**Reason Unused**
Qiu et al.	Effects of calcium on the uptake and elimination of cadmium and zinc in Asiatic clams	2005	Mixture
Rachlin and Grosso	The effects of pH on the growth of *Chlorella vulgaris* and its interactions with cadmium toxicity	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Rachlin and Grosso	The growth response of the green alga *Chlorella vulgaris* to combined divalent cation exposure	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Radenac et al.	Bioaccumulation and toxicity of four dissolved metals in *Paracentrotus lividus* sea-urchin embryo	2001	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure
Radhakrishnan and Hemalatha	Sublethal toxic effects of cadmium chloride to liver of freshwater fish *Channa striatus* (Bloch.)	2010	Only one exposure concentration
Radhakrishnan and Hemalatha	Bioaccumulation of cadmium in the organs of freshwater fish *Heteropneustes fossilis* (Bloch, 1794)	2011	Not North American species
Rai et al.	Chromium and cadmium bioaccumulation and toxicity in *Hydrilla verticillata* (l.f.) Royle and *Chara corallina* Wildenow.	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Raimundo et al.	Geographical variation and partition of metals in tissues of *Octopus vulgaris* along the Portuguese coast	2004	Bioaccumulation: steady state not documented
Raimundo et al.	Sub-cellular partitioning of Zn, Cu, Cd and Pb in the digestive gland of native *Octopus vulgaris* exposed to different metal concentrations (Portugal)	2008	Bioaccumulation: steady state not documented
Raimundo et al.	Association of Zn, Cu, Cd and Pb with protein fractions and sub-cellular partitioning in the digestive gland of *Octopus vulgaris* living in habitats with different metal levels.	2010	Bioaccumulation: steady state not documented
Raimundo et al.	Decrease of Zn, Cd and Pb concentrations in marine fish species over a decade as response to reduction of anthropogenic inputs: the example of Tagus estuary.	2011	Bioaccumulation: steady state not documented
Rainbow	Accumulation of Zn, Cu and Cd by crabs and barnacles	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Rainbow and Black	Cadmium, zinc and the uptake of calcium by two crabs, *Carcinus maenas* and *Eriocheir sinensis*	2005	Excised tissue/cells
Rainbow and Kwan	Physiological responses and the uptake of cadmium and zinc by the amphipod crustacean *Orchestia gammarellus*	1995	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Rainbow and Wang	Comparative assimilation of Cd, Cr, Se, and Zn by the barnacle *Elminius modestus* from phytoplankton and zooplankton diets	2001	Dietary exposure
Rainbow and Wang	Trace metals in barnacles: the significance of trophic transfer	2005	Review
Rainbow and White	Comparative strategies of heavy metal accumulation by crustaceans: Zinc, copper and cadmium in a decapod, and amphipod and a barnacle	1989	Not North American species
Rainbow et al.	Effects of chelating agents on the accumulation of cadmium by the barnacle *Semibalanus balanoides*, and the complexation of soluble Cd, Zn and Cu	1980	Not North American species
Rainbow et al.	Geographical and seasonal variation of trace metal bioavailabilities in the Gulf of Gdansk, Baltic Sea using mussels (*Mytilus trossulus*) and barnacles (*Balanus improvisus*) as biomonitors	2004a	Bioaccumulation: steady state not documented
Rainbow et al.	Acute dietary pre-exposure and trace metal bioavailability to the barnacle *Balanus amphitrite*	2004b	Dietary exposure
Rainwater et al.	Metals and organochlorine pesticides in caudal scutes of crocodiles from Belize and Costa Rica	2007	Bioaccumulation: steady state not documented
Raissy et al.	Mercury, arsenic, cadmium and lead in lobster (*Panulirus homarus*) from the Persian Gulf	2011	Bioaccumulation: steady state not documented
Ralph and Burchett	Photosynthetic response of *Halophila ovalis* to heavy metal stress	1998	Not North American species
Ramachandran et al.	Effect of copper and cadmium on three Malaysian tropical estuarine invertebrate larvae	1997	Not North American species
Ramesha et al.	Toxicity of cadmium to common carp *Cyprinus carpio* (Linn.)	1996	Review of previously published data
Ramos et al.	Metal contents in Porites corals: Anthropogenic input of river run-off into a coral reef from an urbanized area, Okinawa	2004	Bioaccumulation: steady state not documented
Ramsak et al.	Evaluation of metallothioneins in blue mussels (*Mytilus galloprovincialis*) as a biomarker of mercury and cadmium exposure in the Slovenian Waters (Gulf of Trieste): A long-term field study	2012	Bioaccumulation: steady state not documented
Rangsayatorn et al.	Ultrastructural changes in various organs of the fish *Puntius gonionotus* fed cadmium-enriched cyanobacteria	2004	Dietary exposure
Rank et al.	DNA damage, acetylcholinesterase activity and lysosomal stability in native and transplanted mussels (*Mytilus edulis*) in areas close to coastal chemical dumping sites in Denmark	2007	Mixture
Rao and Madhyastha	Toxicities of some heavy metals to the tadpoles of frog, *Microhyla ornata* (Dumeril and Bibron)	1987	Not North American species
Rao et al.	Toxic effect of two heavy metals on phytoplankton photosynthesis	1979	No species name given; dilution water not characterized
Rao et al.	Distribution of contaminants in aquatic organisms from East Fork Poplar Creek	1996	Bioaccumulation: steady state not documented

NMED Exhibit 70

Authors	**Title**	**Year**	**Reason Unused**
Raposo et al.	Trace metals in oysters, *Crassotrea sps*., from UNESCO protected natural reserve of Urdaibai: Space-time observations and source identification	2009	Bioaccumulation: steady state not documented
Rasmussen et al.	Effect of age and tissue weight on the cadmium concentration in Pacific oysters (*Crassostrea gigas*)	2007	Lack of details; exposure concentration not known
Raungsomboon and Wongrat	Bioaccumulation of cadmium in an experimental aquatic ecosystem involving phytoplankton, zooplankton, catfish and sediment	2007	Bioaccumulation: steady state not documented (only 72 hour exposure), sediment exposure
Ray and White	Selected aquatic plants as indicator species for heavy metal pollution	1976	Bioaccumulation: steady state not documented
Ray et al.	Accumulation of copper, zinc, cadmium and lead from two contaminated sediments by three marine invertebrates - a laboratory study	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Rayms-Keller et al.	Effect of heavy metals on *Aedes aegypti* (Diptera: Culicidae) larvae	1998	The materials, methods or results were insufficiently described
Raynal et al.	Cadmium uptake in isolated adrenocortical cells of rainbow trout and yellow perch	2005	In vitro
Razinger et al.	Real-time visualization of oxidative stress in a floating macrophyte *Lemna minor* L. exposed to cadmium, copper, menadione, and AAPH	2010	Mixture
Re et al.	Estuarine sediment acute toxicity testing with the european amphipod *Corophium multisetosum* Stock, 1952	2009	Sediment
Reader et al.	The effects of eight trace metals in acid soft water on survival, mineral uptake and skeletal calcium deposition in yolk-sac fry of brown trout, *Salmo trutta* L.	1989	No interpretable concentration, time, response data or examined only a single exposure concentration
Rebhun and Ben-Amotz	The distribution of cadmium between the marine alga *Chlorella stigmatophora* and sea water medium	1984	Not North American species
Rebhun and Ben-Amotz	Effect of NaCl concentration on cadmium uptake by the halophilic alga *Dunaliella salina*	1986	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Rebhun and Ben-Amotz	Antagonistic effect of maganese to cadmium toxicity in the alga *Dunaliella salina*	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Reboucas do Amaral et al.	Bioaccumulation and Depuration of Zn and Cd in Mangrove Oysters (*Crassostrea rhizophorae*, Guilding, 1828) Transplanted to and from a Contaminated Tropical Coastal Lagoon	2005	Bioaccumulation: steady state not documented
Reddy and Fingerman	Effect of cadmium chloride on amylase activity in the red swamp crayfish, *Procambarus clarkii*	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Reddy et al.	Effects of cadmium and mercury on ovarian maturation in the red swamp crayfish, *Procambarus clarkii*	1997	Organisms were exposed to cadmium in food or by injection or gavage
Reddy et al.	Biochemical effects of cadmium on the liver of catfish, *Mystus tengara* (Ham.)	2010	In vitro

Authors	Title	Year	Reason Unused
Reddy et al.	Cadmium and mercury-induced hyperglycemia in the fresh water crab, *Oziotelphusa senex senex*: Involvement of neuroendocrine system	2011	Mixture
Reddy et al.	Effect of cadmium, lead and zinc on growth of some cyanobacteria	2002	Lack of details; exposure concentration not known
Rehwoldt et al.	The effect of increased temperature upon the acute toxicity of some heavy metal ions	1972	Questionable treatment of organisms; River water is dilution water (uncharacterized)
Reichelt-Brushett and Harrison	The effect of selected trace metals on the fertilization success of several scleractinian coral species	2005	Not North American species, duration too short
Reichert et al.	Uptake and metabolism of lead and cadmium in coho salmon (*Oncorhynchus kisutch*)	1979	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Reid and McDonald	Metal binding activity of the gills of rainbow trout (*Oncorhynchus mykiss*)	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Reinfelder and Fisher	The assimilation of elements ingested by marine planktonic bivalve larvae	1994a	Organisms were exposed to cadmium in food or by injection or gavage
Reinfelder and Fisher	Retention of elements absorbed by juvenile fish (*Menidia menidia*, *Menidia beryllina*) from zooplankton prey	1994b	Organisms were exposed to cadmium in food or by injection or gavage
Reinfelder et al.	Assimilation efficiencies and turnover rates of trace elements in marine bivalves: a comparison of oysters, clams and mussels	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Reish et al.	The effect of cadmium and DDT on the survival and regeneration in the amphinomid polychaete *Eurythoe complanata*	1988	Not North American species
Rejomon et al.	Trace metal concentrations in zooplankton from the eastern Arabian Sea and western Bay of Bengal	2008	Bioaccumulation: steady state not documented
Rejomon et al.	Trace metal dynamics in fishes from the southwest coast of India	2010	Bioaccumulation: steady state not documented
Remacle et al.	Cadmium fate in bacterial microcosms	1982	Results were only presented graphically
Ren et al.	Using factorial experiments to study the toxicity of metal mixtures	2004	Modeling
Ren et al.	Bioavailability and oxidative stress of cadmium to *Corbicula fluminea*	2013	Sediment exposure
Revathi et al.	Effect of cadmium on the ovarian development in the freshwater prawn *Macrobrachium rosenbergii* (De Man)	2011	Only one exposure concentration, dilution water not characterized
Reynders et al.	Dynamics of cadmium accumulation and effects in common carp (*Cyprinus carpio*) during simultaneous exposure to water and food (*Tubifex tubifex*)	2006a	Dietary exposure
Reynders et al.	Patterns of gene expression in carp liver after exposure to a mixture of waterborne and dietary cadmium using a custom-made microarray	2006b	Dietary exposure

Authors	Title	Year	Reason Unused
Reynders et al.	Accumulation and effects of metals in caged carp and resident roach along a metal pollution gradient	2008	Bioaccumulation: steady state not documented
Rhea et al.	Biomonitoring in the Boulder River watershed, Montana, USA: Metal concentrations in biofilm and macroinvertebrates, and relations with macroinvertebrate assemblage	2006	Bioaccumulation: steady state not documented
Rhodes et al.	Interactive effects of cadmium, polychlorinated biphenyls, and fuel oil on experimentally exposed English sole (*Parophrys vetulus*)	1985	Organisms were exposed to cadmium in food or by injection or gavage
Riba et al.	The influence of pH and salinity on the toxicity of heavy metals in sediment to the estuarine clam *Ruditapes philippinarum*	2004	Non-applicable
Ribo	Interlaboratory comparison studies of the luminescent bacteria toxicity bioassay	1997	No interpretable concentration, time, response data or examined only a single exposure concentration
Rice	A simple mass transport model for metal uptake by marine macroalgae growing at different rates	1984	Review of previously published data
Rice and Chien	Uptake, binding and clearance of divalent cadmium in *Glycera dibranchiata* (Annelida: Polychaeta)	1979	Bioaccumulation: not renewal or flow-through; injected toxicant; dilution water not characterized
Richards et al.	Effects of natural organic matter source on reducing metal toxicity to rainbow trout (*Oncorhynchus mykiss*) and on metal binding to their gills	2001	Mixture
Richelle et al.	Experimental and field studies on the effect of selected heavy metals on three freshwater sponge species: *Ephydatia fluviatilis*, *Ephydatia muelleri* and *Spongilla lacustris*	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Riches et al.	Effect of heavy metals on lipids from the freshwater alga *Selenastrum capricornutum*	1996	In vitro
Riddell et al.	Behavioral responses to sublethal cadmium exposure within an experimental aquatic food web	2005b	Only two exposure concentrations, duration too long
Riddell et al.	Sublethal effects of cadmium on prey choice and capture efficiency in juvenile brook trout (*Salvelinus fontinalis*)	2005a	Only two exposure concentration, atypical endpoint
Ridlington et al.	Metallothionein and Cu-chelation: Characterization of metal-binding proteins from the tissues of four marine animals	1981	Questionable treatment of test organisms or inappropriate test conditions or methodology
Ridout et al.	Concentrations of manganese iron copper zinc and cadmium in the mesopelagic decapod Systellaspis debilis from the east Atlantic ocean	1985	Bioaccumulation: steady state not documented
Riedel and Christensen	Effect of selected water toxicants and other chemicals upon adenosine triphosphatase activity in vitro	1979	In vitro
Riget et al.	Influence of length on element concentrations in blue mussels (*Mytilus edulis*)	1996	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Riisgard et al.	Accumulation of cadmium in the mussel *Mytilus edulis*: Kinetics and importance of uptake via food and sea water	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ringwood	Accumulation of cadmium by larvae and adults of an Hawaiian bivalve, *Isognomon californicum*, during chronic exposure	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ringwood	Effects of chronic cadmium exposures on growth of larvae of an Hawaiian bivalve, *Isognomon californicum*	1992b	Dilution water not characterized
Ringwood	Comparative sensitivity of gametes and early developmental stages of a sea urchin species (*Echinometra mathaei*) and a bivalve species (*Isognomon californicum*) during metal exposures	1992a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ringwood	Age-specific differences in cadmium sensitivity and bioaccumulation in bivalve molluscs	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Risso-de Faverney et al.	Cadmium induces apoptosis and genotoxicity in rainbow trout hepatocytes through generation of reactive oxygen species	2001	In vitro
Ritterhoff et al.	Calibration of the estuarine amphipods, *Gammarus zaddachi* Sexton (1912), as biomonitors: Toxicokinetics of cadmium and possible role of inducible metal-binding proteins in Cd detoxification	1996	Not North American species
Roach et al.	Assessment of metals in fish from Lake Macquarie, New South Wales, Australia	2008	Bioaccumulation: steady state not documented
Roast et al.	Impairment of mysid (*Neomysis integer*) swimming ability: An environmentally realistic assessment of the impact of cadmium exposure	2001a	Only two exposure concentrations, duration too long, Not North American species
Roast et al.	Behavioural responses of estuarine mysids to hypoxia and disruption by cadmium	2002a	Not North American species
Roast et al.	Trace metal uptake by the Chinese mitten crab *Eriocheir sinensis*: the role of osmoregulation	2002c	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Roast et al.	Distribution and swimming behaviour of *Neomysis integer* (Peracarida: Mysidacea) in response to gradients of dissolved oxygen following exposure to cadmium at environmental concentrations	2002b	Review; Not North American species
Roberto et al.	Carbonic anhydrase activity in Mytilus galloprovincialis digestive gland: Sensitivity to heavy metal exposure	2010	Mixture
Robertson and Liber	Bioassays with caged *Hyalella azteca* to determine in situ toxicity downstream of two Saskatchewan, Canada, uranium operations	2007	Mixture

Authors	Title	Year	Reason Unused
Roccheri et al.	Cadmium induces the expression of specific stress proteins in sea urchin embryos	2004	Not North American species
Roch and Mccarter	Metallothionein induction, growth, and survival of chinook salmon exposed to zinc, copper, and cadmium	1984	Mixture
Roch and McCarter	Metallothionein induction growth and survival of rainbow trout exposed to mixed heavy metal contamination	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Roch et al.	Determination of no effect levels of heavy metals for rainbow trout using hepatic metallothionein	1986	Mixture
Rodgher and Espindola	Effects of interactions between algal densities and cadmium concentrations on *Ceriodaphnia dubia* fecundity and survival	2008	Dietary exposure
Rodrigues and Pawlowsky	Acute toxicity tests by bioassays applied to the solubilized extracts of solid wastes Class II A - non inerts and Class II B	2007	Text in foreign language
Rodriguez et al.	Accumulation of lead, chromium, and cadmium in muscle of capitan (*Eremophilus mutisii*), a catfish from the Bogota River Basin	2009	Bioaccumulation: steady state not documented
Roesijadi and Fellingham	Influence of Cu, Cd, and Zn preexposure on Hg toxicity in the mussel *Mytilus edulis*	1987	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Roesijadi et al.	Dietary cadmium and benzo(a)pyrene increased intestinal metallothionein expression in the fish *Fundulus heteroclitus*	2009	Dietary exposure
Roh et al.	A cadmium toxicity assay using stress responsive *Caenorhabditis elegans* mutant strains	2009	Data previously reported
Roline and Boehmke	Heavy metals pollution of the Upper Arkansas River, Colorado, and its effects on the distribution of the aquatic macrofauna	1981	Bioaccumulation: steady state not documented
Roman et al.	Seasonal studies on cadmium toxicity in *Choromytilus chorus* (Molina 1782)	1994	Not North American species
Rombough	The influence of the zona radiata on the toxicities of zinc, lead, mercury, copper and silver ions to embryos of steelhead trout *Salmo gairdneri*	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Romeo	Toxicology of trace metals in the marine	1991	Text in foreign language
Romeo and Gnassia-Barelli	Metal distribution in different tissues and in subcellular fractions of the Mediterranean clam *Ruditapes decussatus* treated with cadmium, copper, or zinc	1995	Not North American species
Romera et al.	Comparative study of biosorption of heavy metals using different types of algae	2007	No cadmium toxicity information; treatment study
Romera et al.	Biosorption of heavy metals by *Fucus spiralis*	2008b	Mixture
Romera et al.	Biosorption of Cd, Ni, and Zn with mixtures of different types of algae	2008a	Bioaccumulation: steady state not documented
Romero et al.	Toxic effects of cadmium on microalgae isolated from the northeastern region of Venezuela	2002	Non-applicable
Ros and Slooff	Integrated criteria document cadmium; Appendix 1. Effects	1988	Review

Authors	**Title**	**Year**	**Reason Unused**
Rosas and Ramirez	Effect of chromium and cadmium on the thermal tolerance of the prawn *Macrobrachium rosenbergii* expose to hard and soft water	1993	No interpretable concentration, time, response data or examined only a single exposure concentration
Rosas et al.	Trace metal concentrations in southern right whale (*Eubalaena australis*) at Peninsula Valdes, Argentina.	2012	Bioaccumulation: steady state not documented
Roseman et al.	bsorption of cadmium from water by North American zebra and quagga mussels (Bivalvia: Dreissenidae)	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Rossi and Jamet	In situ heavy metals (copper, lead and cadmium) in different plankton compartments and suspended particulate matter in two coupled Mediterranean coastal ecosystems (Toulon Bay, France)	2008	Bioaccumulation: steady state not documented
Rouleau et al.	Kinetics and body distribution of waterborne ^{65}Zn(II), ^{109}Cd(II), ^{203}Hg(II), and $CH_3{}^{203}$Hg(II) in phantom midge larvae (*Chaoborus americanus*) and effects of complexing agents	1998	No useable data on cadmium toxicity or bioconcentration
Rowe	Elevated standard metabolic rate in a freshwater shrimp (*Palaemonetes paludosus*) exposed to trace element-rich coal combustion waste	1998	Mixture
Roy et al.	Adsorption of heavy metals by green algae and ground rice hulls	1993	In vitro
Ruan	Contents of and assessment on heavy metals in aquatic organisms in the Yuandang Lake of Xiamen	2006	Bioaccumulation: steady state not documented
Ruangsomboon and Wongrat	Bioaccumulation of cadmium in an experimental aquatic food chain involving phytoplankton (*Chlorella vulgaris*), zooplankton (*Moina macrocopa*), and the predatory catfish *Clarias macrocephalus* x *C. gariepinus*	2006	Dietary exposure
Rubinstein et al.	Accumulation of PCBs, mercury and cadmium by *Nereis virens*, *Mercenaria mercenaria* and *Palaemontes pugio* from contaminated harbor sediments	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ruelaqs-Inzunza and Paez-Osuna	Trophic Distribution of Cd, Pb, and Zn in a Food Web from Altata-Ensenada del Pabellon Subtropical Lagoon, SE Gulf of California	2008	SS not do
Ruelas-Inzunza et al.	Trophic distribution of Cd, Pb, and Zn in a food web from Altata-Ensenada del Pabellon subtropical lagoon, SE Gulf of California	2010	Bioaccumulation: steady state not documented
Ruelle and Keenlyne	Contaminants in Missouri River pallid sturgeon	1993	Bioaccumulation: steady state not documented
Rumolo et al.	Heavy metals in benthic foraminifera from the highly polluted sediments of the Naples Harbour (southern Tyrrhenian Sea, Italy)	2009	Bioaccumulation: steady state not documented
Saavedra et al.	Interspecific variation of metal concentrations in three bivalve mollusks from Galicia	2004	Bioaccumulation: steady state not documented
Safadi	The use of freshwater planarians in acute toxicity test with heavy metals	1998	Not North American species

Authors	Title	Year	Reason Unused
Saglam et al.	Investigations on the osmoregulation of freshwater fish (*Oreochromis niloticus*) following exposures to metals (Cd, Cu) in differing hardness	2013	Only one exposure concentration
Saglamtimur et al.	Effects of different concentrations of copper alone and a copper+cadmium mixture on the accumulation of copper in the gill, liver, kidney and muscle tissues of *Oreochromis niloticus* (L.)	2003	Mixture
Sahu et al.	Accumulation of metals in naturally grown weeds (aquatic macrophytes) grown on an industrial effluent channel	2007	Effluent
Saiki et al.	Copper, cadmium, and zinc concentrations in juvenile chinook salmon and selected fish-forage organisms (aquatic insects) in the upper Sacramento River, California	2001	Bioaccumulation: steady state not documented
Sajwan et al.	Elemental status in sediment and American oyster collected from Savannah marsh/estuarine ecosystem: A preliminary assessment	2008	Bioaccumulation: steady state not documented
Salahshur et al.	Use of *Solen brevis* as a biomonitor for Cd, Pb and Zn on the intertidal zones of Bushehr-Persian Gulf, Iran.	2012	Bioaccumulation: steady state not documented
Salanki et al.	Heavy metals in animals of Lake Balaton	1982	Bioaccumulation: steady state not documented
Salazar-Lugo et al.	Effect of chronic cadmium exposure on structure of head kidney of neotropical fish *Colossoma macropomum*	2011	Abstract only
Salazar-Medina et al.	Inhibition by Cu2+ and Cd2+ of a mu-class glutathione S-transferase from shrimp *Litopenaeus vannamei*	2010	In vitro
Saleem et al.	Heavy metal concentration in the fish and shellfish of Karachi harbour area	1999	Bioaccumulation: steady state not documented
Salice et al.	Demographic responses to multigeneration cadmium exposure in two strains of the freshwater gastropod, *Biomphalaria glabrata*	2009	Prior exposure, unmeasured chronic exposure
Salice et al.	Adaptive responses and latent costs of multigeneration cadmium exposure in parasite resistant and susceptible strains of a freshwater snail	2010	Too few exposure concentrations, atypical endpoint
Salvado et al.	Monitoring of nutrients, pesticides, and metals in waters, sediments, and fish of a wetland	2006	Bioaccumulation: steady state not documented
Samecka-Cymerman and Kempers	Heavy metals in aquatic macrophytes from two small rivers polluted by urban, agricultural and textile industry sewages SW Poland	2007	Bioaccumulation: steady state not documented
Samecka-Cymerman et al.	Heavy metals in aquatic bryophytes from the Ore mountains (Germany)	2002	Bioaccumulation: steady state not documented
Sanchez	Development of novel biomarkers of fish exposure to environmental contaminants	2009	Injected toxicant
Sanchez-Chardi et al.	Bioaccumulation of lead, mercury, and cadmium in the greater white-toothed shrew, *Crocidura russula*, from the Ebro Delta (NE Spain): Sex- and age-dependent variation	2007	Bioaccumulation: steady state not documented
Sanchiz et al.	Bioaccumulation of Hg, Cd, Pb and Zn in four marine phanerogams and the alga *Caulerpa prolifera* (Forsskal) Lamouroux from the east coast of Spain	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Sanchiz et al.	Relationships between sediment physico-chemical characteristics and heavy metal bioaccumulation in Mediterranean soft-bottom macrophytes	2001	Bioaccumulation: steady state not documented
Sanchiz et al.	Mercury, cadmium, lead and zinc bioaccumulation in soft-bottom marine macrophytes from the east coast of Spain	2002	Bioaccumulation: steady state not documented
Sandau et al.	Heavy metal sorption by microalagae	1996	The materials, methods or results were insufficiently described
Sandhu et al.	Cadmium-mediated disruption of cortisol biosynthesis involves suppression of corticosteroidogenic genes in rainbow trout	2011	In vitro
Sandhu et al.	Exposure to environmental levels of waterborne cadmium impacts corticosteroidogenic and metabolic capacities, and compromises secondary stressor performance in rainbow trout	2014	Only two exposure concentrations
Sandrini et al.	Short-term responses to cadmium exposure in the estuarine polychaete *Laeonereis acuta* (Polychaeta, Nereididae): Subcellular distribution and oxidative stress generation	2006	Only one exposure concentration, duration too short, not North American species
Sanger et al.	The effects of cadmium on *Mytilus edulis*: Metallothionein, micronuclei and heart rate	2002	Non-applicable
Santojanni et al.	Prediction of fecundity in chronic toxicity tests on *Daphnia magna*	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Santoro et al.	Bioaccumulation of heavy metals by aquatic macroinvertebrates along the Basento River in the south of Italy	2009	Bioaccumulation: steady state not documented
Santos et al.	Biomonitoring of metal contamination in a marine prosobranch snail (*Nassarius reticulatus*) by imaging laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS)	2009	Bioaccumulation: steady state not documented
Sapozhnikova et al.	Evaluation of pesticides and metals in fish of the Dniester River, Moldova	2005	Bioaccumulation: steady state not documented
Sarosiek et al.	The effect of copper, zinc, mercury and cadmium on some sperm enzyme activities in the common carp (*Cyprinus carpio* L.)	2009	Mixture
Sasikumar et al.	Monitoring trace metal contaminants in green mussel, *Perna viridis* from the coastal waters of Karnataka, southwest coast of India	2006	Bioaccumulation: steady state not documented
Sasmaz et al.	The accumulation of heavy metals in *Typha latifolia* L. grown in a stream carrying secondary effluent	2008	Effluent
Sassi et al.	Influence of high temperature on cadmium-induced skeletal deformities in juvenile mosquitofish (*Gambusia affinis*)	2010	Only one exposure concentration, dilution water not characterized
Sastry and Shukla	Influence of protective agents in the toxicity of cadmium to a freshwater fish (*Channa punctatus*)	1994	Not North American species
Sastry and Sunita	Effect of cadmium and chromium on the intestinal absorption of glucose in the snakehead fish, *Channa punctatus*	1982	Not North American species

Authors	Title	Year	Reason Unused
Satake et al.	Inorganic elements in some aquatic bryophytes from streams in New Caledonia	1984	Bioaccumulation: steady state not documented
Sauvant et al.	Toxicity assessment of 16 inorganic environmental pollutants by six bioassays	1997	No interpretable concentration, time, response data or examined only a single exposure concentration
Sauve et al.	Phagocytic response of terrestrial and aquatic invertebrates following in vitro exposure to trace elements	2002a	In vitro
Sauve et al.	Phagocytic activity of marine and freshwater bivalves: In vitro exposure of hemocytes to metals (Ag, Cd, Hg and Zn)	2002b	In vitro
Saxena et al.	Experimental studies on toxicity of zinc and cadmium to *Heteropneustes fossilis* (Bl.)	1993	Not North American species
Saygideger and Dogan	Lead and cadmium accumulation and toxicity in the presence of EDTA in *Lemna minor* L. and *Ceratophyllum demersum* L.	2004	Mixture
Saygideger and Dogan	Variation of lead, cadmium, copper, and zinc in aquatic macrophytes from the Seyhan River, Adana, Turkey	2005	Bioaccumulation: steady state not documented
Saygideger et al.	Adsorption of Cd(II), Cu(II) and Ni(II) ions by *Lemna minor* L.: Effect of physicochemical environment	2005	Mixture
Sayk and Schmidt	Algae fluorescence auto meter, a computer-controlled measuring apparatus biotest	1986	Text in foreign language
Schaeffer et al.	Evaluation of the reference toxicant addition procedure for testing the toxicity of environmental samples	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Schiff et al.	Characterization of stormwater toxicants from an urban watershed to freshwater and marine organisms	2002	Effluent
Schintu et al.	Trace metals in algae from the south-western coast of Sardinia (Italy)	2007	Bioaccumulation: steady state not documented
Schmidt	Possible use and results of an algal fluorescence bioassay	1987	Text in foreign language
Schmitt	Concentrations of arsenic, cadmium, copper, lead, selenium, and zinc in fish from the Mississippi River basin, 1995	2004	Bioaccumulation: steady state not documented
Schmitt et al.	Organochlorine residues and elemental contaminants in U.S. freshwater fish, 1976-1986: National contaminant biomonitoring program	1999	Bioaccumulation: steady state not documented
Schmitt et al.	Biochemical effects of lead, zinc, and cadmium from mining on fish in the tri-states district of northeastern Oklahoma, USA	2005	Bioaccumulation: steady state not documented
Schmitt et al.	A screening-level assessment of lead, cadmium, and zinc in fish and crayfish from northeastern Oklahoma, USA	2006	Bioaccumulation: steady state not documented
Schmitt et al.	Accumulation of metals in fish from lead-zinc mining areas of southeastern Missouri, USA	2007	Bioaccumulation: steady state not documented
Schmitt et al.	Concentrations of cadmium, cobalt, lead, nickel, and zinc in blood and fillets of northern hog sucker (*Hypentelium nigricans*) from streams contaminated by lead-zinc mining: Implications for monitoring	2009a	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Schmitt et al.	Concentrations of metals in aquatic invertebrates from the Ozark National Scenic Riverways, Missouri	2009b	Bioaccumulation: steady state not documented
Schoenert et al.	The sensitivity of six strains of unicellular algae *Selenastrum capricornutum* to six reference toxicants	1983	Abstract only
Schor-Fumbarov et al.	Characterization of cadmium uptake by the water lily *Nymphaea aurora*	2003	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Schorr and Backer	Localized effects of coal mine drainage on fish assemblages in a Cumberland plateau stream in Tennessee	2006	Mixture
Schroeder	Development of models for the prediction of short-term and long-term toxicity to *Hyalella azteca* from separate exposures to nickel and cadmium	2008	Bioaccumulation: steady state not documented
Schuwerack et al.	The dynamics of protein and metal metabolism in acclimated and Cd-exposed freshwater crabs (*Potamonautes warreni*)	2009	Only one exposure concentration, duration too short, not North American species
Schwartz et al.	Influence of natural organic matter source on acute copper, lead, and cadmium toxicity to rainbow trout (*Oncorhynchus mykiss*)	2004	Mixture
Secor et al.	Bioaccumulation of toxicants, element and nutrient composition, and soft tissue histology of zebra mussels (*Dreissena polymorpha*) from New York State waters	1993	Bioaccumulation: steady state not documented
Sedlacek et al.	Influence of different aquatic humus fractions on uptake of cadmium to alga *Selenastrum capriconutum* Printz	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Seebaugh and Wallace	Assimilation and subcellular partitioning of elements by grass shrimp collected along an impact gradient	2009	Bioaccumulation: steady state not documented
Seebaugh et al.	Digestive toxicity in grass shrimp collected along an impact gradient	2011	Fed toxicant
Seebaugh et al.	Carbon assimilation and digestive toxicity in naive grass shrimp (*Palaemonetes pugio*) exposed to dietary cadmium	2012	Fed toxicant
Segner and Lenz	Cytotoxicity assays with the rainbow trout R1 cell line	1993	In vitro
Segovia-Zavala et al.	Cadmium and silver in Mytilus californianus transplanted to an anthropogenic influenced and coastal upwelling areas in the Mexican northeastern Pacific	2004	Bioaccumulation: steady state not documented
Sehgal and Saxena	Determination of acute toxicity levels of cadmium and lead to the fish *Lebistes reticulatus* (Peters)	1987	Not North American species
Sekine and Noriko	Studies on the accumulation and transfer of pollutants through food chain. 6. Study on the optimum condition on simulation test and effect of culturing density on the toxicity of cadmium for killifish throughout the year	1985	Text in foreign language

Authors	Title	Year	Reason Unused
Sekkat et al.	Study of the interactions between copper, cadmium, and ferbam using the protozoan *Colpidium campylum* bioassay	1992	The materials, methods or results were insufficiently described
Selck and Forbes	The relative importance of water and diet for uptake and subcellular distribution of cadmium in the deposit-feeding polychaete, *Capitella sp.*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Sellin et al.	Cadmium exposures in fathead minnows: Are there sex-specific differences in mortality, reproductive success, and Cd accumulation?	2007	Only one exposure concentration, duration too short
Semsari and Megateli	Effect of cadmium toxicity on survival and phototactic behaviour of *Daphnia magna*	2007	Duration too short, only one exposure concentration
Sen and Sunlu	Effects of cadmium (CdCl(2)) on development and hatching of eggs in European squid (*Loligo vulgaris* Lamarck, 1798) (Cephalopoda: Loliginidae)	2007	No acclimation to test media, not North American species
Senadheera and Pathiratne	Bioaccumulation potential of three toxic heavy metals in shrimp, *Penaeus monodon* from different fractions of the culture environment	2003	Bioaccumulation: field study, exposure concentration not known
Senger et al.	In vitro effect of zinc and cadmium on acetylcholinesterase and ectonucleotidase activities in zebrafish (*Danio rerio*) brain	2006	In vitro
Serafim and Bebianno	Kinetic model of cadmium accumulation and elimination and metallothionein response in *Ruditapes decussatus*	2007	Bioaccumulation: not whole body or muscle content; not North American species
Serafim and Bebianno	Effect of a polymetallic mixture on metal accumulation and metallothionein response in the clam *Ruditapes decussatus*	2010	Mixture
Serafim et al.	Effect of temperature and size on metallothionein synthesis in the gill of *Mytilus galloprovincialis* exposed to cadmium	2002	Dilution water not characterized, only one exposure concentration
Serfozo	Necrotic effects of the xenobiotics' accumulation in the central nervous system of a crayfish (*Astacus leptodactylus* Eschz.)	1993	Lack of exposure details
Servizi and Martens	Effects of selected heavy metals on early life of sockeye and pink salmon	1978	Questionable treatment of test organisms or inappropriate test conditions or methodology
Seth et al.	Toxic effect of arsenate and cadmium alone and in combination on giant duckweed (*Spirodela polyrrhiza* L.) in response to its accumulation	2007	Excessive EDTA in medium (2,628 ug/L)
Shanmukhappa and Neelakantan	Influence of humic acid on the toxicity of copper, cadmium and lead to the unicellular alga, *Synechosystis aquatilis*	1990	Not North American species
Sharma and Patino	Effects of cadmium, estradiol-17beta and their interaction on gonadal condition and metamorphosis of male and female african clawed frog, *Xenopus laevis*	2010	Only one exposure concentration
Sharma and Selvaraj	Zinc, lead and cadmium toxicity to selected freshwater zooplankters	1994	Organisms only acclimated 5 days, lake water (dilution water) not completely characterized
Sharma et al.	Diurnal variation of Texas "brown tide" (*Aureoumbra lagunensis*) in relation to metals	2000	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Shaw et al.	Gene response profiles for *Daphnia pulex* exposed to the environmental stressor cadmium reveals novel crustacean metallothioneins	2007	Lack of detail
Shazili	Effects of salinity and pre-exposure on acute cadmium toxicity to seabass, *Lates calcarifer*	1995	Not North American species
Shcherban	Toxicity of some heavy metals for *Daphnia magna* Strauss, as a function of temperature	1977	The materials, methods or results were insufficiently described
Sheela et al.	Impact of cadmium on food utilization, growth and body composition in the fish *Oreochromis mossambicus*	1995	The materials, methods or results were insufficiently described
Sheir and Handy	Tissue injury and cellular immune responses to cadmium chloride exposure in the common mussel *Mytilus edulis*: Modulation by lipopolysaccharide	2010	In vitro
Shi and Wang	Understanding the differences in Cd and Zn bioaccumulation and subcellular storage among different populations of marine clams	2004	Bioaccumulation: steady state not documented
Shiber and Shatila	Lead cadmium copper nickel and iron in limpets mussels and snails from the coast of Ras Beirut Lebanon	1978	Bioaccumulation: steady state not documented
Shilla et al.	Distribution of heavy metals in dissolved, particulate and biota in the Scheldt Estuary, Belgium	2008	Bioaccumulation: steady state not documented
Shirakashi and El-Matbouli	Effect of cadmium on the susceptibility of *Tubifex tubifex* to *Myxobolus cerebralis* (Myxozoa), the causative agent of whirling disease	2010	Mixture
Shirvani and Jamili	Assessing Cd, Pb accumulation in the tissues of *Chalcalbumus chalcoides* in Anzali Port	2009	Bioaccumulation: steady state not documented
Shivaraj and Patil	Toxicity of cadmium and copper to a freshwater fish *Puntius arulius*	1988	Not North American species
Shuhaimi-Othman and Pascoe	Bioconcentration and depuration of copper, cadmium, and zinc mixtures by the freshwater amphipod *Hyallela azteca*	2007	Bioaccumulation: steady state not documented (only 5 day exposure)
Shuhaimi-Othman et al.	Toxicity of eight metals to Malaysian freshwater midge larva *Chironomus javanus* (Diptera, Chironomidae)	2011	Not North American species
Shuhaimi-Othman et al.	Toxicity of metals to tadpoles of the common Sunda toad, *Duttaphrynus melanostictus*	2012a	Not North American species
Shukla et al.	Effect of cadmium individually and in combination with other metals on the nutritive value of fresh water fish, *Channa punctatus*	2002	Dilution water not characterized, not North American species
Shukla et al.	Bioaccumulation of Zn, Cu and Cd in *Channa punctatus*	2007b	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Shukla et al.	Preferential accumulation of cadmium and chromium: Toxicity in *Bacopa monnieri* L. under mixed metal treatments	2007a	Mixture
Shulkin and Presley	Metal concentrations in mussel *Crenomytilus grayanus* and oyster *Crassostrea gigas* in relation to contamination of ambient sediment exposures	2003	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Shulkin et al.	The influence of metal concentration in bottom sediments on metal accumulation by *Mytilids crenomytilus grayanus* and *Modiolus kurilensis*	2002	Sediment exposure
Siboni et al.	Coastal coal pollution increases Cd concentrations in the predatory gastropod *Hexaplex trunculus* and is detrimental to its health	2004	Bioaccumulation: steady state not documented
Sick and Baptist	Cadmium incorporation by the marine copepod *Pseudodiaptomous coronatus*	1979	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
Sidoumou et al.	Cadmium and calcium uptake in the mollusc *Donax rugosus* and effect of a calcium channel blocker	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Sidoumou et al.	Heavy metal concentrations in molluscs from the Senegal coast	2006	Bioaccumulation: steady state not documented
Sieratowicz et al.	Effects of test media on reproduction in *Potamopyrgus antipodarum* and of pre-exposure population densities on sensitivity to cadmium in a reproduction test	2013	Only one exposure concentration
Sikorska and Wolnicki	Cadmium toxicity to rudd (*Scardinius erythrophthalmus* L.) larvae after short-term exposure	2006	Dilution water not characterized, duration too short, not North American species
Silva et al.	Utilization of *Odontesthes regia* (Atherinidae) from the south eastern Pacific as a test organism for bioassays: Study of its sensitivity to six chemicals	2001	Duration too short, not North American species
Silva et al.	Effects of phenanthrene- and metal-contaminated sediment on the feeding activity of the harpacticoid copepod, *Schizopera knabeni*	2009	Sediment exposure
Silvestre et al.	Uptake of cadmium through isolated perfused gills of the chinese mitten crab, *Eriocheir sinensis*	2004	Non-applicable
Silvestre et al.	Hyper-osmoregulatory capacity of the Chinese mitten crab (*Eriocheir sinensis*) exposed to cadmium; Acclimation during chronic exposure	2005	High control mortality (26%), not North American species
Simas et al.	Shrimp - a dynamic model of heavy-metal uptake in aquatic macrofauna	2001	Modeling
Simoes Goncalves et al.	Effect of nutrients, temperature and light on uptake of cadmium by *Selenastrum capricornutum* Printz	1988	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Simoes Goncalves et al.	Effect of speciation on uptake and toxicity of cadmium to shrimp *Crangon crangon* (L.)	1989	Not North American species
Simon et al.	In situ evaluation of cadmium biomarkers in green algae	2011	Effluent
Simonetti et al.	Heavy-metal concentrations in soft tissues of the burrowing crab *Neohelice granulata* in Bahia Blanca estuary, Argentina	2012	Bioaccumulation: steady state not documented
Simonova et al.	Comparison of tolerance of *Brassica juncea* and *Vigna radiata* to cadmium	2007	Non-aquatic plants

Authors	Title	Year	Reason Unused
Sindhe et al.	Ovarian changes in response to heavy metal exposure to the fish, *Notopterus notopterus* (Pallas)	2002	Dilution water not characterized, lack of exposure details, not North American species
Singh	Toxic effects of cadmium chloride n growth and oogonium formation in *Oedogonium hatei*	2005	Lack of details, no statistical analysis
Singh and Ferns	Accumulation of heavy metals in rainbow trout *Salmo gairdneri* (Richardson) maintained on a diet containing activated sewage sludge	1978	Effluent
Singh et al.	Changes in haematocrit values of *Labeo rohita* (Ham.) under the toxicity of cadmium chloride	2003	Lack of details, not North American species
Singh et al.	Heavy metal concentrations in water, sediments and body tissues of red worm (*Tubifex spp*.) collected from natural habitats in Mumbai, India	2007b	Bioaccumulation: steady state not documented
Singh et al.	Cadmium induced changes on the secretion of branchial mucous cells of peppered loach, *Lepdocephalichthys guntea*	2007a	Dilution water not characterized, only one exposure concentration, not North American species, duration too long
Singh et al.	Bioaccumulation of cadmium in tissues of *Cirrihna mrigala* and *Catla catla*	2008	Lack of details; not North American species
Sinha et al.	Bioaccumulation and toxicity of Cu and Cd in *Vallisneria spiralis* (L.).	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Sinha et al.	Calorific changes in liver, ovary and muscle of hill stream fish *Garra mullya* (sykes) due to cadmium toxicity	2001	Unmeasured chronic exposure, only one exposure concentration, not North American species
Siva Kiran et al.	Bioaccumulation of cadmium in blue green alga *Spirulina* (*Arthrospira*) *indica*	2012	Excessive EDTA in medium (80,000 ug/L)
Skinner et al.	Heavy metal concentrations in wild and cultured blacklip abalone (*Haliotis rubra* Leach) from southern Australian waters	2004	Bioaccumulation: steady state not documented
Skorkowski et al.	Effect of cadmium and glutathione on malic enzyme activity in brown shrimps (*Crangon crangon*) from the Gulf of Gdansk (Baltic Sea, Poland)	2011	Bioaccumulation: steady state not documented
Skowronski and Przytocka-Jusiak	Effect of cadmium on the growth of *Chlorella vulgaris* and *Stichococcus baccillaris*	1981	Cannot determine effect concentration, no statistical analysis
Skowronski and Przytocka-Jusiak	Cadmium removal by green alga *Stichococcus bacillaris*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Skowronski et al.	Reduction of cadmium toxicity to green microalga *Stichococcus bacillaris* by manganese	1988	Review of previously published data

Authors	Title	Year	Reason Unused
Skowronski et al.	The influence of pH on cadmium toxicity to the green alga *Stichococcus bacillaris* and on the cadmium forms present in the culture medium	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Slobodskova et al.	Evaluation of the genotoxicity of cadmium in gill cells of the clam *Corbicula japonica* using the Comet Assay	2010	In vitro
Sloman et al.	The effects of trace metal exposure on agonistic encounters in juvenile rainbow trout, *Oncorhynchus mykiss*	2003a	Only one exposure concentration, duration too short
Sloman et al.	Cadmium affects the social behaviour of rainbow trout, *Oncorhynchus mykiss*	2003b	Only one exposure concentration, duration too short
Sloof et al.	Kinetics of cadmium uptake by green algae	1995	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Smith et al.	Distribution and significance of copper, lead, zinc and cadmium in the Corio Bay ecosystem	1981	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Smith et al.	Chemical contaminants, lymphocystis, and dermal sarcoma in walleyes spawning in the Thames River, Ontario	1992	Bioaccumulation: steady state not documented
Smith et al.	Inhibited cytotoxic leukocyte activity in tilapia (*Oreochromis niloticus*) following exposure to immunotoxic chemicals	1999a	Injected toxicant
Smith et al.	Tilapia (*Oreochromis niloticus*) and rodents exhibit similar patterns of inhibited antibody production following exposure to immunotoxic chemicals	1999b	Injected toxicant
Smokorowski et al.	Quantifying the uptake and release of cadmium and copper by the opossum shrimp *Mysis relicta* preying upon the cladoceran *Daphnia magna* using stable isotope tracers	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Snodgrass et al.	Microcosm investigations of stormwater pond sediment toxicity to embryonic and larval amphibians: Variation in sensitivity among species	2008	Sediment exposure
Soares et al.	Vanadium and cadmium in vivo effects in teleost cardiac muscle: Metal accumulation and oxidative stress markers	2008	Mixture
Sobhan and Sternberg	Cadmium removal using cladophora	1999	No useable data on cadmium toxicity or bioconcentration
Sobral et al.	In vitro development of parthenogenetic eggs: a fast ecotoxicity test with *Daphnia magna*?	2001	In vitro
Sobrino-Figueroa and Caceres-Martinez	Alterations of valve closing behavior in juvenile catarina scallops (*Argopecten ventricosus* Sowerby, 1842) exposed to toxic metals	2009	Mixture
Softeland et al.	Toxicological application of primary hepatocyte cell cultures of Atlantic cod (*Gadus morhua*)--effects of BNF, PCDD and Cd	2010	In vitro

Authors	Title	Year	Reason Unused
Sokolova et al.	Effects of temperature and cadmium exposure on the mitochondria of oysters (*Crassostrea virginica*) exposed to hypoxia and subsequent reoxygenation	2012	Abstract only
Sokolova et al.	Cadmium exposure affects mitochondrial bioenergetics and gene expression of key mitochondrial proteins in the eastern oyster *Crassostrea virginica* Gmelin (Bivalvia: Ostreidae)	2005b	Only one exposure concentration, unmeasured chronic exposure
Sokolova et al.	Tissue-specific accumulation of cadmium in subcellular compartments of eastern oyster *Crassostrea virginica* Gmelin (Bivalvia: Ostreidae)	2005a	Bioaccumulation: steady state not documented; unmeasured exposure
Sokolowski et al.	The relationship between metal concentrations and phenotypes in the Baltic clam *Macoma balthica* (L.) from the Gulf of Gdansk, southern Baltic	2002	Bioaccumulation: steady state not documented
Sola et al.	Heavy metal bioaccumulation and macroinvertebrate community changes in a Mediterranean stream affected by acid mine drainage and an accidental spill (Guadiamar River, SW Spain)	2004	Bioaccumulation: steady state not documented
Solanke	Toxicity of cadmium in fresh water fish *Cyprinus carpio*	2012	Dilution water not characterized; only one exposure concentration
Sole Rovira et al.	Effects on metallothionein levels and other stress defenses in Senegal sole larvae exposed to cadmium	2005	Bioaccumulation: steady state not documented; unmeasured exposure; not North American species
Soltan and Rashed	Laboratory study on the survival of water hyacinth under several conditions of heavy metal concentrations	2003	Distilled water without the proper salts, only one exposure concentration
Sommer and Winkler	The effect of heavy metals on the rates of photosynthesis and respiration of *Fontinalis antipyretica* Hedw.	1982	Text in foreign language
Song et al.	Single and joint toxic effects of benzo(a)pyrene and cadmium on development of three-setiger juvenile of ploychaete *Pernereis aibuhitensis* Grube	2011	Text in foreign language
Sooksawat et al.	Phytoremediation potential of charophytes: Bioaccumulation and toxicity studies of cadmium, lead and zinc	2013	Only two exposure concentration; Bioaccumalation: steady state not documented
Sorgeloos et al.	The use of *Artemia nauplii* for toxicity tests - a critical analysis	1978	Artemia
Sornom et al.	Effects of sublethal cadmium exposure on antipredator behavioural and antitoxic responses in the invasive amphipod, *Dikerogammarus villosus*	2012	Only one exposure concentration, not North American species
Soto-Jimenez et al.	Nonessential metals in striped marlin and Indo-Pacific sailfish in the southeast Gulf of California, Mexico: concentration and assessment of human health risk	2010	Bioaccumulation: steady state not documented
Souid et al.	Effect of acute cadmium exposure on metal accumulation and oxidative stress biomarkers of *Sparus aurata*	2013	Only one exposure concentration
Soukupova et al.	Effect of cadmium(II) ions on level of biologically active compounds in carps and invertebrates	2011	Abstract only

Authors	Title	Year	Reason Unused
Sovenyi and Szakolczai	Studies on the toxic and immunosuppressive effects of cadmium on the common carp	1993	The materials, methods or results were insufficiently described
Spann et al.	Size-dependent effects of low level cadmium and zinc exposure on the metabolome of the asian clam, *Corbicula fluminea*	2011	Mixture
Specht et al.	Structural, functional, and recovery responses of stream invertebrates to fly ash effluent	1984	Effluent
Sprague	Measurement of pollutant toxicity to fish i. bioassay methods for acute toxicity	1969	Review
Sprenger et al.	Concentrations of trace elements in yellow perch (Perca flavescens) from six acidic lakes	1988	Bioaccumulation: steady state not documented
Spry and Wiener	Metal bioavailability and toxicity to fish in low-alkalinity lakes: A critical review	1991	Review of previously published data
Srivastav et al.	Ultimobranchial gland of a freshwater teleost, *Heteropneustes fossilis*, in response to cadmium treatment	2009	In vitro
Srivastava and Appenroth	Interaction of EDTA and iron on the accumulation of Cd2+ in duckweeds (Lemnaceae)	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Srivastava et al.	Physiological changes in a freshwater catfish, *Heteropneustes fossilis* following exposure to cadmium	2001	Dilution water not characterized, not North American species
St. Louis	Element concentrations in chironomids and their abundance in the littoral zone of acidified lakes in Northwestern Ontario	1993	Bioaccumulation: steady state not documented
Stary and Kratzer	The cumulation of toxic metals on alga	1982	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Stary et al.	The cumulation of zinc and cadmium in fish (*Poecilia reticulata*)	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Stary et al.	Cumulation of zinc, cadmium and mercury on the alga *Scenedesmus obliquus*	1983	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Staub et al.	Respiratory and reproductive characteristics of eastern mosquitofish (*Gambusia holbrooki*) inhabiting a coal ash settling basin	2004	Effluent
Stawarz et al.	Heavy-metal concentration in the toad *Bufo bufo* from a region of Mochovce, Slovakia	2003	Bioaccumulation: steady state not documented
Stefano et al.	Cholinesterase activities in the scallop *Pecten jacobaeus*: Characterization and effects of exposure to aquatic contaminants	2008	Non-applicable

Authors	Title	Year	Reason Unused
Stepanyan et al.	Effect of molybdenum, chrome and cadmium ions on metamorphosis and erythrocytes morphology of the marsh frog *Pelophylax ridibundus* (Amphibia: Anura)	2011	Not North American species, only one exposure concentration
Stephenson and Macki	Net cadmium flux in *Hyalella azteca* (Crustacea: Amphipoda) populations from five central Ontario lakes	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Stern and Stern	Effects of fly ash heavy metals on *Daphnia magna*	1980	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Stoiber	Analysis of toxicity biomarkers for understanding copper and cadmium stress in freshwater algae	2011	EDTA in exposure media not defined
Stoiber et al.	Relationships between surface-bound and internalized copper and cadmium and toxicity in *Chlamydomonas reinhardtii*	2012	Bioaccumulation: steady state not documented
Stokes and Dreier	Copper requirement of a copper-tolerant isolate of *Scenedesmus* and the effect of copper depletion on tolerance	1981	Not applicable
Stolyar et al.	Comparison of metal bioavailability in frogs from urban and rural sites of western Ukraine	2008	Bioaccumulation: steady state not documented
Stom and Zubareva	Comparative resistance of *Daphnia* and *Epischura* to toxic substances in acute exposure	1994	The materials, methods or results were insufficiently described
Storelli and Marcotrigiano	Heavy metal monitoring in fish, bivalve molluscs, water, and sediments from Varano Lagoon, Italy	2001	Bioaccumulation: steady state not documented
Storelli and Marcotrigiano	Content of mercury and cadmium in fish (*Thunnus alalunga*) and cephalopods (*Eledone moschata*) from the southeastern Mediterranean Sea	2004	Bioaccumulation: steady state not documented
Storelli et al.	Accumulation of mercury, cadmium, lead and arsenic in swordfish and bluefin tuna from the Mediterranean Sea: A comparative study	2005b	Bioaccumulation: steady state not documented
Storelli et al.	Trace elements in loggerhead turtles (*Caretta caretta*) from the eastern Mediterranean Sea: overview and evaluation	2005a	Bioaccumulation: steady state not documented
Storelli et al.	Metals and organochlorine compounds in eel (*Anguilla anguilla*) from the Lesina lagoon, Adriatic Sea (Italy)	2007	Bioaccumulation: steady state not documented
Storelli et al.	Total and subcellular distribution of trace elements (Cd, Cu and Zn) in the liver and kidney of green turtles (*Chelonia mydas*) from the Mediterranean Sea	2008	Bioaccumulation: steady state not documented
Stout et al.	Phytoprotective influence of bacteria on growth and cadmium accumulation in the aquatic plant *Lemna minor*	2010	Only one exposure concentration
Strady et al.	Roles of regional hydrodynamic and trophic contamination in cadmium bioaccumulation by Pacific oysters in the Marennes-Oleron Bay (France)	2011a	Bioaccumulation: steady state not documented
Stripp et al.	Trace element accumulation in the tissues of fish from lakes with different pH values	1990	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Stromgren et al.	Acute toxic effects of produced water in relation to chemical composition and dispersion	1995	Effluent
Stubblefield et al.	Acclimation-induced changes in the toxicity of zinc and cadmium to rainbow trout	1999	The materials, methods or results were insufficiently described
Stuhlbacher and Maltby	Cadmium resistance in *Gammarus pulex* (L.)	1992	Not North American species
Sullivan	Effects of salinity and temperature on the acute toxicity of cadmium to the estuarine crab *Paragrapsus gaimardii* (Milne Edwards)	1977	Not North American species
Sun and Zhou	Oxidative stress biomarkers of the Polychaete *Nereis diversicolor* exposed to cadmium and petroleum hydrocarbons	2008	Dilution water not characterized, duration too short, unmeasured chronic exposure
Sun et al.	Influences of petroleum on accumulation of copper and cadmium in the polychaete *Nereis diversicolor*	2006	Mixture
Sun et al.	Joint effects of arsenic and cadmium on plant growth and metal bioaccumulation: A potential Cd-hyperaccumulator and As-excluder *Bidens pilosa* L	2009	Mixture
Sunda and Huntsman	Antagonisms between cadmium and zinc toxicity and manganese limitation in a coastal diatom	1996	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Sunda et al.	Effect of chemical speciation on toxicity of cadmium to grass shrimp, *Palaemonetes pugio*: Importance of free cadmium ion	1978	Questionable treatment of test organisms or inappropriate test conditions or methodology
Sunil et al.	A method for partitioning cadmium bioaccumulated in small aquatic organisms	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Sunila and Lindstrom	Survival, growth and shell deformities of copper- and cadmium-exposed mussels (*Mytilus edulis* L.) in brackish water	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Sunlu	Trace metal levels in mussels (*Mytilus galloprovincialis* L. 1758) from Turkish Aegean Sea coast	2006	Bioaccumulation: steady state not documented
Sura et al.	Cadmium toxicity related to cysteine metabolism and glutathione levels in frog *Rana ridibunda* tissues	2006	Only two exposure concentrations, not North American species
Suresh	Effect of cadmium chloride on liver, spleen and kidney melano macrophage centres in *Tilapia mossambica*	2009	Duration too long, lack of exposure details
Suryawanshi	Accumulation and depuration of cadmium in oyster *Crassostrea cattuckensis* from Bhatye Estuary in Ratnagiri coast	2006a	Bioaccumulation: steady state not documented
Suryawanshi	Zinc and cadmium content in the estuarine oyster from Ratnagiri coast of Maharashtra	2006b	Bioaccumulation: steady state not documented
Suryawanshi and Langekar	Zinc and cadmium toxicity to estuarine rock oyster *Crassostrea cattuckensis* on Ratnagiri coast	2006	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Suzuki et al.	Environmental and injected cadmium are sequestered by two major isoforms of basal copper, zinc-metallothionein in gibel (*Carassius auratus langsdorfi*) liver	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Svecevicius	The use of fish avoidance response in identifying sublethal toxicity of heavy metals and their mixtures	2007	Mixture
Swansburg et al.	Mouthpart deformities and community composition of chironomidae (Diptera) larvae downstream of metal mines in New Brunswick, Canada	2002	Mixture
Swartz et al.	Sediment toxicity, contamination, and macrobenthic communities near a large sewage outfall	1985	Sediment
Swinehart	Final Technical Report for U.S.G.S. Grant: The effects of humic substances on the interactions of metal ions with organisms and liposo	1990	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Szarek-Gwiazda and Amirowicz	Bioaccumulation of trace elements in roach, silver bream, rudd, and perch living in an inundated opencast sulphur mine	2006	Bioaccumulation: steady state not documented
Szarek-Gwiazda et al.	Trace element concentrations in fish and bottom sediments of an eutrophic dam reservoir	2006	Bioaccumulation: steady state not documented
Szczerbik et al.	Influence of long-term exposure to dietary cadmium on growth, maturation and reproduction of goldfish (subspecies: Prussian carp *Carassius auratus gibelio* B.)	2006	Dietary exposure
Szebedinszky et al.	Effects of chronic Cd exposure via the diet or water on internal organ-specific distribution and subsequent gill Cd uptake kinetics in juvenile rainbow trout (*Oncorhynchus mykiss*)	2001	Only one exposure concentration
Szefer et al.	A comparative assessment of heavy metal accumulation in soft parts and byssus of mussels from subarctic, temperate, subtropical and tropical marine environments	2006	Bioaccumulation: steady state not documented
Szivak et al.	Metal-induced reactive oxygen species production in *Chlamydomonas reinhardtii* (Chlorophyceae)	2009	Lack of details
Tabari et al.	Heavy metals (Zn, Pb, Cd and Cr) in fish, water and sediments sampled form Southern Caspian Sea, Iran	2010	Bioaccumulation: steady state not documented
Takamura et al.	Effects of Cu, Cd and Zn on photosynthesis of freshwater benthic algae	1989	Not North American species
Talas et al.	Antioxidative role of selenium against the toxic effect of heavy metals (Cd+2, Cr+3) on liver of rainbow trout (*Oncorhynchus mykiss* Walbaum 1792)	2008	Mixture
Talbot	Relationship between cadmium concentrations in seawater and those in the mussel *Mytilus edulis*	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Talbot	Relationship between lead concentrations in seawater and in the mussel *Mytilus edulis*: A water-quality criterion	1987	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Tan et al.	Comparative evaluation of the cytotoxicity sensitivity of six fish cell lines to four heavy metals in vitro	2008	In vitro
Tan et al.	Effect of dietary cadmium level on the growth, body composition and several hepatic enzymatic activities of juvenile yellow catfish, *Pelteobagrus fulvidraco*	2010b	Fed toxicant
Tan et al.	Validation of an in vitro cytotoxicity test for four heavy metals using cell lines derived from a green sea turtle (*Chelonia mydas*)	2010a	In vitro
Tan et al.	Phytoaccumulation of cadmium through *Azolla* from aqueous solution	2011	Bioaccumulation: not renewal or flow-through; excessive EDTA in media
Tan et al.	Role of titanium dioxide nanoparticles in the elevated uptake and retention of cadmium and zinc in *Daphnia magna*	2012	Mixture
Tanhan et al.	Histopathological alterations in the edible snail, *Babylonia areolata* (spotted Babylon), in acute and subchronic cadmium poisoning	2005	Not North American species
Tao et al.	Toxicity of Cd2+ on the photosynthetic and respiratory rate and atpase activity of *Nymphoides peltatum* (Gmel.) O'Ktze	2002	Text in foreign language
Tapia et al.	Study of the content of cadmium, chromium and lead in bivalve molluscs of the Pacific Ocean (Maule Region, Chile)	2010	Bioaccumulation: steady state not documented
Tarasov et al.	Efficiency of batteries of tests for estimating potential mutagenicity of chemicals	2003	Review
Taravati et al.	Determination of lead, mercury and cadmium in wild and farmed *Barbus sharpeyi* from Shadegan Wetland and Azadegan aquaculture site, South of Iran	2012	Bioaccumulation: steady state not documented
Tarzwell and Henderson	Toxicity of less common metals to fishes	1960	The materials, methods or results were insufficiently described
Tawari-Fufeyin et al.	Toxicity of cadmium to *Parachanna obscura*: As evidenced by alterations in hematology, histology, and behavior	2007	Not North American species
Taylor	Impacts of cadmium contamination and fish presence on wetland invertebrate communities: An application of population measures and multi-metric tests	2010	Bioaccumulation: steady state not documented
Taylor and Maher	Exposure-dose-response of *Anadara trapezia* to metal contaminated estuarine sediments. 1. Cadmium spiked sediments	2012	Sediment
Taylor et al.	Surface binding of contaminants by algae: Consequences for lethal toxicity and feeding to *Daphnia magna* Straus	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	Title	Year	Reason Unused
Tehseen et al.	A scientific basis for proposed quality assurance of a new screening method for tumor-like growths in the planarian, *Dugesia dorotocephala*	1992	Mixture (Cd and PCBs; Cd and Aroclor)
Tekin-Ozan and Kir	Seasonal variations of heavy metals in some organs of carp (*Cyprinus carpio* L., 1758) from Beysehir Lake (Turkey)	2008	Bioaccumulation: steady state not documented
Temara et al.	Experimental cadmium contamination of *Asterias rubens* (Echinodermata)	1996a	Not North American species
Temara et al.	Allometric variations in heavy metal bioconcentration in the asteroid *Asterias rubens* (Echinodermata)	1996b	Not North American species
Temara et al.	Factors influencing the concentrations of heavy metals in the asteroid *Asterias rubens* L. (Echinodermata)	1997	Bioaccumulation: steady state not documented
Templeman and Kingsford	Trace element accumulation in *Cassiopea sp*. (Scyphozoa) from urban marine environments in Australia	2010	Bioaccumulation: steady state not documented
Ten Hoopen et al.	Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. I. Development of cadmium tolerance in batch cultures	1985	Not North American species
Tepe	Metal concentrations in eight fish species from Aegean and Mediterranean Seas	2009	Bioaccumulation: steady state not documented
Tepe et al.	Assessment of heavy metals in two commercial fish species of four Turkish seas	2008	Bioaccumulation: steady state not documented
Terra et al.	Chronic assays with *Daphnia magna*, 1820, Straus in sediment samples from Cai River, Rio Grande Do Sul, Brazil	2007	Sediment exposure
Tessier et al.	Modeling Cd partitioning in oxic lake sediments and Cd concentrations in the freshwater bivalve *Anodonta grandis*	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Tessier et al.	Laboratory study of Cd and Hg uptake by two freshwater molluscs in relation to concentration, age and exposure time	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Tevlin	An improved experimental medium for freshwater toxicity studies using *Daphnia magna*	1978	Complexing chelators used in test media
Thaker and Haritos	Cadmium bioaccumulation and effects on soluble peptides, proteins and enzymes in the hepatopancreas of the shrimp *Callianassa tyrrhena*	1989	Not North American species
Thebault et al.	Short term cadmium intoxication of the shrimp *Palaemon serra*tus: Effect on adenylate metabolism	1996	Not North American species
Theede et al.	Temperature and salinity effects on the acute toxicity of cadmium to *Laomedea loveni* (Hydrozoa)	1979	Not North American species
Thilaga and Sivakumar	Accumulation of heavy metals in the gastropod *Bullia vittata* at Gulf of Mannar	2006	Bioaccumulation: steady state not documented
Thirumathal et al.	Effect of heavy metal (cadmium borate) on the biochemical composition of chironomus larvae (Diptera: chironomidae)	2002	Lack of details, inappropriate form of chemical, cadmium borate

Authors	**Title**	**Year**	**Reason Unused**
Thomann et al.	A pharmacokinetic model of cadmium in rainbow trout	1997	Review of previously published data
Thomas et al.	A comparison of the accumulation and protein binding of environmental cadmium in the gills, kidney and liver of rainbow trout (*Salmo gairdneri* Richardson)	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Thomas et al.	A comparison of the sequestration of cadmium and zinc in the tissues of rainbow trout (*Salmo gairdneri*) following exposure to the metals singly or in combination	1985	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Thompson et al.	Concentration factors of the chemical elements in edible aquatic organisms	1972	Review of previously published data
Thongra-Ar	Toxicity of cadmium, zinc and copper on sperm cell fertilization of sea urchin, *Diadema setosum*	1997	In vitro
Thongra-Ar and Matsuda	Effects of cadmium and zinc on growth of *Thalassiosira weissflogii* and *Heterosigma akiashiwo*	1995	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Thophon et al.	Histopathological alterations of white seabass, *Lates calcarifer*, in acute and subchronic cadmium exposure	2003	Not North American species
Thophon et al.	Ultrastructural alterations in the liver and kidney of white sea bass, *Lates calcarifer*, in acute and subchronic cadmium exposure	2004	Not North American species, only two exposure concentrations
Thorpe	A toxicological assessment of cadmium toxicity to the larvae of two estuarine crustaceans, *Rhithropanopeus harrisii* and *Palaemonetes pugio*	1988	Inappropriate test medium
Thorpe and Costlow	The relation of the acute (96-h) uptake and subcellular distribution of cadmium and zinc to cadmium toxicity in larvae of *Rhithropanopeus harrisii* and a *Palaemonetes pugio*	1989	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Thorsson et al.	Effects of settling organic matter on the bioaccumulation of cadmium and BDE-99 by Baltic Sea benthic invertebrates	2008	Bioaccumulation: steady state not documented
Thwala et al.	Influence of salinity and cadmium on the survival and osmoregulation of *Callianassa kraussi* and *Chiromantes eulimene* (Crustacea: Decapoda)	2011	Not North American species
Tiam et al.	Development of Q-PCR approaches to assess water quality: Effects of cadmium on gene expression of the diatom *Eolimna minima*	2012	In vitro
Tichy et al.	The *Tubifex tubifex* assay for the determination of acute toxicity	2007	Dilution water not characterized, duration too short
Tilton et al.	Effects of cadmium on the reproductive axis of Japanese medaka (*Oryzias latipes*)	2003	Not North American species
Timmermans	Ecotoxicity of trace metals for chironomids	1992	Review
Titus and Pfister	Bacteria and cadmium interactions in natural and laboratory model aquatic systems	1984	Bacteria
Tiwari et al.	Time kinetic study of metallothionein mRNA expression due to cadmium exposure in freshwater murrel, *Channa punctata* (Bloch)	2010	In vitro

Authors	**Title**	**Year**	**Reason Unused**
Tkalec et al.	Cadmium-induced responses in duckweed *Lemna minor* L.	2008	Only one exposure concentration
Todd et al.	Effects of acid rock drainage on stocked rainbow trout (*Oncorhynchus mykiss*): An in-situ, caged fish experiment	2007	Mixture
Tokunaga and Kishikawa	Acute visible and invisible injuries to submerged plants by water pollutants	1982	Text in foreign language
Tomasik et al.	Metal-metal interaction in biological systems. Part IV. Freshwater snail *Bulinus globosus*	1995b	Not North American species
Topcuoglu et al.	Heavy metal concentrations in marine algae from the Turkish Coast of the Black Sea, during 1979-2001	2004	Bioaccumulation: steady state not documented
Topperwien et al.	Cadmium accumulation in *Scenedesmus vacuolatus* under freshwater conditions	2007a	Mixture
Topperwien et al.	Competition among zinc, manganese, and cadmium uptake in the freshwater alga *Scenedesmus vacuolatus*	2007b	Mixture
Tortell and Price	Cadmium toxicity and zinc limitation in centric diatoms of the genus *Thalassiosira*	1996	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Toussaint et al.	A comparison of standard acute toxicity test with rapid-screening toxicity test	1995	Review of previously published data
Tran et al.	How water oxygenation levels influences cadmium accumulation pattern in the Asiatic clam *Corbicula fluminea*: A laboratory and field study	2001	Bioaccumulation: steady state not documented (only 14 day exposure)
Tran et al.	Relationship between feeding-induced ventilatory activity and bioaccumulation of dissolved and algal-bound cadmium in the Asiatic clam *Corbicula fluminea*	2002	Bioaccumulation: steady state not documented; dilution water not characterized
Trannum et al.	Effects of copper, cadmium and contaminated harbour sediment exposures on recolonisation of soft-bottom communities	2004	Sediment exposure
Trehan and Maneesha	Cadmium mediated control of nitrogenase activity and other enzymes in a nitrogen fixing cyanobacterium	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Trevors et al.	Cadmium transport, resistance, and toxicity in bacteria, algae, and fungi	1986	Review of previously published data
Trieff et al.	Effluent from bauxite factory induces developmental and reproductive damage in sea urchins	1995	Effluent
Trinchella et al.	Differential gene expression profiles in embryos of the lizard *Podarcis sicula* under in ovo exposure to cadmium	2010	In vitro
Tryfonas et al.	Metal accumulation in eggs of the red-eared slider (*Trachemys scripta elegans*) in the lower Illinois River	2006	Bioaccumulation: steady state not documented
Tsui and Wang	Biokinetics and tolerance development of toxic metals in *Daphnia magna*	2007	Review
Tucker and Matte	In vitro effects of cadmium and lead on ATPases in the gill of the rock crab, *Cancer irroratus*	1980	No pertinent adverse effects reported

NMED Exhibit 70

Authors	Title	Year	Reason Unused
Tuerkmen et al.	Determination of metals in fish species from Aegean and Mediterranean Seas	2009	Bioaccumulation: steady state not documented
Tueros et al.	Integrating long-term water and sediment pollution data, in assessing chemical status within the European water framework directive	2009	Review
Tuezen et al.	Investigation of trace metal levels in fish species from the Black Sea and the River Yesilirmak, Turkey by atomic absorption spectrometry	2004	Bioaccumulation: steady state not documented
Turan et al.	Levels of heavy metals in some commercial fish species captured from the Black Sea and Mediterranean coast of Turkey	2009	Bioaccumulation: steady state not documented
Turk Culha et al.	Heavy metals levels in some fishes and molluscs from Inop Peninsula of the Southern Black Sea, Turkey	2007	Bioaccumulation: steady state not documented
Turkmen et al.	Heavy metals in three commercially valuable fish species from Iskenderun Bay, Northern East Mediterranean Sea, Turkey	2005	Bioaccumulation: steady state not documented
Turkmen et al.	Metal levels in tissues of the European anchovy, *Engraulis encra*sicolus L., 1758, and picarel, *Spicara smaris* L., 1758, from Black, Marmara and Aegean Seas	2008	Bioaccumulation: steady state not documented
Turkmen et al.	Heavy metal contaminants in tissues of the garfish, *Belone belone* L., 1761, and the bluefish, *Pomatomus saltatrix* L., 1766, from Turkey waters	2009	Bioaccumulation: steady state not documented
Turner et al.	Influence of salinity and humic substances on the uptake of trace metals by the marine macroalga, *Ulva lactuca*: Experimental observations and modeling using WHAM	2008	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Turoczy et al.	Cadmium, copper, mercury, and zinc concentrations in tissues of the king crab (*Pseudocarcinus gigas*) from southeast Australian waters	2001	Bioaccumulation: steady state not documented
Tuzen	Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey	2009	Bioaccumulation: steady state not documented
Tuzen et al.	Trace element content in marine algae species from the Black Sea, Turkey	2009	Bioaccumulation: steady state not documented
Tyurin and Khristoforova	Effect of toxicants on the development of the chiton *Ischnochiton hakodadensis*	1993	Not North American species
Udoidiong and Akpan	Toxicity of cadmium, lead and lindane to *Egeria radiata* Lamarck (Lamellibranchia, Donacidae)	1991	Not North American species
Ugolini et al.	Behavioural responses of the supralittoral amphipod *Talitrus saltator* (Montagu) to trace metals contamination	2012	Mixture
Uluozlu et al.	Trace metal content in nine species of fish from the Black and Aegean Seas, Turkey	2007	Bioaccumulation: steady state not documented
Uluturhan and Kucuksezgin	Heavy metal contaminants in red pandora (*Pagellus erythrinus*) tissues from the eastern Aegean Sea, Turkey	2007	Bioaccumulation: steady state not documented
Urech	Melimex, an experimental heavy metal pollution study: effects of increased heavy metal load on crustacea plankton	1979	Mixture

Authors	Title	Year	Reason Unused
Urek and Tarhan	Response of the antioxidant systems of the cyanobacterium *Spirulina maxima* to cadmium	2011	Abstract only
Usero et al.	Heavy metals in fish (*Solea vulgaris*, *Anguilla anguilla* and *Liza aurata*) from salt marshes on the southern Atlantic coast of Spain	2004	Bioaccumulation: steady state not documented
Uthe et al.	Cadmium in American lobster (*Homarus americanus*) from the area of a lead smelter	1982	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Uysal and Taner	Determination of growth rate change and accumulation efficiency of *Lemna minor* exposed to cadmium and lead ions	2012	Bioaccumulation: steady state not documented
Valencia et al.	The effect of estrogen on cadmium distribution in rainbow trout (*Oncorhynchus mykiss*)	1998	Not North American species
Valova et al.	Spatiotemporal trends of heavy metal concentrations in fish of the River Morava (Danube basin)	2010	Bioaccumulation: steady state not documented
van Aardt and Booysen	Water hardness and the effects of Cd on oxygen consumption, plasma chlorides and bioaccumulation in *Tilapia sparrmanii*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
van Aardt and Erdmann	Heavy metals (Cd, Pb, Cu, Zn) in mudfish and sediment exposures from three hard-water dams of the Mooi River catchment, South Africa	2004	Bioaccumulation: steady state not documented
Van Campenhout et al.	Cytosolic distribution of Cd, Cu and Zn, and metallothionein levels in relation to physiological changes in Gibel carp (*Carassius auratus gibelio*) from metal-impacted habitats	2010	Bioaccumulation: steady state not documented
Van den Hurk et al.	Interaction of cadmium and benzo[a]pyrene in mummichog (*Fundulus heteroclitus*): Effects on acute mortality	1998	Organisms were exposed to cadmium in food or by injection or gavage
Van Gemert et al.	Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. II. Light-limited growth in continuous culture	1985	Not North American species
Van Ginneken et al.	Bioavailability of cadmium and zinc to the common carp, *Cyprinus carpio*, in complexing environments: A test for the validity of the free ion activity model	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Van Ginneken et al.	Bioavailability of Cd to the common carp, *Cyprinus carpio* in the presence of humic acid	2001	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Van Hattum et al.	Trace metals in populations of freshwater isopods: Influence of biotic and abiotic variables	1996	Bioaccumulation: steady state not documented
Van Leeuwen et al.	The use of cohorts and populations in chronic toxicity studies with *Daphnia magna*: A cadmium example	1985b	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	**Title**	**Year**	**Reason Unused**
Van Leeuwen et al.	Effects of chemical stress on the population dynamics of *Daphnia magna*: A comparison of two test procedures	1987	Review of previously published data
Van Steveninck et al.	Heavy-metal (Zn, Cd) tolerance in selected clones of duck weed (*Lemna minor*)	1992	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Vardanyan and Ingole	Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems	2006	Bioaccumulation: steady state not documented
Vashchenko and Zhadan	Ecological assessment of marine environment using two sea urchin tests: Disturbance of reproduction and sediment embryotoxicity	1993	Not North American species
Vasseur and Pandard	Influence of some experimental factors on metals toxicity to *Selenastrum capricornutum*	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Vassiliev et al.	Heavy metal concentrations in lobster (*Homarus americanus*)	2005	Bioaccumulation: steady state not documented
Vazquez-Sauceda et al.	Cadmium, lead and zinc concentrations in water, sediment and oyster (*Crassostrea virginica*) of San Andres Lagoon, Mexico	2011	Bioaccumulation: steady state not documented
Vecchia et al.	Morphogenetic, ultrastructural and physiological damages suffered by submerged leaves of *Elodea canadensis* exposed to cadmium	2005	Dilution water not characterized, only one exposure concentration
Vellinger et al.	Antagonistic toxicity of arsenate and cadmium in a freshwater amphipod (*Gammarus pulex*)	2012a	Not North American species
Vellinger et al.	Comparison of arsenate and cadmium toxicity in a freshwater amphipod (*Gammarus pulex*)	2012b	Not North American species; duration too long
Vellinger et al.	Behavioural and physiological responses of *Gammarus pulex* exposed to cadmium and arsenate at three temperatures: Individual and combined effects	2012c	Not North American species, only two exposure concentrations
Vellinger et al.	Single and combined effects of cadmium and arsenate in *Gammarus pulex* (Crustacea, Amphipoda): Understanding the links between physiological and behavioural responses	2013	Not North American species, only two exposure concentrations
Venanzi et al.	Effects of heavy metals on some photosynthetic characteristics in *Lemna trisulca* L.	1989	Text in foreign language
Venkateswara Rao et al.	The use of marine sponge, *Haliclona tenuiramosa* as bioindicator to monitor heavy metal pollution in the coasts of Gulf of Mannar, India	2009	Bioaccumulation: steady state not documented
Venkatrayulu et al.	Hepatogonadal changes in the female fresh water field crab, *Oziotelphusa senex senex* (Fabricius) in response to cadmium toxicity	2005	Duration too short, unmeasured chronic exposure, not North American species
Verbost et al.	Cadmium inhibition of Ca2+ uptake in rainbow trout gills	1987	No interpretable concentration, time, response data or examined only a single exposure concentration
Vergauwen et al.	Effect of temperature on cadmium toxicity in zebrafish: From transcriptome to physiology	2012	Abstract only
Verma	Effect of cadmium on fin regeneration in the freshwater fish, *Oreochromis mossambicus*	2005	Inappropriate form of toxicant, Cd acetate

Authors	**Title**	**Year**	**Reason Unused**
Verma et al.	Short term toxicity tests with heavy metals for predicting safe concentrations	1980	The materials, methods or results were insufficiently described
Verriopoulos and Moraitou-Apostolopoulou	Effects of some environmental factors on the toxicity of cadmium to the copepod *Tisbe holothuriae*	1981	Not North American species
Verriopoulos and Moraitou-Apostolopoulou	Differentiation of the sensitivity to copper and cadmium in different life stages of a copepod	1982	Not North American species
Verslycke et al.	The toxicity of metal mixtures to the estuarine mysid *Neomysis integer* (Crustacea: Mysidacea) under changing salinity	2003	Not North American species
Viarengo et al.	Effects of heavy metals on the Ca2+-ATPase activity present in gill cell plasma-membrane of mussels (*Mytilus galloprovincialis* Lam.)	1993	In vitro
Vieira et al.	Mercury, cadmium, lead and arsenic levels in three pelagic fish species from the Aatlantic Ocean: Intra- and inter-specific variability and human health risks for consumption	2011	Bioaccumulation: steady state not documented
Vigneault and Campbell	Uptake of cadmium by freshwater green algae: effects of pH and aquatic humic substances	2005	Mixture
Villar et al.	Metals contents in two fishes of different feeding behaviour in the lower Parana River and Rio de la Plata Estuary	2001	Bioaccumulation: steady state not documented
Vinagre et al.	Accumulation of heavy metals by flounder, *Platichthys flesus* (Linnaeus 1758), in a heterogeneously contaminated nursery area	2004	Bioaccumulation: steady state not documented
Vincent et al.	Susceptibility of *Catla catla* (Ham.) to the toxic effects of the heavy metals, cadmium and chromium	1994	Not North American species
Vincent et al.	Accumulation of Al, Mn, Fe, Cu, Zn, Cd, and Pb by the bryophyte *Scapania undulata* in three upland waters of different pH	2001	Field bioaccumulation: steady state not documented, exposure concentration unknown
Vincent et al.	Impact of cadmium on food utilization of the Indian major carp, *Catla catla* (Ham)	2002	Not North American species, unmeasured chronic exposure
Vincent-Hubert et al.	Early genotoxic effects in gill cells and haemocytes of *Dreissena polymorpha* exposed to cadmium, B[a]P and a combination of B[a]P and Cd	2011	In vitro
Vincent-Hubert et al.	DNA strand breaks detected in embryos of the adult snails, *Potamopyrgus antipodarum*, and in neonates exposed to genotoxic chemicals	2012	In vitro
Viparelli et al.	Inhibition of the R1 fragment of the cadmium-containing zeta-class carbonic anhydrase from the diatom *Thalassiosira weissflogii* with anions	2010	In vitro
Visviki and Rachlin	The toxic action and interactions of copper and cadmium to the marine alga *Dunaliella minuta*, in both acute and chronic exposure	1991	Not North American species
Visviki and Rachlin	Acute and chronic exposure of *Dunaliella salina* and *Chlamydomonas bullosa* to copper and cadmium: Effects on growth	1994	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Voets et al.	Differences in metal sequestration between zebra mussels from clean and polluted field locations	2009	Bioaccumulation: steady state not documented
Vogiatzis and Loumbourdis	Cadmium accumulation in liver and kidneys and hepatic metallothionein and glutathione levels in *Rana ridibunda*, after exposure to CdCl2	1998	Not North American species
Vogt et al.	Effects of cadmium and tributyltin on development and reproduction of the non-biting midge *Chironomus riparius* (Diptera)-baseline experiments for future multi-generation studies	2007	Sediment exposure
Vogt et al.	Effects of cadmium on life-cycle parameters in a multi-generation study with *Chironomus riparius* following a pre-exposure of populations to two different tributyltin concentrations for several generations	2010	Sediment exposure
Voigt	Concentrations of mercury and cadmium in some coastal fishes from the Finnish and Estonian parts of the Gulf of Finland	2003	Bioaccumulation: steady state not documented
Voigt	Heavy metal concentrations in four-horn sculpin *Triglopsis quadricornis* (L.) (Pisces), its main food organism *Saduria entomon* L. (Crustacea), and in bottom sediments in the Archipelago Sea and the Gulf of Finland (Baltic Sea)	2007	Bioaccumulation: steady state not documented
Vuori	Influence of water quality and feeding habits on the whole-body metal concentrations in lotic trichopteran larvae	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Vuori	Rapid behavioral and morphological responses of hydropsychid larvae (Trichoptera, Hydropsychidae) to sublethal cadmium exposure	1994	Not North American species
Vykusova and Svobodova	Comparison of the sensitivity of male and female guppies (*Poecilia reticulata* Peters) to toxic substances	1987	The materials, methods or results were insufficiently described
Vymazal	Short-term uptake of heavy metals by periphyton algae	1984	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Vymazal	Uptake of lead, chromium, cadmium and cobalt by *Cladophora glomerata*	1990b	Not North American species
Vymazal	Toxicity and accumulation of lead with respect to algae and cyanobacteria: A review	1990a	Review of previously published data
Vymazal	Influence of pH on heavy metals uptake by *Cladophora glomerata*	1995	Not North American species
Wachs	Concentration of heavy metals in fishes from the River Danube	1982	Text in foreign language
Walker et al.	Influence of culture conditions on metal-induced responses in a cultured rainbow trout gill epithelium	2007	In vitro
Wall	Sublethal effects of cadmium and diazinon on reproduction and larval behavior in zebrafish (*Brachydanio rerio*)	1999	Only one exposure concentration
Wall et al.	Fish bioturbation of cadmium-contaminated sediments: Factors affecting Cd availability to *Daphnia magna*	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Wallace and Lopez	Bioavailability of biologically sequestered cadmium and the implications of metal detoxification	1997	Organisms were exposed to cadmium in food or by injection or gavage

Authors	**Title**	**Year**	**Reason Unused**
Walsh and Hunter	Influence of phosphorus storage on the uptake of cadmium by the marine alga *Macrocystis pyrifera*	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Walsh et al.	Differential bioaccumulation of heavy metals and organopollutants in the soft tissue and shell of the marine gastropod, *Austrocochlea constricta*	1995	Not North American species
Wang	Investigation of heavy metal content in fish at Chongqing section of the Yangtze River before water storage in the three Gorges Reservoir	2008	Bioaccumulation: steady state not documented
Wang	A study of the New York/New Jersey coastal water: Bio-optical characteristics of the harbor estuary and the effects of heavy metals on brown tide alga of the Bight	2011	Bioaccumulation: steady state not documented
Wang and Dei	Metal uptake in a coastal diatom influenced by major nutrients (N, P, and Si)	2001	Bioaccumulation: steady state not documented
Wang and Fisher	Assimilation of trace elements and carbon by the mussel *Mytilus edulis*: Effects of food composition	1996	Organisms were exposed to cadmium in food or by injection or gavage
Wang and Fisher	Accumulation of trace elements in a marine copepod	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Wang and Ke	Dominance of dietary intake of cadmium and zinc by two marine predatory gastropods	2002	Dietary exposure
Wang and Wang	Cadmium in three marine phytoplankton: accumulation, subcellular fate and thiol induction	2009a	Mixture
Wang and Wang	Biochemical response of the copepod *Tigriopus japonicus* Mori experimentally exposed to cadmium	2009b	Not North American species
Wang and Wong	Combined effects of food quantity and quality on Cd, Cr, and Zn assimilation to the green mussel, *Perna viridis*	2003	Mixture
Wang and Yin	Accumulation of Heavy Metals in Arca Granosa.	1987	Text in foreign language
Wang and Zauke	Size-dependent bioaccumulation of metals in the amphipod *Gammarus zaddachi* (Sexton 1912) from the River Hunte (Germany) and its relationship to the permeable body surface area	2004	Bioaccumulation: steady state not documented
Wang et al.	Reciprocal effect of Cu, Cd, Zn on a kind of marine alga	1995	No interpretable concentration, time, response data or examined only a single exposure concentration
Wang et al.	Kinetic determinations of trace element bioaccumulation in the mussel *Mytilus edulis*	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Wang et al.	Metal and oxygen uptake in the green mussel *Perna viridis* under different metabolic conditions	2005a	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Wang et al.	Seasonal study on the Cd, Se, and Zn uptake by natural coastal phytoplankton assemblages	2005b	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Wang et al.	Safety assessment and acute toxicity of copper, cadmium and zinc to white clound mountain minnow *Tanichthys albonubes*	2006	Non-applicable
Wang et al.	Ecotoxicological effect of Cu, Pb, Zn and Cd on *Prorocentrum donghaiense* Lu.	2008a	Non-applicable
Wang et al.	Single and joint effects of petroleum hydrocarbons and cadmium on the polychaete *Perinereis aibuhitensis* Grube.	2008b	Not North American species
Wang et al.	Assessment of mixture toxicity of copper, cadmium, and phenanthrenequinone to the marine bacterium *Vibrio fischeri*	2009a	Mixture
Wang et al.	Alteration of metallothionein mRNA in bay scallop *Argopecten irradians* under cadmium exposure and bacteria challenge	2009b	Mixture
Wang et al.	Acute and chronic cadmium toxicity to a saltwater cladoceran *Moina monogolica* Daday and its relative importance	2009d	Not North American species, test species fed
Wang et al.	Toxicity of lead, cadmium and mercury on embryogenesis, survival, growth and metamorphosis of *Meretrix meretrix* larvae	2009c	Not North American species
Wang et al.	Formation of a combined Ca/Cd toxicity on lifespan of nematode *Caenorhabditis elegans*	2010a	Only one exposure concentration; dilution water is deionized water
Wang et al.	Single and joint toxicity of mercury, cadmium and benzo(a) pyrene, polychlorinated biphenyls1254 for juvenile *Chlamys farreri*	2010c	Text in foreign language
Wang et al.	Analysis of metallotionein expression and antioxidant enzyme activities in *Meretrix meretrix* larvae under sublethal cadmium exposure	2010e	In vitro
Wang et al.	Molecular characterization and expression analysis of elongation factors 1A and 2 from the Pacific white shrimp, *Litopenaeus vannamei*	2011a	In vitro
Wang et al.	Biomarkers and bioaccumulation of clam *Ruditapes philippinarum* in response to combined cadmium and benzo(a)pyrene exposure	2011b	Mixture
Wang et al.	The content variation characteristics and risk analysis for cadmium, copper, lead and zinc in some species of shellfish	2011c	Bioaccumulation: steady state not documented
Wang et al.	Cadmium-induced oxidative stress and apoptotic changes in the testis of freshwater crab, *Sinopotamon henanense*	2011d	Not North American species
Wang et al.	Characterization of phospholipid hydroperoxide glutathione metabolizing peroxidase (gpx4) isoforms in Coho salmon olfactory and liver tissues and their modulation by cadmium	2012a	In vitro
Wang et al.	Effects of Cd, Cu, Ni, and Zn on brown tide alga *Aureococcus anophagefferens* growth and metal accumulation	2012b	Only two exposure concentrations, excessive EDTA in growth media
Wang et al.	Cadmium induces hydrogen peroxide production and initiates hydrogen peroxide-dependent apoptosis in the gill of freshwater crab, *Sinopotamon henanense*	2012c	Not North American species
Wang et al.	Cadmium bioaccumulation and bioelimination in *Patinopecten yessoensis*	2012d	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Wang et al.	Effects of cadmium stress on antioxidant defense system of *Patinopecten yessoensis*	2012e	Not North American species
Wang et al.	The effects of chronic exposure to environmentally relevant levels of waterborne cadmium on reproductive capacity and behavior in fathead minnows	2014b	Only three exposure concentrations
Wani	Toxicity of heavy metals to embryonic stages of *Cyprinus carpio* Communis	1986	The materials, methods or results were insufficiently described
Ward and Mendonca	Chronic exposure to coal fly ash causes minimal changes in corticosterone and testosterone concentrations in male southern toads *Bufo terrestris*	2006	Fly Ash
Waring et al.	Trace metal bioaccumulation in eight common coastal Australian polychaeta	2006	Field bioaccumulation: steady state not documented, exposure concentration unknown
Warnau et al.	Allometry of heavy metal bioconcentration in the echinoid *Paracentrotus lividus*	1995a	Not North American species
Warnau et al.	Experimental cadmium contamination of the echinoid *Paracentrotus lividus*: Influence of exposure mode and distribution of the metal in the organism	1995b	Not North American species
Warnau et al.	Effect of feeding on cadmium bioaccumulation in the echinoid *Paracentrotus lividus* (Echinodermata)	1995c	Not North American species
Warnau et al.	Biokinetics of selected heavy metals and radionuclides in two marine macrophytes: The seagrass *Posidonia oceanica* and the alga *Caulerpa taxifolia*	1996a	Not North American species
Warnau et al.	Spermiotoxicity and embryotoxicity of heavy metals in the echinoid *Paracentrotus lividus*	1996b	Not North American species
Warnau et al.	Cadmium bioconcentration in the echinoid *Paracentrotus lividus*: Influence of the cadmium concentration in seawater	1997	Not North American species
Warren et al.	Modelling cadmium accumulation by benthic invertebrates in situ: The relative contributions of sediment and overlying water reservoirs to organism cadmium concentrations	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Watling	Effects of metals on the development of oyster embryos	1981	No pertinent adverse effects reported
Watling	Accumulation of seven metals by *Crassostrea gigas*, *Crassostrea margaritacea*, *Perna perna*, and *Choromytilus meridionalis*	1983a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Wayland and Crosley	Selenium and other trace elements in aquatic insects in coal mine-affected streams in the Rocky Mountains of Alberta, Canada	2006	Bioaccumulation: steady state not documented
Weber	Concentration of metals in fish from the River Rednitz	1985	Bioaccumulation: steady state not documented
Weber et al.	Effects of multiple effluents on resident fish from Junction Creek, Sudbury, Ontario	2008	Effluent

Authors	**Title**	**Year**	**Reason Unused**
Webster et al.	Cadmium exposure and phosphorus limitation increases metal content in the freshwater alga *Chlamydomonas reinhardtii*	2011	Bioaccumulation: steady state not documented
Wehr and Whitton	Aquatic cryptogams of natural acid springs enriched with heavy metals: The Kootenay Paint Pots, British Columbia	1983	Bioaccumulation: steady state not documented
Wei et al.	Interactions between Cd, Cu, and Zn influence particulate phytochelatin concentrations in marine phytoplankton: Laboratory results and preliminary field data	2003	Mixture
Weimin et al.	Metal bioavailability to the soldier crab *Mictyris longicarpus*	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Weir and Salice	High tolerance to abiotic stressors and invasion success of the slow growing freshwater snail, *Melanoides tuberculatus*	2012	Only two exposure concentrations
Weis et al.	Effects of cadmium, zinc, salinity, and temperature on the teratogenicity of methylmercury to the killifish (*Fundulus heteroclitus*)	1981	No pertinent adverse effects reported
Wentsel et al.	Avoidance response of midge larvae (*Chironomus tentans*) to sediments containing heavy metals	1977	Sediment
Werner	Development of methods to assess metallothionein expression in lake trout (*Salvelinus namaycush*) during a reproductive cycle and the effects of cadmium and ethynyestradiol	2007	Field bioaccumulation: steady state not documented, exposure concentration unknown
Werner et al.	Biomarker responses in *Macoma nasuta* (Bivalvia) exposed to sediment exposures from northern San Francisco Bay	2004	Sediment exposure
Westernhagen and Dethlefsen	Combined effects of cadmium and salinity on development and survival of flounder eggs	1975	Not North American species
Westernhagen et al.	Combined effects of cadmium and salinity on development and survival of garpike eggs	1975	Not North American species
Westernhagen et al.	Fate and effects of cadmium in an experimental marine ecosystem	1978	Not North American species
White and Rainbow	Regulation and accumulation of copper, zinc and cadmium by the shrimp *Palaemon elegans*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
White and Rainbow	Accumulation of cadmium by *Palaemon elegans* (Crustacea: Decapoda)	1986	Not North American species
White et al.	Metal concentrations in loggerhead sea turtle eggs from the Florida Gulf and Atlantic Coasts	2008	Bioaccumulation: steady state not documented
Whyte et al.	Ethoxyresorufin-o-deethylase (EROD) activity in fish as a biomarker of chemical exposure	2000	Review
Wicklund and Runn	Calcium effects on cadmium uptake, redistribution, and elimination in minnows, *Phoxinus phoxinus*, acclimated to different calcium concentrations	1988	Not North American species

Authors	Title	Year	Reason Unused
Wicklund et al.	Cadmium and zinc interactions in fish: effects of zinc on the uptake, organ distribution, and elimination of 109Cd in the zebrafish, *Brachydanio rerio*	1988	Not North American species
Widmeyer and Bendell-Young	Influence of food quality and salinity on dietary cadmium availability in *Mytilus trossulus*	2007	Dietary exposure
Wiesner et al.	Temporal and spatial variability in the heavy-metal content of *Dreissena polymorpha* (Pallas) (Mollusca: Bivalvia) from the Kleines Haff (northeastern Germany)	2001	Bioaccumulation: steady state not documented
Wikfors and Ukeles	Growth and adaptation of estuarine unicellular algae in media with excess copper, cadmium or zinc, and effects of metal-contaminated algal food on *Crassostrea virginica* larvae	1982	Questionable treatment of test organisms or inappropriate test conditions or methodology
Wildgust and Jones	Salinity change and the toxicity of the free cadmium ion [Cd2+(aq)] to *Neomysis integer* (Crustacea: Mysidacea)	1998	Not North American species
Williams and Gallagher	Effects of cadmium on olfactory mediated behaviors and moleculat biomarkers in coho salmon (*Oncorhynchus kisutch*)	2013	Only two exposure concentrations
Williams et al.	Accumulation of Hsp70 in Juvenile and Adult Rainbow Trout Gill Exposed to Metal-Contaminated Water and/or Diet.	1996	Mixture
Williams et al.	Comparison between biosorbents for the removal of metal ions from aqueous solutions	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Williams et al.	Trends in trace metal burdens in sediment, fish species and filtered water of Igbede River, Lagos, Nigeria	2007	Bioaccumulation: steady state not documented
Williams et al.	Transcriptomic responses of European flounder (*Platichthys flesus*) to model toxicants	2008	Injected toxicant; not North American species
Williams et al.	Metal (as, Cd, Hg, and CH_3Hg) bioaccumulation from water and food by the benthic amphipod *Leptocheirus plumulosus*	2010	Bioaccumulation: not renewal or flow-through
Williamson and Nelson	Bacterial bioassay for level I toxicity assessment	1983	Bacteria
Windom et al.	Metal accumulation by the polychaete *Capitella capitata*: Influences of metal content and nutritional quality of detritus	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
WindWard Environmental	Results of 2000 toxicity testing	2001	Dilution water not characterized
Winger and Andreasen	Contaminant residues in fish and sediments from lakes in the Atchafalaya River Basin (Louisiana)	1985	Bioaccumulation: steady state not documented
Winger et al.	Residues of organochlorine insecticides, polychlorinated biphenyls, and heavy metals in biota from Apalachicola River, Florida, 1978	1984	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Winner and Gauss	Relationship between chronic toxicity and bioaccumulation of copper, cadmium and zinc as affected by water hardness and humic acid	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Winter	Cadmium uptake kinetics by freshwater mollusc soft body under hard and soft water conditions	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Witeska	Changes in the common carp blood cell picture after acute exposure to cadmium	2001	No scientific name given, only one exposure concentration, atypical endpoint
Witeska and Baka	The effect of long-term cadmium exposure on common carp blood	2002	No scientific name given, only one exposure, duration too short
Witeska and Wakulska	The effects of heavy metals on common carp white blood cells in vitro	2007	In vitro
Witeska et al.	The influence of cadmium on common carp embryos and larvae	1995	The materials, methods or results were insufficiently described
Witeska et al.	Changes in oxygen consumption rate and red blood parameters in common carp *Cyprinus carpio* L. after acute copper and cadmium exposures	2010	Mixture
Wo et al.	A comparison of growth biomarkers for assessing sublethal effects of cadmium on a marine gastropod, *Nassarius festivus*	1999	Not North American species
Wolfe et al.	Sediment toxicity in the Hudson-Raritan Estuary: Distribution and correlations with chemical contamination	1996	Mixture
Wolff et al.	The use of *Salvinia auriculata* as a bioindicator in aquatic ecosystems: biomass and structure dependent on the cadmium concentration	2012	Only four plants per exposure concentration
Won et al.	Response of glutathione S-gransferase (GST) genes to cadmium exposure in the marine pollution indicator worm, *Perinereis nuntia*	2011	In vitro
Wong	Toxicity of cadmium to freshwater microorganisms, phytoplankton, and invertebrates	1987	Review of previously published data
Wong	Effects of cadmium on the feeding behavior of the freshwater cladoceran *Moina macrocopa*	1989	Organisms were exposed to cadmium in food or by injection or gavage
Wong and Au	Contents of cadmium iron manganese and zinc in the tissue of *Katelysia-hiantina* collected from Tolo Harbor Hong-Kong an almost land-locked sea	1984	Bioaccumulation: steady state not documented
Wong and Beaver	Algal bioassays to determine toxicity of metal mixtures	1980	Mixture
Wong and Chan	A study of cadmium, copper and lead uptake by the unicellular green alga *Chlorella salina* Cu-1	1979	Excessive EDTA
Wong and Chau	Toxicity of metal mixtures to phytoplankton	1988	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Wong and Li	An ecological survey of the heavy metal contamination of the edible clam *Paphia sp*. on the iron-ore tailings of Tolo Harbour, Hong Ko	1977	Bioaccumulation: steady state not documented
Wong et al.	Toxicity of a mixture of metals on freshwater algae	1978	Mixture
Wong et al.	Physiological and biochemical responses of several freshwater algae to a mixture of metals	1982	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Wood	Trace metal uptake by *Cladophora* Chlorophyta	1974	Non-applicable
Wood et al.	Environmental toxicology of metals	1997	Modeling
Wood et al.	The protective role of dietary calcium against cadmium uptake and toxicity in freshwater fish: an important role for the stomach	2006	Review
Woodall et al.	Responses of trout fry (*Salmo gairdneri*) and *Xenopus laevis* tadpoles to cadmium and zinc	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Woodling	Survival and mortality of brown trout (*Salmo trutta*) exposed to in situ acute toxic concentrations of cadmium and zinc	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Woodling et al.	Nonuniform accumulation of cadmium and copper in kidneys of wild brown trout (*Salmo trutta*) populations	2001	Bioaccumulation: steady state not documented
Woodward et al.	Brown trout avoidance of metals in water characteristic of the Clark Fork River, Montana	1995a	Mixture
Woodward et al.	Metals-contaminated benthic invertebrates in the Clark Fork River, Montana: Effects on age-0 brown trout and rainbow trout	1995b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Woodworth and Pascoe	Cadmium uptake and distribution in sticklebacks related to the concentration and method of exposure	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Wright	Dose-related toxicity of copper and cadmium in striped bass larvae from the Chespeake Bay: Field considerations	1988	High control mortality reported
Wright and Welbourn	Cadmium in the aquatic environment: A review of ecological, physiological, and toxicological effects on biota	1994	Review of previously published data
Wright et al.	Effect of calcium on cadmium uptake and toxicity in larvae and juveniles of striped bass (*Morone saxatilis*)	1985	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Wu and Chen	Metallothionein induction and heavy metal accumulation in white shrimp *Litopenaeus vannamei* exposed to cadmium and zinc	2005b	Bioaccumulation: unmeasured exposure
Wu and Deng	Effect of cadmium on hematological functions in tilapia (*Oreochromis mossambicus*)	2006	Injected toxicant
Wu and Wang	NMR-based metabolomic studies on the toxicological effects of cadmium and copper on green mussels *Perna viridis*	2010	Only one exposure concentration
Wu and Yang	A new view explaining how cadmium-treated parents have higher Cd-resistant offspring: the case of tilapia larvae (*Oreochromis mossambicus*)	2008	Injected toxicant; lack of details

Authors	**Title**	**Year**	**Reason Unused**
Wu et al.	A settlement inhibition assay with cyprid larvae of the barnacle *Balanus amphitrite*	1997	Not North American species
Wu et al.	Toxic effects of several heavy metal on amphioxus and living activity of *Branchiostoma belcheri* Tsingtaoensis Tchang Et Koo	1999	Text in foreign language
Wu et al.	The joint-biotoxicity effect of different forms of nitrogen on heavy metals in water by the phototacti behavior of Daphnia	2006a	Text in foreign language
Wu et al.	Changes of cortisol and metallothionein upon cadmium exposure and handling stressed in tilapia (*Oreochromis mosssambicus*)	2006b	Injected toxicant
Wu et al.	Relationships among metallothionein, cadmium accumulation, and cadmium tolerance in three species of fish	2006c	Bioaccumulation: unmeasured exposure
Wu et al.	Toxicological stress response and cadmium distribution in hybrid tilapia (*Oreochromis sp*.) upon cadmium exposure	2007	Only one exposure concentration, duration too short, unmeasured exposure
Wu et al.	The effects of maternal Cd on the metallothionein expression in tilapia (*Oreochromis mossambicus*) embryos and larvae	2008a	Injected toxicant
Wu et al.	Phototaxis index of *Daphnia carinata* as an indicator of joint toxicity of copper, cadmium, zinc, nitrogen and phosphorus in aqueous solutions	2008b	Non-applicable
Wu et al.	Histopathological and biochemical evidence of hepatopancreatic toxicity caused by cadmium and zinc in the white shrimp, *Litopenaeus vannamei*	2008c	Lack of exposure details, dilution water not characterized, only two exposure concentrations
Wu et al.	Histopathological alterations in gills of white shrimp, *Litopenaeus vannamei* (Boone) after acute exposure to cadmium and zinc	2009	Dilution water not characterized, duration too short, only one exposure concentration
Wu et al.	Bioaccumulation of cadmium bound to humic acid by the bivalve *Meretrix meretirx* Linnaeus from solute and particulate pathways	2010	Sediment
Wu et al.	NMR-based metabolomic investigations on the differential responses in adductor muscles from two pedigrees of Manila clam *Ruditapes philippinarum* to cadmium and zinc	2011a	Bioaccumulation: steady state not documented
Wu et al.	The preferential accumulation of cadmium in the head portion of the freshwater planarian, *Dugesia japonica* (Platyhelminthes: Turbellaria)	2011b	Not North American species, duration too short
Wu et al.	Bioaccumulation of cadmium bound to ferric hydroxide and particulate organic matter by the bivalve *M. meretrix*	2012a	Sediment
Wu et al.	Maternal cadmium exposure induces mt2 and smtB mRna expression in zebrafish (*Danio rerio*) females and their offspring	2012b	Duration too short
Wundram et al.	The *Chlamydomonas* test: A new phytotoxicity test based on the inhibition of algal photosynthesis enables the assessment of hazardous leachates from waste disposals in salt mines	1996	Not North American species; no interpretable concentration, time, response data or examined only a single exposure concentration
Xiaorong et al.	Effects of chelation on the bioconcentration of cadmium and copper by carp (*Cyprinus carp*io L.)	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	Title	Year	Reason Unused
Xie and Klerks	Changes in cadmium accumulation as a mechanism for cadmium resistance in the least killifish *Heterandria formosa*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Xie et al.	Trophic transfer of Cd from natural periphyton to the grazing mayfly *Centroptilum triangulifer* in a life cycle test	2010	Dietary exposure
Xie et al.	Cadmium accumulation in the rootless macrophyte *Wolffia globosa* and its potential for phytoremediation	2013	Excessive EDTA (848 ug/L)
Xin et al.	Responses of different water spinach cultivars and their hybrid to Cd, Pb and Cd-Pb exposures	2010	Soil exposure
Xu et al.	Heavy metal distribution in tissues and eggs of Chinese alligator (*Alligator sinensis*)	2006a	Bioaccumulation: steady state not documented
Xu et al.	Generation of active oxygen and change of antioxidant enzyme activity in *Hydrilla verticillata* under Cd, Cu and Zn stress	2006b	Text in foreign language
Xu et al.	Acute toxicity and synergism of binary mixtures of antifouling biocides with heavy metals to embryos of sea urchin *Glyptocidaris crenularis*	2010	Not North American species
Xu et al.	Study on single and joint toxic effects of cadmium and lead on *Ruditapes phillippinarum*	2013	Text in foreign language
Xuan et al.	Oxygen consumption and metabolic responses of freshwater crab *Sinopotamon henanense* to acute and sub-chronic cadmium exposure	2013	Not North American species, only three exposure concentrations
Xue and Sigg	Cadmium speciation and complexation by natural organic ligands in freshwater	1998	No interpretable concentration, time, response data or examined only a single exposure concentration
Yager and Harry	The uptake of radioactive zinc, cadmium and copper by the freshwater snail, *Taphius glabratu*	1964	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Yamamoto and Inoue	Lethal tolerance of acute cadmium toxicity in rainbow trout previously exposed to cadmium	1985	The materials, methods or results were insufficiently described
Yamamura and Suzuki	Metallothionein induced in the frog *Xenopus laevis*	1983	Injected toxicant
Yamamura et al.	Cadmium uptake and induction of cadmium-binding protein in the waterflea (*Moina macrocopa*)	1983b	Bioaccumulation: steady state not documented (only 72 hour exposure)
Yan and Wang	Metal exposure and bioavailability to a marine deposit-feeding sipuncula, *Sipunculus nudus*	2002	Bioaccumulation: steady state not documented (only 24 hour exposure)
Yan et al.	Demographic and genetic evidence of the long-term recovery of *Daphnia galeata* Mendotae (Crustacea: Daphniidae) in Sudbury Lakes following additions of base: The role of metal toxicity	1996	Mixture
Yang and Kong	Bioavailability of copper and cadmium speciation in sediment exposure for aquatic organism under varying temperature	1997	Sediment exposure

Authors	Title	Year	Reason Unused
Yang et al.	Involvement of polyamines in adaptation of *Potamogeton crispus* L. to cadmium stress	2010	Mixture
Yang et al.	Acute temperature and cadmium stress response characterization of small heat shock protein 27 in large yellow croaker, *Larimichthys crocea*	2012a	In vitro
Yang et al.	Cd2+ toxicity to a green alga *Chlamydomonas reinhardtii* as influenced by its adsorption on TiO2 engineered nanoparticles	2012b	Mixture
Yap et al.	Correlations between speciation of Cd, Cu, Pb and Zn in sediment exposure and their concentrations in total soft tissue of green-lipped mussel *Perna viridis* from the west coast of Peninsular Malaysia	2002	Bioaccumulation: steady state not documented
Yap et al.	Accumulation, depuration and distribution of cadmium and zinc in the green-lipped mussel *Perna viridis* (Linnaeus) under laboratory conditions	2003a	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Yap et al.	Background concentrations of Cd, Cu, Pb and Zn in the green-lipped mussel *Perna viridis* (Linnaeus) from Peninsular Malaysia	2003b	Bioaccumulation: steady state not documented
Yap et al.	Heavy metal (Cd, Cu, Pb and Zn) concentrations in the green-lipped mussel *Perna viridis* (Linnaeus) collected from some wild and aquaculture sites in the west coast of Peninsular Malaysia	2004a	Bioaccumulation: steady state not documented
Yap et al.	Allozyme polymorphisms and heavy metal levels in the green-lipped mussel *Perna viridis* (Linnaeus) collected from contaminated and uncontaminated sites in Malaysia	2004b	Bioaccumulation: steady state not documented
Yap et al.	Distribution of heavy metal concentrations in the different soft tissues of the freshwater snail *Pomacea insularum* (D'orbigny, 1839; Gastropoda), and sediments collected from polluted and unpolluted sites from Malaysia	2009	Bioaccumulation: steady state not documented
Yarsan et al.	Copper, lead, cadmium and mercury concentrations in the mussel *Elliptio*	2007	Bioaccumulation: steady state not documented
Yasuno et al.	Characteristic distribution of chironomids in the rivers polluted with heavy metals	1985	Bioaccumulation: steady state not documented
Yeh et al.	Heavy metal concentrations of the soldier crab (*Mictyris brevidactylus*) along the inshore area of Changhua, Taiwan	2009	Bioaccumulation: steady state not documented
Yigit and Altindag	Accumulation of heavy metals in the food web components of Burdur Lake, Turkey	2002	Bioaccumulation: steady state not documented
Yilmaz	Bioaccumulation of heavy metals in water, sediment, aquatic plants and tissues of *Cyprinus carpio* from Kizilirmak, Turkey	2006	Bioaccumulation: steady state not documented
Yin et al.	Induction of phytochelatins in *Lemna aequinoctialis* in response to cadmium exposure	2002	Lack of exposure details, no statistical analysis
Yipmantin et al.	Pb(II) and Cd(II) Biosorption on *Chondracanthus chamissoi* (a red alga)	2011	Mixture
You et al.	Chemical availability and sediment toxicity of pyrethroid insecticides to *Hyalella azteca*: Application to field sediment with unexpectedly low toxicity	2008	Sediment exposure

Authors	**Title**	**Year**	**Reason Unused**
Young and Harvey	Metals in chironomidae larvae and adults in relation to lake pH and lake oxygen deficiency	1988	Bioaccumulation: steady state not documented
Youssef and Tayel	Metal accumulation by three *Tilapia spp*. from some Egyptian waters	2004	Bioaccumulation: steady state not documented
Yu and Wang	Kinetic uptake of bioavailable cadmium, selenium, and zinc by *Daphnia magna*	2002	Mixture
Yu et al.	New method for evaluating toxicity of heavy metals on marine macroalgae	1999	Text in foreign language
Zabotkina et al.	Influence of cadmium ions on some morphofunctional and immune-physiological parameters of perch (*Perca fluviatilis*, Perciformes, Percidae) underyearlings	2009	Unmeasured chronic exposure, duration too short, not North American species, only one exposure
Zadory	Monitoring heavy metal pollution and genetic consequences in aquatic invertebrates	1983	Bioaccumulation: steady state not documented
Zadory	Freshwater molluscs as accumulation indicators for monitoring heavy metal pollution	1984	Bioaccumulation: steady state not documented
Zaki and Osman	Clinicopathological and pathological studies on *Tilapia nilotica* exposed to cadmium chloride (0.25 ppm)	2003	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Zanders and Rojas	Cadmium accumulation, LC50 and oxygen consumption in the tropical marine amphipod *Elasmopus rapax*	1992	Not North American species
Zanders and Rojas	Salinity effects on cadmium accumulation in various tissues of the tropical fiddler crab *Uca rapax*	1996	Not North American species
Zanella	Shifts in caddisfly species composition in Sacramento River invertebrate communities in the presence of heavy metal contamination	1982	Bioaccumulation: steady state not documented
Zaosheng et al.	Effects of dietary cadmium exposure on reproduction of saltwater cladoceran *Moina monogolica* Daday: Implications in water quality criteria	2010	Fed toxicant
Zauke and Schmalenbach	Heavy metals in zooplankton and decapod crustaceans from the Barents Sea	2006	Bioaccumulation: steady state not documented
Zauke et al.	Validation of estuarine gammarid collectives (Amphipoda: Crustacea) as biomonitors for cadmium in semi-controlled toxicokinetic flow-through experiments	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Zauke et al.	Heavy metals of inshore benthic invertebrates from the Barents Sea	2003	Bioaccumulation: steady state not documented
Zbigniew and Wojciech	Individual and combined effect of anthracene, cadmium, and chloridazone on growth and activity of SOD izoformes in three *Scenedesmus* species	2006	Mixture
Zbikowski et al.	Distribution and relationships between selected chemical elements in green alga *Enteromorpha sp*. from the southern Baltic	2006	Bioaccumulation: steady state not documented
Zeng and Wang	Temperature and irradiance influences on cadmium and zinc uptake and toxicity in a freshwater cyanobacterium, *Microcystis aeruginosa*	2011	Mixture

Authors	Title	Year	Reason Unused
Zeng et al.	Toxicity effects of Cd and Cu on the respiration and excretion metabolism of asian clam	2007	Non-applicable
Zhang and Wang	Waterborne cadmium and zinc uptake in a euryhaline teleost *Acanthopagrus schlegeli* acclimated to different salinities	2007a	Mixture; not North American species
Zhang and Wang	Gastrointestinal uptake of cadmium and zinc by a marine teleost *Acanthopagrus schlegeli*	2007b	Mixture; not North American species
Zhang and Wang	Size-dependence of the potential for metal biomagnification in early life stages of marine fish	2007c	Mixture; not North American species
Zhang et al.	Study on the relationship between speciation of heavy metals and their ecotoxicity	1992	The materials, methods or results were insufficiently described
Zhang et al.	Influence of toxicity of heavy metal ions to growth of *Phaeodactylum tricornutum*	1995	Text in foreign language
Zhang et al.	Heavy metal accumulation and tissue damage in goldfish *Carassius auratus*	2005	Bioaccumulation: unmeasured exposure,; not whole-body or muscle content
Zhang et al.	Enhanced bioaccumulation of cadmium in carp in the presence of titanium dioxide nanoparticles	2007a	Inappropriate form of toxicant, nanoparticles
Zhang et al.	Effects of cadmium stress on photosynthetic function of leaves of *Lemna minor* L.	2007b	Text in foreign language
Zhang et al.	Long-term toxicity effects of cadmium and lead on *Ibufo raddei* tadpoles	2007c	Unmeasured chronic exposure, not North American species
Zhang et al.	A review; research on cadmium in aquatic animals	2007d	Review
Zhang et al.	Toxicity and behavioral effects of cadmium in planarian (*Dugesia japonica* Ichikawa Et Kawakatsu)	2010a	Not North American species
Zhang et al.	Cadmium accumulation and translocation in four emergent wetland species	2010b	Excessive EDTA
Zhang et al.	Concentrations of cadmium and zinc in seawater of Bohai Bay and their effects on biomarker responses in the bivalve *Chlamys farreri*	2010c	Mixture
Zhang et al.	Cadmium-induced oxidative stress and apoptosis in the testes of frog *Rana limnocharis*	2012a	Not North American species, duration too long
Zhang et al.	The toxicity of cadmium (Cd2+) towards embryos and pro-larva of Soldatov's catfish (*Silurus soldatovi*)	2012b	Not North American species
Zhang et al.	Identification and expression profile of a new cytochrome P50 isoform (CYP414A1) in the hepatopancreas of *Venerupis* (*Ruditapes*) *philippinarum* exposed to benzo(a)pyrene, cadmium and copper	2012c	Mixture
Zhang et al.	Expression profiles of seven glutathione S-transferase (GST) genes from *Venerupis philippinarum* exposed to heavy metals and benzo(a)pyrene	2012d	Mixture
Zhang et al.	Biological effect of cadmium in *Daphnia magna*: Influence of nitrogen and phosphorus	2012e	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Zheng et al.	Reproductive toxic effects of sublethal cadmium on the marine polychaete *Perinereis nuntia*	2010	Not North American species
Zhou et al.	Growth response of *Isochrysis galbana* 3011 to seven kinds of heavy metals	1990	Lack of details; abstract only
Zhu et al.	Gonad differential proteins revealed with proteomics in oyster (*Saccostrea cucullata*) using alga as food contaminated with cadmium	2012	Fed toxicant
Zhuang and Lin	The effects of nutrients and heavy metals on the plankton in marine enclosed ecosystem	1991	Mixture
Zia and McDonald	Role of the gills and gill chloride cells in metal uptake in the freshwater-adapted rainbow trout, *Oncorhynchus mykiss*	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Zolotukhina et al.	Effect of some heavy metal ions on cholorophyll photostability in marine green macroalgae	1993	Text in foreign language
Zou and Bu	Acute toxicity of copper, cadmium, and zinc to the water flea, *Moina irrasa* (Cladocera)	1994	Not North American species

Appendix K Issue Summary Regarding Test Conditions and Methods for Water Only Toxicity Testing with *Hyalella azteca*

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL HEALTH AND ENVIRONMENTAL EFFECTS
RESEARCH LABORATORY
MID-CONTINENT ECOLOGY DIVISION
6201 CONGDON BOULEVARD · DULUTH, MINNESOTA 55804-2595

OFFICE OF
RESEARCH AND DEVELOPMENT

August 6, 2015

MEMORANDUM

SUBJECT: Issue summary regarding test conditions and methods for water only toxicity testing with *Hyalella azteca*

FROM: David R. Mount and J. Russell Hockett

TO: Kathryn Gallagher
Health and Ecological Criteria Division/OST/OW

We are writing at the request of your staff to summarize current understanding regarding appropriate procedures and conditions for water only toxicity testing with the amphipod, *Hyalella azteca*, with an emphasis on how this understanding intersects with the selection of toxicity data for deriving ambient water quality criteria. Recommendations are provided based on our experience and interpretation of published and unpublished data. A draft of this document was provided to two outside experts, Drs. Chris Ingersoll (USGS Columbia, MO) and David Soucek (Illinois Natural History Survey, Champaign, IL), for their comment and input.

A complicating factor is that recent research has found that organisms taxonomically described as *Hyalella azteca* comprise a complex of numerous genetically distinct, but thus far undescribed species; for the purposes of this memo, we refer to them as "strains." Major et al. (2013) determined that most North American laboratories that cultured and tested *Hyalella azteca* had the same strain (called the "US Lab" strain). A single laboratory, in Burlington, ON, had a different strain or species in culture; they called this the "Burlington" strain. These two strains show some differences that may require different evaluation criteria to be applied. As much of the available toxicological data published are known or presumed to have been generated using the US Lab strain, the bulk of the discussion that follows pertains to the US Lab strain, though notes are included where differences with the Burlington strain may be important.

1) **Bromide**

Bromide was originally proposed as an essential micronutrient by Borgmann (1996) in work conducted using the Burlington strain. Subsequent studies using the US Lab strain indicate bromide is also an essential micronutrient for that strain, though the apparent levels of sufficiency appear to differ from the original suggestion by Borgmann (0.8 mg/L). Research conducted by USGS in Columbia, MO indicates that a much lower bromide concentration of around 0.02 mg/L is sufficient to support long-term survival, growth, and reproduction of the US Lab strain (Ivey et al. SETAC 2011 poster; see Figure 1). Here in our laboratory, we have found that the ambient Br concentration in Lake Superior water (about 0.01 to 0.015 mg/L) will support cultures of the US Lab strain). While these concentrations are much lower than the 0.8 mg/L, they are not necessarily in conflict with Borgmann's findings, as Borgmann's original experimental design was not structured to determine minimum concentrations with a high level of resolution (he was also using a different strain). In addition, experiments conducted by USGS in Columbia, MO (CD Ivey and CG Ingersoll, personal communication) have shown that bromide concentrations as high as 80 mg/L are not detrimental to the US Lab strain. It is uncertain whether the overall composition (e.g., hardness, specific ion content) of the water influences the Br requirement. Limited survey work done by USGS-Columbia suggests that natural waters (ground or surface waters) typically have sufficient Br to support the US Lab strain (C.G. Ingersoll, personal communication). The 0.8 mg Br/L contained in Borgmann "SAM-5" water is much higher than is found in typical fresh waters, but as noted above, we have no evidence that this would be problematic unless the toxicant of concern interacts with Br.

Recommendation: Reconstituted waters used for testing with *Hyalella azteca* should have at least 0.02 mg Br/L. For tests conducted with natural waters (ground or surface) with accompanying Br measurements, it is reasonable to presume that sufficient Br was present, as long as control performance appears adequate.

2) **Chloride**

Chloride also appears to be important to supporting long term survival, growth, and reproduction of the US Lab strain. A survey of waters used successfully by various laboratories for culture of *Hyalella azteca* (known or presumed to be the US Lab strain) indicates that most have Cl concentrations at or above those typical of natural surface waters (Figure 2). And, notably, the concentrations in reconstituted waters often recommended by ASTM and EPA for aquatic toxicity studies have very low concentrations of Cl, relative to natural waters. Studies in our laboratory found that the roughly 2 mg Cl/L found in Lake Superior water limited performance of the US Lab Strain. Performance was improved by the addition of sodium chloride up to a concentration of about 15 mg/L, above which there was no additional improvement (Figure 3; Soucek et al. 2015). Longer-term studies conducted at the Illinois Natural History Survey demonstrated a similar response to chloride for long-term growth and reproduction (Figure 4; Soucek et al., 2015). It is unclear whether the minimum Cl concentrations apply equally across all water types or if the Cl requirement is dependent on other aspects of water chemistry. Natural waters with hardness less than 80 mg/L commonly have <10 mg Cl/L (about 0.3 mM; see Figure 2).

An additional finding by Soucek et al. (2015) is that the acute sensitivity of the US Lab strain to sodium sulfate and sodium nitrate varied with chloride in a manner similar to that observed for control performance (Figure 5). However, when the Burlington strain was tested, both control growth and toxicant sensitivity were independent of chloride concentrations. This suggests, though does not prove, that the Cl-dependence of toxicity shown for the US Lab strain may be related more to its innate Cl requirement rather than a broader toxicological interaction of Cl and those toxicants. It's also worth noting that the change in toxicant sensitivity was observed even though control survival was good across all Cl concentrations; this means that meeting control survival requirements is not by itself a good indication that chloride concentrations were sufficient.

Recommendation: For toxicity data generated using the US Lab strain, it is preferred that control/dilution waters have Cl concentrations at or above about 15 mg/L. Where control/dilution waters have lower Cl concentrations, toxicity data should be used with great caution unless there are ancillary data demonstrating that organism health was not impaired despite lower Cl.

3) Reconstituted Waters

As noted above, reconstituted waters based on the formula proposed by Marking and Dawson (1973; this includes reconstituted waters recommended by EPA for effluent testing, and by some ASTM standards) have low Cl concentrations and have been directly shown to be insufficient to support long-term health of the US Lab strain. In addition to low Cl, they do not include added Br. A modification of these waters proposed by Smith et al. (1997) has sufficient chloride, but does not have added Br. Results obtained with this water have been inconsistent and it is not recommended unless it is supplemented with Br. The Borgmann (1996) "SAM-5" water has an unnaturally high Br concentration, but there is no reason to believe this concentration is harmful, unless it would interact with the toxicant being tested.

Recommendation: Data generated using Marking and Dawson-based waters should not be used. Data generated using "Smith" water should not be used unless Br was supplemented. Data generated using "Borgmann SAM-5" water should be acceptable unless there is reason to think the excess Br would compromise the test. Other reconstituted water formulations should be evaluated in light of the Br and Cl recommendations above.

4) Substrate

There is general consensus that a substrate should be provided when conducting water-only testing with *Hyalella azteca*. Common substrates include stainless steel screen, nylon (e.g., Nitex®) screen, quartz sand, cotton gauze, and maple leaves. In general, more inert substrates, such as screen or sand, are preferred over plant material, which may break down during testing and/or encourage microbial growth. Consideration should be given to whether one would expect interactions between the toxicant and the substrate; hydrophobic organic compounds in particular can bind strongly to Nitex® screen, which might reduce exposure concentrations, especially for studies using static or intermittent renewal exposure methods.

Recommendation: A fine layer of clean quartz sand is a preferred substrate. Nylon screen may be used if known to be compatible with the test chemical. Analytical confirmation of exposure concentrations in "old" solutions (prior to renewal) is very important, particularly where there could be interactions between the substrate and the test chemical.

5) Control Survival in Long-Term Tests

Experience with 42-d exposures (beginning with 7-8 d old organisms) is that 42-d survival is frequently well above 80% (e.g., 85%-95%) and 80% seems a reasonable minimum for control survival. For tests longer than 42 days, some decline in control survival might be expected, though experience is limited for these longer exposures. In general, survival should not decline by more than 2-3% per week beyond 6 weeks, unless exposures continue so long that organisms are becoming senescent.

Recommendation: Control survival should not be below 80% in 42-d tests; slightly lower control survival may be acceptable in tests substantially longer than 42 d.

6) Control Growth/Weight and Reproduction

The bulk of the available data on control growth comes from the context of 42-d exposures, which generally begin with 7-8-d old organisms (starting size typically 0.02-0.03 mg dwt). In experiments with the US Lab strain (including a 24-laboratory round robin evaluation), improved diets have been shown to produce average weights of ≥0.35 mg dwt (about 1.75 mg wwt assuming 80% water) at d 28 of a 42-d tests (35-36 d of overall age) and ≥0.50 mg dwt (about 2.5 mg wwt assuming 80% water) at d 42. Information on growth rates for tests longer than 42 d is limited, though growth rates are thought to decrease markedly as organisms reach reproductive stages. Data generated at EPA-Duluth show that the standard diet recommended in EPA and ASTM test methods for 42-d testing with *Hyalella azteca* (1 ml/beaker-d of YCT) limits growth relative to higher rations (either more YCT or other foods such as Tetramin® + YCT; see Figure 6). However, this limited growth does not seem to be so stressful as to reduce long-term survival, and reproduction still occurs though at lower rates than higher rations. Where 28-d and 42-d growth is comparable to that described above, reproduction is typically ≥6 young per female.

David Soucek of the Illinois Natural History Survey has conducted some laboratory culture and control growth experiments using the Burlington strain. From those experiments, it appears that the Burlington strain grows at about the same rate (provided similar rations) as the US Lab strain, but appears to reproduce at a lower rate (one-third to one-half the rate of the US Lab strain; D.J. Soucek, personal communication).

Recommendation: For 42-d exposures with the US Lab strain (beginning with 7-8-d old organisms), control organism average dry weight should be ≥0.35 mg after 28 days and ≥0.50 mg after 42 days. At the end of a 42-day test, control reproduction should average ≥6 young per female. Lower performance may indicate diet/ration may have been limiting. For tests with the Burlington strain, similar growth would be expected, but reproductive rate may be somewhat lower.

7) Applicability of Data from Different Strains of *Hyalella azteca*

The organisms of the US Lab strain are generally thought to trace to an original collection by Alan Nebeker of EPA-Corvallis in 1982. *Hyalella azteca* identified as the same US Lab strain have been found in the wild in several states, including FL, KS, OK, TX, CA, and their original collection location in OR (D.J. Soucek, personal communication). It is less clear whether the chloride requirement found for the US Lab strain is present in all wild populations, or whether the US Lab strain occurs naturally in waters with chloride below 15 mg/L. David Soucek (Illinois Natural History Survey) conducted a study examining response to chloride in a culture started from a wild population of the US Lab strain collected in Kansas, and found indication of reduced performance at low Cl concentrations, though the magnitude of the effect may be somewhat smaller.

It is noteworthy that in strain comparisons of sensitivity to sodium nitrate and sodium sulfate, the sensitivity of the US Lab strain at Cl ≥15 mg/L was generally similar to the sensitivity of the Burlington strain. Absent data to the contrary, we know of no compelling reason to think that the toxicant sensitivity of the US Lab strain in waters with adequate Cl and Br should not be appropriate for inclusion in species sensitivity distributions as is intended for deriving water quality criteria.

References:

Borgmann, U. 1996. Systematic analysis of aqueous ion requirements of *Hyalella azteca*: A standard artificial medium including the essential bromide ion. Arch. Environ. Contam. Toxicol. 30: 356-363.

Ivey, C.D., W.G. Brumbaugh, C.G. Ingersoll, N.E. Kemble, J.K. Kunz, D.R. Mount and J.R. Hockett. 2011. Evaluation of the influence of bromide on the performance of the amphipod *Hyalella azteca* in reconstituted waters. Presented at the SETAC North America 32nd Annual Meeting, Boston, MA, November 2011.

Major, K.M., D.J. Soucek, R. Giordano, M.J. Wetzel and F. Soto-Adames. 2013. The common ecotoxicology laboratory strain of *Hyalella azteca* is genetically distinct from most wild strains sampled in eastern North America. Environ. Toxicol. Chem. 32: 2637-2647.

Marking, L.L. and V.K. Dawson. 1973. Toxicity of quinaldine sulfate to fish. Investigative Fish Control, No. 48, U.S. Fish and Wildlife Service, Department of the Interior, Washington, DC.

Smith, M.E., J.M. Lazorchak, L.E. Herrin, S. Brewer-Swartz and W.T. Thoney. 1997. A reformulated, reconstituted water for testing the freshwater amphipod, *Hyalella azteca*. Environ. Toxicol. Chem. 16: 1229-1233.

Soucek, D.J., D.R. Mount, A. Dickinson, J.R. Hockett and A.R. McEwen. 2015. Contrasting effects of chloride on growth, reproduction, and toxicant sensitivity in two genetically distinct strains of *Hyalella azteca*. Environ. Toxicol. Chem. 34(10): 2354-2362.

Figure 1. Long-term performance of *Hyalella* as a function of Br concentration in water (from Ivey et al. 2011). Different symbols represent different trials and/or different water compositions (other than Br).

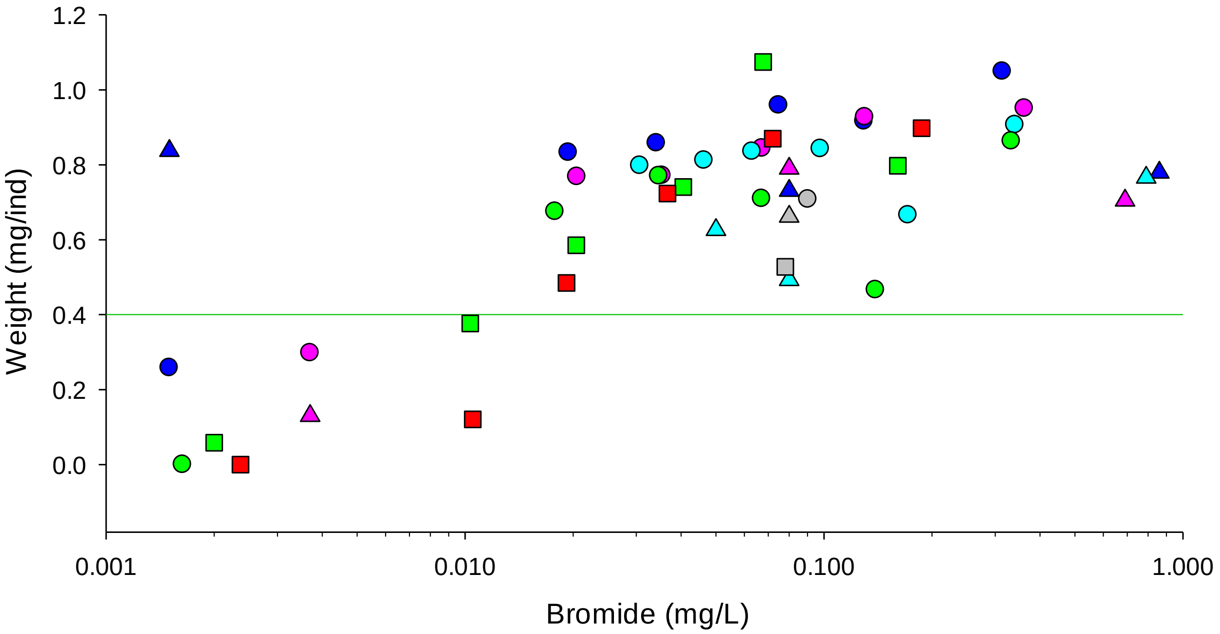


Figure 2. Concentrations of Cl in natural surface waters, waters used successfully to culture *Hyalella*, and in reconstituted waters based on Marking and Dawson (EPA/ASTM).

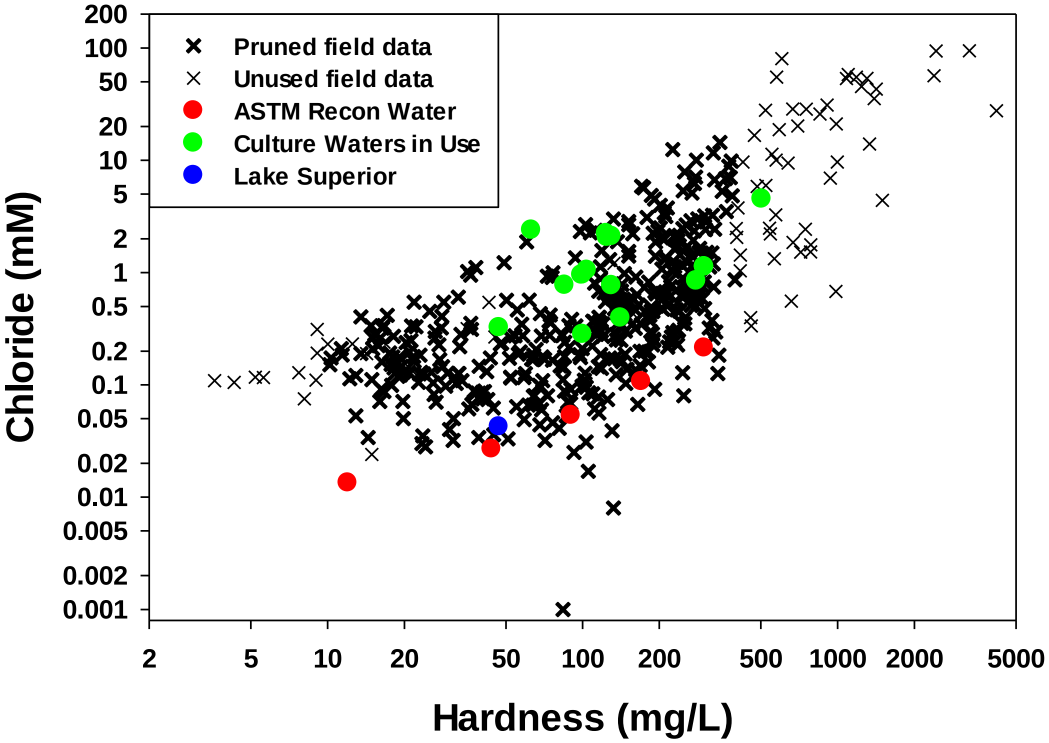


Figure 3. 10-d weights of *Hyalella* reared in Lake Superior water with varying Cl concentrations (from Soucek et al. 2015).

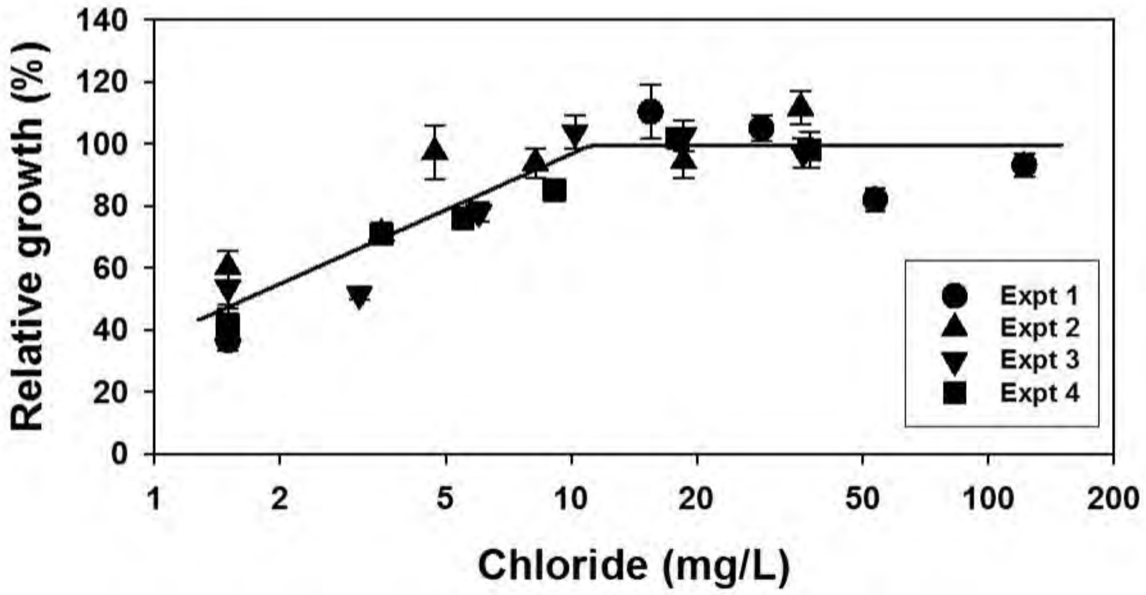


Figure 4. Influence of chloride on growth and reproduction of the US Lab strain in a 42-d test (from Soucek et al. 2015).

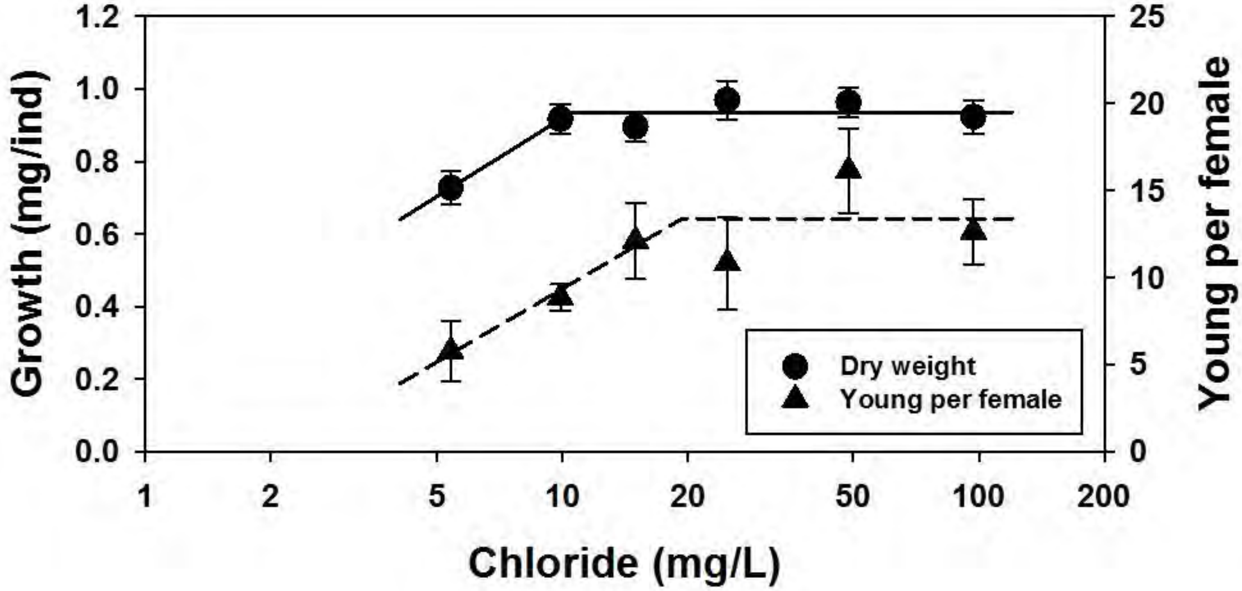


Figure 5. Comparison of control growth (a), and acute toxicity of sodium nitrate (b) and sodium sulfate (c) between the US Lab and Burlington strains of *Hyalella azteca* (from Soucek et al. 2015).

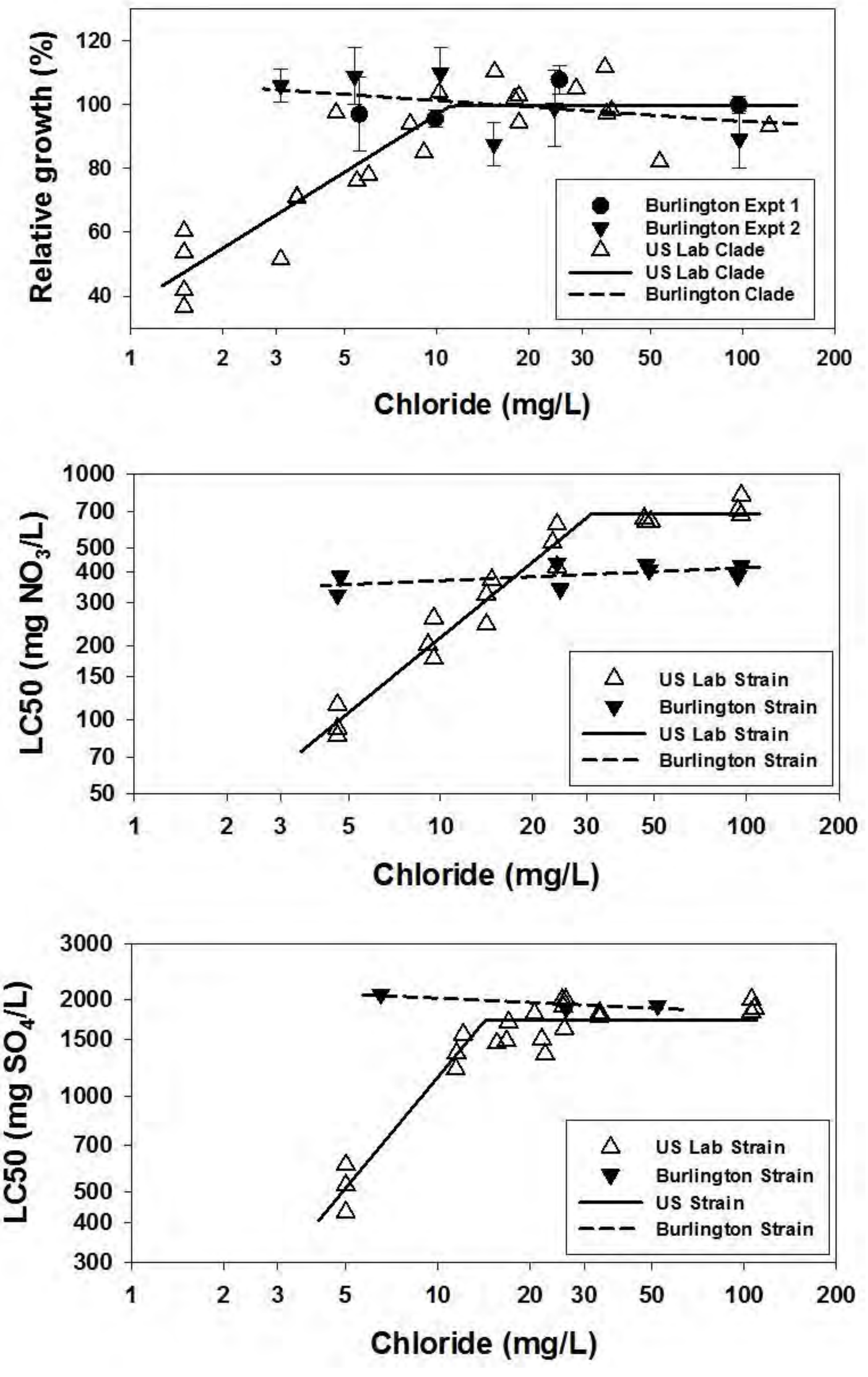


Figure 6. Growth rates of *Hyalella* reared on standard (EPA or ASTM 2000) ration of 1 ml YCT/d or on alternate rations (D.R. Mount unpublished data).