EAST WATERWAY OPERABLE UNIT

SUPPLEMENTAL REMEDIAL INVESTIGATION/

FEASIBILITY STUDY

FINAL SUPPLEMENTAL REMEDIAL INVESTIGATION REPORT

For submittal to:

The US Environmental Protection Agency
Region 10
Seattle, WA

Prepared by:

Wind Ward environmental LLC
200 West Mercer Street • Suite 401
Seattle, Washington • 98119

and

ANCHOR QEA
720 Olive Way • Suite 1900
Seattle, Washington • 98101

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LIST OF ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
AET	apparent effects threshold
aka	also known as
ASAOC	Administrative Settlement Agreement and Order on Consent
AWQC	ambient water quality criteria
BAF	bioaccumulation factor
Battelle	Battelle Marine Research Laboratory
BBP	butyl benzyl phthalate
BCA	bias-corrected accelerated
BCM	bed composition model
BEHP	bis(2-ethylhexyl) phthalate
bgs	below ground surface
BHC	benzene hexachloride
BMP	best management practice
BNSF	Burlington Northern Santa Fe
BOD	biochemical oxygen demand
BSAF	biota-sediment accumulation factor
BTEX	benzene, toluene, ethylbenzene, and xylene
C	Celsius
CCA	chromate copper arsenate
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
CFU	colony-forming unit
City	City of Seattle
cm/s	centimeters per second
cm/yr	centimeters per year
COC	contaminant of concern
COPC	contaminant of potential concern

County	King County
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CPUE	catch-per-unit effort
Cs-137	cesium-137
CSL	cleanup screening level
CSM	conceptual site model
CSO	combined sewer overflow
CT	central tendency
CWA	Clean Water Act
cy	cubic yards
DA	discharge authority
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DL	detection limit
DMMP	Dredged Material Management Program
DNR	Washington State Department of Natural Resources
DOC	dissolved organic carbon
DPD	Seattle Department of Planning and Development
DPM	diesel particulate matter
DQO	data quality objective
dw	dry weight
Ecology	Washington State Department of Ecology
EF	exceedance factor
EIM	Environmental Information Management
EISR	existing information summary report
EOF	emergency overflow
EPC	exposure point concentration
EPA	US Environmental Protection Agency
ERA	ecological risk assessment
ESA	Endangered Species Act

ESG	Environmental Solutions Group
ETM	estuarine turbidity maximum
EW	East Waterway
EWG	East Waterway Group
F	Fahrenheit
FCV	final chronic value
FOG	fats. oil, and grease
FPM	fine particulate matter
FS	feasibility study
FWM	food web model
GIS	geographic information system
gpd	gallons per day
HHRA	human health risk assessment
HI	hazard index
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
HSPF	Hydrologic Simulation Program – Fortran
HWMP	hazardous waste management program
I-5	Interstate 5
ICP	inductively coupled plasma
ID	identification
IDDE	illicit discharge detection and elimination
IDW	inverse distance weighting
IR	ingestion rate
J	estimated concentration
KC	King County
KCIA	King County International Airport
KCIW	King County Industrial Waste
Kinder Morgan	Kinder Morgan Energy Partners
KM	Kaplan-Meier
LA	Letter of Authorization

LAET	lowest apparent effects threshold
2LAET	second lowest apparent effects threshold
LDW	Lower Duwamish Waterway
LOAEL	lowest-observed-adverse-effect level
LOEC	lowest-observed-effect concentration
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
LUST	leaking underground storage tank
MCL	maximum contaminant level
MDL	method detection limit
MIS	multi-increment sampling
MHHW	mean higher high water
MLLW	mean lower low water
MS	mass spectrometry
MSGP	Multi-Sector General Permit
MTCA	Model Toxics Control Act
N	tentative identification
NAAQS	national ambient air quality standards
NCMA	normalized combined mortality and abnormality
NDAMN	National Dioxin Air Monitoring Network
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect level
NOEC	no-observed-effect concentration
NPDES	National Pollutant Discharge Elimination System
NTR	National Toxics Rule
QA	quality assurance
OC	organic carbon
OIG	Office of the Inspector General
O&M	operation and maintenance
OU	operable unit
PAH	polycyclic aromatic hydrocarbon

PARIS	Permit and Reporting Information System
Pb-210	lead-210
PCB	polychlorinated biphenyl
PCC	Pacific Coast Container
PCDD	polychlorinated dibenzo-*p*-dioxin
PCDF	polychlorinated dibenzofuran
pcf	pounds per cubic foot
PDM	post-dredge monitoring
PEF	potency equivalency factor
PM	particulate matter
PM2.5	particulate matter less than 2.5 micrometers in diameter
PM 10	particulate matter less than 10 micometers in diameter
Port	Port of Seattle
POTW	publically owned treatment works
ppt	parts per thousand
PRG	preliminary remediation goal
PSCAA	Puget Sound Clean Air Agency
PSEP	Puget Sound Estuary Program
PSMAF	Puget Sound Maritime Air Forum
PTM	particle tracking model
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
OSV	ocean survey vessel
RBTC	risk-based threshold concentration
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
RfD	reference dose
RI	remedial investigation
RL	reporting limit
RM	River Mile

RME	reasonable maximum exposure
ROC	receptor of concern
ROD	Record of Decision
ROW	right-of-way
RPD	relative percent difference
RSL	regional screening level
SCE	source control evaluation
SCEAM	source control evaluation approach memorandum
ScRAPS	Scrappage and Retrofits for Air in Puget Sound
SD	storm drain
SDOT	Seattle Department of Transportation
SEDGM	source evaluation and data gaps memorandum
SF	slope factor
SIC	Standard Industrial Code
SIU	significant industrial user
SL	screening level
SMC	Seattle Municipal Code
SMS	Washington State Sediment Management Standards
SOW	statement of work
SPI	sediment profile imaging
SPU	Seattle Public Utilities
SPWG	Sediment Phthalates Word Group
SQS	sediment quality values
SRI	supplemental remedial investigation
SSA	Stevedoring Services of America
STE	sediment transport evaluation
STER	sediment transport evaluation report
SVOC	semivolatile organic compound
SWAC	spatially weighted average concentration
SWMP	stormwater management plan
SWPPP	stormwater pollution prevention plan

T-18	Terminal 18
T-24	Terminal 24
T-25	Terminal 25
T-30	Terminal 30
T-46	Terminal 46
T-102	Terminal 102
T-104	Terminal 104
T-105	Terminal 105
T-107	Terminal 107
TBT	tributyltin
TCDD	tetrachlorodibenzo-*p*-dioxin
TCE	trichloroethene
TCP	Toxics Cleanup Program
T&E	threatened and endangered
TEF	toxic equivalency factor
TEQ	toxic equivalent
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TPY	tons per year
TRV	toxicity reference value
TSS	total suspended solids
TTI	Total Terminals International
U	not detected at given concentration
U&A	Usual and Accustomed
UCL	upper confidence limit on the mean
USACE	US Army Corps of Engineers
USC	US Code
USCG	US Coast Guard
USCS	Unified Soil Classification System
USGS	US Geological Survey
LUST	leaking underground storage tank

VOC	volatile organic compound
WAC	Washington Administrative Code
WAD	weak acid dissociable
Windward	Windward Environmental LLC
WQA	water quality assessment
WQC	water quality criteria
WQS	water quality standards
WSDOH	Washington State Department of Health
WSOU	waterway sediment operable unit
WTPH-D	Washington total petroleum hydrocarbons – diesel
WW	West Waterway
ww	wet weight
WWTP	wastewater treatment plant

EXECUTIVE SUMMARY

This document presents the results of the supplemental remedial investigation (SRI) for the East Waterway (EW), Operable Unit of the Harbor Island Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Superfund site. The EW is located in Seattle, Washington, and extends along the east side of Harbor Island (Map ES-1). The SRI provides information on the extent of chemical contamination and the risks to human health and the environment posed by the contamination. The SRI will be used to help make decisions about potential sediment cleanup actions and other actions to manage risks related to contaminants in the EW.

Under the oversight of the US Environmental Protection Agency (EPA), the EW SRI/feasibility study (FS) is being conducted by the East Waterway Group (EWG), which consists of the Port of Seattle, the City of Seattle, and King County. The Port of Seattle signed the Administrative Settlement Agreement and Order on Consent and Statement of Work in October 2006 (EPA 2006), and subsequently signed a Memorandum of Agreement with the City of Seattle and King County to conduct the SRI/FS.

This SRI presents the results of the many investigations conducted for the EW study area, which extends from Elliott Bay to the southern tip of Harbor Island (Map ES-1). The SRI data will support the analyses to be conducted in the FS to allow EPA to make cleanup decisions for the EW.

This SRI describes what is known about the EW, including:

- The environmental setting, habitat, and uses of the EW
- Physical processes within EW including the important processes that affect hydrodynamics and sediment transport
- The distribution of chemical contamination in the EW, including concentrations of contaminants in sediment, water, and tissues
- The results of the baseline human health risk assessment (HHRA) and ecological risk assessment (ERA), which assess risks to people and aquatic life and aquatic-dependent wildlife from contamination within the EW prior to remedial actions

- Background concentrations for key contaminants in sediment and fish and shellfish tissue as well as risk-based threshold concentrations in tissue and sediment for consideration in the FS
- Pathways and potential contaminant sources and ongoing source control efforts

The specific topics addressed in each section of the SRI are summarized below. Details are provided in the SRI, its appendices, and attachments.

ES.1 Environmental Setting

The EW is a maintained waterway that was created during the construction of Harbor Island. Prior to the channelization and industrialization of the Duwamish River, the habitat associated with the river's mouth was predominantly a shallow subtidal and intertidal estuarine mudflat. Since the creation of Harbor Island, the original estuarine mudflat area has been either filled or dredged and channelized to create the EW There are no remaining tidal marshes or expansive mud flat areas within the EW. However, there are a limited number of small intertidal areas with intertidal sediment located within the riprap slopes.

Today, the EW is maintained as a federal navigation channel by the US Army Corps of Engineers. The majority of the EW shoreline has been developed for industrial and commercial operations. The dominant shoreline features include constructed bulkheads, piers, wharves, sheet piling walls, buildings that extend over the water, and steeply sloped banks armored with riprap or other fill material.

The EW is located in one of the City of Seattle's primary industrial/commercial areas. Current land use, industrial zoning requirements, and land ownership within most of this corridor are consistent with the characteristics of an active commercial waterway. The EW provides a critical connection for cargo and other materials moving between water and land. Most vessel traffic consists of shipping companies that move container vessels and assorted tugboats into and out of the EW. While the EW is also used for various recreational activities such as boating and fishing, there is limited public access to the EW. There is one public access park, Jack Perry Park, within the EW and a public fishing pier in the southern portion of the waterway. The EW is frequently used by tribes as a resource and for cultural purposes. Tribal treaties guarantee members of the Muckleshoot and Suquamish Tribes the right to harvest seafood from the EW. Currently, the Muckleshoot Tribe conducts commercial

netfishing in EW for salmon. Tribal fishermen can also engage in clamming activities (by means of boat access) in all intertidal areas of the EW.

The aquatic habitats in the EW include the water column and intertidal and subtidal substrates (typically mud, sand, gravel, cobble, or riprap). The aquatic habitats in the EW include the water column and intertidal and subtidal substrates (typically mud, sand, gravel, cobble, or riprap). The habitat within EW is predominately deep water habitat with relatively little shallow subtidal and intertidal habitat which is found primarily in the Junction/Sill reach, within Slip 27, and south of Slip 36. Although no quantitative characterization of the benthic invertebrate community in the EW has been conducted, benthic invertebrate assemblages observed in studies in EW comprise a variety of species from diverse phyla (e.g., Mollusca, Arthropoda, Annelida, and Echinodermata). In addition, a variety of demersal, benthopelagic, and pelagic fish species have been observed in the EW. However, there is relatively little EW-specific information on wildlife populations. Surveys of wildlife communities have been conducted primarily upstream of the EW in the Lower Duwamish Waterway (LDW), where there is a greater diversity of habitats.

Sixteen aquatic and aquatic-dependent species reported in the vicinity of the Elliott Bay area are listed under either the Endangered Species Act or by the Washington Department of Fish and Wildlife as candidate species, threatened species, endangered species, or species of concern Of these species, Chinook salmon, coho salmon, steelhead salmon, brown rockfish, bald eagle, western grebe, and Pacific herring are commonly observed in the EW.

ES.2 Physical Conceptual Site Model

Information used to develop the physical processes conceptual site model (CSM) included site-specific empirical data and output from hydrodynamic, sediment deposition, and prop wash modeling. Empirical data collected as part of this work include tidal elevations from Elliott Bay, flow data from the Green River, velocity and salinity profile measurements south and north of the Spokane Street Corridor and within the main body of the EW, sedimentation data from the EW, and *in situ* measurements of critical shear stress in the EW. Model output included predictions of current velocities and salinities for average and high flow events within the EW (hydrodynamic model), predictions of annual average deposition patterns from lateral sources within the EW (particle-tracking model [PTM]), and near-bottom current velocities due to vessel operations (prop wash) within the EW.

The key components of the physical CSM are:

- The EW was created by dredging across the shallows and mudflats of the Duwamish delta, and using the dredged material as fill on either side. The inital depths of dredging in the main channel were determined by the need for fill and resulted in an overly deepened main channel that was not subsequently maintence dredged. Depth needs in the channel and berths change with size of vessels visting the Port of Seattle. In recent years, with the coming of larger ships, the portions of the Deep Main Body Reach that were still above -52 ft mean lower low water (MLLW) were deepened to a uniform minimum depth of -51 ft MLLW plus 1 foot for overdredge. Berthing areas are generally maintained at the same depths as the maintenance channel.
- The EW can be generally described as two-layer flow, with saltwater extending from Elliott Bay upstream through the EW and into the LDW underneath a relatively thin layer of fresher water flowing from the Green/Duwamish River System that varies in thickness depending on flow conditions.
- The split in flow of the Green/Duwamish River System between the EW and West Waterway (WW) is about equal during normal flow events (annual average) but approximately 30 to 70% (EW:WW) during 2-year and higher events.
- The preliminary CSM for the EW assumed that sedimentation occurred in most of the EW, but that sedimentation processes were heavily influenced by vessel activity in active channels or slips, which resuspends recently deposited fine-grained material. To better understand sedimentation rates in the EW, geochronology cores were collected to provide sedimentation rates for a refined CSM. Sampling locations were chosen to exclude recently dredged areas (see Map 2-7) and to represent various hydrodynamic regimes within the EW. Therefore, net sedimentation rates measured by geochronological cores do not include the influence of dredging activities.
- The range of measured rates[1] of sediment deposition in the deeper areas of the EW (the Shallow and Deep Main Body Reaches) for recovered geochronological cores, are between 0.1 and 4.2 centimeters per year (cm/yr) (based on cesium-137 [Cs-137] and lead-210 [Pb-210] data). The average net sedimentation rates (based on recovered cores) are 1.6 and 0.5 cm/yr based on Cs-137 and Pb-210 data, respectively.

[1] Measured rates do not include areas where recent dredging activity has occurred.

- Some geochronological cores had no recovery due to the presence of sands and gravels in the surface sediments at the sample locations, and are assumed to represent a zero net sedimentation rate. These locations included the center of the Junction Reach, adjacent to the western berth in the Shallow Main Body Reach, and adjacent to the berth at T-30 (see Map 3-10).
- The range of net sedimentation rates for all cores (including those with no recovery) is assumed to be 0 to 4.2 cm/yr.
- Geochronology cores were not retrieved in the Sill and Junction Reaches due to the presence of sand and gravel surface sediments. Presence of sample locations where geochronology cores could not be collected indicates that physical processes are occurring in these reaches that do not permit long-term sedimentation to occur. While there are areas in the EW that that may not be net depositional (likely due to impacts from prop wash), there is uncertainty in the spatial extent of these areas within the EW.
- In addition to the uncertainty in measured net sedimentation rates from geochronology data, there is an additional uncertainty in extrapolating net sedimentation rates measured at discrete core locations to the entire EW area due to the influence of vessel operations (e.g., prop wash) on bed sediments in portions of the EW.
- Results of the sediment transport modeling completed for the LDW FS and results of PTM modeling of lateral sources within the EW completed for this study suggest that 99% of the sediment load into the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral loads), and less than 0.3% is from lateral loads within the EW itself. Sediment load into the EW from Elliott Bay is assumed to be negligible compared with that of other sources.
- Based on a comparison of model predictions of the sediment load entering the EW and net sedimentation rates provided by the geochronological core data, it is predicted that between 25and 60% of the incoming sediment load deposits in the EW and between 40 and 75% of the incoming sediment load leaves the EW.
- Portions of the Deep Main Body Reach are likely subject to episodic mixing, erosion and re-suspension of bed sediments due to prop wash. The remainder of the Deep Main Body Reach (south of Slip 27), the Shallow Main Body Reach, and the Junction

Reach may be subject to less frequent mixing, erosion or re-suspension of surface sediments due to prop wash.

ES.3 Nature and Extent of Contamination

Prior to the SRI investigations and after 1995, 13 studies were identified with EW surface sediment data and nine studies were identified with subsurface data for EW. There was very little pre-existing tissue data for EW. The data collection studies for the SRI included the collection of approximately 500 additional samples to characterize chemical contamination in the following media:

- Surface sediment (top 10 cm)
- Subsurface sediment (below the top 10 cm)
- Fish, clam, mussel, shrimp, and crab tissue
- Benthic invertebrate tissue (organisms living in and on the sediment)
- Surface water
- Porewater (water in spaces between sediment particles)

ES.3.1 Sediment

Polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and metals were frequently detected in surface sediments. Metals that were frequently detected included arsenic, chromium, copper, lead, mercury, and zinc. Samples from a smaller number of locations in the EW were analyzed for tributyltin (TBT) and dioxins and furans. The primary sediment samples analyzed for dioxin and furans were subtidal composite samples which include 8 to 10 grab samples from each sampling area. Many other organic chemicals, including semivolatile organic compounds (SVOCs), and pesticides, were less frequently or rarely detected. Metals (excluding mercury), most SVOCs, and pesticides rarely exceeded risk thresholds, including the Washington State Sediment Management Standards (SMS). SMS exceedances occurred throughout the EW. However, exceedances of the cleanup screening level (CSL) were more commonly located outside of the areas of the waterway that have been dredged in the past 11 years (Map ES-2). Table ES-1 provides summary statistics for key contaminants that frequently exceeded the SMS (i.e., total PCBs and mercury) or exceeded risk threshold values for human health (i.e., total PCBs, PCB toxic equivalent

[TEQ], dioxin and furans, carcinogenic PAH [cPAH], and arsenic) or ecological receptors: fish (i.e, total PCBs) and benthic invertebrates (i.e., TBT).

Table ES-1

Summary Statistics for Key Contaminants in Surface Sediment

Contaminant	Unit	Detection Frequency	Concentration			
			Mean	Median	95th Percentile	Maximum
Total PCBs[a]	µg/kg dw	227/240	490	270	1,800	8,400
PCB TEQ[b]	ng TEQ/kg dw	13/13[c]	4.37	nc	nc	9.50
Dioxin and furan[b]	ng TEQ/kg dw	13/13[c]	15.7	nc	nc	30.6
		11/11[d]	19.3	nc	nc	49.7
cPAH[e, f]	µg TEQ/kg dw	15/15[g]	1,900	nc	nc	17,000
		233/240	460	220	1,200	10,000
Arsenic[e]	mg/kg dw	162/231	9.0	6.2	17	241
Mercury[e]	mg/kg dw	233/239	0.30	0.24	0.59	1.07
TBT[e]	µg/kg dw	60/67	180	31	560	6,000

[a] Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest reporting limit.

[b] Dioxin and furan TEQ and PCB TEQ were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQ and PCB TEQ were calculated for each sample by summing the TEQs for each congener with a TEF value. Individual congener TEQs were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[c] Subtidal composite samples collected in 13 subareas of the waterway

[d] Sediment grab samples selected for dioxin and furan analysis

[e] Summary statistics were calculated assuming one-half the reporting limit for non-detect results.

[f] Total cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual PAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

[g] Intertidal composite samples

dw – dry weight
cPAH – carcinogenic polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
RL – reporting limit
TBT – tributyltin
TEF – toxic equivalency factor
TEQ – toxic equivalent
nc – not calculated

The distribution of contaminants within subsurface sediment has also been characterized. Contaminants frequently detected in subsurface sediment were similar to those detected in surface sediment (Table ES-2). The contaminants that exceeded SMS in the greatest number of samples were total PCBs and mercury. Metals (except mercury) and SVOCs were also

frequently detected, but with less than 10% of subsurface sediment samples exceeding the SMS.

Table ES-2

Summary Statistics for Key Contaminants in Sediment Cores

Contaminants	Unit	Detection Frequency[a]	Concentration				Depth Interval of Maximum Concentration (ft)[b]
			Mean	Median	95th Percentile	Maximum	
Total PCBs[c]	µg/kg dw	207/290	1,500	275	4,300	17,600	2 – 4
Dioxin and furan[d]	ng TEQ/kg dw	16/16	17.2	2.70	78.0	184	2 – 4
cPAHs[e, f]	µg TEQ/kg dw	218/269	1,000	250	3,600	23,000	2 – 4
Arsenic[e]	mg/kg dw	250/255	10	9	29	96	0 – 2
Mercury[e]	µg/kg dw	249/305	0.6	0.285	1.8	3.37	0 – 2
TBT[e]	µg/kg dw	53/97	470	8	182	21,000	0 – 2

[a] Total number of samples represents all samples collected from any subsurface interval at all locations. Statistics are calculated based on all samples.

[b] Depth interval with highest concentration for a given chemical within any single core within the EW.

[c] Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest reporting limit.

[d] Dioxin and furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQs were calculated for each sample by summing the TEQs for each dioxin and furan congener. Dioxin and furan individual congener TEQs for were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[e] Summary statistics were calculated assuming one-half the reporting limit for non-detect results.

[f] Total cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual PAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

dw – dry weight
cPAH – carcinogenic polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
RL – reporting limit
TBT – tributyltin
TEF – toxic equivalency factor
TEQ – toxic equivalent

In recently dredged areas, the subsurface sediment concentrations were generally less than the surface sediment concentrations. However, in the shallow main body and areas within the main body that have not been recently dredged the subsurface contaminant concentrations were generally greater than the surface sediment concentrations.

ES.3.2 Tissue

Tissue samples of many different fish and invertebrate species have been collected and analyzed. Tissue data included samples of English sole, shiner surfperch, brown rockfish,

juvenile Chinook salmon, red rock and Dungeness crabs, intertidal clams (i.e., butter, little neck, cockles, and Eastern soft-shell), mussels, geoducks, shrimp, and small invertebrates that live in the sediment, such as amphipods and marine worms. These species were selected because they were either known or assumed to be representative of species that could be consumed by people, fish, or aquatic-dependent wildlife within the EW. Their tissues were analyzed for a wide variety of contaminants.

Mean total PCB concentrations were highest for fish tissues including brown rockfish, English sole and shiner surfperch (Table ES-3). Mean total PCB concentrations were lowest for the shellfish tissues (geoducks, mussels, and intertidal clams). Mean dioxin and furan TEQ concentrations were also highest in the fish tissues and lowest in the shellfish tissues. Mean carcinogenic PAH (cPAH) concentrations were highest in clams, mussels, and benthic invertebrates. Inorganic arsenic concentrations were highest for intertidal clams and other shellfish tissues (geoducks and mussels). TBT concentrations were highest in brown rockfish and benthic invertebrates.

Table ES-3
Summary Statistics for Key Contaminants in Tissue

Chemical and Tissue Type	Unit	Detection Frequency[a]	Concentration		
			Minimum	Mean	Maximum
Total PCBs[b]					
Fish					
Brown rockfish, whole body	µg/kg ww	15/15	400 J	2,000	6,200
English sole, whole body	µg/kg ww	13/13	1,460	3,200	7,900 J
Juvenile Chinook salmon, whole body	µg/kg ww	12/12	7.4	59	91.5
Sand sole, whole body	µg/kg ww	5/6	167	540[b]	1,310
Shiner surfperch, whole body	µg/kg ww	11/11	380 JN	1,500	5,400
English sole, fillet	µg/kg ww	20/20	409	1,700	5,700
Striped perch, fillet	µg/kg ww	6/6	104.0	155	203 J
Invertebrates	µg/kg ww				
Crab, soft tissue[c]	µg/kg ww	9/9	180 J	300	860
Crab, edible meat	µg/kg ww	12/12	48 J	130	210 J
Crab, hepatopancreas	µg/kg ww	9/9	310 J	590	1,900
Intertidal Clam, whole body[d]	µg/kg ww	11/11	4.7 JN	56	82

Chemical and Tissue Type	Unit	Detection Frequency[a]	Concentration		
			Minimum	Mean	Maximum
Mussel, whole body[d]	µg/kg ww	14/17	19 JN	26	44 J
Shrimp, whole body[e]	µg/kg ww	1/1	460 J	na	460 J
Geoduck clam, whole body[c]	µg/kg ww	4/4	25 J	28	34 JN
Geoduck clam, edible meat	µg/kg ww	6/6	14	19	24 JN
Geoduck clam, gutball	µg/kg ww	3/3	51 J	66	78
Benthic invertebrates, whole body	µg/kg ww	13/13	93	210	380
PCB TEQ[f]					
Fish					
Brown rockfish, whole body	ngTEQ/kg ww	6/6	5.05	24.8	59.5
English sole, whole body	ngTEQ/kg ww	3/3	32.4	35.0	37.4
Shiner surfperch, whole body	ngTEQ/kg ww	3/3	11.4	13.1	14.3
English sole, fillet	ngTEQ/kg ww	3/3	10.1	12.9	15.4
Invertebrates					
Crab, whole body[c]	ngTEQ/kg ww	3/3	3.67	4.83	5.61
Crab, edible meat	ngTEQ/kg ww	3/3	1.53	1.63	1.71
Crab, hepatopancreas	ngTEQ/kg ww	3/3	8.06	9.92	11.0
Intertidal Clam, whole body	ngTEQ/kg ww	3/3	0.212	0.406	0.734
Geoduck clam, whole body[c]	ngTEQ/kg ww	1/1	0.228	na	0.228
Geoduck clam, edible meat	ngTEQ/kg ww	3/3	0.0910	0.141	0.192
Geoduck clam, gutball	ngTEQ/kg ww	2/2	0.378	0.461	0.544
Dioxins and Furans[g]					
Fish					
Brown rockfish, whole body	ngTEQ/kg ww	6/6	5.71 J	26.9	61.8 J
English sole, whole body	ngTEQ/kg ww	3/3	34.3 J	36.8	39.0 J
Shiner surfperch, whole body	ngTEQ/kg ww	3/3	12.4 J	14.3	15.6 J
English sole, fillet	ngTEQ/kg ww	3/3	10.8 J	13.6	16.1 J
Invertebrates					
Crab, whole body[c]	ngTEQ/kg ww	3/3	4.84 J	6.03	6.80 J
Crab, edible meat	ngTEQ/kg ww	3/3	1.98 J	2.10	2.18 J
Crab, hepatopancreas	ngTEQ/kg ww	3/3	10.3 J	12.2	13.4 J
Intertidal Clam, whole body	ngTEQ/kg ww	3/3	0.446 J	0.688	1.11 J
Geoduck clam, whole body[c]	ngTEQ/kg ww	1/1	0.433 J	na	0.433 J
Geoduck clam, edible meat	ngTEQ/kg ww	3/3	0.337 J	0.375	0.431 J
Geoduck clam, gutball	ngTEQ/kg ww	2/2	0.681 J	0.881	1.08 J

Chemical and Tissue Type	Unit	Detection Frequency[a]	Concentration		
			Minimum	Mean	Maximum
cPAHs[g]					
Fish					
Brown rockfish, whole body	µgTEQ/kg ww	0/13	na	12 U[i]	na
English sole, whole body	µgTEQ/kg ww	9/11	0.45 J	11	11
Juvenile Chinook salmon, whole body	µgTEQ/kg ww	0/6	na	56 U[i]	na
Shiner surfperch, whole body	µgTEQ/kg ww	6/8	0.76 J	1.2[i]	2.2
English sole, fillet	µgTEQ/kg ww	3/11	0.32 J	0.29[i]	0.42 J
Invertebrates					
Crab, whole body[c]	µgTEQ/kg ww	7/7	0.71 J	0.96	1.2 J
Crab, edible meat	µgTEQ/kg ww	6/9	0.40 J	0.60[i]	2.4 J
Crab, hepatopancreas	µgTEQ/kg ww	7/7	0.96 J	1.3	2.4 J
Intertidal Clam, whole body	µgTEQ/kg ww	11/11	2.4	16	63
Mussel, whole body	µgTEQ/kg ww	16/17	3.8 J	20[i]	110
Shrimp, whole body[e]	µgTEQ/kg ww	0/1	na	na	na
Geoduck clam, whole body[c]	µgTEQ/kg ww	4/4	2.1 J	3.1	4.1 J
Geoduck clam, edible meat	µgTEQ/kg ww	6/6	0.99 J	1.6	2.8 J
Geoduck clam, gutball	µgTEQ/kg ww	3/3	6.3	8.2	11 J
Benthic invertebrates, whole body	µgTEQ/kg ww	13/13	45	170	420
Inorganic Arsenic					
Fish					
Brown rockfish, whole body	mg/kg ww	13/13	0.004 J	0.0.008	0.023 J
English sole, whole body	mg/kg ww	11/11	0.023 J	0.032	0.059 J
Juvenile Chinook salmon, whole body	mg/kg ww	na	na	na	na
Shiner surfperch, whole body	mg/kg ww	8/8	0.012 J	0.021	0.037 J
English sole, fillet	mg/kg ww	0/11	na	na	na
Invertebrates					
Crab, whole body[c]	mg/kg ww	9/9	0.031 J	0.042	0.057 J
Crab, edible meat	mg/kg ww	9/9	0.020 J	0.032	0.043 J
Crab, hepatopancreas	mg/kg ww	9/9	0.038 J	0.058	0.089 J
Intertidal Clam, whole body[d]	mg/kg ww	12/12	0.074 J	0.166	0.443
Mussel, whole body[d]	mg/kg ww	11/11	0.040 J	0.078	0.133 J
Geoduck clam, whole body[c]	mg/kg ww	4/4	0.027 J	0.036	0.049 J
Geoduck clam, edible meat	mg/kg ww	6/6	0.012 J	0.029	0.063 J

Chemical and Tissue Type	Unit	Detection Frequency[a]	Concentration		
			Minimum	Mean	Maximum
Geoduck clam, gutball	mg/kg ww	3/3	0.075 J	0.087	0.110 J
Benthic invertebrates, whole body	mg/kg ww	na	na	na	na
TBT					
Fish					
Brown rockfish, whole body	µg/kg ww	13/13	38	160	420
English sole, whole body	µg/kg ww	11/11	17	26	38
Juvenile Chinook salmon, whole body	µg/kg ww	0/5	na	3.6 U	na
Shiner surfperch, whole body	µg/kg ww	8/8	30 J	58	67
English sole, fillet	µg/kg ww	7/14	1.63	5.7[i]	14
Striped perch, fillet	µg/kg ww	6/6	5 J	20	31 J
Invertebrates					
Crab, whole body[c]	µg/kg ww	1/9	13	3.2[i]	13
Crab, edible meat	µg/kg ww	0/12	na	3 U[i]	na
Crab, hepatopancreas	µg/kg ww	1/9	23	6.0[i]	23
Intertidal Clam, whole body[d]	µg/kg ww	10/10	15	47	140
Mussel, whole body[d]	µg/kg ww	16/17	7.5	33[i]	92.8
Geoduck clam, whole body[c]	µg/kg ww	4/4	8.1 J	9.9	12
Geoduck clam, edible meat	µg/kg ww	6/6	5.1 J	7.6	9.8
Geoduck clam, gutball	µg/kg ww	3/3	14	19	29
Benthic invertebrates, whole body	µg/kg ww	12/12	20	110	390

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] This table includes all tissue data in the SRI dataset

[b] Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest reporting limit.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck. No shells were included in these samples.

[d] Whole body clam and mussel samples include all soft tissues. No shells were included in these samples.

[e] Shrimp sample is one composite of 26 individuals collected from multiple shrimp traps.

[f] PCB TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). PCB TEQs were calculated for each sample by summing the TEQs for each PCB congener. PCB individual congener TEQs were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[g] Dioxin and furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQs were calculated for each sample by summing the TEQs for each dioxin and furan congener. Dioxin and furan individual congener TEQs for were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[h] Total cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual PAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

[i] Summary statistics were calculated assuming one-half the reporting limit for non-detect results in cases where non-detected results were present.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
J – estimated concentration
na – not applicable
nd – not detected
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
TBT – tributyltin
TEF – toxic equivalency factor
U – not detected at given concentration
ww – wet weight

ES.3.3 Water

Contaminant concentrations in surface water and porewater were also summarized in the SRI. A large number of surface water grab samples were collected along a transect in the EW (at Station 4950) by King County between October 1996 and June 1997 and analyzed for conventional parameters, metals and SVOCs. Surface water sampling was also conducted in 2008 and 2009 as part of the SRI. Fifty nine samples were collected from 5 locations throughout the waterway during the wet season, the dry season and a large storm event. These samples were analyzed for conventional parameters, metals, SVOCs, and PCB congeners. The metals concentrations in the two datasets were similar. However, SVOCs were not detected in the King County samples; improved sensitivity in the analyses resulted in higher detection frequencies for SVOCs in the SRI dataset.

Total PCB concentrations in whole-water samples ranged from 0.068 to 5.83 ng/L with a mean concentration of 1.31ng/L. cPAHs were infrequently detected in surface water samples (4 out of 59 samples) with concentrations ranging from 0.0091 to 0.011 µg TEQ/L. Dissolved surface water arsenic concentrations ranged from 0.43 to 1.43 µg/L. Finally, TBT was detected in 1 out of 59 samples with a concentration of 0.01 µg/L.

Porewater data were collected from subtidal surface and subsurface sediments for the analysis of TBT primarily in samples collected for dredge material characterization and post-dredge monitoring studies. TBT was detected in 83 out of 99 samples with concentrations ranging from 0.019 to 28 µg/L. In addition, 13 porewater samples were collected from two intertidal areas for the analysis of volatile organic compounds (VOCs). Naphthalene was detected in two samples, benzene was detected in two samples, and cis-1,2-dichloroethene was detected in one sample.

ES.4 Baseline Ecological Risk Assessment

The baseline ERA presents risk estimates for benthic invertebrate, crabs, fish, and aquatic-dependent wildlife species that may be exposed to contaminants in the EW. Contaminants of potential concern (COPCs) were first identified through a conservative risk-based screening process so that risk analyses could focus on contaminants more likely to be of concern. To the extent possible, this ERA is consistent with the approach and methods that were used in the ERA for the LDW, which is a Superfund site that is located upstream of and contiguous with the EW and has many physical and functional characteristics similar to those of the EW.

There were nine receptors of concern (ROCs) evaluated in the ERA (i.e., the benthic invertebrate community, crabs, juvenile Chinook salmon, brown rockfish, English sole, pigeon guillemot, osprey, river otter, and harbor seal). ROCs are species selected to represent larger groups of animals because not all species can be individually evaluated in the ERA. The risk estimates were based either on COPC concentrations in sediment, water, and aquatic biota from the EW or on estimated dietary contaminant doses, depending on the species and contaminant.

For crabs, fish, and wildlife, the site-related contaminant concentrations or doses were compared with concentrations or doses from the scientific literature that have been shown to cause specific harmful effects in the same or related species. The effects of primary concern are those that decrease survival, growth, or reproduction.

To evaluate risks to the benthic macroinvertebrate community, contaminant concentrations in sediment and results of sediment toxicity tests were compared with SMS, which provides both numerical chemical and biological standards. The goal of the SMS is to reduce and ultimately eliminate adverse effects on biological resources (Washington Administrative Code 173-204-100). For benthic invertebrates living in intertidal and subtidal sediments, sediment chemistry and site-specific toxicity test results indicated that no adverse effects are expected in approximately 40% of the EW area (28 ha), based on contaminant concentrations in surface sediment that were less than the sediment quality standards (SQS) of the SMS and toxicity test results. Adverse effects are predicted in approximately 21% of the EW area, which had contaminant concentrations or biological effects in excess of the CSL values. The remaining 39% of the EW area (28 ha) had contaminant concentrations or biological effects

between the SQS and CSL values, indicating the potential for minor adverse effects to benthic invertebrate communities.

Thirty contaminants of concern (COCs) were identified for the benthic invertebrate community based on sediment chemistry data. Specifically, 29 contaminants exceeded the SQS in one or more surface sediment samples and one contaminant that does not have SMS criteria exceeded the Dredged Material Management Program (DMMP) guidelines. Total PCB concentrations exceeded the SQS or CSL in 65% of the samples. Mercury and 1,4-dichlorobenzene concentrations exceeded the SQS or CSL in 19 and 13% of the samples, respectively. In addition, 4 PAH compounds (i.e., acenaphthene, fluoranthene, fluorene, and phenanthrene) exceeded the SQS or CSL in 5 to 10% of the samples and 22 contaminants exceeded the SQS or CSL in less than 5% of the samples, including 6 contaminants that exceeded the SQS or CSL in only 1 sample.Benthic invertebrate community risks were evaluated using a tissue-residue approach for total PCBs, mercury, and TBT. There is a potential for risk from TBT to benthic invertebrates in two areas of the EW because TBT tissue residue concentrations were above the tissue toxicity reference value (TRV). Based on this assessment, TBT was identified as a COC.

Of the three COPCs evaluated for the water exposure pathway (cadmium, mercury, and TBT), only TBT was identified as a COC for the benthic invertebrate community. In addition, only one COC was identified based on porewater data; naphthalene. For TBT, one surface water concentration exceeded the TBT water quality criteria and for naphthalene two porewater samples exceeded the literature-based TRV.

For the other receptors evaluated as ROCs, hazard quotients (HQs) were calculated based on a range of effects data, including no-observed-adverse-effect levels (NOAELs) and lowest-observed-adverse-effect levels (LOAELs). Hazard quotients are the ratio of the exposure amount (concentration or dose) to a TRV for the contaminant. COCs were defined as contaminants with LOAEL-based HQs greater than or equal to 1, which indicates a potential for adverse effects. For the juvenile Chinook salmon ROC, a listed species, COCs were identified if a COPC exceeded the NOAEL to be protective of individuals. Cadmium was the only COC identified for juvenile Chinook salmon. Three COCs (cadmium, copper and zinc) were identified for crabs and five COCs (total PCBs, cadmium, copper, TBT and vanadium)

were identified for English sole or brown rockfish (Table ES-4). No COCs were identified for wildlife receptors.

Table ES-4

COPCs, COCs and Risk Drivers Identified for ERA Receptors

Receptor	Evaluation Type	COPCs	COCs	Risk Driver
Benthic Invertebrate Community	sediment	29 chemicals, including metals, PAHs, total PCBs, phthalates, other SVOCs and total DDTs	30 COPCs[a]	29 SMS chemicals
	tissue residue	TBT, total PCBs	TBT	TBT
	surface water	cadmium, mercury, TBT	TBT	none
	porewater	naphthalene	naphthalene	none
Crab	tissue residue	arsenic, cadmium, copper, zinc, and total PCBs	cadmium, copper, zinc	none
	surface water	cadmium, mercury, TBT	none	none
Fish	dietary	arsenic, cadmium, chromium, copper, vanadium, benzo(a)pyrene	cadmium, copper, vanadium	none
	tissue residue	beta-endosulfan, total PCBs, TBT	total PCBs, TBT	total PCBs
	surface water	cadmium, mercury, TBT	none	none
Birds	dietary dose	mercury, total PCBs, PCB TEQ	none	none
Mammals	dietary dose	mercury, selenium, total PCBs, PCB TEQ	none	none

[a] Arsenic, cadmium, mercury, zinc, acenaphthene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, 1,4-dichlorobenzene, 2-methylnaphthalene, 2,4-dimethylphenol, dibenzofuran, n-nitrosodiphenylamine, phenol, and total PCBs and total DDTs. All COCs had exceedances of SMS chemical criteria except total DDTs, which was based on exceedances of DMMP guideline

COC – contaminant of concern
COPC – contaminant of potential concern
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredge Material Management Program
ERA – ecological risk assessment
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SMS – Washington State Sediment Management Standards
SVOC – semivolatile organic compound
TBT – tributyltin
TEQ – toxic equivalent

A subset of COCs were identified as risk drivers for ROCs based on the risk estimates, uncertainties discussed in the ERA, and regional background concentrations in accordance with EPA guidance. COCs that were identified as risk drivers are noted in Table ES-4. The risk drivers from both the ERA and the HHRA will be the focus of remedial analyses in the FS. In addition, in consultation with EPA and consistent with the evaluation of non-risk drivers in the LDW, COCs not selected as risk drivers in the EW ERA will be evaluated

qualitatively in the EW FS. This evaluation will include a follow-up check for the non-risk driver COCs to ensure that sediment with elevated levels of these COCs will be included in the footprint of the remedial alternatives evaluated in the FS.

ES.5 Baseline Human Health Risk Assessment

The baseline HHRA estimated the risks people could face from exposure to contaminants in EW sediment, surface water, and seafood. The primary exposure scenarios were identified as consumption of seafood collected from the EW; direct contact[2] with sediments during commercial netfishing, clamming, or habitat restoration work in the EW; and direct contact with surface water contact resulting from swimming. As with the ERA, this HHRA is consistent to the extent possible with the approach and methods that were approved by EPA for use in the HHRA for the LDW.

ES.5.1 Exposure Assessment

Reasonable maximum exposure (RME) estimates were calculated to avoid underestimating risks. Consequently, exposure (and thus risk estimates) may be overestimated for many individuals (EPA 1989). This approach is consistent with EPA's policy of "RME," which uses high-end, but plausible, estimates of exposure for assessing risks. Average exposure estimates are not favored in decision-making because they underestimate exposure for a substantial number of individuals (EPA 1989).

There are limited data available on the amount of resident seafood organisms currently being harvested and consumed from the EW. Although the collection and consumption of seafood from the EW are known to occur (a creel study by King County identified the Spokane Street Bridge on the EW as one of the more popular fishing locations along the shores of the Duwamish River and Elliott Bay (King County 1999a)), no seafood consumption surveys that focused solely on the consumption of seafood from the EW were available for individuals (e.g., recreational anglers, tribal members, or other communities) who either currently consume seafood or may consume seafood from this resource in the future. Therefore, the rates of seafood ingestion assumed for the seafood consumption scenarios were selected by

[2] Direct sediment contact scenarios evaluate dermal exposure and incidental ingestion pathways.

EPA based on data collected from several regional surveys (Toy et al. 1996; EPA 1999a; Suquamish Tribe 2000).[3]

Other scenarios with exposure assumptions higher or lower than those of the RME scenarios were also evaluated to characterize the range of risk estimates. For seafood consumption, these other scenarios included consumption rates estimated for the Suquamish Tribe, "average exposure" scenarios using central tendency consumption rate estimates, and a "unit risk" scenario based on an assumed one seafood meal per month. RME risks are generally used to evaluate remedial actions at a site. Risks estimated using Suquamish Tribe consumption rates represent a high-end level of exposure for tribal seafood consumption risks. Risks estimated using central tendency consumption rates are intended to reflect risks associated with average exposure to contaminants in seafood. The one-meal-per-month exposure scenario is not intended to describe seafood consumption that is occurring on the EW. Instead, this "unit of exposure" scenario is intended to allow individuals to evaluate their own exposure depending on how many meals of seafood of different types collected from the EW are consumed per month. For example, if an individual consumed two meals per month, then the risk for this individual would be two times the one-meal-per-month risk estimate.

There are no EW-specific data to estimate the degree to which humans may currently be directly exposed to sediments via tribal or recreational clamming activities or via habitat restoration work. The exposure scenarios assumed for these activities were intended to represent exposures for a health-protective estimation of risks. The tribal netfishing scenario, on the other hand, reflects exposure conditions that could occur under current tribal fishing activities within the EW.

Exposure to surface water in the EW was assessed for a swimming scenario, for which the exposure parameters were based on the adult swimming scenarios presented in the *King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and*

[3] The Tulalip Tribes' survey (Toy et al. 1996), which used RME consumption to develop the tribal scenario for the EW, did not include seafood obtained from the EW. Although the API survey (EPA 1999a) focused on King County, specific seafood harvest locations were not reported. The EW is a very small portion of the much larger fishing area that was included in the Suquamish Tribe's survey.

Elliott Bay (King County 1999a). It should be noted that the parameters used for this scenario are likely significant overestimates of swimming exposure levels for the EW, given that they were developed for areas that include a greater number of recreational access points (e.g., Elliott Bay) than does the EW and swimming in EW will be limited because of the EW's high concentration of large ship and tug boat traffic and the fact that water temperatures in the EW are generally quite cold.[4] Therefore, an RME was not evaluated for human swimming exposure.

ES.5.2 Risk Characterization

Prior to risk analysis, a health-protective screening analysis was performed to determine COPCs for each exposure pathway. Chemistry data for each COPC were then compiled over the assumed exposure area (e.g., intertidal sediments for clamming). For the seafood consumption scenarios, data for a variety of different species (English sole, rockfish, perch, crab, clams, geoduck, and mussels) were used to represent a typical seafood consumer's diet.

Based on health-protective exposure assumptions, estimated cancer risks in the EW were determined to be highest for the seafood consumption scenarios (Table ES-5). The cumulative excess cancer risk[5] for all carcinogenic chemicals ranged from 4 in 10,000 (4×10^{-4}) to 1 in 1,000 (1×10^{-3}) for the RME seafood consumption scenarios (adult tribal RME based on Tulalip Tribes' data, child tribal RME based on Tulalip Tribes' data, and adult Asian and Pacific Islander [API] RME). The COCs that were the primary contributors to the cumulative excess cancer risk were PCBs, cPAHs, inorganic arsenic,[6] and dioxins/furans. The evaluation of non-cancer effects (e.g., immunological, neurological, or integumentary) indicates the potential for adverse effects other than cancer associated with seafood consumption, particularly for PCBs. Table ES-5 shows the maximum non-cancer hazard

[4] Water samples collected in the East Waterway in 2008 and 2009 (September 2008-February 2009) had temperatures ranging from 5.1 to 14.1°C (41 to 57°F), with a mean temperature of approximately 10°C (50°F).

[5] An excess cancer risk is the increased risk (expressed as a probability) that an individual will develop cancer in his or her lifetime based on site-related exposure.

[6] Tissue concentrations of inorganic arsenic in the EW were similar to those in background areas in Puget Sound (i.e., risk estimates based on concentrations in samples collected from background areas were similar to those based on concentrations in samples collected from the EW).

index (HI) (i.e., sum of HQs for a particular endpoint) for each of the seafood consumption scenarios.

Table ES-5

Summary of Exposure Parameters and Risks Associated with Seafood Consumption Scenarios

Scenario	Ingestion Rate (g/day)[a]	Meals per Month[b]	Exposure Duration (years)	Excess Cancer Risk	Maximum Non-Cancer HI[c]
Adult tribal RME (Tulalip data)	97.5	13.1	70	1×10^{-3}	28
Adult tribal CT (Tulalip data)	15	2.0	30	7×10^{-5}	3
Child tribal RME (Tulalip data)	39.0	13.1	6	4×10^{-4}	59
Child tribal CT (Tulalip data)	6.0	2.0	6	4×10^{-5}	6
Adult tribal (Suquamish data)	597.7	80	70	1×10^{-2}	219
Adult API RME	51.5	6.9	30	6×10^{-4}	25
Adult API CT	5.3	0.7	9	1×10^{-5}	1
Adult one-meal-per-month					
Benthic fish	7.5	1.0	30	2×10^{-4}	13
Clam	7.5	1.0	30	3×10^{-5}	0.5
Crab	7.5	1.0	30	2×10^{-5}	0.9
Pelagic fish, rockfish	7.5	1.0	30	4×10^{-4}	21
Pelagic fish, perch	7.5	1.0	30	1×10^{-4}	8

[a] Ingestion rates do not include consumption of adult salmon because these fish acquire most of their contaminant body burden from outside the EW.

[b] It was assumed that one adult meal was equal to 227g (8 ounces). Child consumption rates were based on 40% of adult rates (EPA 2007b). For the purpose of calculating meals per month for children, this 40% conversion is assumed to represent a smaller meal size (40% of adults, which is equal to 91 g or 3.2 ounces).

[c] The sum of non-cancer HQs across all COPCs is not directly interpretable for risk assessment because some HQs may relate to different toxic effects (i.e., endpoints) that are not additive. Thus, the maximum non-cancer HI for any endpoint is presented here. For all scenarios, this maximum is for either the immunological endpoint, neurological endpoint, or integumentary endpoint, all of which include total PCBs in the sum.

API – Asian and Pacific Islander
COPC – contaminant of potential concern
CT – central tendency
EPA – US Environmental Protection Agency
EW – East Waterway
HI – hazard index (a sum of the HQs for individual contaminants)
HQ – hazard quotient
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure

Excess cancer risks for direct sediment exposure RME scenarios for netfishing and clamming were lower than those for seafood consumption RME scenarios (Table ES-6). Risk estimates ranged from 7 in 1,000,000 (7×10^{-6}) to 3 in 100,000 (3×10^{-5}) for the RME scenarios. The COCs that were the primary contributors to the cumulative excess cancer risk for these

scenarios were cPAHs and inorganic arsenic, with the other COCs (PCBs, and total TEQ[7]) contributing a smaller portion of the risk. None of the direct sediment contact RME scenarios had HQs greater than 1 for non-cancer effect, and therefore, non-cancer effects are not expected from direct contact with sediments. Additionally, it should be noted that these direct sediment exposure scenarios included the evaluation of risk for both dermal absorption and incidental ingestion. The proportion of the total risk for each COPC associated with these two pathways varied by COPC and exposure scenario.

Table ES-6
Summary of Exposure Parameters and Risks Associated with Direct Sediment Exposure Scenarios

Scenario	Exposure Area	Incidental Sediment IR (g/day)	Exposed Skin SA (cm^2)	Exposure Frequency (days/yr)	Exposure Duration (years)	Excess Cancer Risk
Netfishing RME	all subtidal and intertidal	0.050	3,600	119	44	7×10^{-6}
Netfishing CT	all subtidal and intertidal	0.050	3,600	63	29	1×10^{-6}
Habitat restoration worker	intertidal area accessible from the shore or from a boat	0.1	6,040	15	20	1×10^{-6}
Tribal clamming RME	intertidal area accessible from the shore or from a boat	0.1	6,040	120	64	3×10^{-5}
Tribal clamming – 183 days per year	intertidal area accessible from the shore or from a boat	0.1	6,040	183	70	6×10^{-5}
Clamming – 7 days per year	intertidal area accessible from the shore	0.1	6,040	7	30	1×10^{-6}

Note: Non-cancer HQs did not exceed 1 for any COPC and are therefore not shown in this table.

COPC – contaminant of potential concern
CT – central tendency
HQ – hazard quotient
IR – ingestion rate
RME – reasonable maximum exposure
SA – surface area

In addition to the seafood consumption and direct sediment contact scenarios, three levels of swimming exposure were evaluated to assess risks based on exposure to surface water in the EW.[8] The only excess cancer risks that were greater than the 1×10^{-6} threshold were for PCB

[7] Total TEQ is the sum of dioxin/furan TEQ and PCB TEQ risks. In this case neither dioxin/furan TEQ nor PCB TEQ individually exceeded unacceptable risk thresholds but the combined TEQ did.

[8] The three levels of exposure evaluated for swimming were high (which assumed a 2.6-hour swim, 24 days per year for 70 years), medium (which assumed a 1-hour swim, 12 days per year for 30 years), and low (which assumed a 10-minute swim [0.17 hours], 2 days per year for 9 years).

TEQ for both the high level of exposure (which assumed 2.4 hours of swimming, 24 days per year) and the medium level of exposure (which assumed 1 hour of swimming, 12 days per year) (equal to 9×10^{-6} and 2×10^{-6}, respectively). The total excess cancer risks (which includes all COPCs) for this scenario were also equal to 9×10^{-6} and 2×10^{-6}, respectively. No other COPCs (including total PCBs) had excess cancer risks greater than 1×10^{-6} or non-cancer HQs greater than 1 for any COPC-exposure level combination.

Twelve chemicals were identified as COCs (a COC has an excess cancer risk estimate greater than 1 in 1,000,000 [1×10^{-6}] or an HQ greater than 1 for an RME scenario) for at least one RME seafood consumption scenario. Based on excess cancer risks for the seafood consumption scenarios, arsenic, cPAH TEQ, pentachlorophenol, total PCBs, PCB TEQ, alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, mirex, and dioxin/furan TEQ were identified as COCs. Based on non-cancer hazards, cadmium and total PCBs were identified as COCs. Four chemicals were identified as COCs based on an excess cancer risk estimate greater than 1 in 1,000,000 (1×10^{-6}) for at least one direct sediment contact RME scenario: arsenic, cPAH TEQ, total PCBs, and total TEQ. Of these COCs, four were identified as risk drivers based on the magnitude of their risk estimates relative to acceptable risk thresholds (including a consideration of background concentrations, if applicable) and the relative percentage of their contributions to total human health risk:

- **Arsenic** – identified as a risk driver based on direct sediment exposure scenarios
- **cPAH TEQ** – identified as a risk driver based on both seafood consumption and direct sediment exposure scenarios
- **PCBs** – identified as a risk driver based on seafood consumption scenarios
- **Dioxin/furan TEQ** – identified as a risk driver based on seafood consumption scenarios

For arsenic, risk estimates based on inorganic arsenic concentrations in tissue samples collected from background areas were similar to risk estimates based on inorganic arsenic concentrations in tissue collected from the EW. Therefore, arsenic was not identified as a risk driver for seafood consumption.

No COCs were defined for the swimming scenario.[9] All COCs, including those identified in the EW ERA (Appendix A) are discussed in this SRI. As noted for the ERA, risk drivers will be the focus of remedial alternatives analyses in the FS, and COCs not selected as risk drivers in the EW HHRA will be evaluated qualitatively in the EW FS.

These findings do not constitute a definitive characterization of human health risks. There are many uncertainties associated with the site-specific risk estimates for each exposure scenario. In spite of these uncertainties, the baseline risk characterization for the EW site is considered to be health-protective and sufficient to support risk management decisions.

ES.6 Preliminary Background Concentrations

Preliminary background concentration data are intended to provide a context for the site characterization data and risk-based threshold concentrations (RBTCs) that are presented in the SRI. Additional evaluation of background concentrations will be documented in the FS.

Concentrations in surface sediment for four risk driver contaminants (total PCBs, arsenic, cPAHs, and dioxins and furans) were calculated using Puget Sound 2008 Bold survey data. This dataset was identified as the primary dataset for natural background because it is the largest and most comprehensive dataset available for Puget Sound reference areas (Table ES-7).

[9] No RME level of exposure was defined because of the uncertainties associated with these levels of exposure, and thus no COCs were identified based on exposure to surface water (see Section B.5.3.3 of the EW HHRA for details [Appendix B]).

Table ES-7

Concentrations of Human Health Risk Driver Contaminants in Samples Collected from Puget Sound Reference Areas, Urban Bays and Lakes, Upstream of the LDW, and the LDW Upper Turning Basin

Risk Driver COC	Unit	Concentration							
		Puget Sound Bold Survey Data[a]		Urban Bays and Lakes[b]		Upstream Sediment			
						Green River[c]		LDW Upper Turning Basin[d]	
		Mean	90th Percentile	Mean	90th Percentile	Mean	90th Percentile	Mean	90th Percentile
Total PCBs	µg/kg dw	1.2[e]	2.8[e]	38 – 87	64 – 217	3,23	6, 40	36	56
Arsenic	mg/kg dw	6.5	11	5.1 – 15	9.8 – 38	7.0, 6.8	10,11	7	12
cPAHs	µg TEQ/kg dw	7.9	15	18, 55	57, 135	76 – 374	185 – 904	73	180
Dioxin and furan	ng TEQ/kg dw	1.4	2.3	1.0, 2.0	3.0, 2.6	14.9	16.3[f]	2.8[g]	2.8[g]

[a] The values are the mean and the 90th percentile concentration of the Puget Sound 2008 Bold Survey data.

[b] Information on concentrations from urban bays and lakes (excluding cleanup and disposal sites) is presented in Section 7.3 to provide additional context to the concentrations summarized in Sections 7.1 and 7.2. Elliott Bay data have been excluded from this summary because the bay receives discharge from EW and the LDW and may be influenced by other known point sources of contamination.

[c] Surface sediment data collected upstream of the LDW. Information relevant to upstream concentrations in sediment is presented in Section 7.2.2. The concentrations presented in this table (for informational purposes only) represent the mean and the 90th percentile concentrations in the upstream dataset (LDW upstream dataset and Ecology Upstream dataset).

[d] Information relevant to concentrations in subsurface sediment from the LDW Upper Turning Basin is presented in Section 7.2.2.1. The mean and 90th percentile concentrations in sediment cores collected between RM 4.3and RM 4.75 are provided as defined in the LDW FS (AECOM 2010a).

[e] The mean and 90th percentile of the total PCB concentration calculated as the sum of PCB congeners.

[f] The TEQ presented for dioxins and furans represents the 90th percentile of the dataset collected near storm drains and other areas receiving surface runoff within the greater Seattle metropolitan area (Section 7.3).

[g] Maximum detected value presented because there was insufficient data to calculate percentiles.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
TEQ – toxic equivalent
Washington Administrative Code
FS – Feasibility Study

The SRI also presents surface sediment data for the risk driver contaminants from other areas outside of the EW such as Green River surface sediment and suspended solids data upstream of the LDW, subsurface sediment data from the LDW Upper Turning Basin, and sediment data from regional urban bays and lakes (Table ES-7). The application of these Puget Sound

reference area data and other regional datasets to remedial decisions will be determined by EPA.

ES.7 Risk-Based Threshold Concentrations

Sediment RBTCs, which are defined as concentrations of risk driver contaminants in sediment that are associated with specific risks, are useful for risk management decisions. If sediment were remediated to meet a sediment RBTC, for example, then the exposure conditions following that cleanup action would be associated with a reduction of risk down to the target risk level for that RBTC. RBTCs were estimated for each of the risk driver contaminants identified in the HHRA and ERA. Sediment RBTCs were calculated for risks associated with direct sediment contact and seafood consumption by people, and for the protection of fish and the benthic invertebrate community.

For each of the direct sediment contact RME scenarios (tribal clamming and tribal netfishing), sediment RBTCs were calculated for three different excess cancer risk levels (Table ES-8). RBTCs for non-RME scenarios were also calculated for informational purposes. For the netfishing scenario, the exposure area is the entire EW. For the tribal clamming scenario, the exposure areas include intertidal areas where such activities may occur.

Table ES-8
Summary of Sediment RBTCs for Human Health Risk Drivers
for RME Direct Sediment Exposure Scenarios

Risk Driver COC	Unit	Exposure Scenario	Sediment RBTCs		
			1 in 1,000,000 Risk Level	1 in 100,000 Risk Level	1 in 10,000 Risk Level
Arsenic	mg/kg dw	tribal clamming	1.3	13	130
		netfishing	3.7	37	370
cPAHs	µg TEQ/kg dw	tribal clamming	150	1,500	15,000
		netfishing	380	3,800	38,000

Note: RBTCs were not calculated for non-cancer endpoints because estimated HQs were all < 1.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
dw – dry weight
HQ – hazard quotient
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TEQ – toxic equivalent

As with the direct contact scenarios, RBTCs were calculated for the seafood consumption RME scenarios based on both three target excess cancer risk thresholds and a non-cancer

threshold of HQ = 1. For seafood consumption, sediment RBTCs for total PCBs were estimated using a food web model. A range of RBTCs was calculated. Sediment RBTCs at the 1 in a million (1×10^{-6}) and 1 in 100,000 (1×10^{-5}) excess cancer risk levels and non-cancer risk of HQ = 1 for the tribal RME (adult and child) scenario could not be calculated; the contribution of total PCBs from water alone was high enough to result in excess cancer risks or non-cancer risk above those risk levels even in the absence of any contribution from sediment (the sediment RBTCs for these scenarios are expressed as < 1 µg/kg dw in Table ES-9). At the 1 in 10,000 (1×10^{-4}) excess cancer risk level, sediment RBTCs for total PCBs ranged from 2 to 250 µg/kg dw for the three RME scenarios (Table ES-9). These sediment RBTCs for total PCBs are lower than the current surface area-weighted average concentration of total PCBs in the EW (approximately 470 µg/kg dw). Sediment RBTCs for total PCBs for the non-RME scenarios ranged from < 1 µg/kg dw for the adult tribal scenario based on Suquamish data to > 470 µg/kg dw for a number of scenarios at the 1×10^{-4} target risk level (Table ES-10). A sediment RBTC of > 470 µg/kg dw indicates that even under current conditions in the EW (i.e., the current EW-wide SWAC is 470 µg/kg dw), excess cancer risks are estimated to be less than the target risk level.

Table ES-9
Sediment RBTCs for Total PCBs Based on Excess Cancer Risks in HHRA RME Seafood Consumption Scenarios

Scenario	Risk Level	Sediment RBTC (µg/kg dw)[a]	Lower-Bound Concentration (µg/kg dw)[b]	Upper-Bound Concentration (µg/kg dw)[b]
Adult tribal RME (Tulalip data)	1×10^{-4}	2	< 1[c]	8
Child tribal RME (Tulalip data)		250	210	323
API RME		100	88	121
Adult tribal RME (Tulalip data)	1×10^{-5}	< 1[c]	< 1[c]	< 1[c]
Child tribal RME (Tulalip data)		< 1[c]	< 1[c]	< 1[c]
API RME		< 1[c]	< 1[c]	< 1[c]
Adult tribal RME (Tulalip data)	1×10^{-6}	< 1[c]	< 1[c]	< 1[c]
Child tribal RME (Tulalip data)		< 1[c]	< 1[c]	< 1[c]
API RME		< 1[c]	< 1[c]	< 1[c]
Adult tribal RME (Tulalip data)	HQ of 1	< 1[c]	< 1[c]	< 1[c]
Child tribal RME (Tulalip data)		< 1[c]	< 1[c]	< 1[c]
API RME		< 1[c]	< 1[c]	< 1[c]

[a] The RBTC was derived using the food web model parameter set that resulted in the closest match between empirical data and model estimates for all species.

[b] Upper and lower bounds were calculated using estimates from parameter sets that met the FWM performance criterion (i.e., empirical data were within a factor of 2 of FWM-estimated concentrations for all species except clams) (see Appendix C, Section C.4.6).

[c] Value could not be calculated because contribution from water alone resulted in estimated tissue concentrations greater than the applicable risk level, even in the absence of any contribution from sediment.

API – Asian and Pacific Islander
dw – dry weight
FWM – food web model
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

Table ES-10
Sediment RBTCs for Total PCBs Based on Excess Cancer Risks in the Non-RME HHRA Seafood Consumption Scenarios

Scenario	Risk Level	Sediment RBTC (µg/kg dw)[a]	Lower-Bound Concentration (µg/kg dw)[b]	Upper-Bound Concentration (µg/kg dw)[b]
Adult tribal CT (Tulalip data)	1×10^{-4}	> 470	> 470	> 470
Child tribal CT (Tulalip data)		> 470	> 470	> 470
API CT		> 470	> 470	> 470
Adult tribal (Suquamish data)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of benthic fish		404	404	> 470
Adult one meal per month of pelagic fish (rockfish)		229	100	323
Adult one meal per month of pelagic fish (shiner surfperch)		323	266	> 470
Adult one meal per month of crabs		> 470	> 470	> 470
Adult one meal per month of clams		> 470	> 470	> 470
Adult tribal CT (Tulalip data)	1×10^{-5}	33	21	50
Child tribal CT (Tulalip data)		126	100	183
API CT		100	83	112
Adult tribal (Suquamish data)		< 1	< 1	< 1
Adult one meal per month of benthic fish		19	19	28
Adult one meal per month of pelagic fish (rockfish)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of pelagic fish (shiner surfperch)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of crabs		363	145	> 470
Adult one meal per month of clams		> 470	> 470	> 470

Scenario	Risk Level	Sediment RBTC (µg/kg dw)[a]	Lower-Bound Concentration (µg/kg dw)[b]	Upper-Bound Concentration (µg/kg dw)[b]
Adult tribal CT (Tulalip data)	1×10^{-6}	< 1[c]	< 1[c]	< 1[c]
Child tribal CT (Tulalip data)		< 1[c]	< 1[c]	< 1[c]
API CT		10	0.2	28
Adult tribal (Suquamish data)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of benthic fish		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of pelagic fish (rockfish)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of pelagic fish (shiner surfperch)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of crabs		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of clams		< 1[c]	< 1[c]	< 1[c]
Adult tribal CT (Tulalip data)	HQ of 1	100	80	100
Child tribal CT (Tulalip data)		13	4	23
API CT		194	157	250
Adult tribal (Suquamish data)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of benthic fish		56	52	76
Adult one meal per month of pelagic fish (rockfish)		< 1[c]	< 1[c]	< 1[c]
Adult one meal per month of pelagic fish (shiner surfperch)		15	14	36
Adult one meal per month of crabs		> 470	284	> 470
Adult one meal per month of clams		> 470	> 470	> 470

[a] The RBTC was derived using the food web model parameter set that resulted in the closest match between empirical data and model estimates for all species.

[b] Upper and lower bounds were calculated using estimates from parameter sets that met the FWM performance criterion (i.e., empirical data were within a factor of 2 of FWM-estimated concentrations for all species except clams) (see Appendix C, Section C.4).

[c] Value could not be calculated because contribution from water alone resulted in estimated tissue concentrations greater than the applicable risk level, even in the absence of any contribution from sediment.

API – Asian and Pacific Islander
CT – central tendency
dw – dry weight
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
FWM – food web model

PCBs are also a risk driver for English sole and brown rockfish ecological ROCs. The sediment RBTCs for total PCBs calculated for these two ROCs ranged from 39 to greater than 470 µg/kg dw.

For human health seafood consumption, sediment RBTCs for dioxin and furan TEQ were estimated using site-specific biota-sediment accumulation factors (BSAFs) for four species: English sole, brown rockfish, shiner surfperch and crab. Sediment RBTCs were calculated for each excess cancer risk target (Table ES-11) using BSAFs, tissue RBTCs and site-specific tissue lipid data and sediment total organic carbon (TOC) data.

Table ES-11
Sediment RBTCs for Dioxins and Furans Based on
Excess Cancer Risks and Non-Cancer Hazards in HHRA RME Seafood Consumption Scenarios

Scenario	Risk Level	Sediment RBTC (ng TEQ/kg dw)[a]
Adult tribal RME (Tulalip data)	1×10^{-4}	18
Child tribal RME (Tulalip data)		94
API RME		48
Adult tribal RME (Tulalip data)	1×10^{-5}	1.8
Child tribal RME (Tulalip data)		9.4
API RME		4.8
Adult tribal RME (Tulalip data)	1×10^{-6}	0.18
Child tribal RME (Tulalip data)		0.94
API RME		0.48
Child tribal RME (Tulalip data)	HQ = 1	8.2

[a] The RBTC is the mean of the RBTCs derived using site-specific BSAFs and tissue RBTCs derived for English sole, rockfish, shiner surfperch and clams based on the market basket allocations for these species (Section 8).

API – Asian and Pacific Islander
dw – dry weight
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

Sediment RBTCs were not calculated for cPAHs for the human seafood consumption pathway because the relationship between sediment and tissue for these contaminants could not be adequately determined (Section 8.3).

A sediment RBTC for TBT for the protection of the benthic invertebrate community was calculated based on a regression relationship developed using benthic invertebrate tissue and co-located sediment TBT and TOC concentrations from the EW and the LDW. The sediment RBTC for TBT was 7.5 mg/kg OC, which results in a range of dry-weight sediment concentrations of 75 to 150 µg/kg dw for TOC values from 1% to 2% which are typical TOC

values for EW sediment. Sediment RBTCs for the remaining risk drivers for benthic invertebrates were set at the SQS and CSL from the SMS.

A comparison of sediment RBTCs to background concentrations will be important in risk management decisions made by EPA because cleanup to concentrations below background is not practicable.

ES.8 Pathways and Potential Contaminant Sources and Ongoing Source Control Efforts

Understanding pathways, identifying potential sources of contamination and controlling on-going sources is critical to the long-term success of any remedial action. As such, source characterization and control efforts have been conducted to characterize sources and pathways by which contaminant inputs can reach the EW. The data developed during this work provide the information necessary to support the future evaluation of potential sediment recontamination as part of the FS.

A variety of source control programs operate in and around the EW. These programs include activities of various regulatory agencies and the work of individual EWG members and other parties. Information available from these ongoing source control programs has been compiled and supplemented with other data and evaluations to characterize potential source inputs to the EW.

Sources of contaminants to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the EW through various pathways. These pathways include the following:

- Direct discharge into the EW (e.g., combined sewer overflows [CSOs] and storm drains (SDs), or sheet flow from properties immediately adjacent to the waterway)
- Groundwater migration/discharge
- Bank erosion
- Abrasion and leaching of treated piling structures
- Atmospheric deposition

- Spills and/or leaks to the ground, surface water, or directly into the EW (may be a potential source or pathway)
- Transport of resuspended contaminated sediments

Direct discharges to the EW include discharges from both CSO and stormwater outfalls as well as sheet flow from adjacent properties. CSO discharge volumes and frequencies are routinely monitored by the City of Seattle and King County; however, stormwater discharges are not routinely monitored. Therefore, stormwater discharge volumes have been estimated based on land use and rainfall. Extensive monitoring has been conducted as part of ongoing source tracing efforts to characterize the chemical quality of storm drain and CSO solids discharged to the EW. A number of source control actions have been completed in parallel with the SRI to reduce contaminant inputs to these systems. The King County and City of Seattle CSO control programs continue to reduce overflow events. In addition, the City of Seattle and Port of Seattle stormwater management programs reduce chemical and solids loadings to the stormwater and combined sewer.

The majority of source control samples had contaminant concentrations below screening levels[10] with the exception of bis(2-ethylhexyl) phthalate, which was found to be ubiquitous within a variety of drainage basins. The highest concentrations of PCBs and mercury were found in a few nearshore SDs and a few locations in the Hanford #2 CSO system whereas the highest concentrations of HPAHs were found in S. Lander St SD and one location in Hanford #2 CSO system. Source tracing and control efforts for the highest concentrations of various contaminants (e.g., arsenic, mercury, total PCBs, dioxins/furans and 1,4-dichlorobenzene) have been completed by the City of Seattle, King County, and the Port of Seattle.

Extensive investigation and cleanup activities and monitoring have been conducted at the nearshore cleanup sites located along the EW and are ongoing at several of these sites. Extensive data were used to characterize current groundwater conditions and evaluate this pathway from a source control perspective. These data have been compared to appropriate

[10] There are no regulatory standards for solids collected from catch basins or in the lines of SD or CSO conveyance systems. State and local source control programs typically compare storm drain solids data to the Washington State Sediment Management Standards (SMS) to provide a rough indication of overall quality.

reference values to assess the potential for contaminant concentrations in groundwater to impact EW sediments.

Bank erosion is another pathway by which contaminants could potentially impact EW sediments. Investigations conducted as part of the SRI verified that nearshore banks of the EW generally consist of engineered slopes with armoring that reduces the potential for bank erosion. Abrasion and leaching are pathways by which treated wood pilings can introduce contaminants into the EW. Most pilings and marine structures present in the EW are constructed of alternative materials (e.g., concrete or steel), and ongoing programs exist to reduce the use and presence of treated wood for waterway structures. Some treated wooden structures remain within the EW and represent potential sources of metals and PAHs.

Spills from over-water and nearshore uses can represent a source by which contaminants can be introduced into the EW. Documented spills to the EW have occurred and most have consisted of relatively small releases of petroleum with the exception of one large spill that released metals to EW. A significant spill occurred in 2008 at Industrial Plating Corporation. The spill event occurred due to the rupture of a 50,000-gallon wood stave storage tank containing wastewater and sludge from electroplating operations. Although a large portion of the spill was contained onsite, some of this material, which contained very high concentrations of cadmium, chromium, copper, and zinc, did reach the EW via the S Lander St storm drain system.

Data for some contaminants (e.g., PCBs, metals, and selected SVOCs) are available to characterize the direct atmospheric deposition pathway by which airborne contamination can be deposited into the EW (the indirect atmospheric deposition pathway is considered as part of the direct discharge pathway [i.e., stormwater, CSO, and sheet flow]). The atmospheric deposition data provide information necessary to support predictions of sediment recontamination during development of the FS.

ES.9 Key Observations and Findings

Key observations and findings for the SRI are summarized below.

- Over the past 100 years, the EW has been highly modified from its natural configuration of a river mouth delta to support urban and industrial development.

Changes have included reductions and control of water flow, channel deepening, significant shoreline modifications, fill of shorelines, loss of intertidal habitat, and installation of riprap, pier aprons and sheet pile walls.

- Commercial facilities are the predominant use of the shoreline.
- The EW is currently and expected to continue to be used as a commercial navigational corridor. In addition to commercial activities, the EW supports the collection of seafood by tribal members, who have tribal treaty rights to harvest seafood from EW, as well others such as recreational fishers or individuals collecting seafood to supplement their diet.
- Despite significant habitat alterations and the presence of areas with elevated contaminant concentrations in sediment, the EW contains a diverse assemblage of aquatic species and a robust food web that includes top predators.
- The range of measured rates[11] of sediment deposition in the deeper areas of the EW (the Shallow and Deep Main Body Reaches) for recovered geochronological cores, are between 0.1 and 4.2 cm/yr (based on cesium-137 [Cs-137] and lead-210 [Pb-210] data). The average net sedimentation rates (based on recovered cores) are 1.6 cm/yr and 0.5 cm/yr based on Cs-137 and Pb-210 data, respectively.
- Some geochronological cores had no recovery due to presenese of sands and gravels in the surface sediments at the sample locations; and are assumed to represent a zero net sedimentation rate. These locations included the center of the Junction Reach, adjacent to the western berth in the Shallow Main Body Reach, and adjacent to the berth at T-30 (see Map 3-10). The range of net sedimentation rates for all cores (including those with no recovery) is assumed to be 0 to 4.2 cm/yr.
- While there are areas in the EW that that may not be net depositional (likely due to impacts from propwash), there is uncertainty in the spatial extent of these areas within the EW.
- Portions of the Deep Main Body Reach (from approximately Slip 27 north toward the mouth of the waterway) are likely subject to mixing, episodic erosion and resuspension of bed sediments due to propwash. The remainder of the Deep Main

[11] Measured rates do not include areas where recent dredging activity has occurred.

Body Reach (between Stations 4200 and 4900), the Shallow Main Body Reach, and the Junction Reach may be subject to occasional mixing, erosion or resuspension of surface sediments due to propwash.

- The influence of propwash on contaminant distribution will be examined in the FS.
- Results of the sediment transport modeling completed for the LDW FS and results of PTM modeling of lateral sources within the EW completed for this SRI suggest that 99% of the sediment load into the EW is from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral loads), and less than 0.3% is from lateral loads within the EW itself.
- Sediment concentrations above the SMS were measured throughout the EW. The majority of the contaminant concentrations above CSL values in surface sediment were located in areas within the EW that have not recently been dredged (i.e. the shallow main body, the perimeter of the deep main body and the slips). The locations of the highest total PCB, cPAH, arsenic, mercury, and TBT concentrations were varied.
- Most of the human health risks are associated with PCBs, arsenic, cPAHs, and dioxins and furans.
- The highest risks to people are associated with consumption of fish, crabs, and clams, with lower risks associated with activities that involve direct contact with sediment, such as clamming, and netfishing.
- Based on surface sediment chemistry and sediment toxicity test results, sediment contamination in approximately 40% of the EW (29 ha) is predicted to have no adverse effects on the benthic invertebrate community; approximately 21% (15 ha) is predicted to have minor adverse effects on the benthic invertebrate community, and the remaining 39% of the EW (28 ha) is predicted to have a potential for minor adverse effects on the benthic invertebrate community. Most these predicted effects were due to PCBs and mercury; however, 29 different contaminants have a potential for minor adverse effects in at least one location.
- In addition, potential risks to benthic invertebrates were found from exposures to TBT in two areas within EW.

- There are potential risks to fish from exposures to total PCBs, cadmium, copper, vanadium and TBT and to crab from cadmium, copper and zinc. Unacceptable risks are not expected for aquatic-dependent wildlife based solely on their exposure within EW.
- Puget Sound sediment data and data from other lines of evidence are available for consideration in the derivation of natural and anthropogenic background concentrations in the FS. Comparisons of background concentrations with risk-based goals in sediment (represented by sediment RBTCs) will be used in the FS in the development of preliminary remediation goals and to provide support for risk management decisions by EPA.
- Sediment RBTCs were calculated for risk drivers identified in the ERA (i.e., TBT and PCBs) and in the HHRA (i.e., arsenic and cPAHs for direct sediment exposure; PCBs and dioxins/furans for seafood consumption[12]). SMS criteria (i.e., SQS and CSL) were also used as sediment RBTCs for benthic invertebrates. The following summarize the comparison of RBTCs based on human health exposure scenarios with upstream or background concentrations.
  - PCB RBTCs for the human health seafood consumption scenarios are estimated to be less than natural background (e.g., Puget Sound 2008 Bold Survey) for the 1×10^{-6} and 1×10^{-5} excess cancer risk thresholds and non-cancer risks based on HQ of 1.
  - Dioxin/furan RBTCs for the human health seafood consumption scenarios are estimated to be less than natural background at the 1×10^{-6} excess cancer risk threshold.
  - Arsenic RBTCs for the human health direct contact RME scenarios are estimated to be less than natural background at the 1×10^{-6} excess cancer risk threshold.
  - cPAHs RBTCs for the human health direct contact RME scenarios are above natural background levels but similar to some anthropogenic background data (e.g., urban bays and streams) at the 1×10^{-6} excess cancer risk threshold.

[12] cPAHs were also identified as a risk driver for the seafood consumption RME scenarios, but sediment RBTCs could not be calculated because a clear relationship could not be established between cPAH concentrations in surface sediment and clam tissues.

RBTCs based on the ERA risk drivers are generally higher than those based on the HHRA exposure scenarios (and are higher than background concentrations).

- Tissue RBTCs were calculated for risk drivers for the human health seafood consumption RME scenarios presented in the HHRA (PCBs, dioxins/furans, and cPAHs). Tissue RBTCs represent an ingestion-weighted average based on the dietary assumptions from the HHRA, and thus are not directly comparable to non-urban Puget Sound background concentrations for specific tissue types. However, this initial comparison indicated that tissue RBTCs for the 10^{-6} risk level (and 10^{-5} risk level for some risk drivers) are similar to or lower than non-urban Puget Sound background levels.
- Key pathways and sources of contaminants were identified with potential sources of contaminates being the result of both historical and on-going inputs. Source control data are available for the different pathways to evaluate recontamination potential of sediments in the FS. The evaluation of recontamination potential will inform future source control actions in EW.

1 INTRODUCTION

This document presents the results of the supplemental remedial investigation (SRI) for the East Waterway (EW) Operable Unit (OU) of the Harbor Island Superfund Site. The EW is located in Seattle, Washington, and extends along the east side of Harbor Island (Map 1-1). The EW is one of eight OUs of the Harbor Island Superfund site (Map 1-2) that were added to the US Environmental Protection Agency's (EPA's) National Priorities List in September 1983 under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. Under the oversight of EPA, the SRI/feasibility study (FS) is being conducted by the East Waterway Group (EWG), which consists of the Port of Seattle, the City of Seattle, and King County. The Port of Seattle signed the Administrative Settlement Agreement and Order on Consent and Statement of Work (SOW) in October 2006 (EPA 2006a), and subsequently signed a Memorandum of Agreement with the City of Seattle and King County to conduct the SRI/FS.

This section describes the basis for the EW SRI and provides an overview of the SRI process. As stated in the SOW (EPA 2006a) and SRI/FS work plan (Workplan) (Anchor and Windward 2007), the purpose of the SRI is to collect data to characterize site conditions, determine the nature of the waste (including historical data, chemical fate, sediment transport, and historical and ongoing sources of contamination), and assess risk to human health and the environment. Where appropriate, the methods used in the EW SRI/FS were consistent with those used in the Lower Duwamish Waterway (LDW) remedial investigation (RI)/FS. The SRI/FS will ultimately lead to an EPA Record of Decision (ROD) outlining cleanup actions to address threats to human health and the environment in the EW. For purposes of the SRI/FS, the EWG will be referenced as the entity managing the project under EPA oversight.

1.1 East Waterway Study Boundaries

The EW OU study boundaries were established in conjunction with EPA and are shown on Map 1-1. The southern EW OU study boundary is also the northern study area boundary of the LDW Superfund Site. The northern EW OU study boundary extends along the western pierhead line to the north until water depths reach -60 ft mean lower low water (MLLW). The study boundary follows the approximate upper edge of this naturally occurring slope at about -60 ft MLLW, then turns to perpendicularly intersect the bulkhead along Terminal 46

(T-46) along the eastern shoreline. These EW OU study boundaries are being utilized during the SRI/FS process. The EW ROD will ultimately establish the cleanup boundary for the site.

1.2 East Waterway Supplemental Remedial Investigation Overview

The ordered work is identified as a "supplemental" RI because an initial RI was developed in 1993 (Weston 1993b), with additional investigation work summarized in 2003 (Windward 2003a, b). The SOW (EPA 2006a) and Workplan (Anchor and Windward 2007) required development of an existing information summary report (EISR) (Anchor and Windward 2008a), which summarizes available environmental and other appropriate data collected in the EW since 1995. Based on the information in the EISR, a conceptual site model (CSM) and data gaps analysis report (Anchor et al. 2008b) was prepared to present an integrated overview of the physical, ecological, and human health conceptual models for the EW, and to facilitate the identification of data needs for the SRI/FS.

Detailed studies to fill identified data gaps for sediment, water, and tissue, as well as potential site uses, were presented to EPA in separate quality assurance project plans (QAPPs). Additional surveys, sampling, and testing were conducted as part of the SRI as follows:

- Tissue studies
  - Clam surveys and tissue sampling and chemical analyses (Windward 2008g, 2009a)
  - Sediment profile imaging (SPI) and benthic invertebrate community tissue sampling, including co-located sediment sampling, and chemical analyses (Windward 2008f)
  - Fish and shellfish tissue sampling and chemical analyses (Windward 2008h)
  - Juvenile Chinook salmon tissue sampling and chemical analyses (Windward 2009i)

- Sediment studies
  - Surface sediment sampling, chemical analysis, and toxicity testing (Windward 2009h, j)
  - Subsurface sediment sampling and chemical analyses and geotechnical testing (Windward 2010i)

- Surface water sampling and chemical analyses (Windward 2009k)
- Porewater sampling and chemical analyses (Windward 2010h)
- Survey to assess potential human use of the EW shoreline (Windward 2008e)
- Sampling and testing to support evaluation of hydrodynamic and sediment transport modeling, including bathymetry, current and salinity measurements, geochronological core sampling and testing, and Sedflume testing (Anchor and Battelle 2009)

This SRI report includes the results of acceptable post-1995 historical data and each of the SRI/FS investigations, as summarized in data reports that were prepared for each field sampling event. EPA-approved data reports are listed below:

- *East Waterway Human Access Survey Report* (Windward 2008a)
- *Final Data Report: Benthic Invertebrate Tissue and Co-located Sediment Samples, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2009d)
- *Final Surface Water Data Report, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2009e)
- *Data Report: Clam Survey, Geoduck Survey, Fish and Shellfish Tissue Collection PCB Congener and Dioxin/Furan Results, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2010a)
- *Data Report: Clam Surveys and Sampling of Clam Tissue and Sediment, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2010b)
- *Data Report: Fish and Shellfish Tissue Collection, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2010c)
- *Data Report: Juvenile Chinook Salmon Tissue Collection, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2010d)
- *Data Report: Surface Sediment Sampling for Chemical Analyses and Toxicity Testing, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2010f)
- *Data Report: Results of Dioxin and Furan Analyses of Archived Surface and Subsurface Sediment Samples, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2011)

- *Data Report: Subsurface Sediment Sampling for Chemical Analysis and Toxicity Testing, East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Windward 2010e)
- *Sediment Transport Evaluation Report*, *East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study* (Anchor QEA and Coast & Harbor Engineering 2012), hereafter referred to as the sediment transport evaluation report (STER)

1.3 Document Organization

The SRI report is organized as follows:

- Section 1 – Introduction
- Section 2 – Environmental Setting
- Section 3 – Physical Processes Conceptual Site Model
- Section 4 – Nature and Extent of Contamination
- Section 5 – Summary of the Baseline Ecological Risk Assessment
- Section 6 – Summary of the Baseline Human Health Risk Assessment
- Section 7 – Preliminary Background Concentrations of Risk Driver Chemicals
- Section 8 – Risk-Based Threshold Concentrations
- Section 9 – Potential Pathways, Source Identification, and Source Control Efforts
- Section 10 – Key Findings
- Section 11 – References

These sections are supported by the following appendices:

- Appendix A – Ecological Risk Assessment
- Appendix B – Human Health Risk Assessment
- Appendix C – Food Web Model and Dioxin BSAF
- Appendix D – Data Management and Interpolation Parameters
- Appendix E – Spill Documentation
- Appendix F – Ongoing Source Tracing and Source Control Activities
- Appendix G – Listed Properties Documentation
- Appendix H – CSO Supporting Documentation
- Appendix I – Stormwater Supporting Documentation
- Appendix J – Groundwater Data Summary Tables

- Appendix K – Compiled Source Control Maps
- Appendix L – Inspections

Section 2 describes the EW and its history, land and human use, and environmental setting, including physical characteristics, meteorology, geology, hydrogeology, surface water hydrology, ecological habitats, and biological resources.

Section 3 provides a description of the Physical Processes CSM based on field investigations and numerical modeling that were conducted to evaluate and characterize sediment transport physical processes in the EW. The sediment transport evaluation approach memorandum (Anchor et al. 2008a) presented various modeling approaches to evaluate hydrodynamics and sediment transport physical processes with respect to solids transport and to identify data needs necessary to evaluate sediment transport processes in the EW. The results of field investigations and modeling evaluations were presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012).

Section 4 presents a summary of the nature and extent of contamination based on the EPA-approved data reports and acceptable historical data. The nature and extent of contamination in various media (e.g., sediment, tissue, and water) are discussed and presented in associated maps. The EW baseline ecological risk assessment (ERA) (Appendix A) and baseline human health risk assessment (HHRA) (Appendix B) have been developed using the data included in this SRI report and are summarized in Sections 5 and 6, respectively.

Relevant background datasets for sediment and tissue are summarized in Section 7. Risk-based threshold concentrations (RBTCs) are developed in Section 8 for tissue and sediment for contaminants of concern (COCs) identified as risk drivers in the ERA and HHRA.

Additional evaluations were also conducted to assess potential sources of contamination to the EW. The source control evaluation approach memorandum (SCEAM) (Anchor and Windward 2008b) was developed to describe the scope of the source control evaluation, including technical and programmatic assumptions, participating and cooperating parties, and how source control-related programs and data implemented by those parties are integrated into the SRI/FS. The initial source evaluation and data gaps memorandum

(SEDGM) (Anchor QEA and Windward 2009) reviewed existing data and identified additional source-related data to be collected to support the SRI/FS. Section 9 presents the sources and pathways of contamination. Finally, the key observations and findings of this SRI report are presented in Section 10.

- Tissue RBTCs were calculated for risk drivers for the human health seafood consumption RME scenarios presented in the HHRA (PCBs, dioxins/furans, and cPAHs). Tissue RBTCs represent an ingestion-weighted average based on the dietary assumptions from the HHRA, and thus are not directly comparable to non-urban Puget Sound background concentrations for specific tissue types. However, this initial comparison indicated that RBTCs for the 10^{-6} risk level (and 10^{-5} risk level for some risk drivers) are similar to or lower than non-urban Puget Sound background levels.
- Key pathways and potential sources of contaminants were identified with potential sources of contaminates being the result of both historic and on-going inputs. Source control data are available for the different pathways to evaluate recontamination potential of sediment in the FS. The evaluation of recontamination potential will inform future source control actions in EW.

2 ENVIRONMENTAL SETTING

This section describes the EW and its history, land and human use, and environmental setting, including physical characteristics, meteorology, geology, hydrogeology, surface water hydrology, ecological habitats, and biological resources.

2.1 Site Description

The EW is located approximately 1 mile southwest of downtown Seattle, in King County, Washington (Map 2-1). It is part of the greater Duwamish River estuary, which includes the fresh water/saltwater interface extending as far as 10 miles upstream from the mouth of the Duwamish River at Elliott Bay. The EW is primarily used for shipping and as a cargo transport terminus. Detailed descriptions of EW use are provided in Section 2.9.

The Duwamish River drains approximately 362,000 ac of the Green/Duwamish watershed, flowing northward to its terminus in Puget Sound at Elliott Bay (see Section 2.7 for additional details on the Green/Duwamish River watershed). Near the mouth of the river, it splits into the EW and the West Waterway (WW), surrounding Harbor Island. The EW and WW extend from the southern end of Harbor Island to the island's northern end at Elliott Bay. The EW runs along the eastern shore of Harbor Island. The EW OU of the Harbor Island site is located immediately downstream from, and adjacent to, the LDW Superfund Site. The northern and southern study area boundaries for the EW OU are shown in Map 2-1. The east and west boundaries of the EW OU are defined by mean higher high water (MHHW) (Map 2-1).

The EW OU is approximately 8,250 ft long and for most of its length is 750 ft wide. It is channelized and has a south-to-north orientation. Map 2-1 provides an aerial photograph of the site. The Port of Seattle uses a measurement system along the length of the Terminal 18 (T-18) berth face, comprised of "stationing" or "station markers." The system is measured in feet from the northern end of Harbor Island (Station 0) to near the southern end of the EW (Station 7700) and is used by the Port of Seattle to define the extents of the berths. The station markers are shown on Map 2-2 and referenced throughout this SRI report.

Two slips are present along the eastern side of the EW. Slip 36 is oriented in an east/west direction and located from approximately Stations -100 to 200. Slip 27 is oriented in a northwest/southeast direction and located from approximately Stations 3800 to 4600. A

shallow area off the northwest corner of Terminal 25 (T-25) and adjacent to Slip 27 is referred to as the "Mound Area" (Map 2-2).

For the purposes of the SRI, three reaches have been identified in the EW, including the Junction Reach (Station 7200 to 7650), Sill Reach (Station 6800 to 7200), and Main Body Reach (Station 0 to 6800; Map 2-2). The Main Body Reach has been further subdivided into two sections: the Deep Main Body Reach (Station 0 to 4950). Six dredging events since 2000[13] have occurred in different parts of Main Body Reach by the Port or US Army Corps of Engineers (USACE). Three of these events were conducted to deepen the navigation channel to -51 ft MLLW, and three events were conducted to maintain a sediment elevation of -51 ft MLLW. The Shallow Main Body Reach (Station 4950 to 6800), which is shallower, located south of the Deep Main Body Reach, and is characterized by fewer historical maintenance dredging activities. Bathymetry and recent EW dredge history are discussed in Sections 2.3.1 and 2.3.2, respectively. The Junction and Sill Reaches are frequently discussed in combination in this report, and are sometimes referred to as the Junction/Sill Reach. Each reach has different physical characteristics, which are discussed in detail in Section 3.2.

2.2 Site History

Industrial development[14] of the EW began immediately following the dredging and filling of the former Duwamish River channel and surrounding Elliott Bay tidelands. Prior to filling, the Elliott Bay tidelands extended east of the site to the current location of Interstate 5 (I-5). Map 2-3 depicts the approximate extent of the tidelands adjacent to the EW and tidelands associated with the historical meanders of the Lower Duwamish River in 1909. Dredging and filling from 1903 to 1905 created the EW, which provided fill material for construction of the upland areas to the west and east (EPA 1993b). By 1909, Harbor Island and the land east of the EW was created using dredge fill removed from the Duwamish River estuary or sluiced from Seattle regrade projects (EPA 1993b). At this time, the extent of Harbor Island was approximately 350 ac and included 5 to 15 ft of placed fill. Upstream of Harbor Island,

[13] Dredge events to -51 ft MLLW include the Stage 1 navigation channel dredging, Phase 1 Removal Action dredging, T-46 berth maintenance dredging, T-30 berth deepening dredging, and two maintenance dredge events along T-18, as described in Section 2.3.2.

[14] Discussions regarding historical land use are provided in Section 9.

the Duwamish River was straightened and deepened starting in 1913 to allow navigation of ocean-going vessels upriver of Elliott Bay (HistoryLink 2001).

With the construction of Harbor Island, further development of the EW occurred. Map 2-4 provides snapshots of the sequence of development of the EW and adjacent upland areas from 1899 to 2009. The EW was initially dredged to a minimum navigable depth of -30 to -40 ft MLLW and widened to 750 ft. Based on historical USACE maps, a turning basin was created along the eastern part of the south end of the EW between approximately Stations 5200 to 6100 (Map 2-5). The turning basin was dredged from -30 to -40 ft MLLW to -54 ft MLLW in 1918 to correspond with the deeper elevations maintained in the Main Body Reach at that time. The turning basin was filled in 1972 and no longer exists. In addition to the turning basin, two slips were dredged along the eastern shore to -28 ft MLLW (currently Slip 27) and -30 ft MLLW (formerly Slip 30; Map 2-5). Slip 30 was filled in 1981 and no longer exists (Map 2-5).

By 1919, the EW, WW, and LDW were authorized as federal navigation channels by Congress (March 2, 1919). The EW was maintained at -40 ft MLLW along most of the 750-ft-wide portion in the mid-1920s. Slip 36 was constructed in 1927 and originally dredged to -35 ft MLLW. That same year, the Port of Seattle first converted areas to container use on portions of T-18 and along T-25. Additional areas were converted to container use in the 1980s, including areas along T-18 and Terminal 30 (T-30).

The federal navigation channel in the EW currently extends from Station 0 to the Spokane Street Bridge, which is approximately Station 6840. The federal navigation channel is 450 ft wide from Stations 0 to 4950. It is 700 ft wide from Stations 4950 to 6140 and 400 ft wide from Stations 6140 to the Spokane Street Bridge (Station 6840). The full federal navigation channel width is authorized to -51 ft MLLW from Stations 0 to 2970 (450 ft wide). It is also authorized to -51 ft MLLW along the western 250 ft from Stations 2970 to 3250 and the western 170 ft from Stations 3250 to 3590. The federal navigation channel is authorized to -34 ft MLLW south of Station 2970. This -34 ft MLLW section is 200 ft wide from Stations 2970 to 3250, 280 ft wide from Stations 3250 to 3590, and 450 ft wide from Stations 3590 to 4950. South of Station 4950, it is authorized to -34 ft MLLW to the Spokane Street Bridge. Most of the area between Stations 4950 to 6200 is currently deeper than -34 ft MLLW and is not anticipated to require maintenance dredging in the near future. Nearly all of the area

south of Station 6200 is shallower than -34 ft MLLW. Authorized depths have not been maintained south of Station 6200, and there are currently no plans to conduct maintenance dredging in this area in the near future. The federal navigation channel information presented here is based on information in the Water Resources Development Act, as summarized in the Port of Seattle Series No. 36 (USACE 2002).

2.3 Physical Characteristics

The EW is a straight channel oriented in a north-south direction. In cross section, the EW is characterized as relatively flat in the center of the channel with steep side slopes armored with riprap (EVS 1996a). In longitudinal profile, the main channel bed elevation generally slopes downward toward the north and the entrance to Elliott Bay, while the bed elevation rises toward the southern end especially in the vicinity of the Sill at the Spokane Street corridor. Current bathymetry and dredge history are described in detail below.

2.3.1 Bathymetry

The Main Body Reach of the EW is 750 ft wide; the federal navigation channel is 450 ft wide north of Station 3015 and 500 ft wide from Stations 3015 to 5715. The most recent bathymetric survey within the EW was completed in January 2010 and is presented in Maps 2-6a and 2-6b (Anchor QEA 2011). Cross sections depicting representative portions of each reach and slip are presented on Maps 2-7a through 2-7d. Current bathymetry within the federal navigation channel shows that the authorized elevation of -51 ft MLLW is met from Station 0 (i.e., mouth of the EW) to Station 4950 (i.e., 4,950 ft upstream of the mouth of the EW), with the exception of the "Mound Area." Some areas within the northern portion of the federal channel reach -60 ft MLLW. Bathymetry in areas north of the northern EW OU study boundary (i.e., within Elliott Bay) quickly become much deeper than -60 ft MLLW, reaching elevations deeper than -200 ft MLLW. Along T-18, elevations south of Station 4950 generally decrease to -37 ft MLLW. Along T-25 (Stations 4600 to 6150), elevations in the berth area are approximately -50 ft MLLW.

Mudline elevations rise to between -13 and -6 ft MLLW in the Sill Reach, in the vicinity of Spokane Street and the West Seattle Bridge (DEA 2010), and then drop to -25 ft MLLW through the Junction Reach. Sediments comprising the Sill Reach under and between the bridges within the Spokane Street corridor have never been dredged following original construction, based on historical records from USACE. The shallow water depths in this area

form a physical constriction across the entry to the EW that can affect flow from the Duwamish River primarily during higher flow events (see Section 2.7.2).

Current Port of Seattle operational berthing elevation requirements vary based on location in the EW. Along T-18 between Station 0 through 4950, the berthing elevation requirement is -51 ft MLLW (Anchor QEA 2011). Along T-25 and T-30, berthing elevation requirements are -50 ft MLLW. The Port of Seattle's requirement for berthing in Slip 27 is generally -40 ft MLLW. In Slip 36, US Coast Guard (USCG) berthing requirements are generally -40 ft MLLW. Dredging activities conducted since 2000 to maintain required navigation and berthing elevations are shown on Map 2-8 and are discussed in Section 2.3.2.

2.3.2 Dredging History

Portions of the EW have been dredged multiple times since its original construction in the early 1900s. Dredging in the EW has been conducted to maintain and deepen existing berths and to deepen part of the federal navigation channel to -51 ft MLLW. Recent dredge events are summarized below and illustrated in Map 2-8 for events occurring from 2000 to 2009 (Anchor QEA 2011):

- Stage 1 navigation channel dredging (December 1999 to February 2000) to -51 ft MLLW from the north end of the EW to Station 4950.
- T-30 berth dredging (January 2002 to February 2002) to -44 ft MLLW (Station 1400 to 2900).
- Phase 1 Removal Action dredging (January 2004 to February 2005) to -51 ft MLLW (Station 3000 to 4950). Contingency dredging occurred to -52 to -53 ft MLLW over most of the dredge footprint, which was followed by placement of sand cover material with a minimum thickness of 6 in. The sand layer thickness measured after placement ranged from 6 in. to more than 1 ft and averaged 10 in. (Anchor and Windward 2005).
- Slip 36 dredging (August 2004 to February 2005) to -40 ft MLLW.
- T-46 berth maintenance dredging (January and February 2005) to -51 ft MLLW (Station -200 to -700).
- T-30 berth dredging (January 2008 to February 2009) to -51 ft MLLW (Station 1700 to 3500).

- T-18 berth dredging in Berths 2 through 5 (January 2005 to November 2006) to -51 ft MLLW (Station 1500 to 4950).
- T-18 minor berth maintenance dredging (January and February 2009) to -51 ft MLLW with less than 1,000 cubic yards (cy) removed (Station 500 to 4900).

Dredge records for events conducted prior to 2000 are limited and exact dimensions are not always known. Based on available data, these older dredging events included:

- T-25 (1970s) berth dredging to -50 ft MLLW up to the federal channel boundary.
- T-25 (1981) keyway dredging[15] to -55 ft MLLW from Stations 4250 to 6100. This event included dredging a narrow keyway along the face of Berth 25 for construction of the T-25 riprap slope. The keyway was backfilled with riprap to approximately -50 ft MLLW. The outer edge of the excavation would likely have been less than 25 ft from the face of the pier. The keyway width was 5 ft and the outer edge sloped from -55 ft MLLW (toe of keyway) to approximately -45 ft MLLW.
- T-30 (1980s) keyway dredging to -55 ft MLLW from Stations 1600 to 3600 before being backfilled with riprap. This keyway dredging was similar to the T-25 keyway dredging described above.

In addition, various portions of the federal navigation channel have been dredged, as needed, at least 13 times since 1960 based on comparison of historic bathymetric surveys in the 1960s and 1970s and known and available dredge records for vessel navigation since the 1980s. However, additional dredge events may have occurred that were not captured in these records.

2.4 Meteorology

The climate in the EW vicinity is characterized as "Pacific marine," typical of the Puget Sound area (WRCC 2011). The prevailing winds move moist air inland from the Pacific Ocean, moderating winter and summer temperatures (WRCC 2011). Winds in the EW are typically from the northerly or southerly direction (i.e., along rather than across the EW), and wave periods are limited by the fetch across Elliott Bay and in the EW.

[15] Keyway dredging is conducted to create a narrow (e.g., 10 to 20 ft) trench along the toe of the underpier riprap slope that is deeper that the berth area dredge depth in order to stabilize the slope.

Winters tend to be mild and wet, and summers are usually dry. Seventy-five percent of the annual precipitation falls from October through March (WRCC 2011). Annual precipitation ranges between 23.8 and 55.1 in. measured at Sea-Tac International Airport between 1931 and 2007 (WRCC 2011). Mean annual precipitation for the same period is 38.2 in. (WRCC 2011). Monthly average winter temperatures range from 2 to 8 °C (36 to 46 °F) (WRCC 2011). Monthly average summer temperatures range from 12 to 23 °C (53 to 73 °F) (WRCC 2011).

2.5 Geology

This subsection provides an overview of regional geological characteristics and a detailed summary of EW sediment stratigraphy, physical characteristics, and lithology. The discussion of geology is focused on relevant geologic properties that influence groundwater flow paths to the EW. Groundwater is discussed in detail in Section 2.6.

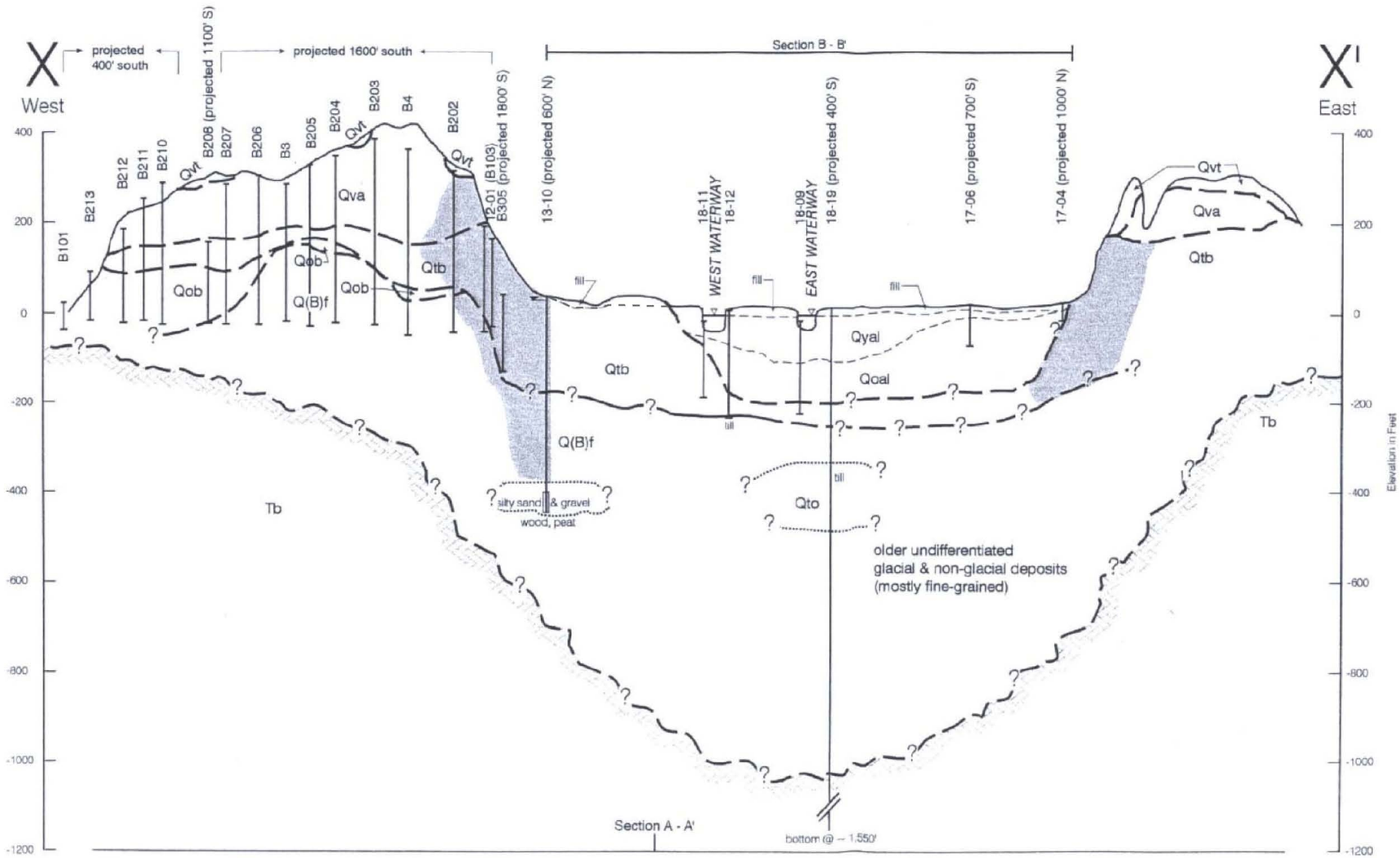
2.5.1 Regional Geology

The EW is a channelized portion of the Duwamish River delta. It is located at the north end of the Greater Duwamish Valley, and rests in a north-south trending, glacially scoured trough bounded by glacial drift uplands deposited during repeated Pleistocene glaciations (approximately 15,000 years ago). The trough contains post-glacial alluvium up to 200 ft thick (Weston 1993b) and includes the waters of the Duwamish River, the EW, and WW. The trough is bounded by upland plateau regions composed of thick sequences of Pleistocene glacial deposits. Map 2-9 presents the surface geology of the lower portion of the Duwamish Valley and provides definitions of the surficial geologic units. Geologic units presented were defined by the US Geological Survey (USGS) and revised to correspond with nomenclature described by Booth and Herman (1998). The stratigraphy of the EW is described in detail below.

2.5.1.1 Regional Stratigraphy

Three principal geologic assemblages within the Greater Duwamish Valley have been recognized to influence the hydrogeologic system. These assemblages have been described in detail in the LDW RI (Windward 2010g) and are discussed below. The assemblages include bedrock, glacial and non-glacial sedimentary deposits, and Duwamish Valley alluvial deposits, which include the channel fill deposits resulting from dredging activities of the

Duwamish River. These geologic assemblages are summarized in the subsections below from oldest to youngest with specific information provided for the EW regional area. Figure 2-1 presents two schematic cross sections (X-X' and B-B') of the regional stratigraphy of the EW and adjacent uplands as seen from the southern end of Harbor Island. The cross section locations are identified on Map 2-9.



Geologic Nomenclature	Definition
Q(A)c	coarse-grained deposits, presumably immediately underlying Olympia -age (approximately 17,000 to 40,000 years ago) deposits (correlation is speculative)
Q(B)c	coarse-grained deposits, immediately underlying unit Q(B)f
Q(B)f	fine-grained deposits, immediately underlying the Q(A)c unit; speculative correlation w ould imply an age of at least 100,000 years old
Q(C)f	older undifferentiated, unconsolidated fine-grained sediment
Qoal	older alluvium
Qob	Olympia beds
Qtb	transitional beds, formed as the ice first advanced and laminated silt and clay w ere deposited; unit is a regionally significant aquitard, allow ing very little movement of groundw ater
Qva	coarser outw ash, deposited by streams derived from the advancing ice-sheet, initiated by the Vashon Advance Outw ash (approximately 15,000 years ago); primary shallow aquifer in the upland areas throughout the region
Qvt	lodgment till, deposited by the melt-out of debris at the base of the glacier; composed of heterogeneous, compact sediment (glacial deposit)
Qyal	younger alluvium

Notes: 1. Cross section and unit descriptions are from Booth and Herman (1998).
2. For plan view of cross section location see Map 2-9.
? = estimated boundary

Figure 2-1

Cross Section of East Waterway Stratigraphy at Southern End of Harbor Island

2.5.1.1.1 Bedrock

Bedrock in the Greater Duwamish Valley is Tertiary in age and provides the lower boundary of the aquifer system, restricting groundwater flow in the basin. Three main units are recognized in the Duwamish Basin and include a lower assemblage of volcanic sedimentary rocks, known as the Tukwila Formation (Tpt); an upper unit of arkosic sedimentary rocks, known as the Renton Formation (Tpr); and the younger Blakely Formation (Tb), which overlies these units and is found in the vicinity of the study area. The Blakely Formation ranges from 50 ft to approximately 1,000 ft below ground surface (bgs) and is composed of marine sandstone, conglomerate, and siltstone (Figure 2-1). Bedrock units throughout the Duwamish valley range from impervious to relatively impervious (Booth and Herman 1998). These bedrock units provide the base for the hydrogeologic system.

2.5.1.1.2 Glacial and Non-glacial Sedimentary Deposits

The EW is bounded by upland plateau regions to the east (i.e., Beacon Hill) and west (i.e., West Seattle). These plateaus contain thick sequences of Pleistocene-aged glacial and intervening non-glacial sedimentary units and consist of complex sequence of interbedded and unconsolidated deposits including glaciolacustrine deposits, glaciomarine deposits, glacial till, and outwash deposits (Figure 2-1) (Booth and Herman 1998).

Evidence of at least five major Pleistocene glacial ice advances have been identified in the sediments deposited in the Puget Sound Basin (Armstrong et al. 1965). The most recent ice-sheet advance into Western Washington was the Vashon Stade (period) of the Fraser glaciation, approximately 15,000 years ago (Armstrong et al. 1965; Easterbrook 1994). The Vashon deposits make up the current land surface and have been mapped to a maximum depth of 5,000 ft in the Puget Lowland. Sediment deposited during this time period varies in textural composition as a result of the rapidly changing environment caused by the advance and retreat of the ice sheet. These units include Transitional Beds (Qtb), Vashon Advance Outwash (Qva), Vashon Till (Qvt), and Vashon Recessional Outwash (Qvr).

Transitional Beds (Qtb) were formed as the ice first advanced in the Puget Lowlands and consist of laminated silt and clay deposits (e.g., Lawton Clay), which form a significant aquitard, restricting groundwater movement. Vashon Advance Outwash (Qva) deposits mark the initiation of the Vashon Stade and consist of very dense glacially consolidated sand with gravel, cobbles, and boulders and some laminated silts. The Vashon Till (Qvt) (i.e., Lodgment

Till) unit overlies the outwash deposits and was deposited by glacial melt at the base of the glacier. Vashon Till (Qvt) deposits compose the primary shallow aquifer throughout the region. Deposits consist of gravelly silty to very silty sand and may contain lenses of sand, gravel, and silt with scattered pebble- to cobble-sized material. Recessional outwash was deposited as the ice sheet withdrew to the north and is composed of gravel and sand that was deposited along the flanks of the plateaus to the west of the study area (Booth and Herman 1998).

Older glacial and inter-glacial sedimentary units within the Duwamish valley underlie the Pleistocene deposits and were formed from overlapping geologic phenomena including glacial advance and volcanic eruptions from Mount Rainier. Units range from well-consolidated coarse- and fine-grained deposits (Q(A)c to Q(B)f and c) to undifferentiated, unconsolidated fine-grained deposits (Q(C)f) (Booth and Herman 1998). These deposits provide a lower geologic boundary to overlying glacial and alluvial deposits, as well as a potential hydraulic pathway for the flow of upland groundwater to Duwamish valley alluvial sediments (Windward 2010g).

2.5.1.2 Duwamish Valley Alluvial and Channel Fill Deposits

Post-Pleistocene alluvial, deltaic, and estuarine deposits overlie the Vashon Stade sediments in much of the south Seattle industrial area (Galster and Laprade 1991). Near-surface alluvium was deposited within the glacially scoured trough and typically includes older sequences of estuarine deposits (fine sand and silt with occasional shell fragments) overlain by younger, complexly interbedded fluvial and deltaic deposits (sand, silt, and gravel). The older alluvium (Qoal) is characterized by estuarine deposits composed of silts and clays with sandy interbeds (USGS 2005). This unit typically occurs at depths of 150 to 180 bgs and largely consists of silt and clay in the vicinity of the EW (Windward 2010g). The younger alluvium (Qyal) rests above the older alluvium and serves as the base of the EW channel. The younger alluvium is primarily composed of fluvially deposited silt, sand, gravel, and cobbles (USGS 2005). These deposits are found at depths extending to approximately 100 ft bgs in the EW. These deposits consist of laminated silts, sands, and clays associated with interbedded and prograding deltaic deposits.

Channel fill materials are present above the alluvial deposits. These fill materials were deposited on either side of the EW from 1904 to 1909, when the Duwamish River was deepened and straightened and Harbor Island was created (refer to Section 2.2). Deposits consist of dredged material from the Duwamish River and EW channels or sluiced from nearby upland areas. The composition of the channel fill materials is primarily sand and silty sand, and is similar in hydraulic conductivity to the younger alluvium (Qyal). The depth of channel fill varies in thickness from 3 to approximately 35 ft in the upland areas adjacent to the EW (Windward 2010g).

The alluvial and channel fill deposits support the shallow aquifer of the EW region and serve as the primary hydraulic pathway for the flow of groundwater to the EW. A detailed discussion of groundwater is provided in Section 2.6.

2.5.2 East Waterway Sediment Characteristics

Sediment stratigraphy, lithology, and physical characteristics have been assessed based on the EW SRI sediment dataset (refer to Section 4.1 for a detailed discussion of the evaluation and selection of studies included within this dataset). Sediment lithology, stratigraphy, and detailed sediment descriptions were documented in core logs and presented in the EW SRI subsurface sediment data report (Windward 2010e). EW sediment stratigraphy has been further characterized beyond the regional assemblages presented in Section 2.5.1 and is not meant to correlate directly with the designations of Quaternary alluvium (e.g., Qoal, Qyal) and channel fill.

2.5.2.1 East Waterway Sediment Stratigraphy

Sediment was grouped into three stratigraphic units identified for the EW based on multiple lines of evidence, but primarily on density, color, sediment type, texture, and fill horizons (e.g., sand cover). Other information used to delineate these units included presence of anthropogenic or engineered materials, bathymetry, proximity to shoreline, and dredge events. The three units are comparable to the stratigraphy identified in the LDW RI, but differ slightly in composition based on the deltaic setting of the EW (Windward 2010g). EW sediment typically includes softer, recent sediments (i.e., silt) overlying alluvial, deltaic sediments. These, in turn, overlie deeper alluvial, deltaic deposits associated with early and pre-industrial time periods. In some areas, dredging and site use have altered the depths at which these units outcrop compared to initial deposition. For example, the deeper alluvial,

deltaic deposits outcrop at the surface in several cores collected from the Deep Main Body Reach.[16]

The primary stratigraphic units are described in detail below, from top (i.e., mudline) to bottom of core.

- **Recent** –This upper unit consisted of recently deposited material dominated by unconsolidated organic silt and inorganic silt. The surface fraction of silt often contained fine sand and gravel. This material was characterized by higher moisture content, soft to medium stiff density, smooth and homogenous texture, and higher visible organic matter compared with the underlying materials. Shell fragments, decomposed wood, and anthropogenic materials were often present scattered throughout the unit (rather than in distinct layers as is common in lower units). A hydrogen sulfide odor was common. The Recent unit was encountered in subsurface cores between 0 and 10 ft below mudline.
- **Upper Alluvium/Transition**[17] – This middle unit formed a transitional bed between Recent and Lower Alluvium units. The Upper Alluvium unit had characteristics that were often a mix of the units lying above and below it. It consisted of a mixture of silty sand and sandy silt matrices with a higher density and a higher percentage of sand compared with the Recent unit. Within this matrix, stratified beds composed of silty sand or silt were present, as well as lenses (pockets) of silt. Organic silt, layers of decomposed wood, and shell fragments were often present. Some multicolored sand grains (e.g., red, beige, black, white, and gray) were located within the units. The Upper Alluvium unit was encountered in subsurface cores between 0 and 9 ft below mudline.
- **Lower Alluvium**[18] – This basal unit was predominantly a sand matrix with laminated and stratified beds of slightly silty to silty sand, and silt. The sand matrix consisted of

[16] The Lower Alluvium was observed at the surface in EW SRI subsurface cores SC37, SC44, SC45, and SC56.

[17] The term Upper Alluvium is synonymous with the term Transition used in the subsurface sediment data report (Windward 2010d).

[18] The term Lower Alluvium is synonymous with the term Native used in the subsurface sediment data report (Windward 2010d).

multicolored grains of red, beige, black, white, and gray. Layers of un-decomposed wood and shells were often present in the matrix. The Lower Alluvium sand unit typically graded to stiff, inorganic silt as depth increased. This unit was encountered between 0 and 13 ft below mudline.

In addition to the primary stratigraphic units, three veneers overlie the existing sediment stratigraphy in discrete locations. These veneers are described below.

- **Engineered Fill** – This layer was present in cores located in close proximity to the shoreline. The composition of Engineered Fill was dominated by light to dark gray, subrounded, gravelly sand and sandy gravel. Gravel and cobbles were up to 3 in. in diameter. Engineered Fill has been designated based on proximity to known developmental activities associated with slope and keyway armoring activities.
- **Anthropogenic Fill** – This layer was present in cores located in close proximity to the shoreline. The composition of Anthropogenic Fill is gray to black, subrounded gravelly sand to coarse gravel. Anthropogenic Fill has been designated where no known development activities have occurred on the slope.
- **Sand Cover –** The sand cover was placed between Stations 3000 to 4900 during the Phase 1 removal, which was completed in 2005 (Anchor and Windward 2005). The extent of this boundary is shown in Map 2-8. Sand cover is present within the top 1 ft of cores collected from this area. The sand cover is primarily very fine to very coarse-grained brown sand that was distinctly different in appearance from other strata within the EW as a result of color and sorting.

Additional discussion of sediment stratigraphy in relation to sediment chemical concentrations is provided in Section 4.2.

2.5.2.2 East Waterway Sediment Physical Characteristics

The sediment physical characteristics quantified in the EW include grain size, total organic carbon (TOC), and total solids, and are described below based on distribution in surface sediment (0-to-10-cm depth) and subsurface sediment (greater than 10-cm depth). The spatial distribution of surface sediment percent fines (silt and clay fractions), TOC, and total solids content is provided in Maps 2-10 through 2-12, respectively.

2.5.2.2.1 Surface Sediment

Surface sediment consisted primarily of silty sands and sandy silts. Sand fractions ranged from 8.1 to 94.7% with a mean concentration of 50%; fines (silt and clay) fractions ranged from 0.8 to 92% with a mean concentration of 40%. The majority of the samples (93.3%) contained various amounts of gravel ranging from 0.01 to 68.1%, with a mean concentration of 8%. Spatially, the Deep Main Body Reach contained lower portions of fines (less than 60% fines) (Map 2-10), with the exception of a few areas between Stations 2000 to 3400 with higher percent fines (greater than 60% fines). Higher fines percentages tended to occur within the Shallow Main Body Reach, at the eastern end of Slip 36, and the northern portion of Slip 27 and vicinity. The fines content of surface sediment was low in the Junction/Sill Reach with the exception of one data point containing higher fines in the vicinity of the West Seattle Bridge.

TOC values throughout the EW ranged from 0.14 to 10.1% with a mean value of 1.6%. The spatial distribution of higher TOC generally corresponds with areas exhibiting higher percent fines content. The TOC content in surface sediments of the Deep Main Body Reach was generally less than 2%, with isolated patches of higher TOC percentages (greater than 2%; Map 2-11). High TOC percentages occurred at the head of Slip 36, within Slip 27, in the Mound Area, and within the majority of the Shallow Main Body Reach. The Junction/Sill Reach exhibited low TOC content with the exception of the area underlying the Spokane Street corridor and the shoreline areas just north of the corridor.

The total solids content in surface sediments can indicate the liquid or flocculent nature of sediment. Fines, such as clay and silt, tend to contain a larger fraction of water (i.e., lower total solids) than do coarser materials like sand and gravel and lower total solids content in fines tends to indicate more flocculent, less cohesive sediments. Total solids concentrations throughout the EW ranged from 40.6 to 95.4%, with a mean value of 62%. Total solids values in the Main Body Reach and Slip 36 were generally above 60% with isolated patches of lower total solids values (less than 60%) that occurred throughout the Main Body Reach (Map 2-12). The Shallow Main Body Reach, Slip 27, and the head of Slip 36 contained low total solids values. Percentages in the Junction/Sill Reach were similar to the Deep Main Body Reach. Overall, total solids were inversely proportional to percent fines (e.g., higher total solids tend to correlate with lower percent fines).

2.5.2.2.2 Subsurface Sediment

Available subsurface sediment physical characteristics are summarized below by the stratigraphic groupings and layers presented in Section 2.5.2.1. Grain size analyses were not performed below 4 ft of depth below the mudline.

Engineered Fill, Anthropogenic Fill, and Sand Cover Layers

These materials included all grain sizes but were predominantly composed of sand and gravel. Mean concentrations included 37.5% sand, 33.3% gravel, and 29.1% fines. TOC values ranged from a low of 0.09 to 2.4%, with a mean percentage of 1.6%. Total solids concentrations ranged from 58.1 to 90.3%, with a mean value of 68.3%.

Recent Unit

The Recent Unit consisted primarily of fines (silt and clay) with fractions ranging from 20 to 96% and a mean concentration of 71%. Sand content ranged from 3.8 to 51.9% with a mean concentration of 26.2%. The majority of the samples (81%) contained small fractions of gravel-sized particles (including shells) that were primarily encountered in the upper layers (i.e., 0 to 3 ft below mudline). Gravel-sized fraction concentrations ranged from 0.1 to 31.3%, with a mean concentration of 3.5%. TOC values ranged from 0.85 to 7.0% with a mean value of 2.6%. Total solids concentrations ranged from 40.7 to 73.8%, with a mean value of 56%. These values were similar to concentrations of total solids measured in surface sediments.

Upper Alluvium Unit

Mean grain size in the Upper Alluvium Unit was dominated by fines (silt and clay fractions) and sand, with higher percentages of sand as compared to the Recent Unit. Fines content ranged from 15 to 88.9% with a mean concentration of 51%, and sand ranged from 10.4 to 78.6% with a mean concentration of 47.7%. Sixty-five percent of samples contained a small fraction of gravel. Gravel concentrations ranged from 0.1 to 7.9%, with a mean concentration of 1.3%. TOC and total solids values were similar to the ranges measured in Recent Units. TOC values ranged from 0.27 to 7.4%, with a mean value of 1.4%, and total solids measurements ranged from 43.8 to 78.5%, with a mean concentration of 67.8%.

Lower Alluvium Unit

Lower Alluvium Unit primarily consisted of sand with lesser amounts of fines and trace amounts of gravel. Sand content ranged from 24.9 to 95.9%, with a mean concentration of 66.2%. Fines (silt and clay) content ranged from 1.6 to 75.1%, with a mean concentration of 32.9%. Sixty-seven percent of samples contained a small amount of gravel. Gravel concentrations ranged from 0.1 to 6.3%, with a mean concentration of 1.4%, which is similar to the gravel composition of the Upper Alluvium Unit. TOC values were much lower than the concentrations measured in Recent and Upper Alluvium Units, and were consistent with the lower proportion of fines in this unit. TOC values ranged from 0.1 to 1.8% with a mean value of 0.7%. Total solids measurements were higher than Recent and Upper Alluvium Units, with a range of 66.7 to 89.7%, and a mean concentration of 75.3%.

2.5.2.3 East Waterway Geotechnical Properties

Supplemental geotechnical testing was performed on a subset of the EW SRI subsurface sediment dataset, which included 13 subsurface core locations selected based on spatial distribution in the EW as shown in Map 2-13. Geotechnical tests included Atterberg limits (i.e., liquid limit, plastic limit, and plastic index), specific gravity, moisture content, and bulk density (dry and wet). Testing was performed on intervals that represented the major sediment.

Geotechnical properties varied with depth and with sediment type, and are summarized by EW stratigraphic grouping as defined in Section 2.5.2.1. In general, moisture content decreased with depth and dry bulk density increased with depth. These data are substantiated in core logs (Windward 2010d), which indicate a decrease in water content and an increase in density down-core.

2.5.2.3.1 Engineered Fill, Anthropogenic Fill, and Sand Cover Layers

These materials exhibited similar ranges of dry bulk density (92.4 to 96.6 pounds per cubic foot [pcf]), wet bulk density (106.6 to 109.7 pcf), moisture content (13.6% to 15.4%), and specific gravity (2.7 g/cc) indicative of coarser-grained soils. Based on the composition of these coarse-grained soils, samples from these layers were not submitted for Atterberg limits testing. Atterberg limits tests measures the plasticity of fine-grained materials (e.g., silt and

clay) and yield no results for coarse-grained soils. Results of the geotechnical tests indicate similarity in soil texture among the three layers.

2.5.2.3.2 Recent Unit

Geotechnical tests were performed on shallow (0 to 3 ft below mudline) recent silts. These shallow silts (Unified Soil Classification System [USCS][19] ML) exhibited similar ranges of dry bulk density (34.1 to 46.9 pcf), wet bulk density (66.7 to 85.2 pcf), and moisture content (81.6 to 110%). The mean specific gravity was 2.53 g/cc. Atterberg limits data included a mean liquid limit of 77.1% dry weight (dw), a mean plastic limit of 28.2% dw, and a mean plasticity index of 48.9% dw. These properties are indicative of fine-grained, wet soils consistent with observations in core logs.

2.5.2.3.3 Upper Alluvium Unit

Mid-depth Upper Alluvium layers (generally 2 to 5 ft below mudline) included a wide range of silts (ML), silty sands (SM), and silt with laminated and stratified beds of sand (USCS ML-SM). Geotechnical properties covered greater ranges of values and are indicative of the varied nature of material in this stratigraphic layer. Dry bulk density values ranged from 52.7 to 89 pcf, wet bulk density value ranged from 84.2 to 119.4 pcf, and moisture content values ranged from 22.9 to 59.7%, with sand units containing the lowest moisture content. Mean specific gravity was 2.65 g/cc. Atterberg limits tests indicated a mean liquid limit of 46.8% dw, a mean plastic limit of 23.4% dw, and a mean plasticity index of 23.4% dw.

[19] Definitions of each USCS symbol are provided below:

CL: Clay: inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, and lean clays

ML: Silt: inorganic silts and very fine sands, rock flour, clayey fine sands or clayey silts with slight plasticity

ML-SM: Inorganic silt with >30% of laminated or stratified layers of silty sand

ML-SP: Inorganic silt with >30% of laminated or stratified layers of sand

SM: Sand: Silty sands and silt-sand mixtures

SM-ML: Silty sand with >30% of laminated or stratified layers of silt

SP: Sand: poorly sorted, well graded sands or gravelly sands with less than 5% fines

SP-ML: Sand with >30% of laminated or stratified layers of silt

GP: Gravel: poorly graded, well sorted gravels and or gravel-sand mixtures

2.5.2.3.4 Lower Alluvium Unit

Deeper Lower Alluvium layers (up to 10.8 ft below mudline) included a wide range of lithological composition (USCS SP, SP-SM, ML-SM, SP-ML, and ML), but generally consist of a predominantly sand matrix with laminated beds of silt. Dry bulk density values ranged from 54.4 to 98.8 pcf, wet bulk density value ranged from 72.0 to 124.6 pcf, and moisture content values ranged from 24.3 to 42.1%, with sand units containing the lowest moisture content. Mean specific gravity was 2.65 g/cc. Atterberg limits indicated a mean liquid limit of 37% dw, a mean plastic limit of 28.8% dw, and a mean plasticity index of 8.2% dw.

2.6 Hydrogeology

The aquifer in the vicinity of the EW is a shallow, unconfined aquifer within fill and alluvial, deltaic, and estuarine sediments as discussed in Section 2.5. The cross sections shown in Figure 2-1 present the stratigraphy of the EW and adjacent uplands as seen from the southern end of Harbor Island. Shallow groundwater in the adjacent nearshore areas flows primarily toward the EW and Elliott Bay. Geologic and groundwater conditions at T-30 and T-25 are used to characterize the eastern nearshore upland area of the EW, and are herein referred to as the "East Uplands." Conditions at T-18 are used to characterize the western nearshore upland area of the EW, and are referred to as the "West Uplands." Table 2-1 provides a list of key documents that describe hydrogeologic conditions along either side of the EW. Additional discussion on groundwater quality and well locations is presented in Section 9.

Table 2-1
Key Reports Examining Hydrogeologic Conditions along the EW

Study	Source
East Uplands	
GATX 2003 groundwater monitoring	RETEC (2004)
USCG 2003 and 2004 groundwater monitoring	Hart Crowser (2004)
T-30 groundwater RI/FS	GeoEngineers (1998)
T-30 February 2007 groundwater sampling event	RETEC (2007)
T-30 final supplemental data report	AECOM (2006b)
T-30 cargo terminal construction completion report	AECOM (2010d)
T-30 supplemental RI/FS	Pacific Groundwater Group (2012)
T-25 1989 to 1990 groundwater sampling	Landau (1990); Sweet-Edwards/EMCON (1990)

Study	Source
T-25 field investigation report	Anchor QEA (2012)
T-104 vicinity 2005 to 2007 groundwater sampling	Environmental Partners (2007)
West Uplands	
Harbor Island RI	Weston (1993b)
Harbor Island well screening technical memorandum	RETEC (2005)
Harbor Island 2005 to 2006 groundwater monitoring	RETEC (2006a)
Groundwater Monitoring Plan - Revision 3, Harbor Island Soil and Groundwater Operable Unit	AECOM (2008b)
Groundwater Conductivity Profile Assessment - Revision 3, Harbor Island Soil and Groundwater Operable Unit	AECOM (2009)
Harbor Island Soil and Groundwater Operable Unit Groundwater Flow Evaluation	AECOM (2010b)

FS – feasibility study
RI – remedial investigation
T-25 – Terminal 25
T-30 – Terminal 30
T-104 – Terminal 104
USCG – US Coast Guard

2.6.1 East Upland Hydrogeology

The majority of groundwater evaluation on the East Uplands has occurred at T-30 due to its designation as a remediation site (GeoEngineers 1998; Pacific Groundwater Group 2012) (see also Section 9 for additional details on remediation activities); however, the same conceptual hydrogeology is presumed to exist at T-25. The studies referenced herein were conducted both prior to and after installation of a new sheetpile wall at T-30. Since the sheetpile wall was constructed for geostructural purposes, it was designed to allow groundwater to flow through. A discussion of the extent of shoreline sheetpiling and how it affects groundwater flow is provided in detail below.

The geologic composition of the east uplands was assessed by GeoEngineers (1998) during the RI and Weston (1993b). A conceptual cross section depicting the hydrogeologic characteristics of the East Uplands is provided in Figure 2-2. Soils observed during these studies include fill material overlying native alluvial and tideland deposits. Fill material is laterally discontinuous and typically consists of sand and gravel with varying amounts of silt, wood, bricks, and construction debris. Most of the fill is hydraulic fill dredged from the channel of the Duwamish River and is, therefore, difficult to distinguish from the alluvial deposits it overlies. The contact between fill and alluvium in the nearshore area is estimated to be 15 to 35 ft bgs (relative to MLLW). The alluvial deposits consist predominantly of black sand with varying amounts of fines and contain varying amounts of shell fragments and

organic materials (GeoEngineers 1998). Beneath the alluvium, very dense till-like glacial sediments were measured at depths ranging from approximately 115 to 135 ft bgs (GeoEngineers 1998). Based on data provided by Booth and Herman (1998), these deeper sediments likely correspond to the Vashon Till or pre-Vashon transitional bed units (see Section 2.5.1.1.2). These three units support the shallow, unconfined aquifer of the EW region.

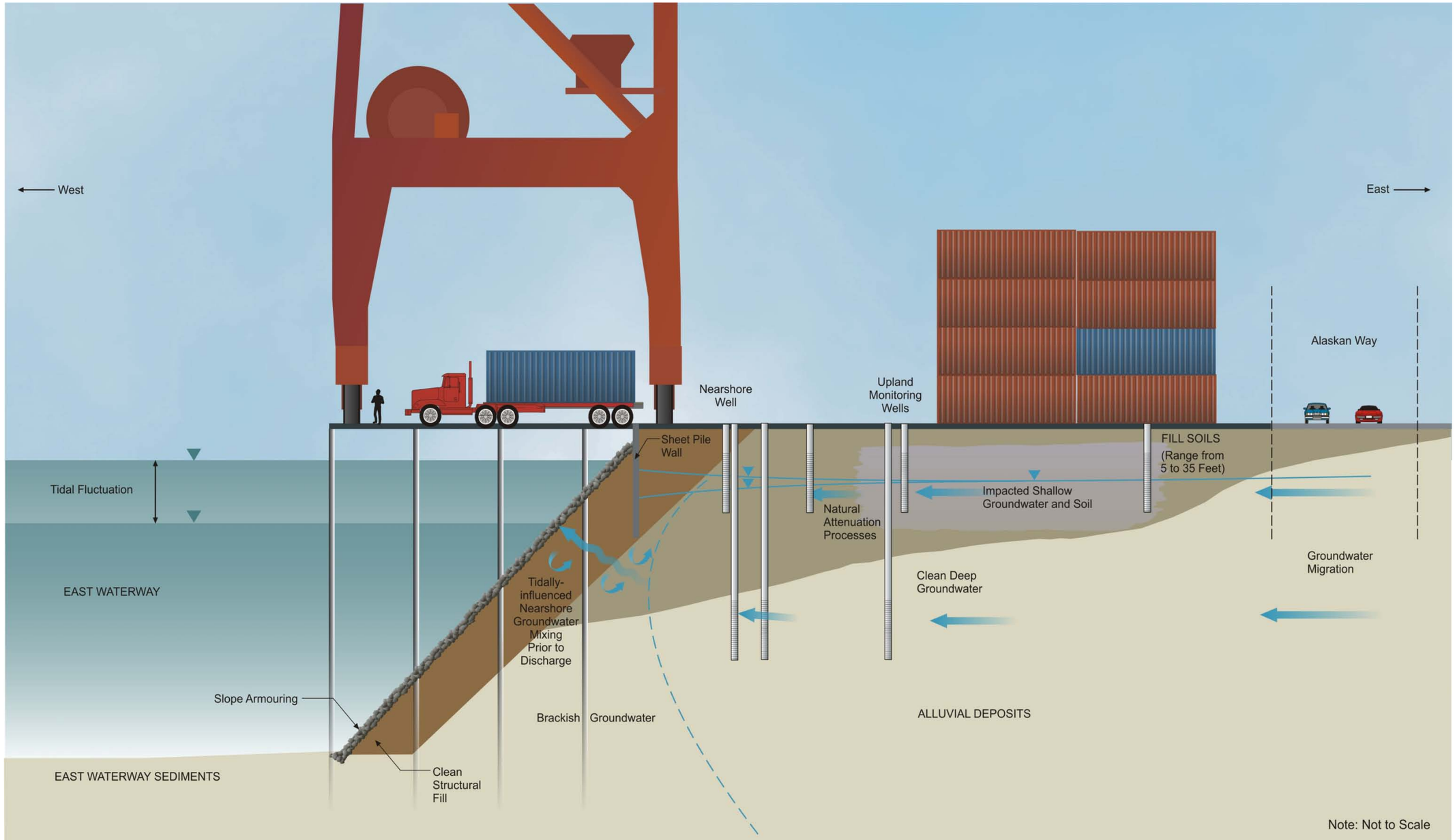


Figure 2-2
Hydrogeologic Characteristics of the East Uplands, T-30 Shoreline

The hydrogeologic characteristics of the East Uplands have been monitored prior to sheetpile wall installation since the early 1990s with the most recent evaluations documented by AECOM (2008a) and Pacific Groundwater Group (2012). Average depth to groundwater water ranges from 8 to 14 ft across the site (Pacific Groundwater Group 2012). Net groundwater flow was determined to originate in upland areas and to discharge to the EW at the shoreline (GeoEngineers 1998). Net flow to the EW occurs despite tidal effects and is caused by local recharge and upland flow. The local recharge component is relatively small due to surface capping of T-30 as part of early site cleanup and redevelopment activities that occurred during the 1980s, and, therefore, most of the net flow is from upland groundwater.

Hydraulic conductivity at T-30 was evaluated by AECOM (2008a) and estimated to be 0.01 centimeters per second (cm/s), typical of an aquifer matrix composed of medium sand and consistent with the reports of grain size data from earlier studies (e.g., GeoEngineers 1998; Weston 1993b). The horizontal groundwater gradient averaged over time and space was estimated at 0.003 foot per foot toward the EW prior to construction of the sheetpile wall (GeoEngineers 1998) After installation of the sheetpile wall, the horizontal groundwater gradient was approximately the same (Pacific Groundwater Group 2012). The vertical groundwater gradient was estimated using 2011 tidal study results that included shallow and deep well pairs located near and upgradient to the sheetpile wall. The average water level elevations in the deeper wells are higher than elevations in the shallower wells by 0.03 to 0.29 ft, indicating a slight net upward vertical component of groundwater flow at a time-averaged head gradient ranging from 0.0012 to 0.0145 ft/ft (Pacific Groundwater Group 2012). Groundwater velocity was calculated as a weighted average value of 0.00025 cm/s, with water table elevation velocities ranging from 0.00019 to 0.00088 cm/s, and deeper groundwater velocities ranging from 0.000081 to 0.00012 cm/s (RETEC 2006b).

The effects of tidal mixing on nearshore groundwater prior to discharge into the EW was reported by GeoEngineers (1998) and further analyzed by AECOM (2008b) and Pacific Groundwater Group (2012). Results indicated that in the nearshore environment: 1) fresh water overrides denser saltwater and thereby confines freshwater discharge to the upper portion of the aquifer near MLLW; 2) upland groundwater mixes with saline groundwater prior to discharging at the shoreline, meaning there is no direct discharge of fresh water to the EW, rather it is all tidally mixed; and 3) tidal influx results in dilution and attenuation of groundwater between nearshore wells and the shoreline. Based on groundwater modeling

conducted at the T-30 site (Appendix H) (RETEC 2006b), the area of tidal mixing is within approximately 50 ft from the shoreline. Conductivity data collected throughout the T-30 well network empirically confirmed the results of the groundwater modeling.

In 2011, an additional tidal study was conducted to evaluate potential effects of the sheetpile wall on the groundwater system (Pacific Groundwater Group 2012). The 2011 tidal study findings were generally similar to results of the previous tidal studies for general groundwater flow direction and average site-wide hydraulic gradient. However, the data indicate decreased tidal efficiency and increased time lag slightly upgradient of the sheetpile wall relative to the earlier studies; suggesting that the sheetpile wall decreased tidal flushing in this area (Pacific Groundwater Group 2012). The sheetpile wall has reduced, but not eliminated, mixing of surface water and groundwater in the nearshore wells. Groundwater/surface water mixing appears to be greater through the sheetpile wall (e.g., through the seams between the sheets) rather than under the sheetpile wall(Pacific Groundwater Group 2012).

The new sheetpile wall was constructed at T-30 between 2007 and 2009 to strengthen the over-water apron and to support new crane rails. The sheetpile wall extends approximately 1,400 linear feet from the north end of T-30 at Station 1800 to Station 3200, and is located at the top of the slope at the interface between the upland and the over-water apron (Map 2-14). It extends to a bottom elevation of -11.60 ft MLLW. The introduction of the sheetpile wall has resulted in minimal change to the groundwater flow paths, including the zone of freshwater discharge and shallow groundwater flow, but appears to have reduced the tidal influence on groundwater in the nearshore area behind the wall (AECOM 2008a, 2010d; Pacific Groundwater Group 2012). The sheetpile wall is substantially above the bottom of the fill and based on the regional geology, the aquifer is deep relative to the depth of the wall. The overall groundwater gradient and flow directions continues to be preferentially toward the EW, discharging within the tidal zone (AECOM 2010d).

2.6.2 West Upland Hydrogeology

The geologic composition of Harbor Island was documented by Weston (1993b) in the Harbor Island RI and generally consists of fill overlying alluvium. Since the RI was completed, a majority of Harbor Island has been capped with low permeability asphalt and graded to minimize ponding (AECOM 2010b). Two units of fill were identified by Weston

(1993b), including units of coarse-grained and fine-grained sand. The coarse-grained fill unit consists of gravelly to coarse sand ranging from 0 to 7 ft in thickness and was placed to create a level subgrade for development on the island. The underlying finer-grained unit was deposited hydraulically from dredge material from the Duwamish River and consists of fine to medium sand ranging in thickness from 3 to 15 ft. The contact between the finer-grained fill unit and underlying deltaic sediments was described as often imperceptible with occasional increase of silt, shell, and wood fragment content. The underlying deltaic sediment consists of unconsolidated sand and silty sand with occasional silt interbeds and an increase in silt content at depth (Weston 1993b).

A conceptual cross section of T-18 depicts the hydrogeologic characteristics of the West Uplands and is provided in Figure 2-3. Results from the 1993 Harbor Island RI indicated that groundwater elevations are highest in the central portion of Harbor Island (with a slight low in the center) and lowest at the shoreline. At the shoreline, shallow, unconfined groundwater is encountered at depths of 2.5 to 11 ft bgs (RETEC 2006a). Groundwater elevations at the shoreline are influenced by tidal fluctuations in the surrounding surface water, as described for the East Uplands. The groundwater elevation distribution documented in the 1993 RI and confirmed in 2010 (AECOM 2010b) indicates a radial flow pattern with recharge in the central portion of the island and discharge to the adjacent waterways (see additional description below). In addition, localized groundwater flows have been documented in the south-central portion of the island (Weston 1993b). Overall, groundwater flows from areas of higher groundwater elevations in the center of the island toward the shoreline, discharging to the adjacent waterways, and toward the local groundwater lows.

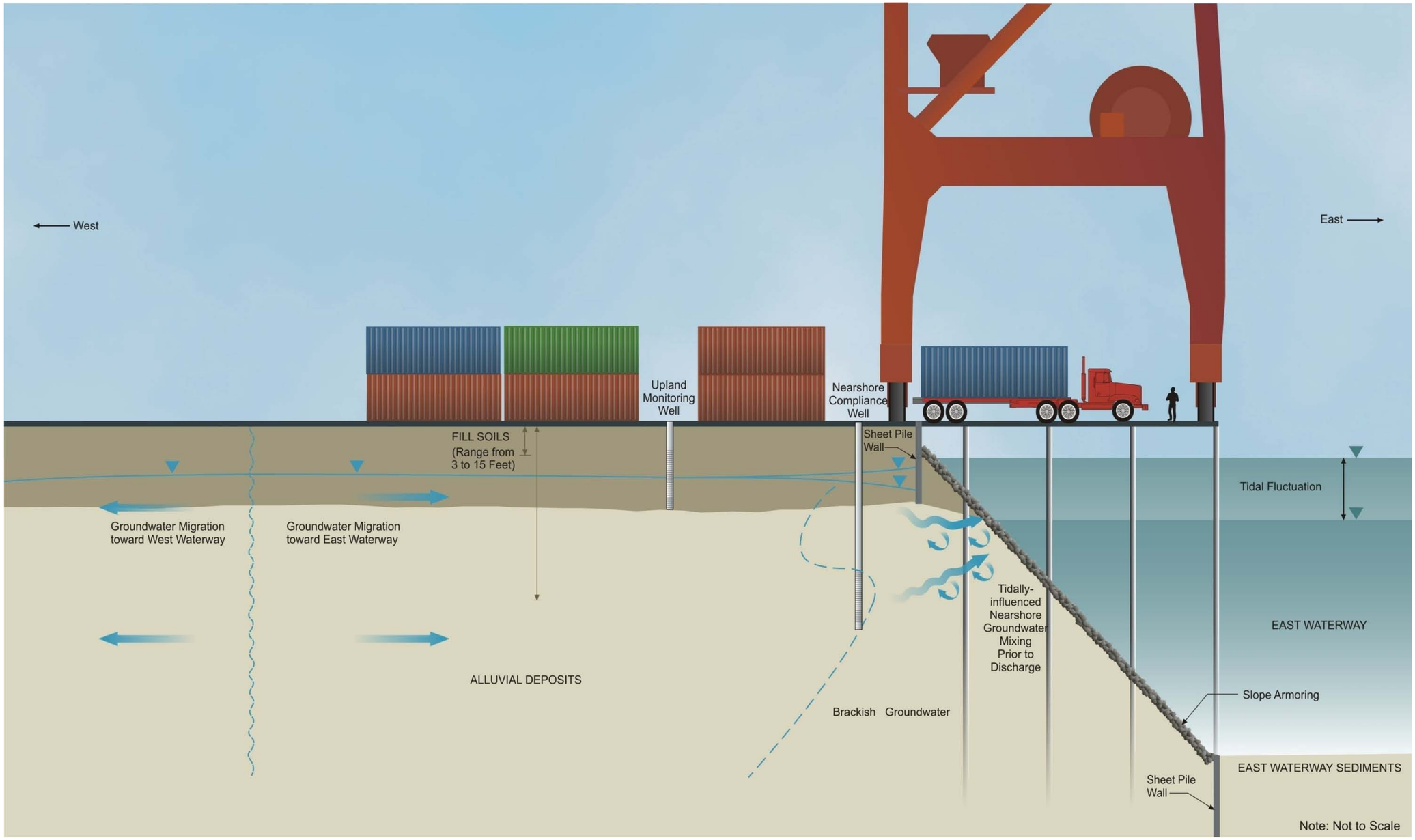


Figure 2-3
Hydrogeologic Characteristics of the West Uplands, T-18 Shoreline

A recent groundwater flow investigation completed after placement of capping on Harbor Island indicate that water levels in the center of the island have a seasonal variation of approximately 1 ft, which is less than the 1.5 to 2 ft of seasonal change observed prior to capping (AECOM 2010b). AECOM tentatively attributes the reduced seasonal variation in groundwater levels to limited infiltration as a result of capping and the collection of precipitation by the stormwater drainage system (AECOM 2010b). Groundwater flow determinations by AECOM are based on fewer measurements from a smaller monitoring well network than those included in the 1993 RI; however, results from the 2010 evaluation agree with previous observations of a slight groundwater low in the center of the island. In addition, AECOM found that slight variations in groundwater flow direction observed near the shoreline during the different tidal stages may be attributed to variations in shoreline features (e.g., bulkheads, storm drains) (AECOM 2010b).

Groundwater at Harbor Island has been shown to behave as a single hydrostratigraphic unit of fresh water floating on a base of saline water (Weston 1993b; RETEC 2006a), the interface of which is encountered at an approximate depth of 20 to 35 ft bgs (RETEC 2005). This CSM has been further refined at the shoreline areas by AECOM (2010c). Monitoring studies have identified a thin, relatively freshwater zone at the water table underlain by a shallow, relatively saline zone. Below this shallow saline zone, the island-wide freshwater lens and basal saline water zone identified in the RI (Weston 1993b) are encountered. This upper saline zone near the shoreline intermixes with surface water during tidal fluctuations. Shallow groundwater (to 20 ft bgs) is most influenced by tidal mixing (RETEC 2005).

Aquifer testing completed by Weston (1993b) during the RI indicated that the hydraulic conductivity ranged from 0.003 to 0.01 cm/s. This range is similar to that documented in the East Uplands (e.g., 0.01 cm/s) and indicative of alluvial deposits.

Sheetpile walls were installed at both the top and toe of slope in order to provide slope stability to allow dredging along the toe of the berth slopes (Map 2-14). The top of slope sheetpile wall extends over the entire length of the T-18 property and was constructed during the mid-1960s to the mid-1970s. Specifically, sheetpiling along Stations 0 to 3200 was constructed between 1966 and 1967 and sheetpiling along Stations 3200 to 6150 was built between 1973 and 1974 (KPFF 2011). The toe of slope sheetpile wall was installed from Stations 1900 to 4950 and includes the toe of the slope at the outer extent of the over-water

apron. The toe wall tip elevations are between -84 and -86 ft MLLW. Toe of slope sheetpile wall construction occurred from approximately 2003 to 2005. The introduction of the sheetpile walls have resulted in localized effects to groundwater. Groundwater discharge occurs beneath the sheetpile walls and creates a "dam flow" effect that restricts groundwater to surface water flow primarily to the region from the base of the sheetpile wall to the shoreline (RETEC 2006a). Because the sheetpile walls are substantially above the bottom of the aquifer, and since the aquifer is deep relative to the depth of the walls, the overall groundwater gradient and flow directions continue to be preferentially toward the EW, with shallow groundwater discharging within the tidal zone.

2.7 Surface Water Hydrology

This section provides an overview of the regional surface water hydrology associated with the environmental setting of the EW. A detailed discussion of the Physical CSM, including hydrodynamics, is provided in Section 3 and is based on the results of hydrodynamic modeling.

The EW receives freshwater flows from the approximately 362,000-ac Green/Duwamish River watershed (Map 2-15). The Howard Hanson Dam impounds the Green River at River Mile (RM) 64.5 (USACE 2005), and was constructed to provide flood control in the Lower Green River (USACE 2007). The Green River becomes the Duwamish River at the historical confluence of the Green River and former Black River near Fort Dent Park in Tukwila. The Duwamish River estuary flows into Elliott Bay through the EW and the WW. The annual average flow of the Green River near Auburn at RM 22.6 since 1962 was 1,318 cubic feet per second (cfs), as measured at the USGS gage on the Green River (USGS 2007). With the construction of the Howard Hanson Dam in 1962, the Green River hydrology was altered, and flood frequency is now controlled by reservoir operations.

2.7.1 Freshwater Input to the East Waterway

Seasonal variations in Green River flow exist, such that peak flows occur November through February, and minimum flows occur in August. Flow statistics for the Green River are shown in Table 2-2 and are based on measured daily-average flow rates from the USGS gage near Auburn, Washington. Mean annual flow rate was estimated as the average monthly flow rate over all 12 months of the year, and mean "wet season" flow rate was taken as the average

monthly flow rate for the months of November through May (Anchor QEA and Coast & Harbor Engineering 2012).

Table 2-2
Green River Flow Rates

Flow Condition	Flow Rate (cfs)
Mean annual	1,330
Mean wet season	1,875
2-Year high-flow event	8,400
10-Year high-flow event	10,800
100-Year high-flow event	12,000

Source: Anchor QEA and Coast & Harbor Engineering (2012)
cfs – cubic feet per second

The EW receives freshwater discharges from 39 outfalls (Map 2-14). The relative contribution of fresh water from the storm drains (SDs) and combined sewer overflow (CSO) outfalls is small in comparison with flows from the Green River. Additional discussion of stormwater and CSO discharges is presented in Section 9.

2.7.2 Estuarine Conditions

The EW is influenced by the freshwater flows from the Duwamish River and the tidal conditions of Elliott Bay (Anchor and Windward 2008a). The average tidal range measured at the Seattle waterfront is 11.36 ft MLLW, with an extreme low of -5.04 ft MLLW and an extreme high of +14.48 ft MLLW (National Oceanic and Atmospheric Administration [NOAA] Station identification [ID] 9447130; Map 2-15) (Anchor and Windward 2008a). The outflow of fresh water from the Duwamish River along with the marine tidal waters entering from Elliott Bay produce the estuarine conditions in the EW with the characteristic increase in salinity with water depth and net outflow to Elliott Bay. The flows are characterized by a net outflow to Elliott Bay in the surface layer and net inflow to the EW near the bottom. These conditions influence the hydrodynamics and sediment transport in the system (Anchor and Windward 2008a). Hydrodynamic modeling results presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012) indicate that current velocities within the EW caused by tidal and riverine currents are relatively low during periods of low upstream inflow. As upstream inflow increases, surface velocities within the EW increase. Surface velocities are highest in the Junction/Sill Reach (maximum 95 cm/s based on 100-yr

flow), and are lower in the Main Body Reach (maximum 40 cm/s based on 100-yr flow). Near-bed velocities are highest in the Deep Main Body Reach near the mouth of the EW (maximum 30 cm/s based on 100-yr flow) and lowest in the area south of Slip 27 (maximum 2 cm/s based on 100-yr flow). The presence of distinct two-layer flow (inflow of higher density saline water at depth with outflow of fresher water at the surface) becomes more prevalent as upstream inflow increases. During low flow events, vertical gradients in salinity are consistent throughout the EW. During high flow events, vertical gradients in salinity are more pronounced in the Main Body Reach, where a layer of fresh water overlies high salinity water. During high flow events in the Junction/Sill Reach, fresh water may be present throughout the water column (Anchor QEA and Coast & Harbor Engineering 2012).

The distribution of flow rate between the EW and WW as a function of upstream inflow was also modeled and validated for lower flows with Acoustic Doppler Current Profiler (ADCP) transect data collected in the EW as part of the sediment transport evaluation (STE). Results indicated that freshwater input to the EW and WW from upstream sources is split equally during periods of lower flow (i.e., less than 2-yr flood). During higher flow events greater than the 2-yr flow, the EW receives about 30% and the WW receives about 70% (from 2- to 100-yr flows) (Anchor QEA and Coast & Harbor Engineering 2012).

2.8 Ecological Habitats and Biological Communities

This section briefly summarizes the types of ecological habitats in the EW, as well as the species that use these habitats, including benthic invertebrates, fish, and aquatic-dependent wildlife. Additional information on the ecological habitats and biological communities of the EW study area is provided in the ERA (Appendix A, Sections A.2.1 and A.2.2).

2.8.1 Ecological Habitats

Dredging and development since the early 1900s have substantially altered nearshore environments in Elliott Bay and the Duwamish River. Prior to the channelization and industrialization of the Duwamish River, the habitat associated with the river's mouth was predominantly an intertidal/shallow subtidal estuarine mudflat. Since the creation of Harbor Island, all of the original habitat in the area that is now the EW has been either filled or dredged and channelized. There are no remaining tidal marsh or expansive mud flat areas within the EW.

The aquatic habitats in the EW include the water column and intertidal and subtidal substrates (typically mud, sand, gravel, cobble, or riprap). The habitat within EW is predominately deep water habitat with relatively little shallow subtidal habitat which is found primarily in the Junction/Sill reach and within Slip 27.

The shoreline of the EW is approximately 16,000 linear ft (excluding Slip 27 and Slip 36). Most of the shoreline (61%) is covered by wharves with engineered riprap slopes, roughly a third of the shoreline (30%) is covered with armored riprap with no wharf structures, and the remaining shoreline (9%) is predominantly characterized as bulkhead. The shoreline within Slip 27 and Slip 36 is predominantly armored riprap with extensive pier structures, although the southern shore of Slip 27 has an adjacent intertidal bench that was constructed during re-armoring of the Port of Seattle property. A limited number of small intertidal beaches are present above the riprap slopes in locations along the eastern shoreline of the waterway, including the head of Slip 27.

The standard concrete wharves (i.e., aprons or piers) along the Main Body Reach in the EW are 100 ft wide from the pierface (at the pierhead line, as indicated on Map 2-14) to the vertical bulkhead (e.g., sheetpile wall) at +9 ft MLLW (as depicted on Figures 2-2 and 2-3).[20] Areas under the piers downslope from the bulkheads are typically engineered riprap slopes to approximately -50 ft MLLW (with some areas to -40 ft MLLW). The pilings supporting the wharves along the underpier slope typically extend 25 ft below the riprap surface. The fender piles along the pierface typically extend to a depth of -76 ft MLLW (25 ft below mudline) (Figure 2-4). Along the central portion of T-18,[21] a sheetpile wall at the toe of the slope is present that typically extends to -84 to -86 ft MLLW (approximately 33 ft below mudline) (Figure 2-5).

[20] Vertical bulkheads are usually present above +9 ft MLLW because the Washington State Department of Fish and Wildlife (WDFW) requirements limit their intertidal range.

[21] Along the northern portion of T-18, from Stations 1900 to 4950 (Map 2-14), the sheetpile wall was installed as a retrofit to support modification to the pier and slope, which was originally designed for a berthing depth of -48 ft MLLW.

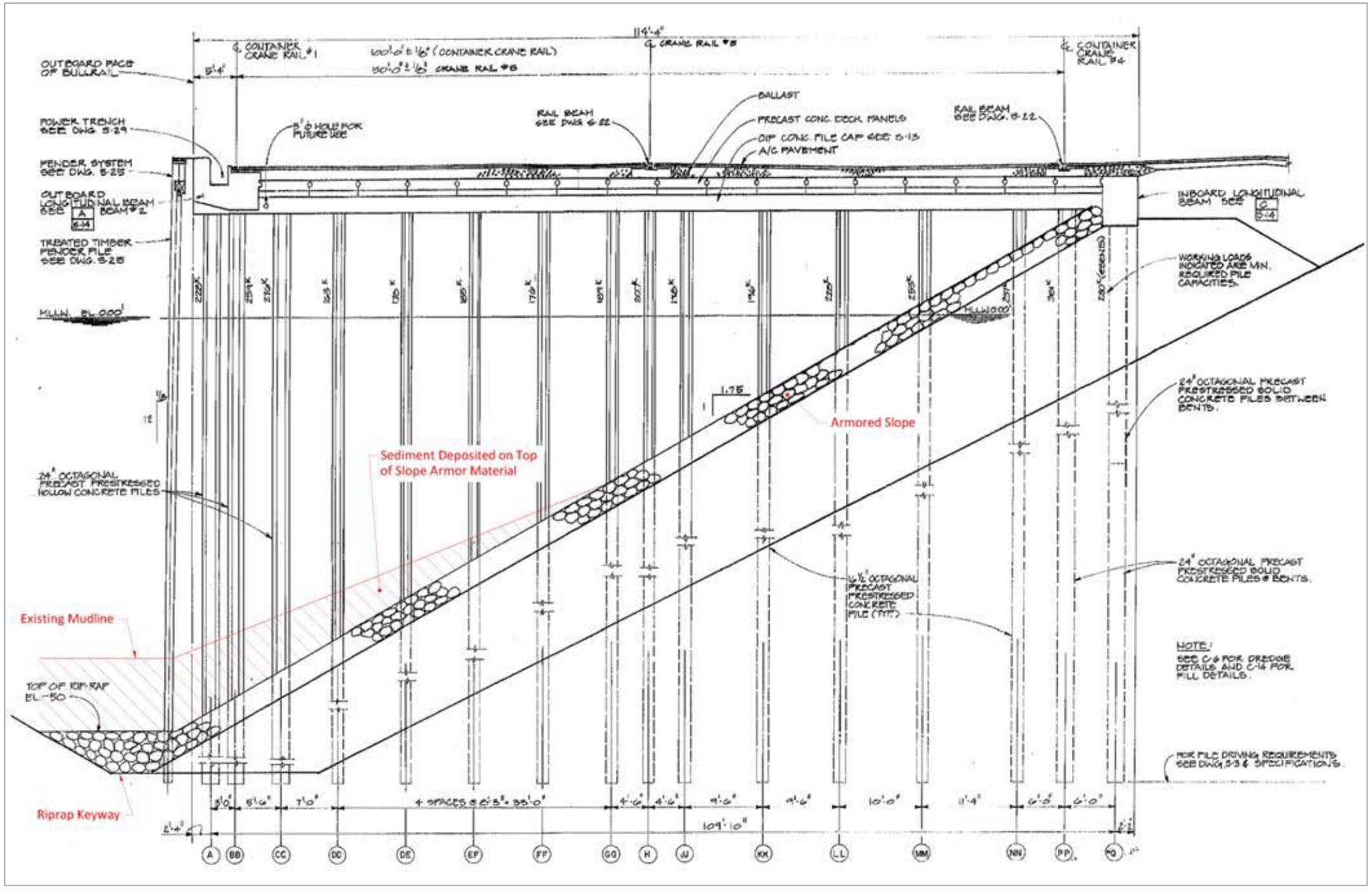


Figure 2-4
Typical Cross Section of Terminal 25 and 30

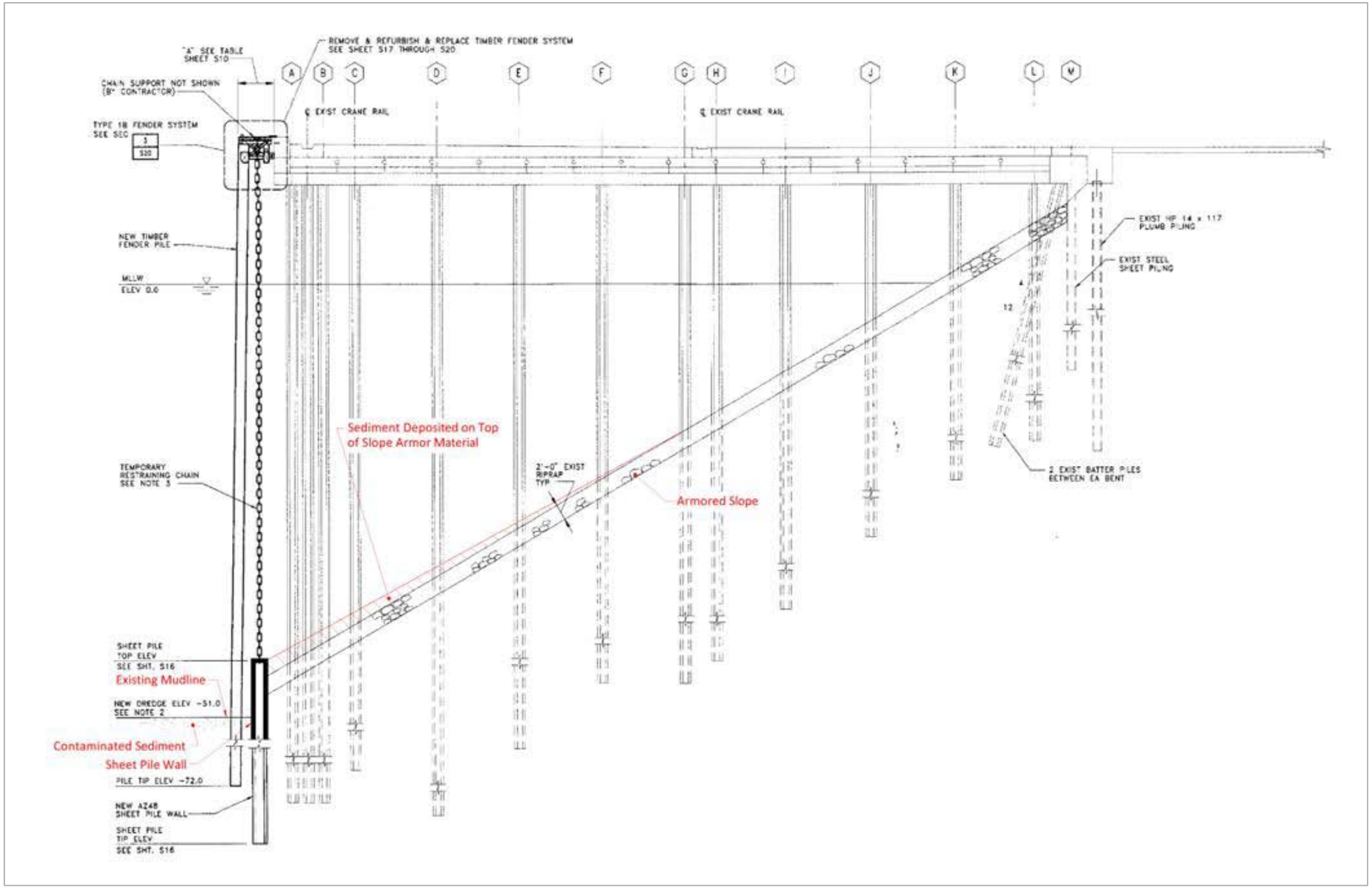


Figure 2-5
Typical Cross Section of Terminal 18 Sheetpile Toe Wall

Shoreline armoring is present throughout most of the upper intertidal zone, but a few areas of sloping mud and sand flats and gravel/cobble exist in the lower intertidal zone. These lower intertidal flats are isolated from each other because of the shoreline armoring. In addition, overwater structures, which are common throughout the EW, shade shallow water and intertidal habitats, and inhibit the growth of plant communities (Battelle et al. 2001). Along the western shore of EW intertidal sediment is limited to small areas. Gravel and cobble are the dominant matrices in the exposed intertidal areas.

The salinity measured during SRI surface water sampling events and King County water quality monitoring, typically ranged from approximately 15 to 28 parts per thousand (ppt), with higher salinity measured in the bottom of the water column as compared with that at the top (Windward 2009e). The flows are characterized by outflow to Elliott Bay in the surface layer and inflow to the EW near the bottom of the waterway during the flood tide and outflow to Elliot Bay in the surface and bottom waters during the ebb tide. The temperature ranges observed in the SRI sampling and King County water quality monitoring were 7.5 to 14.7 °C in the surface water collected 1 m below the water surface and 7.5 to 12.6 C in the deeper samples collected 1m above the sediment surface. The warmer temperatures were typically observed in July and August. There were no consistent differences between the surface water and deeper water samples. The EW is tidally influenced, with an approximate average tidal range of 11.36 ft, as measured at the nearby Seattle waterfront NOAA station.

2.8.2 Benthic Invertebrate Community

Benthic invertebrate assemblages in Puget Sound marine environments comprise a variety of species from diverse phyla (e.g., Mollusca, Arthropoda, Annelida, and Echinodermata). Benthic invertebrates can be classified as infaunal (living within the sediment) or epifaunal (living on the surface of sediment or other substrates) and, by definition, are in direct contact with the sediment during part or all of their lives. Most benthic invertebrates tend to be sessile (i.e., stay in place) or have limited mobility as adults. Benthic invertebrates have numerous types of feeding modes that expose them to sediment. These include filtering suspended sediment, plankton, and detritus from the water column; gathering detritus or sediment grains coated with organic material from the sediment surface or near-bottom

nepheloid layer; engulfing subsurface sediment to process the associated organic material; parasitizing other sediment-dwelling organisms; and preying on other invertebrates.

Benthic invertebrates are an important contributor to aquatic ecosystems, and their diversity and abundance are indicators of ecosystem health. Benthic invertebrates that process sediment or detritus support essential functions, such as nutrient cycling and sediment oxygenation. Benthic invertebrates are an important food source for other invertebrates and fish; larger invertebrates are also preyed on by some birds and mammals.

In general, key physical factors that may influence the distribution and abundance of benthic invertebrates are salinity, tidal elevation (affecting the duration of exposure to air or heat), water depth, substrate composition, sediment TOC content, sediment stability, wave and current magnitude, and frequency of disturbance (e.g., flooding, prop wash, and anchor drag).

Limited characterization of the benthic invertebrate community in the EW has been conducted. Targeted invertebrate groups have been sampled as part of four studies: a 1999 epifaunal survey assessing salmonid prey (Taylor et al. 1999) and three tissue collection efforts (small benthic invertebrates and larger clams, mussels, shrimp, and crab) conducted as part of this SRI (Windward 2009d, 2010b, c) (Table 2-3). No quantitative sampling of benthic community structure was conducted for the SRI; however, an SPI survey of the EW that examined the successional stage of the benthic community was conducted in October 2009 (Windward 2009d).

Table 2-3

Summary of Studies that Assessed Benthic Invertebrates in the EW

Study	Year Completed	EW Location	Sampling Period	Sampling Method	Targeted Organisms
EW benthic invertebrate tissue and sediment sampling (Windward 2009d)	2009	throughout the EW	2008–2009	grab samples	subtidal benthic invertebrates
EW SPI survey (Germano & Associates 2009)	2008	throughout the EW	October 2008	SPI camera	infaunal invertebrates
EW clam survey and tissue sampling (Windward 2010b)	2008	selected areas with clam habitat	summer and fall 2008	hand-collection; hydraulic extraction for geoduck	clams

Study	Year Completed	EW Location	Sampling Period	Sampling Method	Targeted Organisms
EW fish and crab tissue sampling (Windward 2010c)	2008	throughout the EW	summer and fall 2008	trawls and traps; hand-collection for mussels	Fish, crabs, shrimp and mussels
Epibenthic species assessment (Taylor et al. 1999)	1999	Slip 27	unknown	epibenthic suction pump	epibenthic invertebrates

EW – East Waterway
SPI – sediment profile imaging

Crab represent some of the larger benthic invertebrates that inhabit the EW. Crab species that are known to be present in the EW include Dungeness crab (*Cancer magister*), red rock crab (*Cancer productus*), graceful crab (*Cancer gracilis*), kelp crab (*Pugettia producta*), decorator crab (*Loxorhynchus crispatus*), and pygmy rock crab (*Cancer oregonensis*). Dungeness crab is the largest crab species present in the EW, and red rock crab was the most abundant species collected during the SRI sampling events (Windward 2010c). Mating typically takes place in deeper, offshore locations but may occasionally occur in estuaries (Pauley et al. 1988). Gravid females migrate to shallow estuarine habitats or other protected areas until their eggs hatch; planktonic larvae tend to settle in vegetated estuaries, which also serve as nurseries for juvenile crab. The highest densities of juvenile crab are usually associated with eelgrass or other kinds of aquatic vegetation that are not present in the EW.

Although crab are primarily carnivores and scavengers, crab diets are characteristic of their life stage and size (Pauley et al. 1986). Planktonic larval crab ingest both zooplankton and phytoplankton. Following metamorphosis, the diet of juvenile crab consists largely of very small fish, molluscs, and crustaceans. Adult crab primarily prey on clams, crustaceans, and fish. Juvenile and adult crab may incidentally ingest sediment when preying on clams and crustaceans, but the rate of ingestion is likely to be low because many prey species (e.g., mussels and barnacles on pilings, and shrimp) do not dwell on the sediment surface. Planktonic crab larvae (megalopae) are preyed upon by many fish, including juvenile salmon. Juvenile crab are eaten by various demersal fish in the nearshore area. Adult and juvenile crab in Puget Sound waters are preyed upon by river otters, fish, aquatic birds (e.g., pigeon guillemots), and octopuses. Cannibalism is also common among crab.

Taylor et al. (1999) conducted a survey of epibenthic invertebrates as part of a juvenile salmonid prey assessment in several intertidal areas of the lower 2 mi (3.2 km) of the

Duwamish River (including EW) and the northern shore of Elliott Bay in support of disposal site selection for an EW navigation project. Sampling was conducted at one location in the EW, Slip 27 (at the head and at the entrance of the slip); epifaunal samples (primarily crustaceans) were collected at 0 and 2 ft (0.6 m) MLLW using a suction pump. Most of the 110 invertebrate taxa collected at this location and the two other locations sampled outside of EW were potential fish prey species. The most diverse taxonomic groups were harpacticoid copepods, with 62 taxa, and gammarid amphipods, with 18 taxa. The dominant species at Slip 27 were harpacticoid copepods, including *Harpacticus uniremis*, *Tisbe* spp., and *Dactylopusia* sp. Other abundant crustaceans were gammarid amphipods such as *Paracalliopeilla pratti* (Table 2-4). The highest epibenthic invertebrate density reported in this study was at Slip 27.

Table 2-4

Benthic Invertebrate Taxa Collected in the EW in 1999

Benthic Taxa		
Cnidaria		
Anthozoa		
Platyhelminthes		
Turbellaria		
Nematoda		
Annelida		
Polychaeta		
Mollusca		
Gastropoda juveniles	Nudibranchia	Bivalvia juveniles
Acarina		
Halacaridae		
Calanoida		
Pseudodiaptomus marinum	*Stephos* spp.	
Harpacticoida		
Ameira spp.	*Harpacticus compressus*	*Normanella* sp.
Ancorabolidae	*Harpacticus obscurus* group	*Parastenhelia spinosa*
Leimia vaga	*Harpacticus spinulosus*	Peltidiidae
Mesochra spp.	*Harpacticus uniremis*	*Tachidius discipes*
Cletodidae spp.	*Harpacticus* sp. A	*Tachidius traingularis*
Acrenhydrosoma sp.	*Harpacticus* sp.	Tegastidae
Enhydrosoma spp.	*Harpacticus* copepodids	Thalestridae spp.
Amonardia perturbata	*Zaus* spp.	*Dactylopusia* sp.
Amonardia normani	*Huntemannia jadensis*	*Dactylopusia crassipes*

Benthic Taxa		
Disaccus sp.	Laophontidae spp.	*Datrylopusia tisboides*
Diosaccus spinatus	*Echinolaophonte* sp.	*Dactylopusia paratisboides*
Amphiascopis cinctus	*Heterolaophonte discophora*	*Dactylopusia glacialis*
Amphiascus spp.	*Heterolaophonte longisetigera*	*Dactylopusia vulgaris*
Stenhelia spp.	*Heterolaophonte harmondi*	*Diarthrodes* spp.
Typhlamphiascus sp.	*Laophonte cornuta*	*Idomene* sp.
Amphiascoides spp.	*Laophonte elongate*	*Paradactylopodia* spp.
Amphiascoides sp. A	*Paralaophonte* sp.	*Parathalestris* spp.
Bulbamphiascus sp.	*Paralaophonte pacifica*	*Rhynchothalestris helgolandica*
Robertsonia cf. *knoxi*	*Paralaophonte perplexa*	*Tisbe* spp.
Ectinosomatidae	*Pseudonychocamptus* spp.	*Scutellidium* spp.
Harpacticus arcticus	*Longipedia* sp.	
Copepoda		
Hemicyclops sp.	Ergasilidae	Cyclopoida
Ostracoda		
Podocopa		
Thoracica		
Unidentified nauplii	Unidentified cyprids	
Cumacea		
Diastylis santamariensis	*Nippoleucon hinumensis*	*Cumella vulgaris*
Isopoda		
Gnorimosphaeroma oregonense	*Munnogonium* sp.	*Leptochelia savignyi*
Munna sp.		
Tanaidacea		
Tanaidacea		
Gammaridae		
Anisogammaridae juveniles	*Corophium* spp.	*Photis* sp.
Eogammarus confervicolus	*Hyalella* sp.	Pleustidae spp.
Ampithoe sp.	*Gammaropsis* sp.	*Pleusirus secorrus*
Aoroides sp.	*Ischyrocerus* sp.	*Sympleustes* sp.
Capelliopius sp.	Melitidae	*Paramoera* sp.
Paracallipiella pratti	Oedicerotidae	*Pontogeneia* cf. *rostrata*
Caprellidae		
Caprella sp.		
Decapoda		
Unidentified larvae	Caridea	*Upogebia pugettensis*
Insecta		
Chironomidae	Unidentified larvae	

Source: Taylor et al. (1999)
EW – East Waterway

Surveys that documented larger benthic invertebrates were conducted in 2008, during which clam, crab, shrimp, and mussel tissue data were collected for this SRI (Windward 2009d, 2010b, c). Clam surveys were conducted at 11 beach areas (Windward 2010b); five of these areas were located in the southern narrow portion of the EW, three were located in and near Slip 27, and three were located along the shoreline of Slip 36 (Map 2-16). During this survey, Macoma clams (*Macoma* spp.) were the most frequently observed species, followed by Japanese littleneck clams (*Venerupis philippinarum*) and butter clams (*Saxidomus gigantean*). Cockles (*Clinocardium nuttali*) and eastern soft-shell clams (*Mya arenaria*) were observed only in the southernmost portion of the EW.

Crab and shrimp were collected for the SRI using 12 crab traps and 16 shrimp traps dispersed throughout the EW in August 2008, as well as during 10 trawls conducted using a high-rise otter trawl in September 2008. The crab and shrimp species collected during these sampling events are listed in Table 2-5; anemones, sea stars, and sea urchins were also identified during these sampling events, although they were not targeted species. Only 26 individual shrimp were collected in the shrimp traps. However, during the brown rockfish sampling event, scuba divers also noted the presence of numerous small shrimp that were too small to be collected in the shrimp traps. During the mussel survey conducted in July 2008, mussels were present wherever there was a suitable substrate, which was primarily pilings and sheetpile walls (Map 2-16).

Table 2-5
Invertebrate Species Collected in the EW in 2008

Common Name	Scientific Name
Crab	
Decorator crab	*Loxorhynchus crispatus*
Dungeness crab	*Cancer magister*
Kelp crab	*Pugettia producta*
Pygmy rock crab	*Cancer oregonensis*
Red rock crab	*Cancer productus*
Graceful crab	*Cancer gracilis*
Bivalves	
Blue mussel	*Mytilus* spp.
Butter clam	*Saxidomus gigantean*
Cockle	*Clinocardium nuttali*
Eastern soft-shell clam	*Mya arenaria*

Common Name	Scientific Name
Geoduck	*Panopea generosa*
Japanese littleneck clam	*Venerupis (= Tapes) philippinarum (= japonica)*
Macoma clam	*Macoma* spp.
Native littleneck clam	*Leukoma (= Protothaca) staminea*
Other Invertebrates	
Coonstripe or dock shrimp	*Pandalus danae*
Plumose anemone	*Metridium senile*
Sea star	*Evasterias* sp.
Sea star	*Luidia* sp.
Solaster star	*Solaster stimpsoni*
Sunflower sea star	*Pycnopodia helianthoides*
Sea urchin	*Strongylocentrotus* sp.

Source: Windward (2009d, 2010b, c)
EW – East Waterway

2.8.3 Fish

Fish in the EW can be classified as demersal (living on or near the sediment and feeding on benthic organisms), benthopelagic (living and feeding near the sediment as well as in the water column), or pelagic (living and feeding in open water) (FishBase 2007). Demersal fish are, by definition, in direct contact with sediment during part or all of their lives, whereas benthopelagic and pelagic fish have less direct contact with sediment.

Fish species present in the EW are generally mobile predators and are exposed to chemicals through the ingestion of contaminated prey, incidental ingestion of sediment during prey capture, and uptake of chemicals in surface water through the gills during respiration. Fish are an important food source for other fish, some larger invertebrates, birds, and mammals. Fish from the EW also provide important recreational value and are a source of food for people, including tribal members.

Data on the fish species present in the EW are available from six studies that investigated site use by fish (Table 2-6). From all 6 studies, 42 fish species have been identified in the EW (Table 2-7). Taken together, these studies provide a fairly comprehensive characterization of the EW fish community because the range of available habitats was sampled and both active and passive collection methods were used. In addition, sampling using beach seines has been carried out during three seasons (winter, spring and summer), thus providing an indication of seasonal differences. Furthermore, because trawl, trap, and Scuba sampling was conducted

during summer, these methods also characterize the season with the greatest productivity and diversity in the fish community in the Duwamish River estuary (Miller et al. 1977a; Dexter et al. 1981; Shannon 2006), as well as the period when most recreational fishing occurs.

Table 2-6
Summary of Studies that Assessed the Fish Community in the EW

Study	Year Completed	EW Location	Sampling Period	Equipment Type	No. of Locations Sampled
EW juvenile Chinook salmon tissue collection data report (Windward 2010d)	2010	Slip 27	June 2009	beach seine	1
EW fish and shellfish tissue collection data report (Windward 2010c)	2008	throughout the EW	August to October 2008	otter trawl, scuba, and crab and shrimp traps	10 trawls, 13 scuba dives, 12 crab traps, 16 shrimp traps
EW fish tissue sampling (Windward 2006)	2005	throughout the EW	July 20, 2005	otter trawl	9
EW Phase 1 Removal Action Chinook salmon and bull trout monitoring (Taylor Associates 2005)	2004	Slip 27	February 15 to March 1, 2004	beach seine	2
EW channel deepening project, juvenile salmonid and epibenthic prey assessment (Shannon 2006)	2003	Slip 27	April to August 1998, 2000, and 2003 (biweekly)	beach seine	2
EW juvenile Chinook salmon tissue chemistry results (Windward 2002c)	2002	Slip 27	June 2002	beach seine	1

EW – East Waterway

Table 2-7
Fish Species Collected in the EW

Common Name	Scientific Name	Environment	Habitat	Source
American shad	*Alosa sapidissima*	marine and fresh water	demersal, bays, estuaries, fresh water	Gilbert and Williams (2002)
Bay goby	*Lepidogobius lepidus*	marine	demersal (mostly on mud bottom)	Eschmeyer et al. (1983)
Bay pipefish	*Syngnathus grisiolineatum*	marine	demersal (associated with eel grass in the intertidal areas)	Dawson (1985)

Common Name	Scientific Name	Environment	Habitat	Source
Brown rockfish	*Sebastes auriculatus*	marine	dermersal, shallow, low-profile, rip rap and submerged structures	Gilbert and Williams (2002)
Chinook salmon	*Oncorhynchus tshawytscha*	marine and fresh water	benthopelagic	Groot and Margolis (1998)
Chum salmon	*Oncorhynchus keta*	marine and fresh water	benthopelagic	Groot and Margolis (1998)
Coho salmon	*Oncorhynchus kisutch*	marine and fresh water	benthopelagic	Groot and Margolis (1998)
Crescent gunnel	*Pholis laeta*	marine (estuary)	demersal (intertidal areas, under rocks)	Eschmeyer et al. (1983)
Cutthroat trout	*Oncorhynchus clarki*	marine and fresh water	benthopelagic	Morrow (1980)
Decorated warbonnet	*Chirolophis decoratus*	marine	demersal	Eschmeyer et al. (1983)
English sole	*Parophrys vetulus*	marine (estuary)	dermersal, (sand and mud bottoms)	Clemens and Wilbey (1961)
Flathead sole	*Hippoglossoides elassodon*	marine	benthic (soft mud bottom, adults below 180 m)	Eschmeyer et al. (1983)
Great sculpin	*Myoxocephalus polyacanthocephalus*	marine	benthic (sand and mud bottoms, often near shore)	Eschmeyer et al. (1983)
Kelp perch	*Brachyistius frenatus*	marine	demersal, among fronds in kelp beds from near surface to depths of about 30 m	Gilbert and Williams (2002)
Longfin smelt	*Spirinchus thaleichthys*	marine and fresh water	demersal, in sea, usually inshore	Eschmeyer et al. (1983)
Pacific herring	*Clupea pallasi*	marine	benthopelagic (coastal, first year in bays)	Hart (1973)
Pacific sand dab	*Citharichthys sordidus*	marine	benthic, over soft sand bottoms	Eschmeyer et al. (1983)
Pacific sandlance	*Ammodytes hexapterus*	marine (brackish)	benthopelagic (surface or burrowed in sand)	Eschmeyer et al. (1983)
Pacific staghorn sculpin	*Leptocottus armatus*	marine (lower estuary, offshore)	benthic (sandy bottom)	Eschmeyer et al. (1983)
Pacific tomcod	*Microgadus proximus*	marine (brackish)	dermersal, over sand)	Cohen et al. (1990)
Penpoint gunnel	*Apodichthys flavidus*	marine (estuary)	demersal (intertidal tide pools)	Eschmeyer et al. (1983)
Pink salmon	*Oncorhynchus gorbuscha*	marine and fresh water	benthopelagic	Groot and Margolis (1998)
Plainfin midshipman	*Porichthys notatus*	marine	demersal	Eschmeyer et al. (1983)
River lamprey	*Lampetra ayresi*	marine and fresh water	demersal	Hart (1973)

Common Name	Scientific Name	Environment	Habitat	Source
Rock sole	*Lepidopsetta bilineata*	marine (estuary)	benthic (more pebbly bottom than most other flatfish)	Eschmeyer et al. (1983)
Rockfish	*Sebastes* spp.	marine	demersal (near structure)	Lamb and Edgell (1986)
Saddleback gunnel	*Pholis ornata*	marine (estuary)	demersal (sandy bottom)	Eschmeyer et al. (1983)
Sailfin sculpin	*Nautichthys oculofasciatus*	marine	demersal, over rocks from inshore to depths of 110 m, often with algae	Gilbert and Williams (2002)
Sand sole	*Psettichthys melanostictus*	marine, estuary	benthic (sandy bottom)	Hart (1973)
Shiner surfperch	*Cymatogaster aggregata*	marine (estuary)	demersal (in shallow water; around eelgrass beds, piers, and piles; commonly in bays and quiet back waters)	Eschmeyer et al. (1983)
Skate	*Rajidae* sp.	marine	demersal	Eschmeyer et al. (1983)
Slender sole	*Lyopsetta exilis*	marine	benthic (greater than 200 m in depth)	Eschmeyer et al. (1983)
Snake prickleback	*Lumpenus saggita*	marine	benthopelagic (shallow bays and offshore waters)	Eschmeyer et al. (1983)
Speckled sanddab	*Citharichthys stigmaeus*	marine	benthic (sand bottom near shore)	Eschmeyer et al. (1983)
Spiny dogfish	*Squalus acanthias*	marine	benthopelagic	Cox and Francis (1997)
Spotted ratfish	*Hydrolagus colliei*	marine	demersal	Eschmeyer et al. (1983)
Starry flounder	*Platichthys stellatus*	marine (estuary, brackish)	benthic	Morrow (1980)
Steelhead	*Oncorhynchus mykiss*	marine and fresh water	benthopelagic	Gall and Crandell (1992)
Striped seaperch	*Embiotoca lateralis*	marine	demersal	Eschmeyer et al. (1983)
Surf smelt	*Hypomesus pretiosus*	marine (brackish)	benthopelagic	Morrow (1980)
Three-spine stickleback	*Gasterosteus aculeatus*	marine and fresh water	benthopelagic (in/near vegetation)	Page and Burr (1991)
Whitespotted greenling	*Hexagrammos stelleri*	marine (intertidal)	demersal (nearshore near rocks, piles, and eelgrass beds)	Cohen et al. (1990)

EW – East Waterway

The most extensive surveys of fish populations in the EW have been conducted for the Port of Seattle by Taylor et al. (1999) using beach seines, which tend to capture small fish in nearshore habitats. Taylor et al. collected fish at the head and mouth of Slip 27 in 1998, 2000, 2002, 2003, and 2004. Sampling was conducted in April through August 1998, April through October 2000 and 2002, and February through April 2003. Additional sampling was conducted February 15 through March 2, 2004, at Slip 27 and nearby locations (Taylor Associates 2005). Twenty-two species of fish were captured during these studies. The top three numerically dominant species at the Slip 27 sampling location were juvenile chum salmon, juvenile Chinook salmon, and shiner surfperch. Together, these species represented 98% of the total catch at Slip 27. Additional species commonly captured in beach seines included juvenile coho salmon, Pacific staghorn sculpin, Pacific herring, surf smelt, and three-spine stickleback.

Trawling throughout the EW was conducted one day each in July 2005 and September 2008 to capture fish for tissue sampling (Windward 2006, 2010c). Trawling captured moderately slow-moving benthic species of fish from intertidal to deep subtidal depths. In 2005, 17 fish species were captured in 9 trawls, and in 2008, 23 fish species were captured in 10 trawls. English sole was the most abundant species in both efforts and constituted more than 50% of the total catch in 2005 and more than 40% of the total catch in 2008. Pacific tomcod, rock sole, sand sole, and shiner surfperch were also abundant in both trawling events, with a catch-per-unit effort (CPUE) greater than or equal to three individuals per trawl. Sanddab, Pacific staghorn sculpin, starry flounder, and Pacific herring were also common in both trawling events, with a CPUE greater than one individual per trawl. In 2005 surf smelt were also common, whereas in 2008 plainfin midshipman, bay goby, rat fish, and speckled sanddab were common, with a CPUE greater than one individual per trawl.

A few fish (Pacific staghorn sculpin and brown rockfish) were collected in traps set for crabs and shrimp on August 26 and 27, 2008 (Windward 2010c). Scuba divers collected brown rockfish by spearfishing over 3 days in August and during 1 day in October 2008 at 13 locations throughout the EW. Brown rockfish were the only rockfish species encountered, and the divers noted that they were common in riprap habitat.

2.8.3.1 Anadromous salmonids – Pacific salmon

Five species of juvenile salmon (Chinook, chum, coho, pink, and steelhead) have been documented in the EW. Juvenile chum and Chinook salmon were the most abundant salmonid species captured in Slip 27 (Taylor Associates 2004; Shannon 2006; Windward 2010d). Sockeye salmon have been found in the LDW (Kerwin and Nelson 2000).

Salmon use the Duwamish River for rearing of juveniles and as a migration corridor for adults and juveniles. Adult salmon found in the LDW and EW spawn mainly in the middle reaches of the Green River and its tributaries (Grette and Salo 1986). Among the beneficial uses identified for the Duwamish Waterway (including the LDW and EW), habitat for outmigrating juvenile salmonids is one of the most important (Harper-Owes 1983). Peak outmigration usually lasts from mid-July through early August for most species (Warner and Fritz 1995; Nelson et al. 2004). In the EW, juvenile salmon were caught in seine nets from April through September, with peak numbers in April through July (Shannon 2006). During that time, juveniles complete their physiological adaptation to higher salinity, and they use the estuary to feed on epibenthic and neritic food sources (Salo 1991). As the juveniles move into estuaries and inhabit deeper water, their dietary preference appears to shift toward water column organisms such as larval and juvenile fish (Healey 1991). No specific information is available on their residence time in the EW.

2.8.3.2 Non-salmonid fish

Of non-salmonid fish, English sole, Pacific tomcod, rock sole, sand sole, shiner surfperch, sanddab species, Pacific staghorn sculpin, starry flounder, surf smelt, three-spine stickleback, and Pacific herring are at least seasonally abundant in the EW. Pacific herring, Pacific sandlance, surf smelt, and longfin smelt were encountered infrequently in recent beach seine and trawl samples in the EW but occasionally were present in large numbers (Shannon 2006; Windward 2006, 2010c). Three-spine stickleback were abundant in monthly beach seine samples collected from both Slip 27 and Kellogg Island[22] sampling locations (Shannon 2006). Longfin smelt abundance was highest in the summer, fall, and early winter based on historical otter trawl data from the LDW (Miller et al. 1977a). Miller et al. (1977a) suggested that the fall-winter peak abundance period (with 80- to 115-mm-long fish) may have

[22] Kellogg Island is located in the LDW.

represented part of a spawning run and that the late summer peak (with 30- to 50-mm-long fish) may have represented downstream migrant young-of-the-year individuals. Pacific herring were reported in purse seine samples from the LDW in May, June, July, November, and December (Shannon 2006; Weitkamp and Campbell 1980) and were present in trawl samples in the EW in July and September (Windward 2006, 2010c). In Puget Sound, three-spine stickleback and surf smelt feed on both epibenthic and pelagic invertebrates; epibenthic invertebrates constitute a slight majority of their diet (Miller et al. 1977b; Fresh et al. 1979). Pacific herring and longfin smelt generally feed on pelagic invertebrates but also ingest epibenthic invertebrates to a lesser extent (Miller et al. 1977b; Fresh et al. 1979). Pacific tomcod is a demersal species that is associated with sandy bottoms (Cohen et al. 1990); they primarily feed on amphipods and shrimp (Fresh et al. 1979).

In the LDW, shiner surfperch abundance peaks in summer during the bearing of young (Miller et al. 1975). Taylor Associates recorded abundant shiner surfperch in the EW and LDW in May through October, with peak abundance in July (Shannon 2006). Shiner surfperch are opportunistic omnivores, feeding primarily on benthic invertebrates, including polychaetes, molluscs, and other benthic organisms (Fresh et al. 1979; Wingert et al. 1979; Miller et al. 1977b). Shiner surfperch are also noted to feed on zooplankton, small crustaceans, algae, and detritus (Gordon 1965; Bane and Robinson 1970).

English sole were the most abundant fish captured in recent trawl sampling of the EW, constituting approximately 50% of the total catch by number (Windward 2006, 2010c). In Puget Sound, adult English sole are typically found on soft sand or mud bottoms at depths of 80 to 150 ft (25 to 50 m) (Smith 1936). English sole may exist in discrete populations with some site fidelity. Day (1976) conducted a tagging study in Puget Sound, the results of which suggested that fish captured and released at the same location remained within an area approximately equal to 5 to 10 km^2. In addition, catch rates for fish captured and released dozens of miles from their original capture site were higher at their original capture site than at the release site or other sites sampled (Day 1976).

English sole migrate to their spawning grounds in Puget Sound in winter (Forrester 1969) and typically spawn in Puget Sound during February and March (Smith 1936). In central Puget Sound, adult populations of English sole spawn in Elliott Bay and Port Gardner but disperse after spawning (Pallson 2001). Angell et al. (1975, as cited in King County 1999)

reported the offshore migration in winter and spring of all age groups of central Puget Sound English sole from Meadow Point to Carkeek Park (northwest Seattle) at depths of 3 to 30 m. Juveniles (10 to 25 mm standard length), not all completely metamorphosed, migrated from spawning areas to nursery grounds as pelagic fish and moved to benthic habitats in December or May and June (King County 1999a). Data from Malins et al. (1982) indicated that during the winter and spring, more than 50% of the English sole in the LDW were juveniles (less than 150 mm standard length). Juvenile English sole (those less than 110 mm long) ingest annelids (Smith 1936), copepods, amphipods, and molluscs (Holland 1954). Adult English sole studied in Puget Sound ingest clams, clam siphons, small molluscs, marine worms, small crabs, and small shrimp (Fresh et al. 1979; Wingert et al. 1979).

Rock sole was among the most common species of fish captured in recent trawl sampling in the EW, while starry flounder was somewhat less common (Windward 2006, 2010c). Similar to English sole, starry flounder and rock sole are also noted to migrate from shallow water and estuaries during the summer to deeper water in the winter (Morrow 1980; NOAA 2008). Young and adult starry flounder are tolerant of fresh water (Morrow 1980). Rock sole tend to be found on rocky or gravel substrates but are also found on sand and mud bottoms (NOAA 2008). Because they have larger mouths, starry flounder and rock sole are capable of consuming somewhat larger organisms than those consumed by English sole, although their diets greatly overlap. Starry flounder and rock sole in Puget Sound were reported to consume primarily benthic invertebrates, with bivalves, amphipods, and shrimp serving as important prey items for starry flounder, and polychaetes, amphipods, and bivalves being the primary prey for rock sole (Fresh et al. 1979).

Other flatfish that were common in recent EW trawl sampling included the Pacific sanddab and sand sole (Windward 2006, 2010c). Pacific sanddab are found on sand and mud bottoms and consume a mixture of benthic invertebrate and pelagic invertebrate prey (Fresh et al. 1979). Sand sole are found over sandy bottoms and consume primarily fish from the water column, such as shiner surfperch (Love 1996).

The highest trophic-level fish species identified in the EW included brown rockfish, Pacific staghorn sculpin, Pacific tomcod, spotted ratfish, spiny dogfish, sand sole, great sculpin, and starry flounder (Windward 2006, 2010c). Dietary studies from Puget Sound showed that fish constitute a large fraction of the diets of sand sole, brown rockfish, spiny dogfish, and great

sculpin, whereas the other fish species in the EW consume primarily invertebrates and are at a lower trophic level (Miller et al. 1977b; Wingert et al. 1979; Fresh et al. 1979). Great sculpin are rare in the EW (Windward 2006, 2010c). Wingert et al. (1979) reported that brown rockfish from central Puget Sound primarily consume shrimp and fish. Tagging studies showed that brown rockfish demonstrated limited movement with home ranges on the order of 30 to 1,500 m^2 (Matthews 1990). Brown rockfish are associated with structures such as riprap, piers, or submerged debris (Matthews 1990; Love et al. 2002). During scuba sampling in the EW, brown rockfish were found to be common under piers in riprap habitats (Windward 2010c).

2.8.4 Birds

There is relatively little EW-specific information on bird populations. Surveys of the bird community have been conducted primarily upstream of the EW in the LDW, where there is a greater diversity of bird habitat. Formal studies, field observations, and anecdotal reports indicate that up to 87 species of birds use the LDW during at least part of the year to feed, rest, or reproduce (Table 2-8). The relatively large home ranges associated with many bird species make the LDW data relevant to the EW, although the number of species dependent upon riparian, intertidal, and shallow water habitat is likely fewer in the EW because those habitats are limited in the EW. Instead, birds that feed in the pelagic zone or dive in deeper waters to feed on benthic fish and invertebrates are more likely to frequent the EW. The Puget Sound area is within the Pacific Flyway, a major route of travel for migratory birds in the Americas that extends from Alaska in the north to Patagonia in the south. Water bodies are important to birds for feeding and resting during their migratory travels.

Table 2-8
Bird Species Found in the Vicinity of the LDW

Common Name	Scientific Name	Common Name	Scientific Name
Passerine/Upland Species			
Blackbird, red-winged	*Agelaius phoeniceus*	Sparrow, English (house)	*Passer domesticus*
Bushtit, common	*Psaltriparus minimus*	Sparrow, fox	*Passerella iliaca*
Chickadee, black-capped	*Poecile atricapillus*	Sparrow, golden-crowned	*Zonotrichia atricapilla*
Cowbird, brown-headed	*Molothrus ater*	Sparrow, savannah	*Passerculus sandwichensis*
Crow, northwestern	*Corvus corrinus*	Sparrow, song	*Melospiza melodia*
Dove, rock	*Columba livia*	Sparrow, white-crowned	*Zonotrichia leucophrys*

Common Name	Scientific Name	Common Name	Scientific Name
Finch, house	*Carpodacus mexicanus*	Starling, European	*Sturnus vulgaris*
Flicker, northern	*Colaptes auratus*	Swallow, barn	*Hirundo rustica*
Goldfinch, American	*Spinus tristis*	Swallow, cliff	*Petrochelidon pyrronota*
Hummingbird, Anna's	*Calypte anna*	Swallow, tree	*Iridoprocne bicolor*
Junco, dark-eyed	*Junco hyemalis*	Swallow, violet-green	*Tachycineta thalassina*
Kingfisher, belted	*Ceryle alcyon*	Thrush, Swainson's	*Hylocichla ustulata*
Kinglet, ruby-crowned	*Regulus calendula*	Towhee, rufous-sided	*Pipilo erythrophthlamus*
Purple martin	*Progne subis*	Warbler, orange-crowned	*Vermivora celata*
Quail, California	*Lophortyx californicus*	Wren, Bewick's	*Thryomanes bewickii*
Robin, American	*Turdus migratorius*	Wren, house	*Troglodytes aedon*
Siskin, pine	*Carduelis pinus*		
Raptors			
Eagle, bald	*Haliaeetus leucocephalus*	Hawk, sharp-shinned	*Accipiter striatus*
Falcon, peregrine	*Falco peregrinus*	Hawk, Swainson's	*Buteo swainsoni*
Hawk, Cooper's	*Accipter cooperii*	Merlin	*Falco columbarius*
Hawk, red-tailed	*Buteo jamaicensis*	Osprey	*Pandion haliaetus*
Shorebirds/Waders			
Dowitcher	*Limnodromus* sp.	Sanderling	*Crocethia alba*
Dunlin	*Erolia alpina*	Sandpiper, least	*Calidris minutilla*
Heron, great blue	*Ardea herodias*	Sandpiper, spotted	*Actitis macularia*
Heron, green	*Butorides virescens*	Sandpiper, western	*Calidris mauri*
Killdeer	*Charadrius vociferus*	Yellowlegs, lesser	*Totanus flavipes*
Waterfowl			
Bufflehead	*Bucephala albeola*	Goose, domestic	*Branta domesticus*
Canvasback	*Aythya valisineria*	Mallard	*Anas platyrhynchos*
Coot, American	*Fulica americana*	Merganser, common	*Mergus merganser*
Duck, domestic	*Anas domesticus*	Merganser, hooded	*Lophodytes cucullatus*
Gadwall	*Anas strepera*	Merganser, red-breasted	*Mergus serrator*
Goldeneye, Barrow's	*Bucephala islandica*	Scoter, surf	*Melanitta perspicillata*
Goldeneye, common	*Bucephala clangula*	Teal, greenwinged	*Anas carolinensis*
Goose, cackling Canada	*Branta canadensis minima*	Wigeon, American	*Mareca americana*
Goose, Aleutian	*Branta canadensis*		
Seabirds			
Cormorant, double-crested	*Phalacrocorax auritus*	Gull, glaucous-winged	*Larus glaucescens*
Cormorant, pelagic	*Phalacrocorax pelagicus*	Gull, mew	*Larus canus*
Grebe, eared	*Podiceps capsicus*	Gull, ring-billed	*Larus delawarensis*
Grebe, horned	*Podiceps auritus*	Loon, common	*Gavia immer*

Common Name	Scientific Name	Common Name	Scientific Name
Grebe, pied-billed	*Podilymbus podiceps*	Loon, Pacific	*Gavia pacifica*
Grebe, red-necked	*Podiceps grisegena*	Loon, red-throated	*Gavia stellata*
Grebe, western	*Aechmophorus occidentalis*	Murre, common	*Uria aalge*
Guillemot, pigeon	*Cepphus columba*	Tern, Caspian	*Hydroprogne caspia*

Source: Windward (2007c)
LDW – Lower Duwamish Waterway

This section provides a general description of birds expected to be found near the EW based on formal surveys or other types of observations conducted in the LDW upstream of the EW, or based on informal observations of birds in the EW. No studies of bird populations have been conducted in the EW. Formal surveys conducted in the LDW include a year-round survey conducted of the entire LDW waterway in 1977–1978 (Canning et al. 1979) and a monitoring study conducted over 14 seasons at 3 general areas of the LDW (Terminal 105 [T-105], Kellogg Island, and the Upper Turning Basin) between 1995 and 2000 (Cordell et al. 2001) and an osprey survey conducted in 2006 (Thompson 2006). Passerine/upland birds, raptors, shorebirds/waders, waterfowl, and seabirds are described in the subsections that follow.

2.8.4.1 Passerine/upland birds

Passerine and upland bird species that have been observed during surveys in and around the LDW are generally associated with terrestrial habitats, although they may occasionally forage in exposed mudflats or freshwater habitats (Canning et al. 1979). Therefore, these species are not expected to frequent the EW, due to the scarcity of acceptable terrestrial and nearshore habitats. Passerine and upland species that have been observed along the EW include northwestern crow, rock pigeon, European starling, English (house) sparrow, and belted kingfisher.

2.8.4.2 Raptors

Osprey and bald eagle have been observed along or in the vicinity of the EW. Two osprey nest boxes have been observed along the EW at Terminal 104 (T-104) and T-18 (Blomberg 2007). In 2006, WDFW reported 10 osprey nest sites located along the LDW, in addition to the nests along the EW (Thompson 2006). Osprey feed almost exclusively on fish captured from the water surface by hunting over open water (Poole et al. 2002). Overwintering migrant eagles have been routinely observed in the vicinity of the LDW from the beginning

of October through late March (King County 1999a). Five bald eagle nests within 8 km of the EW were occupied in 1999 (King County 1999a). The closest nest is located in West Seattle, within 1.6 km of the EW. Bald eagles feed primarily on fish but may also feed on waterfowl during winter months (Buehler 2000). Other raptors in the LDW (e.g., merlin and several species of hawks) feed primarily on upland birds or rodents and are not substantially exposed to aquatic species from the EW. Peregrine falcons have been known to nest along the LDW (Anderson 2006). Peregrine falcons in western Washington feed primarily on rock pigeons and European starlings, although they may also ingest some waterfowl (Anderson 2006).

2.8.4.3 Shorebirds/waders

Of the nine species of shorebirds and wading birds that have been documented in the LDW during monitoring studies conducted by Cordell et al. (2001), great blue heron was the most abundant species recorded; great blue heron have also been observed using the EW but to a lesser extent than observed in LDW. The closest great blue heron colonies are located about 14 km south of the EW in Renton, Washington, and 10 km northwest near Salmon Bay. A colony of up to 37 active great blue heron nests was located in West Seattle a few hundred meters from Kellogg Island until 2000 when the nests were abandoned (Norman 2002). Great blue herons feed while wading in shallow water, primarily on fish, but they may also consume benthic invertebrates (Butler 1992). Other common shorebirds observed in the LDW were spotted sandpiper and killdeer. Sandpipers probe in the sediment while feeding on benthic invertebrates in intertidal areas, resulting in potential exposure to sediment contamination through incidental sediment ingestion. The small amount of shallow water and intertidal habitat in the EW limits the use of the EW by shorebirds and waders, as discussed in more detail in the ERA, Appendix A, Section A.2.3.3.

2.8.4.4 Waterfowl

Waterfowl species commonly observed in the EW include common and red breasted merganser, Barrow's goldeneye, Canada goose, and bufflehead. Cordell et al. (2001) and Canning et al. (1979) observed 20 waterfowl species during monitoring studies conducted in the nearby LDW. In general, the waterfowl species observed in the EW and along the LDW overwinter in the Puget Sound area (and farther south) and migrate north in the summer, although there are some non-migratory populations. The EW and LDW may also serve as feeding and resting areas for birds as they migrate north or south along the Pacific Flyway.

Bufflehead, Barrow's goldeneye, and common and red-breasted merganser are species that eat benthic invertebrates and fish and dive deeper than other ducks; these species are more likely to use the EW for foraging than are other duck species. Dabbling ducks feed primarily on aquatic plants, seeds, and grasses, and Canada geese feed on grass and terrestrial vegetation; habitat types for these waterfowl species are generally lacking in the EW.

2.8.4.5 Seabirds

Seabirds observed using the EW include pelagic and double-crested cormorants, pigeon guillemot, grebes (especially Western grebe), and gulls (especially glaucous-winged gull). Sixteen species of seabirds were documented in the nearby LDW by Cordell et al. (2001) and Canning et al. (1979).

Pigeon guillemot nests have been observed under the T-18 piers (Hotchkiss 2007), and the birds have been observed feeding in the EW (Musgrove 2010a). Pigeon guillemot are present in the Puget Sound region year-round (Seattle Audubon Society 2008). Wintering cormorants use the LDW from November to May, with large numbers present from December to April (Canning et al. 1979; Cordell et al. 1996). Grebes arrive from October to November and depart by early May. Several species of gulls use the LDW and EW; glaucous-winged and mew gulls are the only species reported to use the area in large numbers.

Pelagic cormorants and pigeon guillemot are both deep divers and feed primarily on bottom-dwelling fish, and benthic invertebrates (Ewins 1993; Hobson 1997). Double-crested cormorants feed primarily on fish in shallower waters. Western grebe feed primarily on fish (Storer and Nuechterlein 1992). Gulls are omnivorous scavengers, consuming a wide variety of fish and shellfish.

2.8.5 Mammals

There is very little information on mammal populations in the vicinity of the EW or the LDW. The relatively large home ranges associated with many mammal species make the LDW data relevant to the EW.

Three marine mammal species can enter the EW and LDW from Elliott Bay: harbor seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), and harbor porpoise (*Phocoena phocoena*) (Dexter et al. 1981). Harbor seals and California sea lions have been observed in

the EW (Walker 1999). Recent information on harbor porpoise use was not available, although it has been noted that they occasionally enter the LDW (Dexter et al. 1981).

A survey was conducted to monitor for the presence of California sea lions and harbor seals in the EW on 30 individual days between December 1998 to June 1999 (Walker 1999). California sea lions were observed on 8 days, and harbor seals were observed on 1 day. California sea lions, harbor seals, and harbor porpoise are opportunistic feeders, consuming various fish species depending on availability (Marine Mammal Center 2002; Pitcher 1980; Pitcher and Calkins 1979; Schaffer 1989). Harbor seals may also feed on invertebrates such as squid, and California sea lions and harbor porpoises may also feed on squid and octopus.

Three species of aquatic-dependent terrestrial mammals use the LDW: raccoon (*Procyon lotor*), muskrat (*Ondatra zibethicus*), and river otter (*Lutra canadensis*). Raccoons are reported to be common along the forested ridge slopes to the west of the LDW, but information is not available regarding their presence in the EW. Raccoons are scavengers that feed on carrion and occasionally on fish and invertebrates. Muskrat populations have been reported to exist in the LDW at Terminal 107 (T-107) (near Kellogg Island) and at the Upper Turning Basin (approximately 8 km upstream from Harbor Island (Canning et al. 1979). Muskrats are herbivores, feeding primarily on aquatic and semi-aquatic plants. The EW has limited aquatic and semi-aquatic plant populations because of limited shallow water habitat, so muskrats are less likely to use the EW habitat. Anecdotal information indicates that a river otter family lives year-round on Kellogg Island in the LDW, and a mother and her young have been observed feeding among the pilings in the WW (Musgrove 2010b). Local river otters feed primarily on fish but will also feed on crabs, mussels, and clams (Strand 1999).

2.9 Human Use

Early industrial and commercial use of the EW consisted of fish processing facilities, shipyards, and facilities with flour mills, grain elevators, lumber yards, and cold storage originally focused on the eastern shore. Wharves constructed on creosoted piles were built in the early 1900s along both sides of the EW. Commercial and industrial use continued after the 1940s on both sides of the EW, including oil terminals, shipyards, rail transfer terminals, cold storage, lumber yards, and sand and gravel transfer stations. Additional discussions on historical uses of EW are presented in Section 9.

This section provides current information regarding the land use and maritime use and ownership. In addition, the current site uses including tribal use, water and shore recreation uses and commercial uses are described.

2.9.1 Land Use and Ownership

Land use, zoning, and land ownership along the EW are consistent with an active commercial waterway. The east and west sides of the EW contain hardened shorelines with extensive overwater structures, commercial and industrial facilities, and other development. The EW is a commercial waterway used primarily for container loading and transport. Table 2-9 provides a summary of land ownership and current users, tenants, or operators. Property boundaries and ownership information are provided on Map 2-17, which also show the current operators and tenants. As described below, nearly all upland properties are owned by the Port of Seattle.

Table 2-9
Current Land Uses Along the East Waterway

Property	Owner	Tenant	Uses/ Operations	Approximate Location (stations)	Approximate Size (ac)
T-18	Port of Seattle	Kinder Morgan	petroleum loading/unloading	0 – 400	1
		SSA	container storage, intermodal transfer	400 – 6150	115
Duwamish Properties	Duwamish Properties	Harley Marine Services	tug and barge terminal	6150 – 6800	3.2
T-102	Harbor Real Estate	various	industrial park	7250 – 7500	2.5
T-102	Port of Seattle	various	industrial park, marina	7200 – 7700	18.5
T-46	Port of Seattle	TTI	container storage, intermodal transfer	north of -100	72
Pier 36, Pier 37	USCG	USCG	USCG offices, boat maintenance	-100 – 750	18
T-30	Port of Seattle	public access	public access	750 – 800	2
		SSA	container storage, intermodal transfer	800 – 1800	9.5
		SSA	container storage, intermodal transfer	1800 – 4200	10
T-25	Port of Seattle	SSA	container storage, intermodal transfer	4200 – 5850	22.5
T-25S	Port of Seattle	vacant	storage of ground cement/gravel	5850 – 6800	19

Property	Owner	Tenant	Uses/ Operations	Approximate Location (stations)	Approximate Size (ac)
Spokane Street Bridge	City of Seattle	none	road	6850 – 6950	na
T-104	Port of Seattle	vacant (north)	vacant land	7000 – 7200	2.7
		PCC Logistics (south)	cargo transloading	7200 – 7700	13.8
West Seattle Bridge	City of Seattle	none	road	7050 – 7150	na
Railroad Bridge	BNSF Railway	BNSF Railway	railroad	7150 – 7200	na
Service Road Bridge	Port of Seattle	none	fire department access	7200 – 7250	na

BNSF – Burlington Northern Santa Fe
Kinder Morgan – Kinder Morgan Energy Partners
na – not available
SSA – Stevedoring Services of America
T-18 – Terminal 18
T-24 – Terminal 24
T-25 – Terminal 25
T-30 – Terminal 30
T-46 – Terminal 46
T-102 – Terminal 102
TTI – Total Terminals International
USCG – US Coast Guard

Properties on the west side of the EW consist of two Port of Seattle-owned parcels, T-18 and Terminal 102 (T-102), and a third parcel owned by Duwamish Properties. T-18 borders the EW from the northern boundary of Harbor Island to the point where the EW narrows (approximately 6,150 ft), at which point the property extends away from the water to the Spokane Street corridor. Including recently enlarged areas, T-18 encompasses approximately 196 ac, which are used for container storage and intermodal transfer. T-18 is operated by Stevedoring Services of America (SSA). The southernmost portion of the T-18 parcel is leased by Westway Feed Products, Inc. Molasses and other liquid food products are stored in numerous aboveground tanks and transferred to and from rail cars in this leased area.

The Port of Seattle leases a portion of the northernmost portion of T-18 to Kinder Morgan Energy Partners (Kinder Morgan). This leased area is approximately 1 ac in size and extends approximately 450 ft along the EW. The leased area also extends onto a portion of state-owned land. Kinder Morgan uses this area to load and unload petroleum products.

The property immediately east of the south end of T-18 is owned by Duwamish Properties and extends along the EW to the Spokane Street corridor. This 3.2-ac property is occupied by Harley Marine Services, which owns Olympic Tug and Barge. Harley Marine Services has an office building and maintenance shop on the property. Its tugs and barges are moored in the EW along this parcel.

The other Port of Seattle-owned parcel on the west side of the EW is T-102, which is occupied by an office park called the Harbor Marina Corporate Center. Buildings E and F in the office park are on a 2.5-ac parcel owned by Harbor Real Estate, which is located northeast of the Port of Seattle-owned parcel. T-102 extends from Spokane Street to the southern tip of Harbor Island, and further south along the LDW (Map 2-17). The Port of Seattle also operates a marina, which extends into the LDW as well as the junction area of EW.

There are four bridges over the EW in the Spokane Street corridor. Land on either side of the EW at the Railroad Bridge is owned by the BNSF Railway. At the Service Road Bridge, land on either side of the EW is owned by the City of Seattle. The ownership of the various bridges is shown in Table 2-9.

On the east side of the EW and south of the Spokane Street corridor, the Port of Seattle owns T-104. T-104 consists of 13.8-ac parcel south of the railroad right-of-way (ROW) and a 2.7-ac parcel north of the railroad ROW. The larger parcel is leased to PCC Logistics and is designated as Foreign Trade Zone No. 5. This property is used for cargo transloading. The smaller parcel is currently vacant. No water access is available at T-104 on the north side of the railroad ROW.

North of the Spokane Street corridor, the Port of Seattle owns T-25, which extends north along the EW to Slip 27. At the south end of T-25 is Pier 24, which consists of 19 ac north of Spokane Street. The northern portion of this area was also used for loading contaminated dredged sediment from barges onto rail cars using a rail spur in 2005 and 2006. The main parcel of T-25 contains 22.5 ac of container storage and intermodal transfer. SSA currently operates T-25.

A bridge connects T-25 to T-30 across the head of Slip 27. Pier 28 is located on the north side of Slip 27 and is used for miscellaneous vessel moorage. The Port of Seattle owns the vacated portion of S Forest Street, which constitutes the northern portion of Slip 27.

T-30 is a 31-ac Port of Seattle-owned property. T-30 is currently being used for container storage and intermodal transfer operated by SSA.

Jack Perry Memorial Shoreline Public Access is located along the northern portion of T-30. This public access extends from E Marginal Way S to the EW. Parking is available along with shoreline and water access. To the north of the public access is the Pier 36 USCG station.

The USCG station is located north of T-30 and on either side of Slip 36. This property includes USCG offices and Pier 36 (south side of Slip 36) and Pier 37 (north side of Slip 36). USCG uses the area on either side of Slip 36 as a training facility and for boat maintenance, USCG offices, and water access.

T-46 is located north of Pier 37 and is used for container storage and intermodal transfer. The south end of T-46 is adjacent to the EW area. T-46 is operated by Total Terminals International (TTI).

2.9.2 Maritime Waterway Use and Ownership

The EW provides a critical connection for cargo and other materials moving between water and land. Most vessel traffic consists of shipping companies that move container vessels and assorted tugboats into and out of the EW.

Table 2-10 summarizes the vessel activity in the EW from 1990 to 2011. Most of the vessel activity in the EW is from container ships (Port of Seattle 2012). In addition to ship traffic, tugboats, barges, and small craft also use the EW. Each container ship requires at least one tugboat to maneuver the ship during docking and undocking. Numerous barges and tugboats are moored along Harley Marine Services, at the head of the EW. At the north end, along T-18, tugs and barges use the Kinder Morgan petroleum products transfer facility. Cruise ships also frequented the EW from 2002 to 2008, when the southern portion of T-30 was being used as a cruise ship terminal.

Table 2-10
Summary of Number of East Waterway Vessels Calls from 1990 to 2011

Year	Container Ship	Cruise Ship	Barge[a]	Total
2011	384	0	256	640
2010	371	0	282	653
2009	368	0	360	728
2008	347	128	na	475
2007	373	109	na	482

Year	Container Ship	Cruise Ship	Barge[a]	Total
2006	394	125	na	519
2005	476	91	na	567
2004	447	86	na	533
2003	470	42	na	512
2002	501	2	na	503
2001	511	0	na	511
2000	584	0	na	584
1999	578	0	na	578
1998	596	0	na	596
1997	661	0	na	661
1996	714	0	na	714
1995	695	0	na	695
1994	605	0	na	605
1993	530	0	na	530
1992	575	0	na	575
1991	560	0	na	560
1990	515	0	na	515

[a] Tracking began in 2009; since each vessel call for barge traffic cannot be verified, docking days were used instead.

na – not available

USCG vessels frequent Slip 36, which serves Pier 36 (on the southside) and Pier 37 (on the north side). Slip 36 extends 1,050 ft to the east of the eastern EW pierhead line (Map 2-17). USCG vessels moored in Slip 36 include icebreakers, cutters (greater than 65 ft in length), and gunboats. Only USCG vessels use this slip.

South of Slip 36, a communication cable crosses the EW between T-18 and the northern portion of T-30 (Map 2-1). This cable was originally buried in 1972 between -61 and -66 ft MLLW in an armored trench. The location of the cable is based on design drawings; however, this cable may have been moved slightly from that location by a vessel anchor based on reports from contractors that located the cable as part of underwater bulkhead construction in 2003 (Oates 2007).

Slip 27 is located south of T-30 (Map 2-1). Slip 27 is primarily used for the moorage of miscellaneous vessels. Slip 27 extends approximately 850 ft to the southeast along the east side of the EW and is 240 ft wide. The northern portion is currently used by the Port of Seattle to moor various vessels.

South of the Spokane Street corridor, recreational and commercial boats move in and out of the Harbor Island Marina (T-102) from the LDW. Along the T-102 shoreline within the EW, the Port of Seattle leases out moorages on a 750-ft-long dock for commercial use. The Spokane Street corridor itself prohibits any type of boat passage, except at low tide by small, shallow-draft boats (e.g., kayaks and skiffs).

Map 2-17 shows aquatic land ownership in the EW and the shoreline as it is generally defined by MHHW. The main body of aquatic land in the EW is owned by the State of Washington and managed by the Washington State Department of Natural Resources (DNR) between the pierhead lines. Land located within the pierhead line is state-owned but managed by the Port of Seattle through a port management agreement. This area includes all aprons that extend approximately 100 ft from the Port of Seattle's upland parcel boundary.

Several aquatic areas within the EW are not state-owned. South of the Spokane Street corridor, the Port of Seattle owns the entire width of the EW. The eastern parcel boundary for T-102 abuts the western parcel boundary for T-104. The Port of Seattle also owns all of Slip 27, including the vacated portion of the S Forest Street ROW and Pier 27 (south side of Slip 27). A portion of aquatic area along Pier 24 that formerly contained timber decking is also owned by the Port of Seattle. All of Slip 36 is owned by USCG.

2.9.3 Site Use

2.9.3.1 Water Recreation

Water recreation can include activities such as swimming, scuba diving, and pleasure boating. The extent to which the EW is used for swimming is unknown, but likely minimal due to the cold water, limited shoreline access, and use of much of the water body by commercial ships. King County, in its issue paper on human site use in Elliott Bay and the Duwamish River, including the EW and the WW (King County 1999b), indicated that if swimming were to occur, it would be limited to warmer summer months because of the generally cold water temperatures of these water bodies. The EW is accessible to the general public via boat, but fewer recreational opportunities exist in the EW compared with adjacent Elliott Bay and the LDW because the EW has limited public access and a greater concentration of commercial shipping activity (Map 2-18).

2.9.3.2 Tribal Use

The EW is frequently used by tribes as a resource and for cultural purposes. Tribal treaties guarantee members of the Muckleshoot and Suquamish Tribes the right to harvest seafood from the EW. Currently, the Muckleshoot Tribe conducts commercial netfishery in EW for salmon. Tribal fishermen can also engage in clamming activities (by means of boat access) in all intertidal areas of the EW (Maps 2-19a and 2-19b) as well as subtidally for geoducks (currently geoduck clams are not being harvested from EW). The south end of T-25 has been unsafe for clamming due to hazards associated with the presence of remnant pilings, but could potentially be an area for shellfish harvesting in the future. Tribal seafood harvesting practices are currently ongoing and will continue to occur in the future.

2.9.3.3 Shore Recreation

Shore recreation can include activities such as visiting parks, playing in intertidal areas, or walking along the shoreline. Other shoreline activities could include habitat restoration or other stewardship activities performed by volunteers.

There are currently only two areas along the EW that have public access, on the southeast bank near the Spokane Street Bridge and the Jack Perry Memorial Park Public Access to the northeast (Map 2-18). There are other areas of the EW where people may access the shore, but these areas are only accessible by boat. In addition, the general public[23] is not allowed in some shore areas (e.g., the outcrop at the mouth of Slip 27 and USCG property at Slip 36) because of security measures.

2.9.3.4 Commercial Use

The EW supports a large number of water-dependent commercial uses. Almost all of the facilities adjacent to the EW rely on vessel traffic on the waterway. Much of the occupational work on the EW, other than commercial fishing, takes place on piers and large ships, and is associated with daily shipping terminal operations. Most of these workers are on docks or aboard vessels and are well above the water surface (generally 20 ft or more above MLLW).

[23] Tribal members with rights to the waterway are not included when making statements about the general public.

However, occupational work that can occur within EW include scuba diving and individuals who perform maintenance and repair work on docks and other structures along the EW.

2.9.3.5 Recreational Fishing and Shellfish Use

Individuals other than tribal members are known to collect fish and crab from EW despite existing fish advisories. Individuals fishing from piers and bridges along Spokane Street corridor have been observed (King County 1999b). The potential clamming area for the general public is small because there are only two places where the public can gain access to intertidal areas of the EW (Map 2-18). It is unknown if clam harvesting by the general public is currently occurring. The Washington State Department of Health (WSDOH) has closed the Duwamish River and the shoreline of King County to shellfish harvesting due to pollution from bacterial contamination.

3 PHYSICAL PROCESSES CONCEPTUAL SITE MODEL

The Physical Processes CSM focuses on the important processes that affect hydrodynamics and sediment transport in the EW. This CSM is based on the current understanding of the EW system derived from the information in the EISR (Anchor and Windward 2008a) and the results of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

Information used to develop the Physical Processes CSM included site-specific empirical data and output from hydrodynamic, sediment deposition, and prop wash modeling. Empirical data include historical bathymetry (Section 2.3.1) and dredging records (Section 2.3.2), tidal elevations from Elliott Bay, flow data from the Green River, velocity and salinity profile measurements south and north of the Spokane Street Corridor and within the main body of the EW, sedimentation data from the EW, and *in situ* measurements of critical shear stress in the EW (Anchor and Windward 2008a; Anchor QEA and Coast & Harbor Engineering 2012). Model output included predictions of current velocities and salinities for average and high flow events within the EW (hydrodynamic model), predictions of annual average deposition patterns from lateral sources within the EW (particle tracking model [PTM]), and near-bottom current velocities due to vessel operations (prop wash) within the EW(Anchor QEA and Coast & Harbor Engineering 2012).

Two maps have been created to depict the Physical Processes CSM in the EW. Maps 3-1a and 3-1b present the hydrodynamic processes during average and high flow conditions, respectively, and Map 3-2 presents the accompanying sediment transport processes as driven by the hydrodynamics and anthropogenic activity (e.g., vessel operations).[24] An overview of the processes depicted on these maps is provided in Section 3.1. Detailed discussion is provided as follows:

- Hydrodynamics of the EW(Section 3.2)
- Vessel operations within the EW(Section 3.3)
- Sediment transport within the EW; from upstream and lateral sources (Section 3.4)
- Erosion potential within the EW; due to estuarine currents and vessel operations (Section 3.5)

[24] Maps showing bathymetry in the EW in plan and cross-section view are found in Section 2, Maps 2-7a through 2-7d.

3.1 Overview of the Physical Processes CSM in the East Waterway

Hydrodynamic circulation in the EW is controlled by tidal exchange with Elliott Bay to the north and freshwater inflow from the Green River (through the LDW) from the south. Flows from stormwater and CSOs have a negligible influence on large-scale circulation in the EW. The composition of the EW can be generally described as two-layer flow, with a wedge of saltwater extending from Elliott Bay upstream through the EW and into the LDW underneath a layer of fresher water flowing from the Green/Duwamish River. The decreasing water depth from the upstream confluence of the EW in the Junction Reach to the Sill Reach; and subsequent increase in water depth moving north into the Shallow and Deep Main Body Reaches, has an influence on velocities structure in the EW. Maps 3-3 through 3-8 illustrate predicted velocities throughout the water column along the centerline of the EW for various upstream flows and tidal phases.

In general, as upstream inflow increases, predicted surface velocities within the EW increase. Average surface velocities range from 20 to 25 cm/s, and maximum surface velocities range from 90 to 95 cm/s (2- to 100-yr flows, respectively). Average and maximum predicted surface velocities at mean annual flow are 10 and 70 cm/s, respectively. Predicted average near-bed velocities are relatively constant over the range of flows from mean annual to the 100-yr upstream flow at 5 cm/s. Maximum near-bed velocities increase with increasing upstream flow; from 18 to 28 cm/s for mean annual and 100-yr flows, respectively. Maximum predicted surface velocities are directed out of the EW (downstream), while maximum predicted near-bed velocities are directed into the EW (upstream). The vertical gradient in salinity in the EW is directly related to upstream flow into the EW, where the range in salinity between surface water and bottom water increases with increasing upstream flow. The split in flow between the EW and WW is predicted from modeling to be about equal during normal flow events (annual average) but approximately 30%:70% (EW:WW) during 2-year flows and higher events. The split in flow was validated over a range of tidal conditions during a higher flow event (4,000 cfs) using ADCP transect data collected within the EW as part of the STE.

Riverine and tidal currents in the EW are not expected to cause significant erosion of *in situ* bed sediments, as the maximum predicted bed shear stress for a 100-year high-flow event is

modeled to be less than the critical shear stress[25] of the bed sediments (estimated from site-specific Sedflume data). Modeled bed shear stress due to large vessel operations (e.g., prop wash) in portions of the Deep Main Body Reach (north of Station 4200) is significantly greater than bed shear stress due to natural forces. Consequently, these areas are likely subject to episodic mixing, erosion and re-suspension of bed sediments due to prop wash activity. The remainder of the Deep Main Body Reach (between Stations 4200 and 4900), the Shallow Main Body Reach, and the Junction Reach are also subject to impacts from vessel operations; however, the vessels that operate in these areas are smaller in size and operate less frequently than in the Deep Main Body Reach (north of Station 4200). Therefore, these areas may be subject to occasional mixing, erosion or re-suspension of surface sediments due to prop wash/vessel activity.

Portions of the EW have been dredged from their original deltal mudflat/shallows condition to create navigation depths for vessel operations and provide material for filling the adjacent uplands. In addition, as vessel sizes have increased, dredging actions have been conducted to deepen portions of the federal navigation channel as required to sustain Port of Seattle operations. There is also a small amount of berth maintenance dredging in some areas along the pier edge. The recent dredging history of the EW is discussed in Section 2.3.2 and illustrated in Map 2-7. In comparing dredging records from the 1970s and 1980s to those from the early 2000s, it is apparent that previously dredged areas of the EW have experienced sediment accumulation subsequent to the dredging.

Sediment sources to the EW include the upstream sources (Green River, LDW bed and bank sediments, and LDW lateral load sediments), downstream sources (Elliott Bay), and local sources (lateral sources that drain directly to the EW). Geochronology cores were collected in the EW to evaluate net sedimentation rates (Anchor QEA and Coast & Harbor Engineering 2012). Cores were placed in areas that had not been recently dredged[26] (see Map 2-7), and in areas representative of different hydrodynamic regimes (Anchor QEA

[25] In this report, critical shear stress is defined as a property of the in situ bed sediments. It represents the value of shear stress (applied to that bed due to current velocities) at which the bed sediment would begin to mobilize (e.g., erode).

[26] Dredged areas within the EW were expected to have a non-detect for the Cs-137 peak due to the depth of sediment below mudline removed during dredging actions.

2009). The evaluation of the 18 geochronology recovered cores (Maps 3-11a and 3-11b) suggests that the majority of the Shallow and Main Body Reaches (between Stations 2800 and 6800) and the interior of Slip 27 (Map 2-2) are net depositional. Net sedimentation rates measured for recoverable cores for these areas range from 0.1 to 4.2 cm/yr. Cores were not collected in the Deep Main Body Reach between Stations 2800 and 5000 because this area had been recently dredged. However, cores collected in the Deep Main Body Reach between Stations 0 and 2800 suggest that this area is net depositional but influenced by localized episodic mixing and/or erosion events due to propwash from vessel operations. Results of the hydrodynamic model and propwash modeling show that the entire Deep Main Body Reach (Stations 0 to 5000) is subject to similar estuarine and propwash velocities. Therefore, it is possible that the entire Deep Main Body Reach has similar sedimentation characteristics as the sampled area between Stations 0 and 2800 (when dredging events are excluded).

Some geochronological cores had no recovery due to presenese of sands and gravels in the surface sediments at the sample locations, likely due to the influence of vessel operations in these areas. These locations included the center of the Junction Reach, adjacent to the western berth in the Shallow Main Body Reach, and adjacent to the berth at T-30 (see Map 3-10). The range of net sedimentation rates for all cores (including those with no recovery) is assumed to be 0 to 4.2 cm/yr.
Geochronology cores were not retrieved in the Sill and Junction Reaches due to presence of sand and gravel surface sediments. Presence of sample locations where geochronology cores could not be collected indicates that physical processes are occurring in these reaches that do not permit long-term sedimentation to occur.

Results of the sediment transport modeling completed for the LDW FS (QEA 2008) and results of the PTM modeling of lateral sources within the EW (Anchor QEA and Coast & Harbor Engineering 2012) completed for the SRI/FS suggest that 99% of the incoming suspended sediment to the EW is from the Green River, approximately 0.7% is from LDW (bed sediments and lateral loads), and less than 0.3% is from lateral loads within the EW itself (see Section 3.4). Results from the LDW sediment transport model (QEA 2008) suggest that essentially 100% of the incoming upstream load to the EW from the Green River and LDW (bed sediments and lateral loads) consist of silts and clays. Sediment load into the EW from Elliott Bay is assumed to be negligible compared to the other sources. Comparing modeled estimates of sediment loads and net sedimentation rates in the EW (measured from

geochronology cores), between 25 to 60% of the incoming suspended sediment is estimated to deposit in the EW and between 40 to 75% of the incoming suspended sediments is estimated to leave the EW, most likely moving out into Elliott Bay. Initial mass deposition patterns within the EW from local lateral sources (evaluated through PTM) show the majority of initial deposition occurs close to the outfall locations, with relatively little deposition (less than 0.2 cm/yr) occurring in the deeper areas of the EW.

3.2 Hydrodynamics of the East Waterway

Hydrodynamics in the EW is tidally driven with influence at high flow events from freshwater inflow from the Green River (through the LDW). The average tide range in the EW (based on MHHW at NOAA gage No. 9441730) is approximately 11.4 ft, which results in an average exchange of 580 million gallons of water over each tidal cycle. Circulation patterns and velocity magnitudes within the EW over a range of upstream flow and tidal conditions were evaluated in the EW STE through use of a three-dimensional hydrodynamic model (Anchor QEA and Coast & Harbor Engineering 2012).

In all modeled events, there is a net outflow (averaged over the tidal cycle) of lower salinity (fresher) water in the upper layers of the EW, and a net inflow (averaged over the tidal cycle) of high-salinity water in the bottom layers.[27] Higher outgoing (downstream) current velocities are located in the surface layer in the Junction and Sill Reaches. Surface velocities are highest in the Junction and Sill Reaches (maximum 95 cm/s), and are lower in the Main Body Reaches (maximum 40 cm/s). Near-bed velocities are highest in the Main Body Reach near the mouth of the EW (maximum 28 cm/s) and lowest in the area south of Slip 27 (maximum 2 cm/s).[28] The magnitude of the bottom current velocity increases in the Sill and Junction Reaches primarily during high flow events, although they are still lower than at the mouth of the Main Body Reach. Salinity is highest in the bottom layers near the mouth of the EW and lowest in the surface layers in the Junction Reach.

[27] At discrete time periods during the tidal cycle and in certain locations within the water column, the flow may be upstream or downstream. Net directions of flow refer to the direction of velocity averaged over a complete tidal cycle.

[28] Current profile data within the EW used for calibration of the hydrodynamic model include upstream flows up to a maximum of 4,000 cubic feet per second (cfs; recorded on May 20, 2009). This flow is significantly higher than the mean annual flow of 1,340 cfs and almost half of the 2-yr flow of 8,400 cfs.

The presence of distinct two-layer flow (inflow of higher density saline water at depth with outflow of fresher water at the surface) becomes more prevalent as upstream inflow increases. During flow events equal to or less than the 2-year flow, vertical gradients in salinity are consistent throughout the EW (Map 3-1a). During higher flow events (10- through 100-year flows), vertical gradients in salinity are more pronounced as a layer of brackish to fresh water overlies higher salinity water (Map 3-1b). During the 100-year flow in the Sill and Junction Reaches, brackish to freshwater[29] conditions are present throughout the water column. At any given location, average salinity decreases as upstream inflow increases.

Current velocities within the EW due to tidal and riverine currents are relatively low during flow events equal to or less than the 2-year flow, based on results of the hydrodynamic model and review of site-specific velocity profile data used to calibrate the model. As upstream inflow increases, surface velocities within the EW increase. Average surface velocities range from 20 to 25 cm/s, and maximum surface velocities range from 90 to 95 cm/s (2- and 100-yr flows, respectively). Average and maximum predicted surface velocities at mean annual flow (1,330 cfs) are 10 and 70 cm/s, respectively (Anchor QEA and Coast & Harbor Engineering 2012). Predicted average near-bed velocities are relatively constant over the range of flows, from the mean annual to the 100-yr upstream flow, at 5 cm/s. Maximum near-bed velocities increase with increasing upstream flow, from 18 cm/s for mean annual flows to 28 cm/s for 100-yr flows.

Maps 3-3 through 3-5 show predicted vertical distributions of salinity and along-channel velocities within the EW for all three reaches for typical flood tide conditions for the mean annual, 2-yr, and 100-yr high-flow events (Table 2-2), respectively. Maps 3-6 through 3-8 show the same information for typical ebb tide conditions for the mean annual, 2-year, and 100-year high-flow events, respectively. These maps illustrate typical extremes of current velocities and salinities within the EW over the tidal cycle with increased river flow rates.

As the flow rate from upstream increases, so does the magnitude of the net current velocities (averaged over the tidal cycle). During the modeled 2- and 100-yr high-flow events, all

[29] Fresh water is defined as having salinities from 0 to 5 ppt.

vertical layers have a net outgoing flow[30] (averaged over the tidal cycle) in the Sill and Junction Reaches. Specific discussion of hydrodynamics within each of the identified reaches of the EW (Map 2-2) is provided in Sections 3.2.1 through 3.2.3.

3.2.1 Main Body Reach

The Main Body Reach is made up of two sub-areas, the Deep Main Body Reach and Shallow Main Body Reach (Map 2-2) with typical bed elevations of approximately -50 ft MLLW and -30 ft MLLW, respectively. The Main Body Reach as a whole is characterized by relatively low current velocities and a discernible distribution of top to bottom salinity, ranging from approximately 14 ppt at the surface to 32 ppt[31] at the bed depending on tidal phase and upstream flow. Velocity magnitudes at the surface range from approximately 0 to 40 cm/s (based on model predictions[32]), with higher current velocities occurring during ebb tide during higher upstream flow events. Surface current velocities tended to be higher in the southern portion of the reach and lower toward the mouth of the EW. Surface water flows towards Elliott Bay during all tidal phases for all flow events; however, velocity magnitudes during flood tide and annual average flow conditions are less than 10 cm/s. Maximum near bottom velocities within this reach ranged from approximately 0 to 28 cm/s, with current velocity increasing as upstream flow increases. Near bottom current velocities were higher near the mouth of the EW (28 cm/s) and were lower to the south. The increase in near bottom velocity at the mouth of the EW, and subsequent reduction in current velocities moving upstream (and with increasing upstream flow), is due to the two-layer density-driven circulation within the EW. During incoming tide, higher salinity water flows from Elliott Bay into the relatively constricted opening of the EW at depth, which produces

[30] At discrete time periods during the tidal cycle and at certain locations within the water column, the flow may be upstream or downstream. However, averaged over a complete tidal cycle (net velocity) the velocities are directed downstream (outgoing).

[31] Based on model predictions (see next footnote) using an initial salinity of 31 ppt in Puget Sound.

[32] Velocities and salinities in this and following sections were taken from model predictions from the hydrodynamic model developed and calibrated using site-specific empirical datafor the EW as part of the EW STE. Additional information about model development and specific empirical data used to calibrate the model can be found in Sections 2.2 and 4.4 of the STER (Anchor QEA and Coast & Harbor Engineering 2012 [in prep]).

higher near bottom velocities at the mouth of the EW. As this flow moves upstream, density-driven circulation and vertical mixing of the incoming tidal waters with the lower salinity surface waters (from upstream flows) causes a reduction in near bottom velocities between the mouth and the Sill Reach in the EW.

A layer of lower salinity water (between 14 and 26 ppt) ranging in depth from about 5 to 20 ft (depending on tide and upstream flow conditions) is found at the top of the water column, with a nearly constant vertical distribution of high salinity water found from the bottom of the fresher water layer to the sediment bed. Over the tidal cycle, surface salinities range from 22 to 26 ppt for mean annual flow and 14 to 18 ppt for 100-yr high-flow event. Bottom salinities range from 30 to 31 ppt for mean annual and 100-yr high-flow event.

3.2.2 Junction Reach

The Junction Reach is shallower than the Main Body Reaches (but deeper than the Sill Reach) with typical bed elevations of approximately -15 ft MLLW. It is characterized by high surface current velocities (compared to the Main Body Reach) with a distinct top to bottom salinity stratification during most flow conditions. Current velocity magnitudes at the surface range from approximately 0 to 90 cm/s, with higher velocities occurring during ebb tide at higher upstream flows. Surface water from EW flows upstream into the LDW during low flow conditions at flood tide; however, these current velocities are quite low. Maximum near bottom velocities range from 0 to 10 cm/s and are generally consistent throughout the reach.[33] Near bottom velocities are highest during ebb tide, increase with increasing upstream flow rate, and are affected by the pervasive two-layer flow that exists in this reach as well as the majority of the EW. Upstream flow of higher salinity water in the bottom layers (compared to surface layer salinities) during flood tide confine high downstream current velocities (due to upstream freshwater input) to the surface layers. This results in lower near bottom current velocities in the Junction Reach than would be expected if the system had single-layer flow (no flow reversal at depth).

[33] Relatively low bottom velocities predicted in the Junction Reach (and the relatively high near bottom velocities in the Main Body Reach) are due to the predominance of a two-layer flow regime in the EW, and are expected due to the estuarine behavior of the EW (as opposed to a purely riverine system that exhibits no tidal influence). Mid-depth velocities and surface velocities in the Junction Reach are relatively high; also due to the estuarine flow pattern of the EW.

A layer of fresher water is found at the top of the water column with a nearly constant vertical distribution of higher salinity water found at the bottom of the water column. The thickness of the fresher water, and top to bottom salinity differences, vary with upstream flow conditions. During periods of high flow, lower salinity water can encompass most of the water column. Top to bottom salinity ranges from 0 to 22 ppt for mean annual flow and 0 to 14 ppt for 100-year high-flow events.

3.2.3 Sill Reach

The Sill Reach is the shallowest point within the EW (not including the bank slopes) with typical bed elevations of approximately -10 ft MLLW. The Sill Reach is similar to the Junction Reach in both current velocity structure and salinity distribution. The Sill Reach is characterized by shallow water, with water depths of approximately 6 ft at MLLW. Surface current velocities have similar magnitudes to the Junction Reach and react similarly to increases in upstream flow and tidal conditions. Maximum near bottom velocities within the Sill Reach are slightly lower than in the Junction Reach and range from 0 cm/s to approximately 7 cm/s. This difference in velocities between the two reaches is caused by the increased width of the Sill Reach. Salinity distribution within the Sill Reach is also similar to the Junction Reach; however, bottom salinities remain slightly higher than in the Junction Reach for all flow conditions. Top to bottom salinity ranges from 0 to 22 ppt for mean annual flow and 0 to 18 ppt for 100-yr high-flow event. Near bottom current velocities within the Sill Reach are similar to the Junction Reach, in that they are also affected by the pervasive two-layer flow that is characteristic of the EW. Therefore, near bottom current velocities in this reach are lower than would be expected if the system were riverine (as opposed to estuarine).

3.2.4 Split in Flow Between East Waterway and West Waterway

The split in upstream flow between the EW and WW was evaluated using model predictions and validated with site-specific ADCP current transect data collected within the EW in May 2009 (Anchor QEA and Coast & Harbor Engineering 2012). A comparison between model predictions and ADCP current transect data was conducted and model results compared favorably with data. Upstream input to the EW and WW from the LDW is split approximately equally during flow events equal to or less than the 2-yr flow. During flow events greater than the 2-yr flow, the EW:WW flow split is consistently about 30%:70% (for

2- to 100-yr flows[34]). The reduction in the percentage of flow within the EW (compared with the WW) is caused by the relatively constricted entrance to the EW.

3.3 Vessel Operations within the East Waterway

Major vessel hydrodynamic characteristics that can have an impact on the mobility of sediment include prop wash,[35] vessel wakes,[36] and pressure fields.[37] Analysis of the effect of vessel hydrodynamics on bottom sediment mobility presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012) and this SRI report included prop wash and pressure fields. Due to low vessel speeds, impacts from vessel wakes are expected to be minimal.

Typical and extreme vessel operations within the EW were developed through interviews and personal conversations with various organizations, agencies, and companies that operate vessels within the EW. Table 3-1 provides a list of these information sources and dates of communication.

Table 3-1
Information Sources Used to Develop Vessel Operation Areas

Type of Information	Organizational Source	Individual Source	Communication Date(s)
Ship and tug operations	Puget Sound Pilots Association	Captain Jonathan Ward and Captain Eric VonBrandenfels	January 2011/ February 2011
USCG operations	USCG	Bobbie Battaglia (Environmental Branch Chief) and Randy Sommerville (Port Services Division Officer)	February 2011
Barge and tug operations	Harley Marine (formerly Olympic Tug and Barge)	Don Meberg	February 7, 2011

[34] The split in flow between the EW and the WW for the 2- through 100-yr flow events were taken from model predictions from the hydrodynamic model developed and calibrated for the EW STE. The split in flow was also validated over a range of tidal conditions during a higher flow event (4,000 cfs) using ADCP transect data collected within the EW as part of the STE.

[35] Prop wash refers to current velocities in the water column that are caused by the motion of the ship's props and/or thrusters.

[36] Vessel wakes refer to bow and stern waves that are produced by a vessel as it moves through the water.

[37] Pressure field refers to currents in the water column produced by the depression in the water that is created as a vessel moves through a waterway.

Type of Information	Organizational Source	Individual Source	Communication Date(s)
General vessel operations and future vessel operations	Port of Seattle	Eric Hanson and Doug Hotchkiss	January 2011 through March 2011
Vessel operations in junction reach	Harbor Island Marina	Kathy Goodman	February 2011

USCG – US Coast Guard

Information on vessel types and typical and extreme vessel operations during berthing and navigation with the EW were compiled from the various sources shown in Table 3-1. This information was used to develop operational areas within the EW where potential vessel operations were similar. Map 3-9 provides a map of the similar type operational areas developed for the EW through this process.

Within each of these operational areas, anticipated extreme vessel operation scenarios (with respect to potential for erosion due to prop wash) were chosen as representative of that operational area. These vessel operations do not represent typical fair weather operating procedures; instead they represent berthing and navigation operations in high winds, high currents, or other atypical environmental conditions within the EW. They do not represent "worst case" emergency operations. Additional evaluation will be conducted during the design phase of the project to address effects of these "worst case" emergency operations on design.

Fifteen scenarios were developed for analyzing the effects of vessel operations within the EW. The scenarios consist of maneuvers for: 1) docking, undocking, and navigating the waterway; 2) using a ship's main power and thrusters; and 3) using various types of tugs. Additional specifics regarding vessel characteristics (e.g., length, depth, and draft) and propulsion were collected from public information obtained from the shipping line, tug companies, and Coast and Harbor Engineering archives and are provided in more detail in the STER (Anchor QEA and Coast & Harbor Engineering 2012).

All simulations assumed a tidal elevation of 0 ft MLLW[38] and maximum draft for the vessel. These assumptions will result in conservatively high estimates of average near-bed velocity and bed shear stress due to prop wash because it represents the case where the ship's propulsion system is close to the bed. Simulations of all vessels, including tugs, in the docking and undocking maneuvers assumed that the source of prop wash was stationary. Tugs transiting scenarios were assumed to have a speed of 4 knots, which represents safe operating speeds within the EW based on interviews with tug pilots. The 15 simulation scenarios and pertinent model input parameters are listed in Table 3-2. Results of the prop wash modeling for erosion potential in the EW are presented in Section 3.5.3.

Table 3-2
Prop Wash Modeling Scenarios for East Waterway

Scenario	Prop Wash Area/ Terminal	Depth at MLLW/ Vessel Draft (ft)	Vessel Type/ Name	Maneuver	Propulsion Type	Available Power (%)
1	Area 1A, Berths 1 and 2/Terminal 18	50/46	container/ Xin Mei Zhou	docking	ship's main power	10
2	Area 1A, Berths 1 and 2/Terminal 18	50/46	container/ Xin Mei Zhou	undocking	bow thruster	100
3	Areas 1A and 1B, all berths/Terminal 18	50/13	tractor tug/ Garth Foss	docking a container ship	Voith-Schneider	75
4	Area 1A, Berths 3 and 4/Terminal 30	50/39	container/ Margrit Rickmers	docking	ship's main power	10
5	Area 1A, Berths 3 and 4/Terminal 30	50/39	container/ Margrit Rickmers	undocking	bow thruster	100
6	Area 2, Slip 36	40/32	USCG icebreaker/ Polar Star	docking	3 controllable pitch props	50
7	Area 2, Slip 36	40/20	USCG cutter/ Hamilton Class	docking	2 controllable pitch props	50
8	Area 3, Slip 27	30/14	tug/Hunter D	docking a barge	2 standard props	50
9	Areas 4, 4A, 4B, and 5/South Terminal 30	40/17	tug/Eagle	docking a barge	twin-ducted props	75

[38] Mean lower low water is considered a representative low water operational condition for the vessel operations within the EW; as extreme low water occurs a small fraction of the time during the year (see Section 5.1.3 of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).

Scenario	Prop Wash Area/ Terminal	Depth at MLLW/ Vessel Draft (ft)	Vessel Type/ Name	Maneuver	Propulsion Type	Available Power (%)
10	Area 6	20/17	tug/Eagle	docking a barge	twin-ducted props	50
11	Area 7	30/17	tug/Eagle	maneuvering with barge	twin-ducted props	50
12	Area 8	20/14	tug/Alaska Mariner	docking	twin props	50
13	Areas 1B and 1C/ Terminals 18 and 30	50/13	tractor tug/ Garth Foss	navigation through EW	Voith-Schneider	50
14	Area 4A (future condition)	46/39	container/ Margrit Rickmers	docking	ship's main power	10
15	Area 4A (future condition)	46/39	container/ Margrit Rickmers	undocking	bow thruster	100

EW – East Waterway
MLLW – mean lower low water
USCG – US Coast Guard

3.4 Sediment Transport within the East Waterway

This section describes sediment transport processes within the EW, including solids sources to the EW and the fate and transport of those solids within the EW Study Area. Solids sources to the EW include upstream and downstream sources (see Section 3.4.1) and EW lateral sources (Section 3.4.3). These incoming solids either settle within the EW Study Area or are transported out of the area based on current velocities and circulation structure in the EW (see Section 3.2). The circulation patterns within the EW were characterized through hydrodynamic modeling (Section 3.2), which predicts low currents in the EW (on average) and a distinct two-layer flow that allows suspended sediment to be transported either upstream or downstream depending on tidal phase, upstream flow, and location of the solids in the water column.[39] Net sedimentation rates in the EW were evaluated using site-specific

[39] The presence or potential influence of sediment trapping at the toe of the saltwater wedge in an estuary (estuarine turbidity maximum [ETM]) was not directly evaluated as part of the EW STE. Based on the results of the LDW hydrodynamic model (Windward and QEA 2008), the toe of the saltwater wedge in the LDW is located between 2 to 4 miles upstream of the EW/WW split. Based on these modeling results, the ETM does not appear to be located or translate through the EW and is, therefore, not expected to impact sedimentation in the EW.

empirical data (Section 3.4.2) and the waterway was found to be net depositional, on average, when dredging activity is excluded. The evaluation of erosion potential in the EW (Section 3.5) found that significant bed scour or erosion of *in situ* bed sediments within the EW is not predicted to occur as a result of tidal or riverine currents. However, mixing, erosion and re-suspension of bed sediments due to prop wash (vessel operations) is likely over a significant portion of the EW (Section 3.5). The following sections describe these processes in more detail.

3.4.1 Upstream Sediment Sources to the East Waterway

Flow enters the EW from the LDW, which includes suspended sediment originating from the Green River (99%) and suspended sediments originating in the LDW (less than 1%), which are a combination of eroded bed sediments and lateral sources that drain into the LDW (QEA 2008). Consequently, it is assumed that the bulk of the sediment reaching the EW from upstream sources is also largely derived from Green River sediments, although this has not been specifically modeled for the EW. Suspended load transport from Elliott Bay and the WW (during flood tide) into the EW is assumed to be negligible compared to contribution from sources upstream of, or lateral to, the EW.[40]

Based on results of the LDW sediment transport model (QEA 2008), the total estimated sediment/solids load transported through the LDW to the junction with the EW and WW over the 30-yr simulation was 3,241,390 metric tons, with 3,215,850 metric tons from the Green River, 7,840 metric tons from eroded bed sediments within the LDW, and 17,770 metric tons from lateral sources (AECOM 2010a). Results from the LDW sediment transport model (QEA 2008) suggest that essentially 100% of the incoming upstream load to the EW from the Green River and LDW (bed sediments and lateral loads) consist of silts and clays. The percentage of flow from the LDW that enters the EW was evaluated in the EW STER (Anchor QEA and Coast & Harbor Engineering 2012) as varying between 50% (for 2-yr flows and below) and 30% (for flows greater than the 2-yr event). Assuming that the

[40] The study of sediment transport in Elliott Bay has identified pathways of transport from Elliott Bay into the EW (McLaren and Ren 1994), but did not quantify the suspended load in Elliott Bay or deposited load into the EW from Elliott Bay sediments. Empirical TSS data collected by King County (in the LDW and Elliott Bay) and TSS values in the LDW predicted by the sediment transport model (QEA 2008) suggest that incoming suspended load from the LDW is significantly larger than suspended sediment coming from Elliott Bay.

split in suspended sediment load between EW and WW follows the split in flow[41] and using the average mass per year (over the 30-yr simulation time of the LDW model), the annual average sediment loads transported into the EW from upstream are predicted to be as follows:[42]

- Green River source = 32,159 to 53,598 metric tons per year
- Eroded bed sediments in the LDW = 78 to 131 metric tons per year
- Lateral sources within the LDW = 178 to 296 metric tons per year

3.4.2 Net Sedimentation Rate

Geochronology cores were collected within the EW to evaluate net sedimentation rates within various portions of the EW that have not been recently dredged. The locations of the cores included the Main Body, Junction, and Sill Reaches of the EW. The geochronological core locations were chosen to provide reasonable spatial coverage at different hydrologic regimes throughout the EW. Sampling locations did not include known dredge areas since using geochronology analysis to estimate net sedimentation rates may be problematic due to the disturbance of the sediment profile (Section 2.3.2 and Figure 1-6 of the EISR (Anchor and Windward 2008a)). These data provide a key line of evidence in the evaluation of net sedimentation rates throughout the study area. Twenty-two sediment cores were proposed for collection. Of the 22 proposed cores, 18 were collected. Four cores were not collected due to the presence of dense substrate near the surface in those proposed locations, which prevented penetration and sampling. The locations of the 18 collected geochronological cores, as well as locations of the four cores that were not collected, are shown in Map 3-10.

An evaluation of 18 geochronology cores recovered within the EW (Maps 3-11a and 3-12b) suggests that the majority of the Shallow Main Body Reach (between Stations 5000 and 6800) and the interior of Slip 27 (Map 2-2) are net depositional with minimal mixing of sediments in these areas. The geochronology core (GC-17) attempted along the western shoreline of the Shallow Main Body Reach (between Stations 6200 and 6800) was not retrieved due to

[41] This assumption was made based on results of the LDW sediment transport model (QEA 2008), which predicts that effectively all of the upstream sediment load input to the EW consists of fine particles (silts and clays), which should be well distributed in the water column.

[42] This estimate is not quantifying what settles in the EW from upstream; only a portion settles in the EW.

consolidated surface sediments (sand and gravels) at this location. The surface sediments in this area are likely impacted by prop wash due to tug and barge operations in the area.

The Deep Main Body Reach (Stations 0 to 5000), including the mouth of Slip 36, appears to be net depositional based on results of lead-210 (Pb-210) data at GC-05 and GC-08, which provide net sedimentation rates of 0.7 and 0.3 cm/year, respectively. This area also appears to be heavily influenced by episodic erosion events due to prop wash from vessel operations based on known vessel operations in this area (see Section 3.5.3) and unreadable cesium-137 (Cs-137) core data in this area (GC-02, GC-05, GC-08, and GC-09). Cores were not collected in the Deep Main Body Reach between Stations 2800 and 5000 because this area had been recently dredged. Therefore, net sedimentation rates described herein represent rates that do not account for recent dredging activities in the EW. It is likely that measured net sedimentation rates in discrete locations within the EW would be different than the average net sedimentation rate if there were no vessel activity in the EW.

Geochronology cores were not retrieved in the Sill and Junction Reaches due to presence of sand and gravel surface sediments. Presence of sample locations where geochronology cores could not be collected indicates that physical processes are occurring in these reaches that do not permit long-term sedimentation to occur. The Sill Reach is not navigable due to shallow water depths; however, Junction Reach is navigable and parts of it are likely influenced by prop wash due to vessel operations along the lateral dock located on the west side of this reach (see Section 3.5.3).

Net sedimentation rates were calculated for each of the eight recovered cores with interpretable Cs-137 activity profiles and eight cores exhibiting high correlation (R^2 values greater than 0.5) Pb-210 activity profiles. The estimated rates are shown in Table 3-3 and Map 3-11a (Cs-137) and Map 3-11b (Pb-210).

Table 3-3

Comparison of Net Sedimentation Rates

Sediment Core ID[a]	Estimated Net Sedimentation Rates from Cs-137 Analysis (cm/yr)		Estimated Net Sedimentation Rate from Pb-210 Analysis (cm/yr)	
	Via Cs-137 Peak	Range[b]	Estimate Based on Best-Fit Line	Range[b]
GC-02	--[c]	--[c]	--[d]	--[d]
GC-05	--[c]	--[c]	0.67	0.26 – 0.67
GC-08	--[c]	--[c]	0.28	0.20 – 0.48
GC-09	--[c]	--[c]	0.56	0.35 – 1.4
GC-10	1.3	1.2 – 1.4	0.61	0.30 – 0.61
GC-11	> 1.7	1.6 – 1.8	0.47	0.27 – 1.8
GC-12	> 1.9	1.8 – 2.0	0.46	0.27 – 1.8
GC-13	--[c]	--[c]	0.69	0.34 – 0.69
GC-14	1.2	1.1 – 1.3	--[d]	--[d]
GC-15	1.3	1.2 – 1.4	--[d]	--[d]
GC-16	1.6	1.5 – 1.7	0.18	0.09 – 4.2
GC-18	> 1.9	1.8 – 2.0	--[d]	--[d]
GC-19A	1.2	1.1 – 1.3	--[d]	--[d]
GC-20	--[e]	--[e]	--[e]	--[e]
Average NSR from recovered interpretable cores	1.6	1.4 – 1.6	0.5	0.3 – 1.5

[a] Sediment cores GC-01, -03, -06, and -07 were archived. Sediment Cores GC-04, -17, -21, and -22 were not recovered due to the presence of sand/gravels in surface sediments.

[b] Average values of the range represent the average value of the low end of the range to the average value of the high end of the range.

[c] No Cs-137 peak observed.

[d] Net sedimentation rate not estimated due to low correlation ($R^2 < 0.50$).

[e] Low recovery in core so data are un-interpretable.

ID – identification

Cs – cesium

Pb – lead

Analyses of Cs-137 and Pb-210 profiles in the recovered cores for which net sedimentation rates can be reliably estimated indicated that measured net sedimentation rates within the EW range between 1.1 and 2.0 cm/yr for Cs-137 data and 0.1 to 4.2 cm/yr for Pb-210 data. Net sedimentation rates measured for Cs-137 data for three cores (GC-11, -12, and -18) may be higher than reported for those cores in Table 3-3 (1.7 to 1.9 cm/yr). These cores had increases in concentration of Cs-137 at the bottom of the recovered core, but the Cs-137

peak may have been below the recovered depth of the core based on comparisons with other cores where the peak was fully captured (see Figures 3-3A to 3-3B in the STER (Anchor QEA and Coast & Harbor Engineering 2012)).

The average net sedimentation rates shown in Table 3-3 for recovered cores are 1.6 cm/yr for Cs-137 data and 0.5 cm/yr for Pb-210 data. Due to the potentially truncated Cs-137 peak for three of the cores as described above, the average net sedimentation rate for recovered cores for Cs-137 data may be higher than 1.6 cm/yr. These net sedimentation rates are consistent with the results of earlier studies in the EW and WW for Cs-137 (1.0 to 2.4 cm/yr) and Pb-210 (0.5 to 0.8 cm/yr) (EVS and Hart Crowser 1995).[43]

There were four locations within the EW (see Map 3-10) where geochronological cores could not be collected due to presense of consolidated sands and gravels in the surface sediment; therefore, the net sedimentation rate is assumed to be zero at these locations. These cores include GC-21 and GC-22, which are located in the Junction Reach adjacent to a lateral dock; GC-17, which is located at an active shallow berth in the Shallow Main Body Reach; and GC-04, which is located in the berthing area for T-30. The range in net sedimentation rates estimated from all cores (including the four with no recovery) is assumed to be 0 to 4.2 cm/yr.

Measured net sedimentation rates do not account for recent dredging activities in the EW, since dredged areas were not sampled. The influence of vessel operations in the EW on net sedimentation rates (e.g., resuspension and re-distribution of EW bed sediments by propwash) are captured implicitly by the measured sedimentation rates at each core location. It is likely that measured net sedimentation rates in discrete locations within the EW would be different than the average net sedimentation rate if there were no vessel activity in the EW. Therefore, there is an additional uncertainty in extrapotating net sedimentation rates measured at discrete core locations to the entire EW area.

[43] There are several potential reasons that the net sedimentation rates differ between Cs-137 and Pb-210 analyses. Pb-210 evaluation generally represents more recent deposition, while Cs-137 analysis represents longer-term (since 1963) deposition. In urban watersheds, it is possible to have lower net sedimentation rates from Pb-210 data (compared to Cs-137 data) due to changing land use and improved stormwater management. The uncertainties and analytical methodologies themselves are also different (see Section 3 of the STER (Anchor QEA and Coast & Harbor Engineering 2012)).

3.4.3 Contribution from Lateral Sources within the East Waterway

Lateral sources to the EW include storm drain, CSO, and groundwater inputs; bank erosion; and a very small area of overland flow (see Section 9 for discussion of sources and pathways). This section focuses on estimates of lateral sediment sources that can be semi-quantitatively estimated from the SDs and CSOs. General physical characteristics of these inputs were summarized in the STER (Anchor QEA and Coast & Harbor Engineering 2012).

Currently, 39 outfalls (36 SDs, one CSO, and two CSO/SDs) to the EW have been identified (Map 2-2). Two of the outfalls (at Hinds and Lander) are shared by the separated storm drain and combined sewer service systems. These outfalls are referred to as CSO/SD outfalls. Flows and total suspended solids (TSS) concentrations for the stormwater and CSO components of these discharges is provided in Section 9.4.3.2 of this report and additional discussions of loading for these lateral sources are provided in Section 7.2.1 and Appendix F of the STER (Anchor QEA and Coast & Harbor Engineering 2012). Solids loading from lateral sources used in the PTM modeling effort are provided in Section 3.4.3.3.

3.4.3.1 Mass Loading from Storm Drains

Sediment loads from stormwater discharges were developed based on the estimated runoff for an average water year (1986) (see Section 9.4.2.3.1). Runoff estimates were developed using a simplified Hydrologic Simulation Program-Fortran model that calculated runoff volumes per unit area for individual land use, soil type, and slope based on regional Puget Sound input parameters and local rainfall data. Sediment loads were calculated by multiplying the annual stormwater volume by a representative TSS concentration. Representative TSS values were estimated based on land use using stormwater data compiled from studies conducted in western Washington and Oregon. TSS values from drainage of parking lots and other paved areas were used to characterize runoff quality for the largely paved port terminal areas. For all other areas, TSS values were based on available stormwater data for the various land use categories within each drainage basin (e.g., industrial, commercial, single-family residential, multi-family residential, roadway/ROW). Section 9.4.3.2.2 of this report provides summery statistics for TSS values, which were used to develop stormwater solids loading for the STE.

The particle size distribution of the four sediment classes for stormwater discharge was developed through evaluation of site-specific data, as described in Appendix F, Attachment 1

of the STER (Anchor QEA and Coast & Harbor Engineering 2012). Characteristic diameters attributed to stormwater were defined in the LDW sediment transport modeling report (Windward and QEA 2008) and are provided in Table 3-4.

Table 3-4
Characteristic Diameter and Particle Size Distribution for Stormwater

Sediment Size Class	Effective Diameter (microns)	Effective Diameter (mm)	Percent of Each Sediment Class in Stormwater		Percent of Each Sediment Class in CSOs
			From Site-Specific Sediment Trap Data[a]	Assumptions Used in LDW Study[b]	Assumptions Used in LDW Study[b]
1A: Clay and fine silt	5	0.005	15%	55%	42%
1B: Medium/coarse silt	20	0.02	23%	18%	41%
2: Fine sand	130	0.13	26%	23%	17%
3: Medium/coarse sand	540	0.54	35%	4%	0%

[a] Anchor QEA and Coast & Harbor Engineering (2012), Appendix F.
[b] Windward and QEA (2008).
LDW – Lower Duwamish Waterway
CSO – combined sewer overflow

3.4.3.2 Mass Loading from CSOs

King County and the City of Seattle monitor CSO discharge frequency and volume as part of their CSO control programs. Sediment loads from CSO discharges were developed based on annual average discharge volumes using approximately 10 years of data. King County has also collected CSO TSS data as part of ongoing source control activities. Summaries of discharge and TSS data are discussed in Sections 9.4.3.2.3 and 9.4.3.2.4 of this report and in Appendix F of the STER (Anchor QEA and Coast & Harbor Engineering 2012), both of which were used to develop CSO solids loading for the STE. The particle size distribution of the four sediment classes shown in Table 3-4 for CSOs was developed through evaluation of data from four King County CSOs, as described in Appendix F of the STER.

3.4.3.3 Particle Tracking Modeling

The initial spatial distribution of sediments deposited within the EW from lateral sources[44] was estimated using the PTM developed by USACE (Anchor QEA and Coast & Harbor Engineering 2012). The purpose of the PTM modeling effort was to estimate the relative contribution and distribution of solids loads from lateral sources to overall sedimentation rates in the EW. In addition, the PTM modeling results will be used to evaluate recontamination potential due to sediment loads from identified lateral sources. Inputs to the PTM model for upstream flows and lateral sediment loads were constant values based on long-term annual average inputs to allow for extrapolation of shorter duration simulations to annual results. Specific inputs to the model include the following:

- Upstream flow – Average annual flow based on hydrology developed by USGS for the gage at Auburn (hydrology is the same as defined for the LDW).
- Tidal conditions were varied over the 28-day simulation and were taken from the NOAA tide gage in Elliott Bay from June 1, 2009 to July 31, 2009 as a representative large amplitude tide cycle.
- Stormwater sediment loads were developed for an average rainfall year (1986; see Section 3.4.2.1).
- CSO sediment loads were developed as annual averages based on approximately 10 years of flow data (see Section 3.4.3.2).

The modeling was completed for a range of sediment mass loadings based on the range of TSS values in stormwater and CSOs (to account for uncertainty and variability in that data). The simulations included a base case (based on the mean TSS values) and upper and lower bounding simulations (based on the 75th and 25th percentile TSS values, respectively).

Estimates of total solids input to the EW from lateral sources ranges from 85 to 151 metric tons per year (based on the 25th and 75th percentile TSS values, respectively). A detailed description of solids loading values from lateral sources in the EW scenarios completed for

[44] The PTM model results represent initial deposition of sediment from lateral sources within the EW. The PTM model did not take into account re-suspension or distribution of deposited sediments, including that caused by vessel operations. Post depositional redistribution of sediment may alter distribution of sediments from lateral sources predicted by the PTM model.

the PTM, including sensitivity evaluation, is provided in Section 7 and Appendix F of the STER (Anchor QEA and Coast & Harbor Engineering 2012). Sediment load inputs for lateral sources (storm drains and CSOs) utilized for the base case and the upper and lower bounding PTM model simulations for each outfall location within the EW (as shown on Maps 3-12 through 3-17) are provided in Table 3-5.

Table 3-5
Solids Input to PTM Model by Outfall

Outfall[a]	Annual Average Solids Load (kg)		
	Base-Case (50th Percentile)	25th Percentile	75th Percentile
1	171	79	239
2	29	13	40
4	1,468	689	2,079
5	643	305	832
6	590	271	932
7	1,632	761	2,284
10	1,032	480	1,440
11	5,223	2,429	7,287
12	923	429	1,288
13	725	337	1,012
14	276	128	386
16	550	255	767
17	306	142	427
18	933	434	1,303
19	752	349	1,049
21	1,408	655	1,965
22	1,519	706	2,119
23	1,410	655	1,967
24	1,209	562	1,687
25	657	328	987
26	1,519	706	2,120
27	981	456	1,368
28	552	257	771
29	1,073	498	1,497
30	866	403	1,210
31	1,147	533	1,601
32	491	228	685
33	1,549	720	2,162
34	2,457	1,129	3,884

Outfall[a]	Annual Average Solids Load (kg)		
	Base-Case (50th Percentile)	25th Percentile	75th Percentile
36	1,061	502	1,399
37	689	320	962
39	234	107	369
39	225	105	314
40	449	239	650
41	857	394	1,354
42	86	39	136
43	1,071	492	1,694
S. Hinds Street[b]	6,920	3,215	10,230
S. Lander Street[b]	31,940	15,070	42,280
Hanford #2 CSO[c]	24,190	18,370	29,810
S. Hinds Street CSO[c]	326	247	401
S. Lander Street CSO[c]	12,960	9,838	15,970

[a] Solids load for stormwater (all outfall numbers, S. Hinds St. and S. Lander St.) taken from runoff modeling completed by Seattle Public Utilities as described in Appendix F, Attachment 1 of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).

[b] Lander drainage basin discharges to the S Lander Street outfall, which is shared with the Lander CSO. S Hinds Street drainage basin discharges to the S Hinds Street outfall, which is shared with the S. Hinds St. CSO.

[c] Solids load for CSOs based on annual average flow discharge data for each CSO and TSS data collected from Hanford #2 and Lander CSOs. Further details are provided in Appendix F, Attachment 2 of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).

CSO – combined sewer overflow
EW – East Waterway
PTM – particle tracking model
STER – sediment transport evaluation model
TSS – total suspended solids

Based on the PTM output, the solids mass contribution to the EW from lateral sources (mass of sediment that settles within the EW) is estimated between 45 and 114 metric tons per year. The contribution of solids from lateral sources to sediment accumulation declines quickly with increasing distance from the outfall location with relatively little deposition occurring in much of the deeper areas of the Main Body, Sill, and Junction Reaches. Generally, coarser sediment size fractions (sands) settle quite close to outfall locations, whereas silts and clays tend to settle farther away from their source or are transported out of the EW.

Annual sediment deposition from lateral sources in the EW was estimated from the PTM runs for the base case and bounding simulations. Maps 3-12 through 3-14 provide estimates of annual sediment deposition from lateral loads within the EW in pounds per square foot per year (lb/ft^2/yr). Maps 3-15 through 3-17 provide the same estimates in centimeters per

year. Annual estimates were obtained from model results by extrapolating the 28-day PTM simulation to 365 days, and assuming a representative average density of sediment as 1.5 g/cm^3 (based on average of all Sedflume data collected within the EW) (see Section 6.1 in the STER (Anchor QEA and Coast & Harbor Engineering 2012)).[45] Note that the deposition patterns illustrated by the PTM modeling results (Maps 3-12 through 3-17) represent initial deposition of solids from EW laterals only (which are a small fraction of the total solids entering the EW) and do not include resuspension, transport, and deposition due to vessel operations (i.e., prop wash) in the EW, which may be significant in portions of the waterway.[46]

Annual initial sediment deposition rates from lateral sources within the EW (as predicted by the PTM modeling results) averaged over the entire EW site are less than 0.01 cm/yr, which is small compared to average net sedimentation rates within the EW measured by recovered geochronological cores in Section 3.4.2 (1.6 and 0.5 cm/yr[47] based on Cs-137 and Pb-210 activity data, respectively). Localized initial deposition rates due to EW lateral sources (Maps 3-15 to 3-17) are less than 0.1 cm/yr over a majority of the area where deposition was predicted by the PTM model. Isolated areas (usually near outfalls) show deposition rates greater than 0.1 cm/yr, with a maximum predicted rate of approximately 2.5 cm/yr. These isolated areas represent approximately 3% of the total deposition footprint.

Hypothetical net sedimentation rates were calculated assuming that the entire incoming solids load (from upstream and lateral sources within the EW) settled evenly in the EW (including Slips 27 and 36). The total average annual mass loading from upstream and lateral

[45] Input to the PTM model for upstream flows and lateral sediment loads were constant values based on long-term annual average inputs to allow for extrapolation of shorter duration simulations to annual results. This methodology was developed in conjunction with EPA and is documented in Section 7.1 of the STER (Anchor QEA and Coast & Harbor Engineering 2012 [in prep]).

[46] These processes will be evaluated during the FS.

[47] These values represent the median (middle) of the average peak range of values of net sedimentation rates for Cs-137 and Pb-210 as shown in Table 3-3. These measured rates do not account for recent dredging activities in the EW, since recently dredged areas were not sampled.

sources into the EW is between approximately 32,500 and 54,176 metric tons per year.[48] This is based on the 30% to 50% proportion of the total LDW flow predicted by the hydrodynamic model to flow into the EW.[49] This mass load into the EW was converted to a volume by setting the density of the incoming sediment load to the *in situ* surface sediment densities measured by the Sedflume core evaluation (1.5 g/cm^3) (Anchor QEA and Coast & Harbor Engineering 2012). This mass was then evenly distributed over the entire EW to calculate a hypothetical net sedimentation rate representing a 100% solids retention (trapping efficiency) in the EW. Net sedimentation rates estimated in this manner range between 3.6 and 6.0 cm/yr. The measured average net sedimentation rate in the EW (1.6 cm/year[50]) can be subtracted from these hypothetical sedimentation rates to estimate the percent of incoming solids that is likely transported out of the EW. This calculation suggests that between 25 and 60% of the solids that enters the EW are transported out of the EW and, conversely, that 40 to 75% of the incoming solids are deposited within the EW.

3.5 Erosion Potential within the East Waterway

Mechanisms for erosion potential of bed sediments within the EW can include currents due to tidal fluctuations and upstream freshwater flows and vessel operations, including prop wash, pressured fields, and wakes.[51] The potential for erosion within the EW from these various sources was estimated through a combination of hydrodynamic modeling, prop wash and pressure field modeling, and evaluation of Sedflume core data collected within the EW (Anchor QEA and Coast & Harbor Engineering 2012).

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[48] This represents the range in average annual upstream solids added to the best estimate of the average annual lateral solids developed for the PTM modeling (existing conditions).

[49] This assumes that the split in suspended solids is the same as the split in flow.

[50] This evaluation was completed using the average net sedimentation rate estimated from the Cs-137 activity data; Cs-137 activity data were more consistent throughout the EW than Pb-210 activity data. The average net sedimentation rate estimated from the Pb-210 activity data is lower than from the Cs-137 activity data (0.85 compared to 1.5 cm/yr), but the Pb-210 activity data have a wider range of predicted sedimentation rates (some as high as 4.2 cm/yr) than the Cs-137 activity data.

[51] Short-term erosion potential due to slumping of steeply dredged side slopes may have occurred in the EW in the past. However, there is no data to evaluate the impacts of this mechanism in the past. Therefore, the issue will be addressed during design, and future dredging efforts within the EW will include stable side slopes.

Sedflume cores were collected within the EW (Section 2.5.1) to evaluate *in situ* critical shear stress of bed sediments (Section 6.1 of the STER (Anchor QEA and Coast & Harbor Engineering 2012). Estimates of bed shear stresses due to tidal/riverine currents and vessel operations (evaluated as part of the EW STER) were compared to critical shear stresses from Sedflume cores to evaluate erosion potential within the EW (Anchor QEA and Coast & Harbor Engineering 2012).

3.5.1 Estimates of Critical Shear Stress of Bed Sediments

Estimates of critical shear stress of bed sediments within the EW were obtained through the use of Sedflume cores. The location and spacing of the Sedflume cores were chosen as part of the Sediment Transport Characterization QAPP (Anchor and Battelle 2009) based on the following criteria:

- Samples should be placed in suspected natural recovery areas
- At least one sample should be placed at each of the boundaries of the study area (north and south boundaries)
- One sample should be placed in the Sill Reach (shallow water) in the vicinity of the bridges
- Samples should be located and spaced appropriately at the various constriction changes within the Sill and Junction Reaches of the EW to evaluate potential spatial variability of results in those areas

Additional detail regarding the methodology for choosing sampling locations is provided in Section 3.1.2.2 of the Sediment Transport Characterization QAPP (Anchor and Battelle 2009)).

Eight Sedflume cores were collected within the Shallow and Deep Main Body Reaches within the EW (Map 3-18) and were tested in a mobile laboratory facility set up near the EW to measure erosion rates as a function of shear stress and depth in the core. Sedflume cores were not proposed for the Junction and Sill Reaches following the results of the geochronological core sampling program. Sedflume erosion rate data were analyzed to estimate the critical shear stress for initiation of erosion. Based on the results of this evaluation (Anchor QEA and Coast & Harbor Engineering 2012), the 95th percentile confidence interval of critical bed shear stress for surface sediments in the EW ranges

between 0.20 and 0.37 Pa). Two of the eight cores had measured critical shear stresses in the surface layer (0 to 5 cm) that were significantly lower than the 95% confidence interval range. In sediments beneath the initial surface sediments, the critical shear stress in both of these cores increased to fall within the 95% confidence level. The evaluation of critical shear stress of bed sediments in the EW is described in detail in Section 6.1.3 of the STER (Anchor QEA and Coast & Harbor Engineering 2012).

3.5.2 Erosion Potential due to Tidal Currents

The maximum bed shear stresses were estimated from the hydrodynamic model mean annual, mean wet-season, 2-, 10-, and 100-yr flow conditions. Maximum bed shear stress predicted by the model ranges from 0.05 Pa during mean annual flow to 0.12 Pa during the 100-yr high-flow event. Thus, even with 100-yr flow conditions, the maximum predicted bed shear stress due to tidal/riverine currents (0.12 Pa) is approximately 35% less than the measured critical shear stress for EW bed sediments. The spatial distribution of tidal-generated bed shear stress within the EW is characterized by the highest bed shear stresses at the mouth of the EW, becoming lower in value moving upstream (to the south). Higher near bottom current velocities (and corresponding higher bed shear stress) at the mouth are due to the two-layer flow structure within the EW. During incoming tide, higher salinity water flows from Elliott Bay into the relatively constricted opening of the EW at depth producing relatively high near bottom velocities at the mouth. As this flow moves upstream, density-driven circulation and vertical mixing of the incoming tidal waters with the lower salinity surface waters (from upstream flows) causes a reduction in near bottom current velocities between the mouth and the Sill Reach in the EW.

Maximum bed shear stresses within the Sill Reach are affected by pervasive two-layer flow that exists in this reach (as well as the majority of the EW). Upstream flow of higher salinity water in the bottom layers (compared to surface layer salinities) confine downstream current velocities (due to upstream freshwater input) to the surface layers. This circulation pattern results in lower bed shear stress in the Sill Reach than would be expected if the system had single-layer flow (i.e., no flow reversal at depth).

Relatively high bed shear stresses (associated with relatively high current velocities) are predicted along the southern half (shallower) of Slip 27. The higher current velocities may be due to the geometry and resolution of the numerical grid in that location. However, bed

shear stresses predicted throughout Slip 27 are still at least 20% lower than estimated critical shear stress values for surface sediments in the EW.

Because the maximum bed shear stress predicted by the model for all flow events is at least 20% below the lower confidence bound value for critical shear stress (0.20 Pa) as estimated from the Sedflume core data collected in the Shallow and Deep Main Body Reaches, it is anticipated that significant bed scour or erosion of *in situ* bed sediments within the EW will not occur as a result of tidal or riverine currents. In addition, critical shear stress of bed sediments generally increases with depth below mudline in the EW (see Section 6.1.2 of the STER (Anchor QEA and Coast & Harbor Engineering 2012)). Therefore, subsurface sediment erosion due to tidal and riverine currents is also not expected to occur in the EW.

3.5.3 Erosion Potential due to Vessel Operations

Maximum near-bed velocities and bed shear stresses within each of the operating areas shown in Map 3-9 were evaluated by choosing the maximum values of near-bed velocity/shear stress in each area from the 15 different scenarios described in Table 3-2. Table 3-6 provides a summary of these values for each operating area. It is important to note that the boundary between operational Area 1B (navigational area) and the berthing areas adjacent to T-18 and T-30 (Area 1A) is an approximation based on the current understanding of vessel operations within the EW. The estimated shear stress value of 2 Pa in Area 1B (navigation area) is representative of typical transiting maneuvers in the navigation channel; however, the navigation channel is expected to experience a range of shear stresses due to adjacent berthing maneuvers. Therefore, it is possible that portions of the navigation channel (Area 1B) along this boundary may experience higher bed shear stress than estimated in Table 3-6 (2 Pa). Area 4 has values associated with current operations (Scenario 9) and future planned operations (Scenario 15).

Table 3-6

Summary of Maximum Near-Bed Velocities and Bed Shear Stresses Due to Prop Wash

Operating Area (see Map 3-9)	Scenario in Area Resulting in Maximum Near-Bed Velocity (see Table 3-2)	Maximum Near-Bed Velocity (ft/s)	Maximum Bed Shear Stress (Pa)
Terminal 18, Berths 1 and 2, Area 1A	Scenario 2	11.4	23
Terminal 18, Berths 3 and 4, Area 1A	Scenario 5	7.1	9
Area 1B	Scenario 13	3.0	2.0
Area 1C	Scenario 13	3.0	2.0
Slip 36, Area 2	Scenario 6	6.5	8.0
Slip 27, Area 3	Scenario 8	3.0	2.0
South Terminal 30, Area 4A[a]	Scenario 9 (future conditions – Scenario 15)	3.0 (future conditions – 9.0)	2.0 (future conditions – 14)
South Terminal 30, Area 4	Scenario 9	3.0	2.0
Area 4B	Scenario 9	3.0	2.0
Area 5	Scenario 9	3.0	2.0
Area 6	Scenario 10	10.6	22
Area 7	Scenario 11	4.7	4
Area 8	Scenario 12	4.2	3

[a] Operational Conditions in Area 4A may change in the future. These future conditions are described in Scenario 15.

Near-bed velocities generated by episodes of prop wash are estimated to be significantly higher than those due to tidal and riverine currents in areas of the EW that are subjected to large vessel operations (generally north of Slip 27). Consequently, bed shear stress due to vessel operations is significantly greater than bed shear stress due to natural forces in those areas. Erosion potential and mixing due to prop wash is anticipated to be more significant north of Slip 27 (compared to areas south of Slip 27) due to concentrated container ship activity in those areas. This assumption is consistent with geochronological core data. Estimates of bed shear stress due to prop wash range from 2 to 23 Pa within the EW based on estimates of vessel operations while navigating and berthing. Based on the prop wash evaluation, extreme vessel operations, which can occur throughout the Main Body Reaches and Junction Reach, have the highest potential to mix and erode surface sediments. This observation is not necessarily consistent with the results of geochronological core data (Section 3 of the STER (Anchor QEA and Coast & Harbor Engineering 2012)), which imply

that areas south of Slip 27 (between Stations 4000 and 5200) are not subject to significant mixing at depth below the mudline. However, it is possible for this area to be net depositional over time (as shown by the geochronological core data) but subject to occasional suspension of surface sediments due to prop wash/vessel activity in those areas. Since the prop wash evaluation focused on extreme vessel operations (as opposed to emergency operations), and there is vessel activity south of Slip 27, it is likely that potential erosional events are infrequent in that area.

4 NATURE AND EXTENT OF CONTAMINATION

This section discusses the nature and extent of contamination in the EW based on available sediment, tissue, and water (surface and porewater) data collected since 1995. Section 4.1 discusses how data were selected for use in the SRI. Section 4.2 summarizes contaminant distributions in sediment, tissue, and water, with a focus on six contaminants or contaminant groups (i.e., polychlorinated biphenyls [PCBs], arsenic, mercury, tributyltin [TBT], carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and dioxins and furans).[52] In addition to these specific contaminants, the nature and extent of contamination for metals, semivolatile organic compounds (semivolatile organic compounds [SVOCs], including polycyclic aromatic hydrocarbons [PAHs]), and organochlorine pesticides in the EW are also discussed in Section 4.2.

4.1 Data Selection, Suitability, and Reduction

This section presents the data quality objectives (DQOs) for available EW sediment, tissue, and water chemistry data and describes how data were selected for use in the SRI. It also describes how raw data from the laboratories were managed for use in the evaluation of the nature and extent of contamination.

4.1.1 Data Quality Objectives

DQOs were established to determine whether chemistry data were acceptable for all uses in the SRI/FS. The DQO process used to identify acceptable datasets was provided in the EISR(Anchor and Windward 2008a). Table 4-1 presents the DQOs that had to be satisfied for chemistry data to be considered acceptable for all uses in the SRI/FS; DQOs are organized according to the level at which each would be applied: event, station, sample, or result. A DQO applied at the result level could cause a result to be qualified for one particular chemical but not for other chemicals analyzed during the same study.

[52] PCBs, arsenic, TBT, cPAHs, and dioxins and furans were selected because they are risk-driver contaminants for ecological receptors and/or humans, as described in Sections 5.5 and 6.5, respectively. Mercury was selected because it is a risk driver contaminant for the benthic invertebrate community and has the second highest number of sediment quality standard or cleanup screening level exceedances (after PCBs).

Table 4-1
Data Quality Objectives for Chemistry Data to be Considered Acceptable for All Uses in the EW SRI/FS

Level	Data Quality Objective
Event	Hard copy or original electronic copy of data report must be available.
	Field coordinates must be available.
	Data must have been collected in 1995 or later.[a]
	Data must have been collected using appropriate sampling methods.
	Existence and location of supporting documentation (i.e., analytical raw data, chain-of-custody forms, and sample handling descriptions) must be known.[a]
Station	Stations located within dredge prisms or remediated areas should be identified.
Sample	Sample depth must be identified.
	Sample type must be clearly identified.
Result	Data validation qualifiers must be present, or derivable from laboratory qualifiers or QA information, and must be applied in a manner consistent with EPA functional guidelines.[a]
	Each result must have a laboratory-generated form (usually referred to as a Form 1).[b]
	For non-detects, RLs and appropriate qualifiers must be given.
	Calculated values must be recalculated.
	Analytical methods must be identified.

[a] The most recent data were selected in order to ensure that the data reflected current site conditions (Anchor and Windward 2008a). No historical tissue datasets were excluded based on this objective.

[b] The existence of supporting documentation, the availability of Form 1s, and a review of the presence and application of data validation qualifiers were not considered necessary if the data had been previously approved by EPA for all uses in the RCRA or CERCLA programs.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
EPA – US Environmental Protection Agency
EW – East Waterway
FS – feasibility study
QA – quality assurance
RCRA – Resource Conservation and Recovery Act
RL – reporting limit
SRI – supplemental remedial investigation

EPA has not established definitive guidelines that specify the level of data validation required for Superfund investigations. However, EPA Order 5360.1 and Office of Solid Waste and Emergency Response Directive 9355.9-01 (EPA 1993a) require that environmental measurements be of known quality, verifiable, and defensible. In an audit of Region 9 Superfund sites (EPA 1995), the EPA Office of the Inspector General (OIG) concluded that data used for cleanup decision-making should be validated using EPA functional guidelines (EPA 1999b, 2002b). According to these guidelines, two levels of data validation are generally recognized for chemistry data: a summary validation and a full validation. A summary data validation (referred to as QA1) represents a lower level of effort compared with that of a full data validation (referred to as QA2). The elements of the

summary and full data validations for environmental chemistry data are presented in Table 4-2

Table 4-2

Elements of Summary and Full Data Validations for Environmental Chemistry Data

Element	Applicable Analyses	Summary Data Validation (QA1)	Full Data Validation (QA2)
QC analysis frequencies	all	X	X
Analysis holding times	all	X	X
Instrument performance check	organic compounds, ICP-MS metals		X
Initial instrument calibration	all		X
Continuing instrument calibration	all		X
Laboratory blanks	all	X	X
ICP interference check sample	metals		X
System monitoring compounds (surrogates)	organic compounds	X	X
Matrix spikes (and matrix spike duplicates as applicable)	all (except for TSS and grain size)	X	X
Laboratory control samples	all	X	X
ICP serial dilution	metals		X
Field QA/QC (field blanks, field duplicates)	all	X	X
Internal standards	VOCs, SVOCs, ICP-MS metals		X
Pesticide cleanup checks	pesticides/PCBs		X
Target compound identification and quantitation (requires verification of reported results with raw data)	organic compounds		X
RLs	all	X	X

ICP – inductively coupled plasma
MS – mass spectrometry
PCB – polychlorinated biphenyl
QA – quality assurance
QC – quality control
RL – reporting limit
SVOC – semivolatile organic compound
VOC – volatile organic compound

Data of acceptable quality may still be associated with uncertainty in the SRI. For example, a chemical not detected in a sample may actually be present, but its concentration below the reporting limit (RL) is unknown. Analytes detected at concentrations between the detection limit (DL) and the RL are qualified as estimated. The magnitude of the uncertainty associated with non-detected or estimated results below the RL increases as the DLs and RLs increase. The uncertainties associated with non-detected results were evaluated in both the ERA (Appendix A, Section A-6) and the HHRA (Appendix B, Section B-6). None of the sampling

events evaluated for inclusion in the SRI were excluded in their entirety because of elevated DLs and RLs.

In general, the detection frequency for risk-driver chemicals (see Sections 5.5 and 6.5) was high in all matrices. The relationship between analytical sensitivity and risk-based concentration goals was evaluated in all SRI QAPPs (Windward 2008f, g, h) in order to ensure the appropriateness of the selected analytical methods. In addition, the uncertainty evaluations in the ERA and HHRA (Appendices A and B, respectively) assessed the influence of non-detected results on the risk assessment results.

The influence of the values selected for the non-detected results (i.e., zero, one-half RL, or full RL) on calculated values of PCB toxic equivalent (TEQ), dioxin and furan TEQ, and cPAH TEQ was evaluated in the data reports (Windward 2010a, b, c, d, e, f) and as appropriate in the risk assessments. The influence of the non-detected results on the calculated TEQ values was consistently small for all TEQ values and matrices due to the high frequency of detection for the PCB congeners, dioxin and furan congeners, and cPAH compounds that contributed the most to their respective TEQ values[53] Uncertainties associated with data quality that are relevant to the conclusions of the ERA and HHRA are discussed in Appendices A and B, respectively.

4.1.2 Data Selection

Environmental investigations conducted within the EW have included the collection of surface sediment, subsurface sediment, fish, shellfish, benthic invertebrate tissue, surface water, and porewater samples for chemical analysis. This section describes the datasets selected for inclusion in the SRI baseline dataset. The "SRI baseline dataset" is the dataset

[53] In the HHRA Section 6.1.1.4 the use of different assumptions for the non-detected components of the cPAH, PCB, and dioxin and furan TEQs were evaluated. The treatment of non-detected congeners resulted in relatively small changes in the tissue exposure concentrations that contributed the most to the TEQ risk estimates (clams for cPAH TEQ, benthic fish fillet/perch/rockfish for PCB TEQ, and clams/crab edible meat/whole body crab/rockfish for dioxin/furan TEQ). In addition, Section 6.1.1.3 of the HHRA evaluated the effect of including non-detected Aroclors on the tissue total PCB concentrations. Including the non-detected results did not change the total PCB concentrations for all tissue types with the exception of mussels. Consideration of ND in the total PCBs in mussels would not change the overall total PCB seafood concentration risk estimate.

that has been used to support analyses in the SRI including the ERA, the HHRA, the nature and extent evaluation and the development of sediment RBTCs. All available data, including data that have been excluded from the SRI baseline dataset are part of the SRI baseline database. For example, sediment data associated with sediments that have been removed from the waterway due to dredging are not included in the SRI baseline dataset because that data do not reflect current waterway conditions. However, the data are available in the SRI database.

4.1.2.1 Surface Sediment

The following considerations were made when selecting surface sediment data for the SRI baseline dataset:

- **Sampling date –** Only data that had been collected in 1995 or later were included.
- **Dredging activities –** Only data that had been collected from locations that were not subsequently dredged were included.
- **Data quality –** Data must be of known quality and defensible. The Office of the Inspector General concluded in an audit of Region 9 Superfund sites (EPA 1995) that data used for cleanup decision-making should be validated using EPA functional guidelines (EPA 1999b, 2002b).

Many of these sediment samples were collected as part of post-dredge monitoring or nature and extent of contamination investigations. As reported in the EISR (Anchor and Windward 2008a), numerous investigations conducted in 1995 or later involved the collection of surface sediment samples in the EW. In addition, 108 sediment samples were collected in 2009 as part of the EW SRI sampling events. The sampling design for the 2009 EW SRI data collection event was presented in the surface sediment QAPP (Windward 2009j). The sampling plan was designed to supplement existing acceptable sediment data in order to provide sufficient spatial coverage for the EW SRI/FS. As part of the SRI surface sediment investigation, surface sediment grab samples were collected by divers from underpier locations throughout the waterway.

Nearly all of the surface sediment sampling data from the older and more recent data collection efforts since 1995 were considered to be relevant and representative of current

conditions. Table 4-3 lists all of the sampling events for which data were reviewed and found to be acceptable for use in the SRI. The locations of the SRI baseline dataset surface sediment samples are shown on Maps 4-1a, 4-1b, and 4-2.

Table 4-3
Surface Sediment Data Included in the EW SRI Baseline Dataset

Sampling Event	Sampling Date	No. of Samples	Analyses	Source
EW Intertidal	2009	15[a]	PAHs, TOC	Windward (2010e)
EW Subtidal Surface Sediment Composites	2009	13	PCB congeners, PCB Aroclors, dioxin/furan congeners, conventionals	Windward (2010f)
EW Intertidal MIS Composites	2009	4	metals, TBT, SVOCs, PCB Aroclors, PCB congeners, dioxin/furan congeners, pesticides, conventionals	Windward (2010f)
EW Surface Sediment	2009	107	metals, TBT, SVOCs, PCB Aroclors, pesticides, grain size, conventionals, a subset of samples (13 samples) were analyzed for dioxins and furans	Windward (2010f)
EW T-30 Post-Dredge Monitoring 2009	2009	22	metals, SVOCs, PCB Aroclors, grain size, conventionals	Windward (2010f)
EW Benthic Tissue	2009	21[a]	metals, TBT, SVOCs, PCB Aroclors, grain size, conventionals	(Windward 2009d)
EW Clam Survey	2008	5[a]	metals, SVOCs, PCB Aroclors, grain size, conventionals	(Windward 2010a)
EW Recontamination Monitoring 2008	2008	22	metals, SVOCs, PCB Aroclors, grain size, conventionals	Windward (2008c)
East Waterway – Slip 27	2007	7	metals, TBT, SVOCs, Aroclors, pesticides, grain size, conventionals	Windward (2007a)
Recontamination Monitoring 2007	2007	19	metals, SVOCs, PCB Aroclors, pesticides, grain size, conventionals	Windward (2008b)
Recontamination Monitoring 2006	2006	16	Metals, SVOCs, PCB Aroclors, pesticides, grain size, conventionals	Windward (2007b)
Post-Dredge Monitoring 2005 Phase 2	2005	15	metals, SVOCs, PCB Aroclors, pesticides, grain size, conventionals	Anchor and Windward (2005)
USCG Pier 36 Post-Dredge Sediment Characterization	2005	13	metals, SVOCs, PCB Aroclors, grain size, conventionals	Hart Crowser (2005)
EW/Harbor Island Nature and Extent Phase 1	2001	54	metals, SVOCs, PCB Aroclors, pesticides, grain size, conventionals	Windward (2002b)
EW/Harbor Island Nature and Extent Phase 2	2001	23	metals, SVOCs, PCB Aroclors, pesticides, grain size, conventionals	Windward (2002b)
T-18 Post-Dredge	2000	1	metals, TBT, PAHs, PCB Aroclors,	Windward (2001)

Sampling Event	Sampling Date	No. of Samples	Analyses	Source
Monitoring			pesticides, conventionals	
Harbor Island Remedial Investigation 95	1995	18	metals, TBT, PAHs, PCB Aroclors, pesticides, conventionals	EVS (1996b, b)

[a] In 2010, composite samples were created to characterize each intertidal sampling area from archived samples collected for the MIS intertidal sampling Windward (2010f).

CSO – combined sewer overflow
EW – East Waterway
HHRA – human health risk assessment
MIS – multi-increment sampling
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SRI – supplemental remedial investigation
SVOC – semivolatile organic compound
T-18 – Terminal 18
T-30 – Terminal 30
TBT – tributyltin
TOC – total organic carbon
TPH – total petroleum hydrocarbons
USCG – US Coast Guard

As noted above, some surface sediment sample data collection efforts were considered to be not relevant and representative of current conditions. These samples were excluded from the SRI baseline dataset (Table 4-4) for one or more of the following reasons:

- Earlier samples were superseded by more recent samples (i.e., any new sample collected from within 10 ft of a previously collected sample was considered to be a more recent sample for that location, and the most recent data was selected for the location).[54]
- Sampling location was dredged subsequent to sample collection.
- In two studies, samples from multiple sediment depth intervals from the same location were analyzed, and only the samples from the 0-to-10-cm interval were selected for the EW SRI baseline dataset.[55]

[54] If a given analyte was analyzed in an earlier sample but was not analyzed in the most recent sample, the results from the earlier sample were used.

[55] Windward Environmental LLC (Windward) (2008c) reported concentrations for sediment material that had settled on top of the sand layer (i.e., sand placed as a cover over residual contaminated sediment) with a range of depth intervals from 0 to 3 cm to 0 to 8 cm. Samples from a depth of 0 to 10 cm were analyzed from the same 10 locations in the Windward study. In another study conducted by Hart Crowser (2005), samples were analyzed from the 0-to-1-cm and 0-to-10-cm intervals from two locations in Slip 36. In both cases, only the samples from the 0-to-10-cm interval were selected for the EW SRI baseline dataset.

Table 4-4

Surface Sediment Data Not Included in the EW SRI Baseline Dataset

Sampling Event	Sampling Date	No. of Samples	Reason for Exclusion	Source
EW Recontamination Monitoring	2008	10	Samples from the 0-to-10-cm interval were selected over the samples from the overlying material intervals (0 to 3 cm and 0 to 8 cm).	Windward (2008c)
EW T-30 Post-Dredge Monitoring 2008	2008	5	Data were superseded by 2009 event.	Windward (2010f)
Post-Dredge Monitoring-2005	2005	6	The post-dredge monitoring data was collected prior to the additional dredging of 1 ft of material in this area. Samples collected after this dredging event are included in the post-dredge monitoring Phase 2 dataset listed in Table 4-3.	Anchor and Windward (2005)
USCG Pier 36 Post-Dredge Sediment Characterization	2005	2	Samples from the 0-to-10-cm interval were selected over those from the 0-to-1-cm interval for two locations.	Hart Crowser (2005)
EW/Harbor Island Nature and Extent Phase 2	2001	2	Location was dredged.	Windward (2002b)
Pier 36/37 – surface sediment	1997	3	Location was dredged.	Tetra Tech (1997)
Harbor Island Remedial Investigation 95	1995	15	Location was dredged.	EVS (1996b, b)

Note: All sediment data not included in the EW SRI baseline dataset is included in the SRI database.

CSO – combined sewer overflow
EW – East Waterway
KC – King County
T-30 – Terminal 30
SRI – supplemental remedial investigation
USCG – US Coast Guard

Table 4-5 identifies the number of surface sediment samples that were excluded from the SRI baseline surface sediment dataset and the rationale for their exclusion. Approximately 80% of the surface sediment samples (334 of 417) were included in the SRI baseline dataset.

Table 4-5

Surface Sediment Samples Excluded from the EW SRI Baseline Dataset and Rationale for Their Exclusion

Final Determination	No. of Samples
Samples considered for inclusion in the SRI surface sediment dataset	375
Samples excluded because of subsequent dredging of locations from which sediment samples were collected	20
Samples excluded because of more recent sampling at the same location	14
Samples excluded because 0-to-10-cm samples were preferred over shallower interval (i.e., 0-to-2-cm) samples at the same location	12

Final Determination	No. of Samples
Total number of surface sediment samples selected for inclusion in the EW SRI baseline dataset	**329**

EW – East Waterway
SRI – supplemental remedial investigation

4.1.2.2 Sediment Toxicity Tests

Bioassays have been conducted as part of multiple projects to characterize the toxicity of EW sediment in the biologically active zone (i.e., the top 10 cm of the sediment column) and to assess the eligibility of dredged material (typically in 1.2-m depth intervals) to be placed in open-water disposal sites. Bioassay test results are included in the SRI dataset if they were conducted with sediment collected within the top 10 cm and in accordance with Puget Sound Estuary Program (PSEP) protocols (PSEP 1995) and if concurrently collected chemistry data are available. Results from bioassays conducted for dredged material assessments are not included in the SRI dataset because the sediment was composited over a 1.2-m depth horizon from multiple locations, and thus does not represent the current benthic invertebrate exposure regime (i.e., the top 10cm). In addition, bioassay results were not included if the tests were conducted with sediment from locations that were subsequently dredged. Nine locations that had chemistry and bioassay results were subsequently resampled for chemistry alone. The more recent chemistry data replaced the older chemistry data for these locations, and the chemistry datasets were compared in terms of their SMS exceedance status to determine whether to retain the bioassay data for the locations. At six locations, differences in the sediment chemistry were sufficient to suggest that the older bioassay data may no longer be representative of site conditions, and therefore the bioassay results were not retained in the SRI dataset. For three locations, the chemistry results were consistent in terms of their SMS exceedance status, and therefore the bioassay results were retained. A detailed discussion of these locations is provided in Appendix A (Section A.2.4.1.5).

There are three studies that conducted sediment toxicity tests in EW. There were six sample locations tested as part of the post-dredge monitoring conducted in 2000 (Windward (2001). Subsequently, as part of an EW-wide nature and extent evaluation, 34 sediment samples, collected throughout EW, were submitted for toxicity testing with the majority of the sample located in the northern portion of the deep main body in the vicinity of the area that

was dredged in 1999. Finally, as part of the EW SRI surface sediment characterization in 2009, 11 sediment samples were submitted for toxicity testing. Nine samples were selected for toxicity testing because they had Washington State Sediment Management Standards (SMS) exceedances for contaminants other than PCBs and two samples with no SMS exceedances were also tested (EW09-SS217 and EW09-SS218).

Fifty-one surface sediment bioassay samples from three studies (Map 4-3 and Table 4-6) met the acceptance criteria and are used in the SRI, as well as the ERA. Each of the studies listed in Table 4-6 included the following three types of bioassays: the acute (10-day) amphipod survival test using the amphipod *Eohaustorius estuarius,* the acute (48-hour) bivalve larvae normal survival test using the blue mussel *Mytilus galloprovincialis,* and the chronic (20-day) juvenile polychaete survival and growth test using *Neanthes arenaceodentata*.

Table 4-6

EW Surface Sediment Bioassays Included in the SRI Baseline Dataset

Event	Sampling Dates	No. of Bioassay Samples	Source
EW SRI Sampling	2009	11[a]	Windward (2010f)
EW/Harbor Island Nature and Extent – Phases 1 and 2	2001	34	Windward (2002b)
T-18 – PDM	2000	6	Windward (2001)

[a] Two samples were tested using the Pacific oyster (*Crassostrea gigas*) rather than the blue mussel *(Mytilus galloprovincialis)* for the acute (48-hour bivalve larvae normal survival test.

EW – East Waterway
T-18 – Terminal 18
PDM – post-dredge monitoring

4.1.2.3 Subsurface Sediment

The following considerations were made in selecting subsurface sediment data for the SRI baseline dataset:

- **Dredging activities –** Only data that had been collected from locations that were not subsequently dredged were included.
- **Data quality –** Data must be of known quality and defensible. The OIG concluded in an audit of Region 9 Superfund sites (EPA 1995) that data used for cleanup decision-making should be validated using EPA functional guidelines (EPA 1999b, 2002b).

As reported in the EISR (Anchor and Windward 2008a), numerous investigations conducted in 1995 or later involved the collection of sediment cores in the EW. As a federally authorized navigation channel, the EW has been dredged for berth and channel deepening and maintenance. For this reason, many of the subsurface sediment characterization investigations within the EW have been focused on collecting the data required for navigation maintenance dredging projects. In addition, 65 sediment cores were collected in 2010 as part of the EW SRI. Table 4-7 presents a summary of all subsurface sediment data that are included in the EW SRI baseline dataset. The locations of the SRI baseline subsurface sediment samples are shown on Maps 4-4a and 4-4b. Sediment cores that were collected from areas that have subsequently been dredged are summarized in Table 4-8. Sediment core data associated with dredged sediment are not included in the SRI subsurface sediment baseline dataset.

Table 4-7
Subsurface Sediment Data Included in the EW SRI Baseline Dataset

Sampling Event	Sampling Date	Collection Method	No. of Samples (description)	Analytes	Reference
EW SRI Subsurface Sediment Sampling	February and March 2010	sediment boring, vibracorer, MudMole	208 (65 core locations sampled at 2-ft intervals except for 5 cores analyzed at 1-ft intervals)	metals, PCB Aroclors, SVOCs, VOCs, pesticides (subset of samples), TBT (subset of samples), dioxins and furans (subset of samples), conventionals, and grain size	Windward (2010e)
EW – Slip 27	January 2007	vibracorer	12 (3 locations sampled at 1-ft intervals)	metals, PCB Aroclors, SVOCs, VOCs, pesticides, TBT, conventionals, and grain size.	Windward (2007a)
EW Pre-Sand Placement Monitoring	2005	surface grab sample[a]	36	metals, SVOCs, PCB Aroclors, pesticides, conventionals	Anchor and Windward (2005)
EW/Harbor Island Nature and Extent – Phase 3b	December 2001	pneumatic corer	30 (11 locations, sampled at 1-to-1.5-ft intervals)	metals, TBT, SVOCs, VOCs, PCB Aroclors, pesticides, conventionals, and grain size	Windward (2002a)
EW Stage 1 Channel Deepening	July and August 1998	vibracorer	52 (38 core locations sampled at 0-to-4-ft intervals, 14 locations sampled at > 4-ft intervals)	metals, TBT, SVOCs, VOCs, PCB Aroclors, pesticides, conventionals, grain size	SAIC (1999a)
Pier 36 – preliminary	April 1997	vibracorer	2 (1 location sampled at a depth of > 4 ft)	metals, SVOCs, VOCs, PCB Aroclors, conventionals, grain size	Berger/Abam (1997)

Sampling Event	Sampling Date	Collection Method	No. of Samples (description)	Analytes	Reference
T-18 Dredging – Phase 1	March 1996	vibracorer	8 (7 core locations sampled at 0-to-4-ft interval, 1 core location at 0-to-5.5 ft)	metals, TBT, SVOCs, VOCs, PCB Aroclors, pesticides, conventionals, grain size	EVS (1998)
T-18 Dredging – Phase 2	March 1996	vibracorer	4 (2 core locations sampled at 0-to-4-ft interval, 2 core locations sampled at > 4-ft intervals)	metals, TBT, SVOCs, VOCs, PCB Aroclors, pesticides, conventionals, grain size	EVS (1998)
Harbor Island SRI	March 1995	impact-driven coring system	3 (1 location sampled at 0-to-2-ft, 2-to-4-ft, and 4-to-9.3-ft intervals)	metals, SVOCs, VOCs, PCB Aroclors, conventionals, grain size	EVS (1996b)
Harbor Island RI	September and October 1991	vibracorer	4 (1 location, 0-to-4-ft core sampled at 1-ft intervals)	metals, SVOCs, VOCs, PCB Aroclors, conventionals, grain size	Weston (1993a)

[a] Samples were collected as surface sediment samples after the 2006 Phase 1 dredging event. The area was subsequently covered with 1 ft of sand cover material. Therefore, they currently represent subsurface sediments from 1 to 2 ft in depth. These samples are not included in the chemical-specific subsurface summaries in Sections 4.2.3 to 4.2.12.

EW – East Waterway
PCB – polychlorinated biphenyl
RI – remedial investigation
SMS – Washington State Sediment Management Standards
SRI – supplemental remedial investigation
SVOC – semivolatile organic compound
T-18 – Terminal 18
TBT – tributyltin
TOC – total organic carbon
VOC – volatile organic compound

Table 4-8

Subsurface Sediment Data Associated with Dredged Sediment in the EW SRI Baseline Dataset

Sampling Event	Sampling Date	Collection Method	No. of Cores	No. of Samples	Analytes[a]	Reference
T-30 Sediment Characterization	July 2006	vibracorer	5	6	DMMP	Anchor (2006)
Pier 36 Suitability Confirmation Sampling	November 2004	vibracorer	6	11	DMMP	GeoEngineers (2004)
T-46 Sediment Characterization	March and April 2004	vibracorer and diver-assisted spoon	2	2	SMS, DMMP	Anchor (2004)
EW/Harbor Island Nature and Extent Recency	February 2003	vibracorer	3	4	SMS, DMMP	Windward (2003c)
Pier 36 Dredging Additional Sampling	November 2002	vibracorer	3	3	DMMP	GeoEngineers (2003)
EW T-18 Stage 1A, Rounds 1 and 2	April 2002 (Round 1) September 2002 (Round 2)	vibracorer	5	5	DMMP	Anchor (2002)

Sampling Event	Sampling Date	Collection Method	No. of Cores	No. of Samples	Analytes[a]	Reference
USCG Pier 36	March 2001	hollow-stem auger	4	12	SMS, DMMP	GeoEngineers (2001)
Pier 36 Characterization	August 1998	vibracorer	8	9	SMS, DMMP	SAIC (1999b)
Pier 36 Preliminary	March 1992	vibracorer	2	1	SMS, DMMP	Shannon & Wilson (1992)
T-18 Dredging – Phase 2	May and June 1996	vibracorer	43	47	SMS, DMMP	EVS (1998)
T-18 Phase 1	March 1996	vibracorer	75	75	SMS, DMMP	EVS (1998)
EW Channel Deepening	July-August 1998	vibracorer	49	45	SMS, DMMP	SAIC (1999)

Note: All data are available in the SRI database and classified as data that represent sediments that have been dredged from EW. Therefore, the data are not presented in the SRI report. The data are included in the SRI dataset as data associated with dredged sediment.

[a] SMS analytes included PCBs (as Aroclors), SVOCs, metals (i.e., arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc), TOC, and grain size. DMMP analytes included PCBs (as Aroclors), pesticides, SVOCs, VOCs, TBT, metals (i.e., antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc), TOC, and grain size.

DMMP – Dredged Material Management Program
EW – East Waterway
PCB – polychlorinated biphenyl
RI – remedial investigation
SMS – Washington State Sediment Management Standards
SVOC – semivolatile organic compound
T-18 – Terminal 18
T-30 – Terminal 30
T-46 – Terminal 46
TBT – tributyltin
TOC – total organic carbon
USACE – US Army Corps of Engineers
VOC – volatile organic compound

4.1.2.4 Fish, Shellfish, and Benthic Invertebrate Tissue

The tissue data that met criteria for the EW SRI baseline dataset is summarized in Table 4-9. The SRI fish and shellfish tissue sampling locations are shown on Map 4-5, and the SRI benthic invertebrate tissue sampling locations are shown on Map 4-6. Intertidal clams (i.e., those ≥ 4 cm in length) and subtidal geoducks were collected from all areas where they were found (Windward 2010b). Intertidal clams were collected from five intertidal areas in the EW, two of which were located near T-104, one was near T-102, one was near Slip 27, and one was near the north end of T-30 (Map 4-5). Subtidal geoducks were collected near the northwestern boundary of the EW near Station -200 (Map 4-5). As reported in the EISR (Anchor and Windward 2008a) and indicated in Table 4-8, five studies conducted outside of the EW SRI/FS process (i.e., all sampling events conducted between 1995 and the 2008 SRI sampling) reported tissue chemical concentrations for fish and shellfish collected throughout the EW. English sole were analyzed Battelle (1996) and Frontier GeoSciences (1996); transplanted mussels were collected by King County in 1996 and 1997 (1999a); red rock crab

and striped perch were collected by Environmental Solutions Group (ESG) (1999); and English sole, shiner surfperch, and rock fish were collected by Windward (2005c). PCBs, mercury, and TBT were the most frequently analyzed chemicals in tissue samples. Prior to the SRI, King County (1999a) conducted the only study with an extensive analytical list that included metals, organometals, SVOCs, PCBs, and pesticides; but they are available only for mussels. The largest dataset that quantifies contaminants in fish, shellfish and benthic invertebrates from the EW is the 2008 SRI sampling (Windward 2010a,b,c,d) which included the collection of English sole, brown rockfish, juvenile Chinook salmon, shiner surfperch, crab, shrimp, mussels, geoducks, clams and benthic invertebrates.

Table 4-9
Tissue Data Included in the EW SRI Baseline Dataset

Species	Sampling Event	Year of Sample Collection	No. of Samples	No. of Individuals per Sample	Sample Type	Analytes	Source
English sole	EW-Fish Collection 2008	2008	11	5	whole body[a]	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans,[b] PCB congeners[b]	Windward (2010a, c)
			11	5	skin-on fillet		
	EW-Fish Collection 2005	2005	6	5	skin-on fillet and remainder[c]	PCB Aroclors, mercury, lipids	Windward (2006)
	EVS 95	1995	3[d]	6 to 8	skinless fillet	PCB Aroclors and subset of PCB congeners, butyltins, mercury, methylmercury, lipids	Battelle (1996) and Frontier GeoSciences (1996)
Brown rockfish	EW-Fish Collection 2008	2008	14	1	whole body	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans,[d] PCB congeners[e]	Windward (2010a, c)
	EW-Fish Collection 2005	2005	2	1		PCB Aroclors, mercury, lipids	Windward (2006)
Juvenile Chinook salmon	EW-Fish Collection 2008	2008	6	4 to36	whole body	PCB Aroclors, pesticides, SVOCs, metals, butyltins, lipids	Windward (2010d)
	EW-Fish Collection 2008	2008	1	165	stomach contents	SVOCs, metals, lipids	Windward (2010d)
	EW Fish Collection 2005	2005	6	6-8	whole body	PCB Aroclors, mercury	(Windward 2002c)
Shiner surfperch	EW-Fish Collection 2008	2008	8	10	whole body	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans,[e] PCB congeners[e]	Windward (2010a, c)
	EW-Fish Collection 2005	2005	3	6 to 8		PCB Aroclors, mercury, lipids	Windward (2006)
Striped perch	WSOU	1998	3	2 to 8	skinless fillet	PCB Aroclors, mercury, TBT, lipids	ESG (1999)
	WSOU	1998	3	2 to 8	skin-on fillet	PCB Aroclors, mercury, TBT, lipids	ESG (1999)
Sand sole	EW-Fish Collection 2005	2005	6	1	whole body	PCB Aroclors, mercury, lipids	Windward (2006)

Table 4-9
Tissue Data Included in the EW SRI Baseline Dataset (cont.)

Species	Sampling Event	Year of Sample Collection	No. of Samples	No. of Individuals per Sample	Sample Type	Analytes	Source
Dungeness crab[f]	EW-Fish Collection 2008	2008	1	7	edible meat	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans,[f] PCB congeners[g]	Windward (2010a, c)
	EW-Fish Collection 2008				hepatopancreas	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans,[f] PCB congeners[b, g]	Windward (2010a, c)
Red rock crab[e]	EW-Fish Collection 2008	2008	8	7	edible meat	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans,[f] PCB congeners[b,g]	Windward (2010a, c)
	WSOU	1998	3	5		PCB Aroclors, mercury, TBT	ESG (1999)
	EW-Fish Collection 2008	2008	8	7	hepatopancreas	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans,[g] PCB congeners[g]	Windward (2010a, c)
Mussels	EW-Fish Collection 2008	2008	11	89 to 101	whole body[h]	PCB Aroclors, pesticides, SVOCs, metals, inorganic arsenic, butyltins, lipids, dioxins/furans[b]	Windward (2010a, c)
	KC WQA	1997	3	50 to 100		PCB Aroclors, SVOCs, pesticides, metals, butyltins, lipids	King County (1999a)
	KC WQA	1996	3	50 to 100		PCB Aroclors, SVOCs, pesticides, metals, butyltins, lipids	King County (1999a)
Clams – butter	EW-Clam Survey	2008	7	6 to 15	whole body[h]	PCB Aroclors, SVOCs, pesticides, metals, butyltins, lipids, dioxins/furans (two samples), PCB congeners (two samples)	Windward (2010a, b)
Clams – littleneck	EW-Clam Survey	2008	2	4 to 9	whole body[h]	PCB Aroclors, pesticides, metals, butyltins, lipids	Windward (2010a, b)
Clams – cockle	EW-Clam Survey	2008	2	13 to 17	whole body[h]	PCB Aroclors, SVOCs, pesticides, metals, butyltins, lipids, dioxins/furans (one sample), PCB congeners (one sample)	Windward (2010a, b)
Clams – soft-shell	EW-Clam Survey	2008	1	15	whole body[h]	PCB Aroclors SVOCs, pesticides, metals, butyltins, lipids	Windward (2010a, b)

Table 4-9
Tissue Data Included in the EW SRI Baseline Dataset (cont.)

Species	Sampling Event	Year of Sample Collection	No. of Samples	No. of Individuals per Sample	Sample Type	Analytes	Source
Geoduck[i]	EW-Clam Survey	2008	5	1	edible meat	PCB Aroclors, SVOCs, pesticides, metals, butyltins, lipids, dioxins/furans[b], PCB congeners[b]	Windward (2010a, b)
	EW-Clam Survey	2008	3	3	gut ball	PCB Aroclors, SVOCs, pesticides, metals, butyltins, lipids, dioxins/furans (subset of samples), PCB congeners[b]	
Shrimp	EW-Fish Collection 2008	2008	1	26	whole body	PCB Aroclors, SVOCs, metals, lipids	Windward (2010a, c)
Benthic invertebrates	EW-Benthic Invertebrate Tissue Sampling	2008	13	na	whole body	PCB Aroclors, PAHs, metals, butyltins, lipids	(Windward 2009d)

[a] Samples were analyzed as whole-body tissue samples separate from the fillet samples (i.e., the data for these samples were not mathematically calculated from tissue type components).

[b] One super composite sample for each species and tissue type was created by combining the existing composites for each species and tissue type (Windward 2010c). Each super composite was analyzed in triplicate.

[c] Data from the fillet composite samples were mathematically combined with data from the remainder composite samples to form composite whole-body samples. The fillet composite samples were weighted based on the fraction of the whole-body mass represented by each sample order to calculate whole-body results (Windward 2006).

[d] The skin-off fillet data, which are included in the SRI dataset, were not included in the HHRA dataset, which consists of only skin-on fillet data.

[e] Six individual brown rockfish were analyzed for dioxins and furans and PCB congeners.

[f] Data from hepatopancreas composite samples were mathematically combined with data from edible-meat composite samples to form composite samples of edible meat plus hepatopancreas. Whole body (i.e., edible meat plus hepatopancreas) crab chemical concentrations were calculated using the relative weights and concentrations of the edible meat and hepatopancreas.

[g] Dungeness and red rock crab species were combined together for the crab tissue supercomposite (Windward 2010c).

[h] Clam and mussel whole body samples include all soft tissue and do not include shells.

[i] Data from gut ball composite samples were mathematically combined with data from edible-meat composite samples to form composite samples of edible meat plus gut ball. Whole body (i.e., edible meat plus gut ball) geoduck chemical concentrations were calculated using the relative weights and concentrations of the edible meat and gut ball.

ESG – Environmental Solutions Group
EW – East Waterway
HHRA – human health risk assessment
KC – King County
na – not available
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SRI – supplemental remedial investigation
SVOC – semivolatile organic compound
TBT – tributyltin
WQA – water quality assessment
WSOU – waterway sediment operable unit

4.1.2.5 Surface Water

The SRI baseline surface water dataset consists of data collected in 2008 and 2009 for the SRI, as well as data collected in 1996–1997 by King County as part of its water quality assessment (WQA) (Table 4-10). King County collected 188 samples from three locations and two depths along a transect across the EW near the Hanford # 2 CSO outfall. Sampling was conducted on a weekly basis from October 1996 to June 1997. The SRI sampling involved the collection of 59 samples during five separate sampling events (two dry-season events, two wet-season events, and one storm event) at five locations and two depths (Map 4-7). The SVOC data collected by King County as part of its WQA were not used in this SRI because the dataset consisted largely of non-detected results with analytical DLs that were higher than those for the SRI sampling event. The metals datasets from both the King County WQA and SRI samples were combined for use in this SRI because the ranges of detected concentrations in the two datasets were generally comparable. King County water quality monitoring data collected from two water depths at two locations for a total of 46 samples from 2009 to 2011 were also used to characterize the temperature, salinity, TOC, dissolved organic carbon (DOC) and TSS for EW.

Table 4-10

Surface Water Data Included in the EW SRI Baseline Dataset

Sampling Event	Years of Sample Collection	No. of Samples Analyzed	Analytes	Source
SRI/FS	2008–2009	59	metals (filtered and unfiltered), PCB congeners, SVOCs, TBT, and conventionals	Windward (2009k)
King County monitoring data	2009-2011	48	conventionals	Williston (2011a)
King County WQA	1996–1997	188[a]	metals (filtered and unfiltered) and conventionals	King County (1999a)

[a] Samples analyzed only for conventional parameters are not included in the number of samples analyzed.

EW – East Waterway
FS – feasibility study
PCB – polychlorinated biphenyl
SRI – supplemental remedial investigation
SVOC – semivolatile organic compound
TBT – tributyltin
WQA – water quality assessment

4.1.2.6 Groundwater

Nearshore groundwater data are available for areas adjacent to the EW (Table 4-11 Map 4-8). This groundwater monitoring has been conducted as part of site characterizations and post remediation monitoring plans. A detailed discussion of the groundwater investigations is provided in Section 9.5.3.

Table 4-11

Groundwater Sampling Locations in the EW

Area Description	Groundwater Sampling Locations	Analytes	Source
Harbor Island Soil and Groundwater OU	7 nearshore wells along the EW shoreline	PCBs, metals, SVOC, VOC, cyanide	EPA (2010b); AECOM (2012)
Terminal 102 LUST site	6 temporary soil borings	petroleum hydrocarbons	RETEC (1997)
Coast Guard (Pier 35)	2 wells and 5 temporary borings all located in upland site areas over 300 ft from the EW	metals, petroleum hydrocarbons, VOCs	Hart Crowser (2004)
Former GATX (Pier 34)	5 nearshore wells and multiple groundwater seep locations	metals, petroleum hydrocarbons, BTEX, PAHs	RETEC (2004)
Former Chevron (Terminal 30)	4 nearshore wells	petroleum hydrocarbons, BTEX, PAHs	Pacific Groundwater Group (2012)
Terminal 25	4 nearshore wells	PCBs, metals, BTEX, petroleum hydrocarbons	Landau (1990); Sweet-Edwards/EMCON (1990); Anchor QEA (2012)
Terminal 104 and vicinity	13 upland wells and 49 temporary borings	metals, petroleum hydrocarbons, VOCs, PAHs, PCBs	EMCON (1992a, b, c, d, 1993); Environmental Partners (2007)

BTEX – benzene, toluene, ethylbenzene, and xylene
EW – East Waterway
LUST – leaking underground storage tank
OU – operable unit
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SVOC – semivolatile organic compound
VOC – volatile organic compound

4.1.2.7 Porewater

The SRI baseline porewater dataset consists of porewater data collected from intertidal areas in 2010 for the analysis of volatile organic compounds (VOCs), as well as historical porewater data from subtidal sediment porewater samples that were originally collected and analyzed for TBT for Dredged Material Management Program (DMMP) characterization. Thirty-seven porewater samples that had been collected in areas that were subsequently dredged or

capped were not included. The existing datasets are summarized in Table 4-12. The locations of the SRI baseline porewater samples are shown on Maps 4-9a and 4-9b.

Table 4-12
Porewater Data Included in the EW SRI Baseline Dataset

Sampling Event	Sample Collection Date	No. of Samples Analyzed	Analytes	Source
SRI/FS	July 2010	13	VOCs	Windward (2010h)
EW Pre-sand Placement Monitoring	February 2005	2	TBT	Windward (2005a)
EW/Harbor Island Nature and Extent – Phase 1	September 2001	32	TBT	Windward (2002b)
EW/Harbor Island Nature and Extent – Phase 2	September 2001	10	TBT	Windward (2002b)
EW Stage 1 Channel Deepening	August 1998	52	TBT	SAIC (1999a)
Pier 36 – preliminary	April 1997	1	TBT	Berger/Abram (1997)
T-18 Dredging – Phase 2	March 1996	2	TBT	EVS (1998)

EW – East Waterway
FS – feasibility study
SRI – supplemental remedial investigation
T-18 – Terminal 18
TBT – tributyltin
VOC – volatile organic compound

4.1.3 Data Suitability

Once data had been determined to meet the DQOs, the suitability of data for specific purposes in the SRI was evaluated according to EPA guidance (EPA 1988, 1992b). Of primary importance was the degree to which the data adequately represented site-related contamination and potential exposure of humans and ecological receptors at the site. Other considerations in determining the suitability of datasets that met the DQOs included the availability of data validation results, whether results may have been confounded by analytical interferences, and whether data represented a significant departure from the standard analytical methods used for other samples in the dataset.

4.1.3.1 Representativeness

This section provides a discussion of whether the available sediment, tissue, and water data are representative of the ranges and distributions of contaminant concentrations in the EW.

4.1.3.1.1 Surface Sediment

Many environmental sampling events have included the collection and analysis of EW surface sediment (Table 4-3). These studies were designed as site-wide investigations or to characterize surface sediment following dredge events. One site investigation was conducted for Slip 27 (2007a).

Of the 334 surface sediment samples in the SRI surface sediment baseline dataset, 234 samples were collected as part of site-wide sampling events (1996b, b; 2002b, 2010f), 93 samples were collected during post-dredge monitoring investigations, and 7 samples were collected as part of a Slip 27 characterization study (2007a), as shown on Maps 4-1a and 4-1b.

The majority of the samples were collected for the purpose of site-wide characterization, and therefore, the samples represent the spatial extent of the EW. In order to characterize the entire waterway with existing surface sediment data, the surface sediment datasets for select contaminants were interpolated using an inverse distance weighting (IDW) approach. It was EPA's intent to follow the LDW IDW parameter selection process not to use the LDW parameters. However, the application of LDW IDW parameters was compared to interpolation based on EW-derived parameters (Appendix D) and the distributions of contaminants within EW were consistent for both interpolations. Therefore, the use of the LDW IDW parameters had no effect on the conclusions of the nature and extent evaluation.

In addition to grab samples, composite samples have been collected in both the intertidal and subtidal areas of the EW. The intertidal sediment has been less frequently sampled than subtidal sediment, in large part because there are few intertidal areas in EW. Multi-increment sampling (MIS) samples were collected to characterize the intertidal sediment for the risk assessments. The MIS samples consisted of three composite samples that were created from a total of 108 discrete surface sediment samples collected throughout the intertidal areas of the EW, each composite sample represents the same area but contains unique sediment samples (Map 4-2). In addition, one composite sample was created from 32 discrete surface sediment samples collected from the intertidal areas that are publically accessible (Map 4-2). In addition, dioxins and furans and PCB congeners were analyzed in 13 subtidal composite samples distributed throughout EW (Map 4-2).

4.1.3.1.2 Subsurface Sediment

Many environmental sampling events have included the collection of subsurface sediment from the EW (Table 4-6). Of the 346 subsurface samples (from 146 cores collected from areas that have not been dredged), 214 samples (from 67 cores) were collected during site-wide investigations, including the SRI subsurface sediment sampling in 2010. The remaining 132 samples (from 79 cores) were collected to characterize sediment dredge prisms that were ultimately not dredged (Maps 4-4a and 4-4b). Because the majority of the data were collected for the purpose of site-wide characterization, the dataset is well distributed spatially and representative of the site as a whole.

4.1.3.1.3 Tissue

To represent contaminant concentrations in tissue within the EW, it was necessary to collect data for various biological tissue types (Table 4-9). A representative set of tissue data had to address spatial coverage for each species according to its home range within EW, appropriate size classes to meet specific sampling objectives (e.g., sizes appropriate for human consumption) for each organism, and sufficient numbers of samples to adequately represent the exposure of the organisms throughout the EW or human health exposure through seafood consumption.

Because there were very limited existing tissue data available for the EW, large numbers of fish and shellfish were collected as part of the SRI for use primarily in the risk assessments (Windward 2008h). These data were also used to summarize the nature and extent of contaminant concentrations in biological matrices of the EW. Species were selected to represent the exposure of humans and representative ecological receptors, and thus various fish, crab and bivalve species as well as benthic invertebrates and shrimp were collected. In addition, a composite sample of juvenile Chinook salmon stomach contents was collected to assess the dietary exposure of the juvenile salmon.[56] Tissue samples were analyzed as whole body and fillet or edible meat depending on the species and needs of the risk assessment.

[56] A total of 165 fish were sampled for stomach contents. Nineteen fish had no measurable amounts of stomach contents, and 146 fish contributed mass to the composite sample. The individual stomach content masses ranged from 0.01 to 0.502 g, with an average of 0.05 g of stomach contents per fish that contained measurable amounts of stomach contents.

Tissue sampling performed for the SRI was designed to generate data representative of the range of concentrations of contaminants to which a target organism may be exposed and to provide adequate spatial coverage of the EW. For mobile species such as fish and crab, spatial representation of the EW was accomplished by compositing organisms collected throughout EW. Brown rockfish have a home range smaller than EW and were collected at 13 locations throughout the EW (Map 4-5) and were analyzed as individual fish. For benthic invertebrates, the EW was divided into 10 sampling areas, which were characterized through the creation of composite samples from benthic invertebrate tissue obtained in 5 to 10 individual grab samples from each sampling area (Map 4-6). For clams, all intertidal areas throughout the EW were surveyed, and where clams were found, they were collected and composited by species and location (Map 4-5). Geoducks were collected at nine subtidal locations off of T-18 at the northwestern end of the deep main channel between Station 0 and Station -400 (Map 4-5). These were the only locations where geoducks were found in EW based on video and diver surveys conducted for the SRI. Geoduck gutball samples were composited into three samples to obtain sufficient mass for analysis, and edible meat samples were analyzed from individual geoducks (Map 4-5). Shrimp samples were collected from and composited across four locations within EW because very few shrimp were retained in the shrimp traps. Mussel composite samples were collected from pilings located throughout EW (Map 4-5). Target sizes of fish and crab collected during the SRI were selected to represent the prey size ranges preferred by piscivorous wildlife receptors and reasonable size ranges of seafood consumed by people (Windward 2008h).

4.1.3.1.4 Surface Water

The SRI surface water baseline dataset consists of data collected in 2008 and 2009 for the SRI and data collected in 1996–1997 by King County as part of its WQA (Table 4-10). King County collected samples weekly from October to June from three locations along a transect across the main channel of the EW. The SRI sampling events included two dry-season events, two wet-season events, and one storm event at five locations distributed throughout the waterway (Map 4-7). The surface water dataset is representative water collected from 1m below the water surface and 1m above the sediment surface at a range of locations and flow conditions within the EW.

4.1.3.1.5 Groundwater

Groundwater samples were collected as part of various upland site characterization or upland remediation monitoring programs throughout the nearshore areas of the EW to evaluate impacts to groundwater quality from various upland releases (see Table 4-11). Samples were collected under different regulatory programs and over various time frames. In addition, the parameters that were analyzed varied depending on the nature of the contaminant release being investigated. These data and an evaluation of potential source control issues associated with groundwater are presented in Section 9.

4.1.3.1.6 Porewater

Porewater samples were collected for the analysis of TBT from 99 locations throughout the EW for primarily purposes of dredge material characterization and post-dredge monitoring because these sampling programs are conducted under the DMMP and the DMMP standard for TBT is based on porewater TBT concentrations. Forty-four surface sediment (0 to 10 cm) porewater samples, 39 subsurface sediment porewater samples from the 0-to-4-ft interval, and 16 subsurface sediment porewater samples from depths ≥ 4 ft were analyzed for TBT (Maps 4-9a and 4-9b). The surface sediment porewater TBT samples are distributed throughout EW. The subsurface porewater TBT samples are predominately located in the shallow main body. These samples were collected for dredge material characterization and there was no subsequent dredge event.

Intertidal porewater samples were also collected as part of the SRI to evaluate risks from VOCs to the benthic invertebrate community. Intertidal porewater samples were used because the VOC exposure of benthic invertebrates cannot be assessed on the basis of sediment concentrations due to the relatively low affinities of these compounds for sediment particles. Twelve porewater samples were collected from four intertidal areas (Maps 4-9a and 4-9b). Porewater locations were selected based on a review of nearshore groundwater data to identify areas with potentially elevated groundwater VOC concentrations. Porewater samples were collected from locations with the lowest-salinity porewater to ensure that the porewater samples were maximally influenced by potential groundwater discharges (i.e., any groundwater was minimally diluted by seawater to characterize porewater associated with upland groundwater flows).

4.1.3.2 Quality Assurance/Quality Control Results

All datasets used in the SRI (i.e., sediment, tissue, surface water, and porewater) were validated by the original authors of the individual studies or by third parties. Summaries of these data validations for historical sampling events were presented in the EISR (Anchor and Windward 2008a). Data validation reports for samples collected as part of the SRI were included in the data reports for each sampling event.

4.1.4 Data Reduction

Data reduction refers to methods used to aggregate raw data received from the laboratory for use in the SRI/FS. A detailed discussion of data reduction methods is presented in Appendix D, and briefly summarized below:

- Detected analyte concentrations obtained from the analysis of laboratory duplicates or replicates (i.e., two or more analyses of the same sample) were averaged. If one duplicate or replicate result was detected and the other was not-detected, only the detected result was used.
- Detected analyte concentrations obtained from the analysis of field duplicates were not averaged for the presentation of summary statistics, but were averaged for mapping purposes. If one duplicate or replicate result was detected and the other was not-detected, only the detected result was used for mapping purposes.
- In some instances, the laboratory generated more than one result for an analyte in a given sample if re-analysis was required or if two different analytical methods were used for that analyte. The procedures for selecting the best result are described in Appendix D. Only the results from the selected procedure are in the SRI baseline dataset.
- The precision of each result was stored in the project database by recording the number of significant figures assigned by the laboratory. These significant figures were treated according to methods described in Appendix D.

For several contaminants (total PCBs, total dichlorodiphenyltrichloroethanes [DDTs], total PAHs, and total chlordane), total concentrations in individual samples were calculated by summing concentrations of individual components (i.e., seven Aroclor mixtures or individual congeners for total PCBs, two DDT isomers each of DDT, dichlorodiphenyldichloroethylene

(DDE), and dichlorodiphenyldichloroethane (DDD) for total DDTs, specific individual PAH compounds for total PAHs, and specific individual chlordane compounds for total chlordane). The treatment of non-detects for these sums were as follows:

- If some of the individual components were detected in a sample and some were not, only the detected concentrations were included in the sum.
- If none of the individual components were detected in a sample, the total concentration was given a value equal to the highest RL of an individual component and assigned a U-qualifier, indicating the lack of a detected concentration.

When calculating mean concentration for a group of samples for contaminants expressed as totals (e.g., Aroclors, DDT-related compounds, individual PAH compounds, or individual chlordane compounds), if none of the individual components of the mixture were detected in a given sample, then one-half the reported non-detect value was used for that sample. The calculation of the reported non-detect value is discussed in Appendix D. TEQs of dioxins and furans and PCBs were calculated by summing the products of concentrations and compound-specific toxic equivalency factors (TEFs) for individual congeners of polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) or PCBs, as discussed in more detail in Appendix D. cPAHs were calculated by summing the products of concentrations and compound-specific potency equivalency factors (PEFs) for individual cPAH compounds, also discussed in more detail in Appendix D. Congeners or individual cPAH compounds that were undetected for a given sample were assigned a value equal to one-half the sample-specific RL for use in the calculations. Only the congeners or compounds that were analyzed were included in the TEQ or cPAH calculations.

4.2 Contaminant-Specific Nature and Extent Information

This section presents the nature and extent of contamination in surface sediment, subsurface sediment, tissue, surface water, and porewater, including maps that show the distributions of select chemicals in the various media. This section begins with a comparison of all EW sediment chemistry data with promulgated standards, the sediment quality standards (SQS) and cleanup screening level (CSL) criteria of the SMS (Washington Administrative Code [WAC] 173-204). This SMS discussion is followed by contaminant-specific descriptions of the nature and extent of contamination in various site media. Sections 4.2.3 through 4.2.9

discuss a subset of contaminants identified as risk drivers in either the ERA or the HHRA (i.e., PCBs, dioxins and furans, total TEQ, cPAHs, arsenic, mercury, and TBT, respectively); and Sections 4.2.10 through 4.2.12 discuss metals, SVOCs, and organochlorine pesticides, respectively because these chemical groups include contaminants identified as COCs in the ERA and HHRA. The intent of the nature and extent evaluation is to describe the distribution of contaminant concentrations in the sampled matrices throughout the waterway. The evaluations of the contaminant concentrations with regard to ecological risk thresholds and human health risk thresholds are provided in Sections 5 and 6 respectively. Finally, sediment risk-based threshold concentrations are described in Section 8 and compared to EW sediment concentrations in Section 10.

Contaminant concentration percentiles for the risk driver contaminants in the SRI baseline surface sediment dataset were calculated to facilitate data presentation. The 95th percentile is the concentration below which 95% of the sample concentrations fall. These percentiles are referred to as numerical percentiles. Area-based percentiles were also calculated based on IDW (ENSR 2008) to facilitate spatial-weighted data presentation. Area-based percentiles are calculated in the same manner as numerical percentiles, except that the percentiles are established by the percentage of the total EW area, rather than the range of sample concentrations (e.g., the 95th percentile is the concentration at which 95% of the EW area has interpolated values below that concentration). All interpolated maps were prepared based on the numeric percentiles of the surface sediment dataset.

Summaries presented in this section are based on data of acceptable quality collected from 1995 to the present, as described in Section 4.1.

4.2.1 Sediment Chemistry and Toxicity Relative to SMS Criteria

This section describes the SMS marine sediment criteria followed by comparisons of surface and subsurface chemistry data and toxicity test results with those criteria. This section presents the locations with exceedances of SMS criteria (for any chemical); detailed information on the locations and extent of SQS/CSL exceedances for specific chemicals or chemical groups is provided in the chemical-specific sections that describe the nature and extent of contamination (Sections 4.2.3 through 4.2.12).

4.2.1.1 SMS Criteria

The SMS provide both chemical and biological effects-based criteria. Numerical SMS chemical criteria are available for 47 chemicals or groups of chemicals. The SQS criteria represent numerical chemical concentrations below which sediment is designated as having no adverse effect on biological resources. The CSL criteria represent chemical concentrations at which minor adverse effects on biological resources are expected to occur. At chemical concentrations above the SQS but below the CSL, sediment is designated as having the potential for minor adverse effect on biological resources. The SMS chemical criteria for the 47 chemicals (or groups of chemicals) are presented in Table 4-13.

Table 4-13
SMS Chemical Criteria for Marine Sediment

Chemical	Unit	SQS	CSL
Metals			
Arsenic	mg/kg dw	57	93
Cadmium	mg/kg dw	5.1	6.7
Chromium	mg/kg dw	260	270
Copper	mg/kg dw	390	390
Lead	mg/kg dw	450	530
Mercury	mg/kg dw	0.41	0.59
Silver	mg/kg dw	6.1	6.1
Zinc	mg/kg dw	410	960
PAHs			
2-Methylnaphthalene	mg/kg OC	38	64
Acenaphthene	mg/kg OC	16	57
Acenaphthylene	mg/kg OC	66	66
Anthracene	mg/kg OC	220	1,200
Benzo(a)anthracene	mg/kg OC	110	270
Benzo(a)pyrene	mg/kg OC	99	210
Benzo(g,h,i)perylene	mg/kg OC	31	78
Total benzofluoranthenes[a]	mg/kg OC	230	450
Chrysene	mg/kg OC	110	460
Dibenzo(a,h)anthracene	mg/kg OC	12	33
Dibenzofuran	mg/kg OC	15	58
Fluoranthene	mg/kg OC	160	1,200
Fluorene	mg/kg OC	23	79
Indeno(1,2,3-cd)pyrene	mg/kg OC	34	88
Naphthalene	mg/kg OC	99	170

Chemical	Unit	SQS	CSL
Phenanthrene	mg/kg OC	100	480
Pyrene	mg/kg OC	1,000	1,400
Total HPAH[b]	mg/kg OC	960	5,300
Total LPAH[c]	mg/kg OC	370	780
Phthalates			
BEHP	mg/kg OC	47	78
BBP	mg/kg OC	4.9	64
Diethyl phthalate	mg/kg OC	61	110
Dimethyl phthalate	mg/kg OC	53	53
Di-n-butyl phthalate	mg/kg OC	220	1,700
Di-n-octyl phthalate	mg/kg OC	58	4,500
Other SVOCs			
1,2,4-Trichlorobenzene	mg/kg OC	0.81	1.8
1,2-Dichlorobenzene	mg/kg OC	2.3	2.3
1,4-Dichlorobenzene	mg/kg OC	3.1	9.0
2,4-Dimethylphenol	µg/kg dw	29	29
2-Methylphenol	µg/kg dw	63	63
4-Methylphenol	µg/kg dw	670	670
Benzoic acid	µg/kg dw	650	650
Benzyl alcohol	µg/kg dw	57	73
Hexachlorobenzene	mg/kg OC	0.38	2.3
Hexachlorobutadiene	mg/kg OC	3.9	6.2
n-Nitrosodiphenylamine	mg/kg OC	11	11
Pentachlorophenol	µg/kg dw	360	690
Phenol	µg/kg dw	420	1,200
PCBs			
Total PCBs	mg/kg OC	12	65

[a] Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.

[b] Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

[c] Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
OC –organic carbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SMS – Washington State Sediment Management Standards
SQS – sediment quality standards
SVOC – semivolatile organic compound

Many of the SQS and CSL criteria are in units normalized to the organic carbon (OC) content in the sediment sample (mg/kg OC). Concentrations originally in units of µg/kg dw were converted to mg/kg OC using the following equation:

$$C_{OC} = \frac{C_{dw}}{TOC} \quad (4\text{-}1)$$

Where:

C_{dw} = dry-weight chemical concentration (mg/kg dw)

C_{oc} = organic carbon-normalized chemical concentration (mg/kg OC)

TOC = fraction of total organic carbon

Organic carbon-normalization is not considered to be appropriate for TOC concentrations ≤ 0.5 or ≥ 4.0% as discussed in Appendix D. In these cases, dry-weight chemical concentrations were compared with the lowest apparent effects threshold (LAET), which is functionally equivalent to the SQS, or the second lowest AET (2LAET), which is functionally equivalent to the CSL. Table 4-14 presents the LAET and 2LAET values for chemicals with SMS criteria that are OC-normalized.

Table 4-14
LAETs for Chemicals with OC-Normalized SMS Criteria

Chemical	Concentration (µg/kg dw)	
	LAET	2LAET
PAHs		
2-Methylnaphthalene	670	670
Acenaphthene	500	500
Acenaphthylene	1,300	1,300
Anthracene	960	960
Benzo(a)anthracene	1,300	1,600
Benzo(a)pyrene	1,600	1600
Benzo(g,h,i)perylene	670	720
Total benzofluoranthenes[a]	3,200	3,600
Chrysene	1,400	2,800
Dibenzo(a,h)anthracene	230	230
Dibenzofuran	540	540
Fluoranthene	1,700	2,500
Fluorene	540	540
Indeno(1,2,3-cd)pyrene	600	690

Chemical	Concentration (µg/kg dw)	
	LAET	2LAET
Naphthalene	2,100	2,100
Phenanthrene	1,500	1,500
Pyrene	2,600	3,300
Total HPAH[b]	12,000	17,000
Total LPAH[c]	5,200	5,200
Phthalates		
BEHP	1,300	3,100
BBP	63	900
Diethyl phthalate	200	1,200
Dimethyl phthalate	71	160
Di-n-butyl phthalate	1,400	5,100
Di-n-octyl phthalate	6,200	6,200
Other SVOCs		
1,2,4-Trichlorobenzene	31	51
1,2-Dichlorobenzene	35	50
1,4-Dichlorobenzene	110	110
Hexachlorobenzene	22	70
Hexachlorobutadiene	11	120
n-Nitrosodiphenylamine	28	40
PCBs		
Total PCBs	130	1,000

[a] Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.

[b] Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

[c] Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LAET – lowest apparent effects threshold
2LAET – second lowest apparent effects threshold
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
nv – no value
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SMS – Washington State Sediment Management Standards
SVOC – semivolatile organic compound

The SMS also include biological criteria (WAC 173-204-315) based on sediment toxicity tests and benthic infaunal abundance. Because apparent effects thresholds (AETs), which form the basis for the SMS chemical criteria, are based on sediment samples with a mixture of chemicals from various locations in Puget Sound and the exceedance of the SMS chemical criteria is not always an accurate predictor of adverse effects, the regulations state that site-specific biological tests (sediment toxicity tests and the assessment of benthic infaunal

abundances) may be conducted to provide confirmation that site-specific chemistry data indicate a hazard to benthic invertebrate communities. The SQS and CSL biological effects criteria for the toxicity tests conducted under the SMS rule are presented in Table 4-15; there were no EW assessments of benthic infaunal abundances, so SMS criteria for those assessments are not included. According to the state regulations, the tested sediments are designated as exceeding the SQS, if the SQS biological criteria are exceeded for any one of the three toxicity tests conducted for a sampling location. Likewise, sediments are designated as exceeding the CSL, if the CSL biological criteria are exceeded for any one of the three toxicity tests or if the SQS biological effects criteria are exceeded in any two of the three toxicity tests conducted for a sampling location (WAC 173-204-420(3)). The SQS and CSL designations based on biological criteria override the SQS and CSL designations based on chemistry results. For example, if a location has a chemical CSL exceedance but is tested and found not to exceed the biological SQS criterion, it is not categorized as an SMS exceedance. When the SMS status of surface sediment locations has been determined by the combined chemistry and toxicity data, it is noted as such. All presentations of SMS status for individual contaminants or groups of contaminants are based on the SMS chemistry comparisons alone.

Table 4-15

SMS Biological Effects Criteria for Marine Sediment Toxicity Tests

Toxicity Test	Biological Effects Criteria	
	SQS	CSL
Amphipod	mean mortality is > 25% on an absolute basis and statistically different from the reference sediment ($p \leq 0.05$)	mean mortality is greater than the response in the reference sediment plus 30% and statistically different from the reference sediment ($p \leq 0.05$)
Bivalve larvae	mean normal survivorship[a] is < 85% of that of the reference sediment and statistically different ($p \leq 0.10$)	mean normal survivorship[a] is < 70% of that of the reference sediment and statistically different ($p \leq 0.10$)
Polychaete	mean individual growth rate is < 70% of that of the reference sediment and statistically different ($p \leq 0.05$)[b]	mean individual growth rate is < 50% of that of the reference sediment and statistically different ($p \leq 0.05$)[b]

[a] Mean normal survivorship is a combined measure of mortality and abnormality (i.e., the number of normal larvae relative to the initial number of organisms).

[b] The mortality endpoint for the polychaete toxicity test is not used for the determination of SMS compliance.

CSL – cleanup screening level

SMS – Washington State Sediment Management Standards

SQS – sediment quality standards

4.2.1.2 Surface Sediment Chemistry Relative to SMS

Table 4-16 presents a summary of chemicals detected in surface sediment samples relative to numerical chemical SMS criteria. The EW surface sediment baseline dataset consists of 296 surface sediment samples collected from 243 locations within the EW. Some locations are represented by more than one sample because of field duplicates or because the same location was sampled during more than one sampling event. Table 4-16 presents summary statistics based on individual samples, whereas Map 4-10 presents results by location based on the average of all samples collected at each location. Of these 243 locations, 167 had one or more exceedance of the chemical SQS (Map 4-10). Thirty chemicals or chemical groups had concentrations that exceeded the SQS in at least one sample (Table 4-16). Eight chemicals or chemical groups had concentrations that exceeded the CSL in at least one sample (Table 4-16). In surface sediment samples, detected total PCBs most frequently (65%) exceeded its SQS or CSL criterion, followed by mercury (19%), and 1,4-dichlorobenzene (13%). All other detected chemicals exceeded their respective SQS or CSL criteria in < 10% of the samples (Table 4-16).

Table 4-16

Comparison of EW Surface Sediment Chemical Data with SMS Chemical Criteria

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. with RL > CSL	
Metals										
Arsenic	162/231	70	0/231	0	0	ne	2/231	0.90	0	2.6
Cadmium	155/231	67	1/231	0.40	0	1.3	1/231	0.40	0	1
Chromium	231/231	100	0/231	0	0	ne	0/231	0	0	ne
Copper	231/231	100	0/231	0	0	ne	0/231	0	0	ne
Lead	228/231	99	0/231	0	0	ne	0/231	0	0	ne
Mercury	233/239	98	36/239	15	0	2.6	10/239	4.2	0	1.8
Silver	97/231	42	0/231	0	0	ne	0/231	0	0	ne
Zinc	231/231	100	4/231	1.7	0	3	1/231	0.40	0	1.3
PAHs										
2-Methylnaphthalene	87/240	36	0/240	0	0	ne	1/240	0.40	0	1.3
Acenaphthene	126/240	53	10/240	4.2	0	14	6/240[d]	2.5	0	4
Acenaphthylene	109/240	45	0/240	0	0	ne	0/240	0	0	ne
Anthracene	209/240	87	1/240	0.40	0	1	0/240	0	0	ne
Benzo(a)anthracene	226/240	94	6/240	2.5	0	3.2	1/240	0.40	0	1.3
Benzo(a)pyrene	225/240	94	6/240	2.5	0	2.4	1/240	0.40	0	1.1
Benzo(g,h,i)perylene	212/240	88	4/240	1.7	0	1.8	0/240	0	0	ne
Total benzofluoranthenes[e]	228/240	95	6/240	2.5	0	4	1/240	0.40	0	2.0
Chrysene	230/240	96	7/240	2.9	0	10	1/240	0.40	0	2.4
Dibenzo(a,h)anthracene	156/240	65	4/240	1.7	0	1.8	0/240	0	0	ne
Dibenzofuran	107/240	45	6/240	2.5	0	11	2/240	0.80	0	2.8

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. with RL > CSL	
Fluoranthene	233/240	97	12/240	5.0	0	40	2/240	0.80	0	5.3
Fluorene	144/240	60	9/240	3.8	0	9.6	3/240[f]	1.3	0	2.8
Indeno(1,2,3-cd)pyrene	210/240	88	6/240	2.5	0	1.7	0/240	0	0	ne
Naphthalene	118/240	49	0/240	0	0	ne	0/240	0	0	ne
Phenanthrene	230/240	96	12/240	5.0	0	7.8	3/240	1.3	0	1.6
Pyrene	235/240	98	0/240	0	0	ne	1/240	0.40	0	2.5
Total HPAHs[g]	237/240	99	8/240	3.3	0	13	1/240	0.40	0	2.4
Total LPAHs[h]	230/240	96	5/240	2.1	0	3.6	3/240	1.3	0	1.7
Phthalates										
BEHP	207/231	90	4/231	1.7	1	40	5/231	2.2	1	24
BBP	101/231	44	9/231	3.9	6	2.9	0/231	0	0	ne
Diethyl phthalate	19/231	8.2	0/231	0	0	ne	0/231	0	0	ne
Dimethyl phthalate	15/231	6.5	0/231	0	0	ne	0/231	0	0	ne
Di-n-butyl phthalate	32/231	14	0/231	0	0	ne	1/231	0.40	0	1.5
Di-n-octyl phthalate	9/231	3.9	0/231	0	0	ne	0/231	0	0	ne
Other SVOCs										
1,2,4-Trichlorobenzene	7/231	3.0	0/231	0	28	ne	0/231	0	13	ne
1,2-Dichlorobenzene	2/231	0.90	0/231	0	0	ne	0/231	0	11	ne
1,3-Dichlorobenzene	2/214	0.9	0/214	0	0	ne	0/214	0	0	ne
1,4-Dichlorobenzene	146/231	63	20/231	8.7	2	350	9/231	3.9	0	120
2,4-Dimethylphenol	14/231	6.1	0/231	0	0	ne	1/231	0.40	36	3.1
2-Methylphenol	6/231	2.6	0/231	0	0	ne	0/231	0	3	ne
4-Methylphenol	48/231	21	0/231	0	0	ne	0/231	0	0	ne
Benzoic acid	3/231	1.3	0/231	0	0	ne	0/231	0	10	ne

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. with RL > CSL	
Benzyl alcohol	2/220	0.90	0/220	0	5	ne	0/220	0	3	ne
n-Nitrosodiphenylamine	2/231	0.90	0/231	0	0	ne	1/231[i]	0.40	0	4.5
Pentachlorophenol	10/231	4.3	0/231	0	8	ne	0/231	0	2	ne
Phenol	94/231	41	5/231	2.2	0	1.5	0/231	0	0	ne
PCBs										
Total PCBs	227/240	95	134/240	56	0	70	23/240[j]	9.6	0	13

[a] Represents the number of detects per total number of samples.

[b] Represents the number of detects > SQS and ≤ CSL per total number of samples. If any individual sample had a TOC content > 4% or < 0.5% and the dry-weight concentration was > LAET and ≤ 2LAET, the concentration was considered to be > SQS and ≤ CSL.

[c] Represents the number of detects > CSL per the total number of samples. If any individual location had a TOC content > 4% or < 0.5% and the dry-weight concentration was > 2LAET, the concentration was considered to be > CSL.

[d] One of these six samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

[e] Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.

[f] One of these three samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

[g] Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

[h] Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

[i] This sample could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

[j] Two of these twenty-three samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
DDT – dichlorodiphenyltrichloroethane
EF – exceedance factor
HPAH – low-molecular-weight polycyclic aromatic hydrocarbon
LPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LAET – lowest-apparent-effect threshold
2LAET – second-lowest-apparent-effect threshold
ne – no exceedance
OC – organic carbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RL – reporting limit
SQS – sediment quality standards
SVOC – semivolatile organic compound
TOC – total organic carbon

Twenty-three contaminants exceeded their respective CSL in at least one sample, with total PCBs being the most frequently detected above its CSL criterion (23 of 240 locations, or 9.6%) followed by mercury (10 of 239 locations, or 4.2%); all other contaminants were detected above their respective CSL criterion in < 4% of the samples. Maps 4-11a through 4-11f present detailed results for each location with SQS or CSL exceedances for any detected chemical in surface sediment.

For certain chemicals, analytical laboratory RLs exceeded the SQS or CSL (Table 4-16). There were 137 samples for which the RL exceeded an SMS criterion; for 112 (82%) of these samples, there was also a detected concentration that exceeded a criterion. The remaining 25 samples had only RL exceedances, which were predominantly associated with 1,2,4-trichlorobenzene (13 locations). These elevated RLs, which generally reflected dilutions or analytical challenges, create some uncertainty in interpreting the data relative to SMS exceedances. Appendix A, Section A.6.1.1.1, presents a detailed discussion of RL exceedances at all locations, including those with detected chemical exceedances.

4.2.1.3 Toxicity Test Results Relative to SMS

The results for the three SMS sediment toxicity tests are provided in Table 4-17 and Map 4-12. For the amphipod mortality endpoint, 6 of the 48 samples had CSL exceedances based on SMS biological effects criteria, and an additional single sample had an SQS exceedance (Table 4-17). For the polychaete growth endpoint, 1 of the 48 samples had a CSL exceedance based on SMS biological effects criteria, and 6 other samples had SQS exceedances. For the bivalve survival and development endpoint, 14 of the 48 samples had CSL exceedances, and 6 had SQS exceedances (Table 4-17). The locations of these SQS and CSL exceedances in the EW are shown by location ID on Map 4-12.

Table 4-17

Site-Specific Toxicity Test Results for Surface Sediment Samples and SMS Designations

Location ID	Amphipod Test			Polychaete Test		Larval Test		
	Mortality (%)	Site Mortality Relative to Reference Mortality (% difference)	SMS Designation	Site Growth Relative to Reference Growth (% difference)	SMS Designation	Site NCMA Relative to Reference NCMA (% difference)[a]	SMS Designation	Overall SMS Designation
2000 T-18 PDM								
PDM-01	8	4	no exceedance	69	SQS	22.4	SQS	CSL
PDM-03	17	13	no exceedance	106	no exceedance	17.3	SQS	SQS
PDM-06	40	36	CSL	91.4	no exceedance	42.5	CSL	CSL
PDM-08	45	41	CSL	69.8	SQS	37.3	CSL	CSL
PDM-10	24	20	no exceedance	81.9	no exceedance	43.6	CSL	CSL
PDM-15	77	73	CSL	65.1	SQS	58.2	CSL	CSL
2001 East Waterway Nature and Extent Study								
EW-100	2	-3	no exceedance	76.8	no exceedance	-40.8	no exceedance	no exceedance
EW-101	3	-2	no exceedance	82.1	no exceedance	-36.1	no exceedance	no exceedance
EW-102	5	0	no exceedance	71.2	no exceedance	-21.2	no exceedance	no exceedance
EW-103	9	7	no exceedance	96	no exceedance	69.9	CSL	CSL
EW-104	11	6	no exceedance	123	no exceedance	3.9	no exceedance	no exceedance
EW-105	2	-3	no exceedance	72.3	no exceedance	-33.8	no exceedance	no exceedance
EW-106	2	-3	no exceedance	71.7	no exceedance	-35.1	no exceedance	no exceedance
EW-107	0	-5	no exceedance	88.6	no exceedance	-6.1	no exceedance	no exceedance
EW-108	0	-5	no exceedance	91.3	no exceedance	-33.9	no exceedance	no exceedance
EW-109	10	5	no exceedance	69.4	SQS	47.6	CSL	CSL
EW-110	0	-2	no exceedance	113.6	no exceedance	67.8	CSL	CSL
EW-111	3	1	no exceedance	75.4	no exceedance	-7.7	no exceedance	no exceedance
EW-112	2	-3	no exceedance	121	no exceedance	-48.4	no exceedance	no exceedance

Table 4-17
Site-Specific Toxicity Test Results for Surface Sediment Samples and SMS Designations (cont.)

Location ID	Amphipod Test			Polychaete Test		Larval Test		Overall SMS Designation
	Mortality (%)	Site Mortality Relative to Reference Mortality (% difference)	SMS Designation	Site Growth Relative to Reference Growth (% difference)	SMS Designation	Site NCMA Relative to Reference NCMA (% difference)[a]	SMS Designation	
EW-113	13	8	no exceedance	110	no exceedance	23	SQS	SQS
EW-114	8	3	no exceedance	87.1	no exceedance	-26.4	no exceedance	no exceedance
EW-115	2	-3	no exceedance	113	no exceedance	-39.7	no exceedance	no exceedance
EW-116	100	98	CSL	-4.5	CSL	102.4	CSL	CSL
EW-117	1	-1	no exceedance	123	no exceedance	56.8	CSL	CSL
EW-118	5	0	no exceedance	87.5	no exceedance	-12.5	no exceedance	no exceedance
EW-119	11	4	no exceedance	80.4	no exceedance	10.9	no exceedance	no exceedance
EW-120	8	3	no exceedance	101	no exceedance	5.4	no exceedance	no exceedance
EW-126	0	-2	no exceedance	111	no exceedance	21.1	SQS	SQS
EW-128	14	9	no exceedance	76.8	no exceedance	2.7	no exceedance	no exceedance
EW-132	6	4	no exceedance	77.5	no exceedance	89.4	CSL	CSL
EW-133	7	5	no exceedance	122	no exceedance	82.8	CSL	CSL
EW-134	14	9	no exceedance	87.3	no exceedance	31.3	CSL	CSL
EW-135	22	17	no exceedance	77.7	no exceedance	43.9	CSL	CSL
EW-136	13	6	no exceedance	94.6	no exceedance	38.2	CSL	CSL
EW-138	17	10	no exceedance	61.2	SQS	28.5	SQS	CSL
EW-141	22	15	no exceedance	98.9	no exceedance	23.9	SQS	SQS
EW-142	4	-1	no exceedance	84.4	no exceedance	7.8	no exceedance	no exceedance
2009 East Waterway SRI/FS								
EW09-SS-005	10	4	no exceedance	87.6	no exceedance	103.5	no exceedance	no exceedance
EW09-SS-030	26	24	SQS	72.6	no exceedance	102.0	no exceedance	SQS

Table 4-17

Site-Specific Toxicity Test Results for Surface Sediment Samples and SMS Designations (cont.)

Location ID	Amphipod Test			Polychaete Test		Larval Test		
	Mortality (%)	Site Mortality Relative to Reference Mortality (% difference)	SMS Designation	Site Growth Relative to Reference Growth (% difference)	SMS Designation	Site NCMA Relative to Reference NCMA (% difference)[a]	SMS Designation	Overall SMS Designation
EW09-SS-032	14	12	no exceedance	81.5	no exceedance	98.8	no exceedance	no exceedance
EW09-SS-033	35	33	CSL	78.5	no exceedance	102.5	no exceedance	CSL
EW09-SS-034	18	16	no exceedance	88.1	no exceedance	94.9	no exceedance	no exceedance
EW09-SS-035	33	31	CSL	75.6	no exceedance	94.9	no exceedance	CSL
EW09-SS-217	2	0	no exceedance	102.6	no exceedance	100.9	no exceedance	no exceedance
EW09-SS-218	3	1	no exceedance	108.7	no exceedance	99.1	no exceedance	no exceedance
EW09-SS-220	0	-2	no exceedance	92.2	no exceedance	93.0	no exceedance	no exceedance
EW09-SS-015	6	0	no exceedance	59.5	SQS	94.9	no exceedance	SQS
EW09-SS-215	13	7	no exceedance	76.7	no exceedance	102.4	no exceedance	no exceedance

[a] NCMA is the number of normal larvae in the site/reference test at the end of the exposure period relative to the number of normal larvae in the seawater control at the end of the exposure period.

CSL – cleanup screening level
CSO – combined sewer overflow
FS – feasibility study
ID – identification
NCMA – normalized combined mortality and abnormality
PDM – post-dredge monitoring
RI – remedial investigation
SMS – Washington State Sediment Management Standards
SQS – sediment quality standards
SRI – supplemental remedial investigation
T-18 – Terminal 18

Thiessen polygons were used to estimate the areal extent of potential effects based on combined toxicity test results and surface sediment chemistry data. Using the final SMS designation based on both sediment chemistry and toxicity test results, approximately 40% of the EW is designated as having no adverse effects to benthic community (all less than SQS), while approximately 21% are expected to have minor adverse affects (greater than or equal to CSL). Approximately 39% of the area was between the SQS and the CSL and is generally interpreted as having a potential for minor adverse effects on the benthic community. Map 4-13 shows the final designation of each area, as represented by Thiessen polygon, according to SMS rules.

4.2.1.4 Subsurface Sediment Chemistry Relative to SMS

Table 4-18 presents a summary of subsurface sediment samples with chemical concentrations greater than the SQS and CSL. Detected concentrations of 36 SMS chemicals were greater than their CSLs at one or more locations. Two additional chemicals (i.e., butyl benzyl phthalate [BBP] and phenol) were detected at concentrations that exceeded the SQS but did not exceed the CSL.

Table 4-18
Comparison of Subsurface Sediment Chemical Data with SMS Criteria

Chemical	Detection Frequency		Detected Concentrations > SQS and ≤ CSL		Detected Concentrations > CSL		Max. Detected SQS EF	Max. Detected CSL EF
	No. of Samples	Percent	No. of Samples	Percent	No. of Samples	Percent		
Metals								
Arsenic	250/255	98	0	0	1	0.39	ne	1.0
Cadmium	199/258	77	11	4.3	13	5.0	18	14
Copper	255/255	100	0	0	4	1.6	ne	1.9
Lead	220/255	86	2	0.78	5	2.0	3.2	2.7
Mercury	249/305	82	48	16	87	29	8.2	5.7
Silver	150/251	60	0	0	10	4.0	ne	1.6
Zinc	255/255	100	24	9.4	9	3.5	39	17
PAHs								
2-Methylnaphthalene	123/269	46	1	0.37	8	3.0	15	11
Acenaphthene	157/269	58	14	5.2	22	8.2	81	23
Acenaphthylene	98/269	36	0	0	1	0.37	ne	3.9
Anthracene	204/269	76	2	0.74	15	5.6	18	18
Benzo(a)anthracene	211/269	78	8	3.0	14	5.2	15	13

Chemical	Detection Frequency		Detected Concentrations > SQS and ≤ CSL		Detected Concentrations > CSL		Max. Detected SQS EF	Max. Detected CSL EF
	No. of Samples	Percent	No. of Samples	Percent	No. of Samples	Percent		
Benzo(a)pyrene	213/269	79	1	0.37	15	5.6	11	11
Benzo(g,h,i)perylene	198/269	74	6	2.2	8	3.0	11	10
Total benzofluoranthenes[a]	217/269	81	5	1.9	13	4.8	9.7	8.6
Chrysene	210/268	78	12	4.5	13	4.9	14	7.1
Dibenzo(a,h)anthracene	165/269	61	3	1.1	12	4.5	4.2	4.2
Dibenzofuran	141/269	52	9	3.3	12	4.5	51	18
Fluoranthene	222/269	83	20	7.4	20	7.4	32	22
Fluorene	174/269	65	9	3.3	19	7.1	36	22
Indeno(1,2,3-cd)pyrene	194/269	72	4	1.5	11	4.1	7.3	6.4
Naphthalene	170/269	63	0	0	7	2.6	ne	16
Phenanthrene	216/269	80	12	4.5	14	5.2	49	49
Pyrene	226/269	84	3	1.1	17	6.3	22	17
Total HPAHs[b]	231/269	86	15	5.6	16	5.9	18	12
Total LPAHs[c]	219/269	81	5	1.9	18	6.7	27	27
Phthalates								
BEHP	197/265	74	34	13	22	8.3	10	4.2
BBP	97/265	37	15	5.7	0	0	5.6	ne
Diethyl phthalate	11/265	4.2	0	0	0	0	ne	ne
Dimethyl phthalate	14/265	5.3	0	0	1	0.38	12	5.5
Other SVOCs								
1,2,4-Trichlorobenzene	10/266	3.8	1	0.38	2	0.75	2.7	1.2
1,2-Dichlorobenzene	3/265	1.1	0	0	1	0.38	ne	1.7
1,3-Dichlorobenzene	6/265	2.3	0	0	0	0	ne	ne
1,4-Dichlorobenzene	76/265	29	6	2.3	10	3.8	5.2	4.9
2,4-Dimethylphenol	16/265	6.0	0	0	8	3.0	ne	48
2-Methylphenol	8/264	3.0	0	0	2	0.76	ne	9.8
4-Methylphenol	69/265	26	0	0	2	0.75	ne	3
Benzoic acid	3/250	1.2	0	0	0	0	ne	ne
Hexachlorobenzene	2/265	0.80	0	0	0	0	ne	ne
Hexachlorobutadiene	2/265	0.80	0	0	0	0	ne	ne
n-Nitrosodiphenylamine	2/265	0.80	0	0	1	0.38	ne	1.9
Pentachlorophenol	4/238	1.7	0	0	0	0	ne	ne
Phenol	46/265	17	1	0.38	0	0	1.5	ne
PCBs								
Total PCBs[d]	207/290	71	86	30	78	27	140	18

[a] Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.

[b] Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

[c] Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

[d] Total PCBs were calculated as the sum of the detected concentrations of the individual Aroclors and one-half the RL for non-detected results. If none of the individual Aroclors were detected in a given sample, then the highest RL for an individual Aroclor was used for that sample.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
DDT – dichlorodiphenyltrichloroethane
EF – exceedance factor
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
ne – no exceedance
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SQS – sediment quality standards
SVOC – semivolatile organic compound
VOC – volatile organic compound

Maps 4-14a through 4-14k show the distribution of chemicals with concentrations that exceeded the SMS criteria in subsurface samples.

Most of the cores collected from the shallow main body (approximately from Station 6850 to Station 4900) had concentrations of at least one contaminant that exceeded the SQS or the CSL in at least one interval. Most of these exceedances were PCB and mercury concentrations that exceeded the SQS and CSL. In a small number of cores there were other contaminants with concentrations that also exceeded the SQS and the CSL; primarily SVOCs (e.g., PAHs, bis(2-ethylhexyl) phthalate [BEHP], 1,4-dichlorobenzene) and metals (e.g., cadmium and zinc).

The deep main body (from Station 4900 to Station -600) had relatively few subsurface samples with contaminant concentrations that exceeded the SQS and CSL, particularly in the deepest areas within the main body that have been recently dredged and at the mouth of the waterway (Maps 4-14c through 4-14i, and 4-14k). Within the recently dredged areas the majority of the SQS and CSL exceedances were for total PCBs in the 0-to 2- and 2-to-4-ft intervals.

CSL exceedances in the deep main body were generally limited to areas that have not been recently dredged. Contaminant exceedances of the SQS and CSL were measured in cores collected outside of the dredged areas along T-25 in the vicinity of Hanford #2 and two storm drains (Map 4-14c). Contaminant concentrations exceeded the SQS and CSL for total PCBs, mercury, and SVOCs (1,4-dichlorobenzene, and phthalates) (Maps 4-14c and 4-14d). In addition, the subsurface sediment samples collected from the mound area at the mouth of Slip 27 exceeded the SQS and CSL for total PCBs, mercury, SVOCs (primarily PAHs), and metals (including lead, silver, and zinc) (Maps 4-14e and 4-14k). Cores collected between Stations 2100 and 2600 in the center of the deep main body had contaminant concentrations

above the CSL for total PCBs, mercury, and SVOCs (PAHs) (Maps 4-14g and 4-14k). In addition, three core collected along the communication cable crossing had mercury concentrations above the CSL in the 0-to-4-ft interval (Maps 4-14g and 4-14k).

Subsurface sediment collected from cores collected south of Slip 36 near the former Rabanco barge loading facility and GATX (Maps 4-14h and 4-14i) exceeded the SQS and CSL for mercury, total PCBs, PAHs and metals (including cadmium, lead, and zinc).

Contaminants most frequently detected in subsurface sediment samples in Slip 27 at concentrations greater than the SQS and CSL were total PCBs, mercury and SVOCs (including PAHs, phthalates). Metals (including cadmium and zinc) exceeded the SQS and CSL less frequently (Maps 4-14j and 4-14k). The subsurface sediment samples in Slip 36 collected after the dredge event within the 2006 dredge area had total PCB concentrations above the SQS and mercury concentrations above the CSL in the 0-to-1-ft interval. One core collected from outside of the dredge prism had total PCB, mercury, and PAH concentrations above the CSL and zinc and BEHP concentrations above the SQS, with exceedances observed in the 0-to-2- and the 2-to-4-ft intervals. The cores collected from the mouth of the waterway (Map 4-14i) had no contaminant concentrations above the SQS. Overall, 95% of the cores collected from the EW during SRI sampling events had chemical concentrations that were less than the SQS in the lowest interval of the core that was analyzed.

For subsurface sediment, 64 of the 165 samples collected and analyzed as part of the SRI were collected entirely from within the lower alluvium unit (Maps 4-15a though 4-15d). The lower alluvium unit is predominantly sand with laminated and stratified beds of slightly silty to silty sand and silt that was deposited prior to the industrialization of the area. Sediment deposited prior to industrialization would be expected to be relatively free of contaminants. The sediment chemistry for the samples collected within the lower alluvium unit was evaluated in order to determine whether or not the contaminant concentrations associated with the lower alluvium unit were consistent with pre-industrial deposition. Sediment intervals that were identified as mixtures of lower alluvium and more recent sediment were not included in this evaluation because the sediment chemistry was likely to be influenced by the presence of recent sediment.

The depth from the sediment surface to the surface of the lower alluvium unit ranged widely from near surface to 11.5 ft, with an average depth of 2.1 ft, and is discussed in greater detail in Section 2.5.2.The areas in the deep main channel that have been recently dredged have the shallowest sediment depths to the lower alluvium unit as a result of the removal of the upper alluvium unit during dredging. The deepest depths from the sediment surface to the surface of the lower alluvium unit are located in the shallow main body (Station 4900 to Station 6800) and within Slip 27 due to the limited dredging activity in this area.

Of the 64 subsurface samples collected entirely within the lower alluvium unit, 10 samples had contaminant concentrations above the SQS (Maps 4-15a though 4-15d). Two samples had concentrations above the CSL (i.e., the total PCB concentration was above the CSL in SC-24, and the mercury concentration was above the CSL in SC-48). The elevated contaminant concentrations in these intervals may be an artifact of the mixing of more recent sediment with lower-alluvium material during sampling or the misidentification of lower-alluvium material in the cores. Seven of the SQS exceedances were due to total PCB concentrations above the SQS (SC-07B, SC-26, SC-30, SC-31, SC-36, SC-48 and SC-52).Four of these cores had SMS exceedances for PCBs in the sediment interval above the lower alluvium unit ((SC-07B, SC-30, SC-48 and SC-52) and therefore the exceedance may have been due to mixing of the layers. Three of the cores were within the Phase 1 dredge area which was covered with sand cover material following dredging due to SMS exceedances in the post-dredge monitoring samples (SC-28, SC-31 and SC-36). Another core (SC-26) was within the Stage 1 dredge area and the lower alluvium layer is the sediment surface and may contain material deposited after the completion of dredging. One sample, collected in Slip 27 (SC-29) contained PAH concentrations above the SQS, and the 0-to-2 and 2-to-4 ft intervals of this core contained PAH concentrations above the CSL.

4.2.1.5 Sediment Chemistry in Phase 1 Dredge Area

One area within EW has two sets of surface sediment chemistry data. The Phase 1 dredge area was dredged in 2004-2005. Following the completion of dredging (February 1, 2005), the exposed sediment surface was sampled in order to identify if areas had contaminant concentrations above the SQS. The area with sediment concentrations above the SQS was immediately dredged a second time (February 3 to 25, 2005) to remove an additional foot of material and then covered with a 1ft thick layer of sand cover material (March 1 to 15, 2005).

Pre-sand placement sediment samples were collected following the removal of the additional foot of material and analyzed for the analytes that exceeded the SMS in the post-dredge surface (metals, mercury, SVOCs and PCBs). The results from the pre-sand placement samples are provided in Table 4-19. Mercury and total PCBs were the contaminants that exceeded the SQS and CSL in the greatest number of samples.

The surface sediments on and near the sand cover area were then sampled for 3 years (2006-2008) following the placement of the sand cover material and the resulting data represents the current surface sediment conditions. The thickness of the sand cover material was evaluated as part of the sediment sampling and the surface sediment samples included sand cover material and overlying material. The SQS exceedances for the current surface sediment data were compared with the surface sediment data prior to the placement of sand cover material (i.e., pre-sand placement sediment) in Map 4-16. The current surface sediment has fewer exceedances of the CSL than was seen in the pre-sand placement samples. The six locations with CSL exceedances in the current sediment surface are associated with surface sediment concentrations of total PCBs, 1,4-dichlorobenzene and BEHP. These locations were not associated with SMS exceedances for 1,4-dichlorobenzene or BEHP in the pre-sand placement sediment sampling. However, SMS exceedances for total PCBs were observed in pre-sand placement locations located near two locations (EW-RM-34 and EW-RM-32) that exceed the SQS and CSL for total PCBs, respectively.

Table 4-19

Pre-Sand Placement Surface Sediment Data Compared with SMS

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. with RL > CSL	
Metals										
Arsenic	1/1	100	0	0	0	ne	0	0	0	ne
Cadmium	1/1	100	0	0	0	ne	0	0	0	ne
Chromium	1/1	100	0	0	0	ne	0	0	0	ne
Copper	1/1	100	0	0	0	ne	0	0	0	ne
Lead	1/1	100	0	0	0	ne	0	0	0	ne
Mercury	36/36	100	17	47	0	27	9	25	0	18
Silver	1/1	100	0	0	0	ne	0	0	0	ne
Zinc	1/1	100	0	0	0	ne	0	0	0	ne
PAHs										ne
2-Methylnaphthalene	3/12	25	0	0	0	ne	0	0	0	ne
Acenaphthene	3/12	25	1	8.3	0	21	1	8.3	0	6
Anthracene	6/12	50	0	0	0	ne	0	0	0	ne
Benzo(a)anthracene	9/12	75	0	0	0	ne	0	0	0	ne
Benzo(a)pyrene	9/12	75	0	0	0	ne	0	0	0	ne
Benzo(g,h,i)perylene	3/12	25	0	0	0	ne	0	0	0	ne
Total benzofluoranthenes[e]	10/12	83	0	0	0	ne	0	0	0	ne
Chrysene	11/12	92	0	0	0	ne	0	0	0	ne
Dibenzofuran	2/12	17	0	0	0	ne	1	8.3	0	4.3
Fluoranthene	12/12	100	1	8.3	0	3.3	0	0	0	ne
Fluorene	4/12	33	1	8.3	0	16	1	8.3	0	4.6

Chemical	Detection Frequency		Frequency of Detected Concentrations > SQS and ≤ CSL			Maximum Detected SQS EF	Frequency of Detected Concentrations > CSL			Maximum Detected CSL EF
	No. of Samples[a]	%	No. of Samples[b]	%	No. with RL > SQS and ≤ CSL		No. of Samples[c]	%	No. with RL > CSL	
Indeno(1,2,3-cd)pyrene	3/12	25	0	0	0	ne	0	0	0	ne
Naphthalene	4/12	33	0	0	0	ne	0	0	0	ne
Phenanthrene	11/12	92	0	0	0	ne	1	8.3	0	2.1
Pyrene	12/12	100	0	0	0	ne	0	0	0	ne
Total HPAHs[g]	12/12	100	1	8.3	0	1.0	0	0	0	ne
Total LPAHs[h]	11/12	92	0	0	0	ne	1	8.3	0	2.4
Phthalates					0					
BEHP	10/12	83	1	8.3	0	1.7	0	0	0	ne
Di-n-butyl phthalate	1/12	8.3	0	0	0	ne	0	0	0	ne
Other SVOCs					0					
1,2,4-Trichlorobenzene	13/36	36	5	14	1	200	3	8.3	0	89
1,2-Dichlorobenzene	7/36	19	0	0	0	ne	0	0	0	ne
1,3-Dichlorobenzene	13/36	36	0	0	0	ne	0	0	0	ne
1,4-Dichlorobenzene	24/36	67	2	5.6	0	11	1	2.8	0	3.8
PCBs					0				0	
Total PCBs	36/36	100	28	78	0	72	5	14	0	13

[a] Represents the number of detects per total number of samples.

[b] Represents the number of detects > SQS and ≤ CSL per total number of samples. If any individual sample had a TOC content > 4% or < 0.5% and the dry-weight concentration was > LAET and ≤ 2LAET, the concentration was considered to be > SQS and ≤ CSL.

[c] Represents the number of detects > CSL per the total number of samples. If any individual location had a TOC content > 4% or < 0.5% and the dry-weight concentration was > 2LAET, the concentration was considered to be > CSL.

[d] One of these six samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

[e] Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.

[f] One of these three samples could not be OC-normalized because the TOC was outside of the appropriate range; the exceedance was based on a comparison with the 2LAET.

[g] Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

[h] Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

CSL – cleanup screening level
DDT – dichlorodiphenyltrichloroethane
EF – exceedance factor
HPAH – low-molecular-weight polycyclic aromatic hydrocarbon
LPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LAET – lowest-apparent-effect threshold
2LAET – second-lowest-apparent-effect threshold
ne – no exceedance
OC – organic carbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RL – reporting limit
SQS – sediment quality standards
SVOC – semivolatile organic compound
TOC – total organic carbon

4.2.2 Water Chemistry Relative to Water Quality Criteria

This section describes the numerical criteria for toxic pollutants in marine waters and summarizes EW surface water data relative to those criteria.

Federal water quality criteria (WQC) developed to protect ecological receptors and human consumers of fish and shellfish are relevant and appropriate requirements or minimum levels or standards for remedial action pursuant to CERCLA Section 121 (d)(2)(A)(ii) and Revised Code of Washington (RCW) 70.105D.030(2)(e). Under CERCLA and the Model Toxics Control Act (MTCA), Washington State water quality standards (WQS) approved by EPA under the Clean Water Act (CWA) are generally applicable requirements. National recommended federal WQC established pursuant to Section 304(a)(1) of the CWA are compiled and presented on the EPA website (EPA 2011b). Although these criteria are only advisory for the purpose of the CWA, the last sentence of CERCLA Section 121 (d)(2)(A)(ii) makes them minimum cleanup levels or standards for the site.

WQS for the protection of aquatic life are provided in WAC 173-201A-240. The numerical criteria for aquatic life meet the federal requirements of Section 303(c)(2)(B) of the CWA, are at least as stringent as the federal WQC, and have been approved by EPA as applicable CWA criteria in accordance with 40 Code of Federal Regulations (CFR) 131.21.[57] The criteria for human health are listed in EPA's regulations at 40 CFR 131.36(d)(14) and cross-referenced in WAC 173-201A-240(5). The federal and state aquatic life and human health WQS and WQC are hereafter referred to collectively as WQC unless otherwise noted.

The aquatic life WQC are presented as both acute and chronic criteria (Table 4-20). Aquatic life WQC are based on dissolved concentrations for metals (except mercury) and total concentrations for mercury and organic compounds. Acute WQC are 1-hour average concentrations not to be exceeded more than once every 3 years, with the exception of silver and pesticide concentrations, which are instantaneous concentrations not to be exceeded at any time, or the PCB concentration, which is a 24-hour average concentration not to be exceeded at any time. Chronic WQC are 4-day average concentrations not to be exceeded

[57] Except for the Washington State copper criteria, which were amended by Washington in 2007 (72 Fed. Reg. 37,109, 37,115 [July 9, 2007]) and approved by EPA (40 CFR 131.36). Federal recommended WQC are also presented in the tables in this section if their values are lower than state WQC.

more than once every 3 years, with the exception of pesticide and PCB concentrations, which are 24-hour average concentrations not to be exceeded at any time.

Table 4-20
WQC for Marine Aquatic Life and Human Health

Chemical	State WQS (µg/L)[a]		Federal WQC (µg/L)[e]		
	Marine Aquatic Life[b]		Marine Aquatic Life[b]		Human Health (based on the consumption of organisms)
	Acute[c]	Chronic[d]	Acute[c]	Chronic[d]	
Metals and Trace Elements					
Antimony	na	na	na	na	640
Arsenic	**69**	**36**	69	36	0.14[f,g]
Cadmium	42	9.3	**40**	**8.8**	na
Chromium (hexavalent)	**1,100**	**50**	1,100	50	na
Chromium (trivalent)	na	na	na	na	na
Copper	**4.8**	**3.1**	4.8	3.1	na
Lead	**210**	**8.1**	210	8.1	na
Mercury	**1.8**	**0.025**	1.8	0.94	0.15[h]
Nickel	**74**	**8.2**	74	8.2	4,600
Selenium	**290**	**71**	290	71	4,200
Silver	**1.9**	na	1.9	na	na
Thallium	na	na	na	na	0.47
TBT	na	na	0.46	0.0074	na
Zinc	**90**	**81**	90	81	26,000
PAHs					
2-Chloronaphthalene	na	na	na	na	1,600
Acenaphthene	na	na	na	na	990
Anthracene	na	na	na	na	40,000
Benzo(a)anthracene	na	na	na	na	0.018[f]
Benzo(a)pyrene	na	na	na	na	0.018[f]
Benzo(b)fluoranthene	na	na	na	na	0.018[f]
Benzo(k)fluoranthene	na	na	na	na	0.018[f]
Chrysene	na	na	na	na	0.018[f]
Dibenzo(a,h)anthracene	na	na	na	na	0.018[f]
Fluoranthene	na	na	na	na	140
Fluorene	na	na	na	na	5,300
Indeno(1,2,3-cd)pyrene	na	na	na	na	0.018[f]
Pyrene	na	na	na	na	4,000
Phthalates					
BEHP	na	na	na	na	2.2[f]

Chemical	State WQS (µg/L)[a]		Federal WQC (µg/L)[e]		
	Marine Aquatic Life[b]		Marine Aquatic Life[b]		Human Health (based on the consumption of organisms)
	Acute[c]	Chronic[d]	Acute[c]	Chronic[d]	
BBP	na	na	na	na	1,900
Diethyl phthalate	na	na	na	na	44,000
Dimethyl phthalate	na	na	na	na	1,100,000
Di-n-butyl phthalate	na	na	na	na	4,500
SVOCs					
1,2,4-Trichlorobenzene	na	na	na	na	70
1,2-Dichlorobenzene	na	na	na	na	1,300
1,2-Diphenylhydrazine	na	na	na	na	0.2[f]
1,3-Dichlorobenzene	na	na	na	na	960
1,4-Dichlorobenzene	na	na	na	na	190
2,4,6-Trichlorophenol	na	na	na	na	2.4[f]
2,4-Dichlorophenol	na	na	na	na	290
2,4-Dimethylphenol	na	na	na	na	850
2,4-Dinitrophenol	na	na	na	na	5,300
2,4-Dinitrotoluene	na	na	na	na	3.4[f]
2-Chlorophenol	na	na	na	na	150
3,3′-Dichlorobenzidine	na	na	na	na	0.028[f]
4,6-Dinitro-o-cresol (2-methyl-4,6-dinitrophenol)	na	na	na	na	280
Benzidine	na	na	na	na	0.0002
Bis(2-chloroethyl)ether	na	na	na	na	0.53[f]
Bis(2-chloroisopropyl)ether	na	na	na	na	65,000
Hexachlorobenzene	na	na	na	na	0.00029[f]
Hexachlorobutadiene	na	na	na	na	18[f]
Hexachlorocyclopentadiene	na	na	na	na	1,100
Hexachloroethane	na	na	na	na	3.3[f]
Isophorone	na	na	na	na	960[g] (**600**[h])
Nitrobenzene	na	na	na	na	690
n-Nitrosodimethylamine	na	na	na	na	3[f]
n-Nitroso-di-n-propylamine	na	na	na	na	0.51[f]
n-Nitrosodiphenylamine	na	na	na	na	6[f]
Pentachlorophenol	**13**	**7.9**	13	7.9	3[f]
Phenol	na	na	na	na	860,000
PCBs					
PCBs	**10**	**0.03**	na	0.03	0.000064[g]
Pesticides					
4,4′-DDD	na	na	na	na	0.00031[f]
4,4′-DDE	na	na	na	na	0.00022[f]

Chemical	State WQS (µg/L)[a]		Federal WQC (µg/L)[e]		
	Marine Aquatic Life[b]		Marine Aquatic Life[b]		Human Health (based on the consumption of organisms)
	Acute[c]	Chronic[d]	Acute[c]	Chronic[d]	
4,4′-DDT	**0.13**	**0.001**	0.13	0.001	0.00022[f]
Aldrin	na	na	**1.3**	na	0.000050[f]
Dieldrin	na	na	**0.71**	**0.0019**	0.000054[f]
Aldrin/dieldrin (sum)[i]	**0.71**	**0.0019**	na	na	na
alpha-BHC	na	na	na	na	0.0049[f]
beta-BHC	na	na	na	na	0.017[f]
gamma-BHC (Lindane)	**0.16**	na	0.16	na	1.8
alpha-Endosulfan	**0.034**[j]	**0.0087**[j]	0.034	0.0087	89 (**2**[h])
beta-Endosulfan	**0.034**[j]	**0.0087**[j]	0.034	0.0087	89 (**2**[h])
Endosulfan sulfate	na	na	na	na	89 (**2**[h])
Endrin	**0.037**	**0.0023**	0.037	0.0023	0.06
Endrin aldehyde	na	na	na	na	0.3
Heptachlor	**0.053**	**0.0036**	0.053	0.0036	0.000079[f]
Heptachlor epoxide	na	na	**0.053**	**0.0036**	0.000039[f]
Toxaphene	**0.21**	**0.0002**	0.21	0.0002	0.00028[f]
Chlordane	**0.09**	**0.004**	0.09	0.004	0.00081[f]
VOCs					
1,1,2,2-Tetrachloroethane	na	na	na	na	4[f]
1,1,2-Trichloroethane	na	na	na	na	16[f]
1,1-Dichloroethene (1,1-dichloroethylene)	na	na	na	na	7,100
1,2-Dichloroethane	na	na	na	na	37
1,2-Dichloropropane	na	na	na	na	15[f]
Acrolein	na	na	na	na	9
Acrylonitrile	na	na	na	na	0.25[f]
Benzene	na	na	na	na	51[f]
Bromodichloromethane (dichlorobromomethane)	na	na	na	na	17[f]
Bromoform	na	na	na	na	140[f]
Bromomethane (methyl bromide)	na	na	na	na	1,500
Carbon tetrachloride	na	na	na	na	1.6[f]
Chlorobenzene	na	na	na	na	1,600
Chloroform	na	na	na	na	470
Dibromochloromethane (chlorobromomethane)	na	na	na	na	13[f]
Dichloromethane (methylene chloride)	na	na	na	na	590[f]
Ethylbenzene	na	na	na	na	2,100

Chemical	State WQS (µg/L)[a]		Federal WQC (µg/L)[e]		
	Marine Aquatic Life[b]		Marine Aquatic Life[b]		Human Health (based on the consumption of organisms)
	Acute[c]	Chronic[d]	Acute[c]	Chronic[d]	
Tetrachloroethene	na	na	na	na	3.3[f]
Toluene	na	na	na	na	15,000
trans-1,2-Dichloroethene	na	na	na	na	10,000
Trichloroethene (trichloroethylene)	na	na	na	na	30[f]
Vinyl chloride	na	na	na	na	2.4[f]
Dioxins and Furans					
2,3,7,8-TCDD	na	na	na	na	5.1E-09[f]

[a] Standards are from WAC 173-201A-240.

[b] Chronic WQC are 4-day average concentrations not to be exceeded more than once every 3 years, with the exception of pesticide and PCB concentrations, which are 24-hour average concentrations not to be exceeded at any time.

[c] Acute WQC are 1-hour average concentrations not to be exceeded more than once every 3 years, with the exception of silver and pesticide concentrations, which are instantaneous concentrations not to be exceeded at any time, or the PCB concentration, which is a 24-hour average not to be exceeded at any time.

[d] Aquatic life WQC are based on dissolved concentrations for metals (except mercury) and total concentrations for mercury and organic compounds.

[e] Criteria are from EPA recommended AWQC (except where noted). Recommended AWQC are available from EPA (2011b).

[f] Human health WQC are based on 1 x 10^{-6} excess cancer risk for carcinogenic chemicals.

[g] Criterion represents the inorganic fraction of arsenic.

[h] Standards are from 40 CFR 131.36 (NTR), as referenced in WAC 173-201A-240.

[i] Aldrin is metabolically converted to dieldrin. Therefore, the sum of aldrin and dieldrin concentrations is compared with the dieldrin criteria.

[j] Standards are for endosulfan.

AWQC – ambient water quality criteria
BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
BHC – benzene hexachloride
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
MCL – maximum contaminant level
na – not available
nc – not calculated
NTR – National Toxics Rule
PAH – polycyclic aromatic hydrocarbon
PCB – polyvinyl chloride
SVOC – semivolatile organic compound
TCDD – tetrachlorodibenzo-*p*-dioxin
VOC – volatile organic compound
WAC – Washington Administrative Code
WQC – water quality criteria
WQS – water quality standards

Bold identifies the lower of the state and recommended federal criteria (only state criteria are bold if the state and recommended federal criteria are the same). **Bold** also identifies the lower of the human health criteria (when multiple criteria are available).

Both marine and freshwater values have been developed for aquatic life WQC. Under state regulations, freshwater values apply to waters with a salinity less than or equal to 1 ppt or less 95% of the time (WAC 173-201A-260). Because there are no areas of the EW for which the freshwater values apply, only the marine values were used in this SRI.

Human health WQC have been established for the consumption of only organisms (i.e., fish and shellfish), as well as for the consumption of both organisms and water. The WQC based on the consumption of both organisms and water are assigned to waters classified for only domestic water supply (40 CFR 131.36 [14]) and thus do not apply to the EW. Human health WQC are based on dissolved concentrations for all chemicals.

4.2.2.1 Surface Water

A summary of surface water samples that exceeded WQC is presented in Table 4-21. The only chemicals for which surface water concentrations exceeded the aquatic life criteria were arsenic, cadmium, and TBT. In addition, human health WQC were exceeded for arsenic, benzo(a)anthracene, chrysene, BEHP, and total PCBs. The one dissolved cadmium concentration above AWQC was an anomalous result that was much greater than the total cadmium result for the same sample and the dissolved concentration measured in the field duplicate collected with the original sample. These exceedances are provided only for informational purposes; comparisons of the data with some of these criteria may not be appropriate.

Table 4-21
Chemicals Detected in Surface Water and WQC for Marine Aquatic Life and Human Health

Chemical	Detection Summary					Exceedances of State WQS		Exceedances of Federal WQC		
		Detection Frequency		Concentration or Range of Concentrations (µg/L)		Marine Aquatic Life		Marine Aquatic Life		Human Health (based on the consumption of organisms)
	No. of Samples	No. of Detects	%	Detected	Non-Detected (RLs)	Chronic	Acute	Chronic	Acute	
Metals and Trace Elements (filtered)										
Antimony	124	89	72	0.0340 J – 0.156 J	0.022 – 0.191	nc	nc	nc	nc	0
Arsenic	130	130	100	0.43 – 1.43	na	0	0	0	0	*130*[a]
Cadmium	130	126	97	0.009 J – 37.8	0.088	1[b]	0	1[b]	**0**	nc
Chromium	118	98	83	0.10 J – 1.15 J	0.70 – 2.36	0	0	0	0	nc
Copper	125	125	100	0.23 – 2.44	na	0	0	0	0	nc
Lead	130	78	60	0.00740 J – 0.814 J	0.150 – 6.80	0	0	0	0	nc
Mercury (unfiltered)	68	23	33	0.000130 – 0.00146	0.0001 – 0.00054	nc	nc	nc	nc	0
Nickel	125	81	65	0.27 J – 0.855 J	0.23 – 1.00	**0**	**0**	0	0	0
Selenium	130	58	45	0.06 J – 0.38 J	0.13 – 0.20	**0**	**0**	0	0	0
Silver	130	1	0.8	0.019	0.025 – 0.13	**0**	na	0	na	
Thallium	130	108	83	0.004 J – 0.012	0.0046 – 0.020	nc	nc	nc	nc	0
Zinc	129	109	85	0.60 – 7.79	0.950 – 116[c]	**0**	**0**	0	0	0
TBT	59	1	1.7	0.010 J	0.008-0.010[d]	**na**	**na**	1	0	na
PAHs (unfiltered)										
Acenaphthene	59	12	20	0.010 – 0.20	0.010	nc	nc	nc	nc	0
Anthracene	59	2	3.4	0.011 J – 0.057	0.010	nc	nc	nc	nc	0
Benzo(a)anthracene	59	1	1.7	0.020	0.010	nc	nc	nc	nc	2
Chrysene	59	4	6.8	0.010 – 0.024	0.010	nc	nc	nc	nc	2
Fluoranthene	59	15	25	0.010 – 0.19	0.010 – 0.018	nc	nc	nc	nc	0

Chemical	Detection Summary					Exceedances of State WQS		Exceedances of Federal WQC		
	No. of Samples	Detection Frequency		Concentration or Range of Concentrations (µg/L)		Marine Aquatic Life		Marine Aquatic Life		Human Health (based on the consumption of organisms)
		No. of Detects	%	Detected	Non-Detected (RLs)	Chronic	Acute	Chronic	Acute	
Fluorene	59	3	5.1	0.015 J – 0.16	0.010	nc	nc	nc	nc	0
Pyrene	59	15	25	0.010 – 0.12	0.010	nc	nc	nc	nc	0
Phthalates (unfiltered)										
BEHP	59	3	5.1	2.3 – 7.8	1.0 – 54	nc	nc	nc	nc	3
Diethyl phthalate	59	2	3.4	1.4 – 2.2	1.0	nc	nc	nc	nc	0
Other SVOCs (unfiltered)										
1,4-Dichlorobenzene	59	1	1.7	3.1	1.0	nc	nc	nc	nc	0
PCBs (unfiltered)										
Total PCBs (congeners)j	57	57	100	0.000068 J – 0.0058 J	na	**0**	**0**	0	nc	57

Note: A chemical is listed if it was detected in at least one EW surface water sample and if it has a marine aquatic life WQC or a human health WQC.

[a] Because the criterion represents the inorganic fraction of arsenic and the water data represent total arsenic (i.e., the sum of the organic and inorganic arsenic species) the comparison is uncertain.

[b] The maximum detected dissolved concentration was 37.8 µg/L. This value should be considered an anomalous value; the total cadmium concentration in the same sample was 1.45 µg/L, and the dissolved cadmium concentration in the field duplicate collected from the same location and at the same time was 0.076 µg/L.

[c] One RL for zinc is elevated above the chronic AWQC

[d] All the TBT RLs are above the chronic AWQC. The TBT MDL value was 0.004 which is below the chronic AWQC value of 0.0074. The lab was instructed to report all values between the MDL and RL as estimated values.

AWQC – ambient water quality criteria
BEHP – bis(2-ethylhexyl) phthalate
CFR – Code of Federal Regulations
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
EW – East Waterway
J – estimated concentration
na – not applicable
nc – no criteria
NTR – National Toxics Rule
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RL – reporting limit
SVOC – semivolatile organic compound
WAC – Washington Administrative Code
WQC –water quality criteria
WQS – Water quality standards

Bold criteria identify the lower of the state and recommended federal criteria (state criteria are bold if the state and recommended federal criteria are the same).

Italics identify WQC when the type of water data available does not match the type of data intended for comparison to a specific criterion (i.e., total vs. dissolved fraction or total arsenic vs. inorganic arsenic).

4.2.2.2 Groundwater

The only contaminants that were detected in groundwater samples above chronic or acute aquatic life WQC were arsenic, copper, nickel and zinc (Table 4-22). The locations associated with AWQC exceedances are provided on Map 4-8. One Harbor Island location (HI-12) had one groundwater sample with copper and zinc concentrations above the chronic AWQC values for those metals. In addition, two locations (SB-SC-02 and SB-SC-05) at the Coast Guard (Pier 35) site had samples with nickel and arsenic concentrations above the AWQC values (Map 4-8). Finally, arsenic and copper were detected in two groundwater samples form GATX (Pier 34) above the AWQC for arsenic and copper (Map 4-8). However, the AWQC for these metals are based on dissolved concentration not the whole water concentrations.

Table 4-22

Detected Contaminants in Groundwater that exceeded aquatic life AWQC

Location	Chemical	No. of Samples Analyzed	Detection Frequency		Range of Detected Concentrations (µg/L)	Exceedances of Federal WQC – Marine Aquatic Life	
			No. of Detects	%		Chronic	Acute
Harbor Island	total cyanide[a]	8	5	63	3.2 – 13.8	4	1
	copper	3	3	100	2.54 – 4.32	1[b]	0
	zinc	3	3	100	51.1 – 86.1	1[b]	0
USCG (Pier 35)	nickel	2	2	100	20 – 30	2[b]	0
	arsenic	1	1	100	180	1[b]	1[b]
GATX (Pier 34)	arsenic	5	2	40	7 – 180	1[b]	1[b]
	copper	5	2	40	4 – 7	2[b]	1[b]

[a] Total cyanide exceeded aquatic life AWQC; however, available cyanide was below chronic and acute aquatic life AWQC in all samples.

[b] Marine aquatic life WQC is based on dissolved water concentration. The groundwater concentrations were measured on unfiltered samples, which may overestimate the dissolved concentration.

AWQC – ambient water quality criteria

USCG – US Coast Guard

WQC – water quality criteria

4.2.3 PCBs (Aroclors and Congeners)

This section presents the nature and extent of PCBs in surface sediment, subsurface sediment, tissue, and surface water. PCBs are hydrophobic organic contaminants with a strong tendency to be associated with particulate OC in both sediment and surface water. Therefore, PCB concentrations in sediment are critical to the evaluation of the nature and extent of PCBs in the EW. PCBs were not analyzed in porewater samples collected from the EW because porewater PCBs are a component of the measured bulk sediment concentration, and risks to benthic organisms were evaluated using whole sediment PCB concentrations (see Section 5.2).

4.2.3.1 Surface Sediment

Total PCBs as Aroclors were analyzed in 240 surface sediment grab samples and all four of the intertidal MIS composites samples.[58] Of the nine PCB Aroclors analyzed, Aroclors 1254 and 1260 were detected most frequently in both surface sediment and MIS composite samples compared to detections of Aroclors 1242 and 1248 (Table 4-23). Aroclors 1016, 1221, 1232, 1262, and 1268 were not detected in the surface sediment grab or the intertidal MIS composite samples. In the surface sediment grab samples total PCB concentrations ranged from 6.0 to 8,400 µg/kg dw, with a mean concentration of 490 µg/kg dw (Table 4-24). Total PCB Aroclor concentrations for the area-wide intertidal MIS composite samples were greater than the mean of the grab samples (490 µg/kg dw) with concentrations ranging from 540 to 1,590 µg/kg dw (Table 4-23). The single public access intertidal MIS composite sample had a total PCB Aroclor concentration of 370 µg/kg dw. PCB Aroclors 1254 and 1260 were the Aroclors detected most frequently in both surface sediment and MIS composite samples (Table 4-23).

[58] Fifteen of the 240 surface sediment grab samples were field duplicates; 225 unique sample locations had surface sediment grab samples analyzed for total PCBs as Aroclors.

Table 4-23
PCB Aroclor and Total PCB Concentrations in Surface Sediment

Contaminant	Sample Type	Detection Frequency		Unit	Concentration					SQS	CSL
		Ratio	%		Minimum Detection	Maximum Detection	Calculated Median[a]	Calculated Mean[a]	Range of RLs[b]		
Aroclor 1242	grab	9/240	3.8	µg/kg dw	14 J	280	10	30	3.8 – 600	na	na
	area-wide intertidal MIS composite	2/3	67	µg/kg dw	96	680	96	260	27	na	na
	public access intertidal MIS composite	0/1	0	µg/kg dw	na	na	na	na	na	na	na
Aroclor 1248	grab	66/240	28	µg/kg dw	4.3	330	29	46	3.9 – 1,100	na	na
	area-wide intertidal MIS composite	1/3	33	µg/kg dw	140	140	18	57	27 – 36	na	na
	public access intertidal MIS composite	1/1	100	µg/kg dw	71	71	na	na	na	na	na
Aroclor 1254	grab	188/240	78	µg/kg dw	6.0	2,000	95	150	3.9 – 780	na	na
	area-wide intertidal MIS subtidal composite	3/3	100	µg/kg dw	220	550	320	360	na	na	na
	public access intertidal MIS composite	1/1	100	µg/kg dw	150	150	na	na	na	na	na
Aroclor 1260	grab	225/240	94	µg/kg dw	7.3	7,100	190	340	3.9 – 160	na	na
	area-wide intertidal MIS composite	3/3	100	µg/kg dw	220	360	310	300	na	na	na
	public access intertidal MIS composite	1/1	100	µg/kg dw	150	150	na	na	na	na	na

Contaminant	Sample Type	Detection Frequency		Unit	Concentration					SQS	CSL
		Ratio	%		Minimum Detection	Maximum Detection	Calculated Median[a]	Calculated Mean[a]	Range of RLs[b]		
Total PCBs[c]	grab	227/240	95	µg/kg dw	6.0	8,400	290	490	3.9 – 35	na	na
	area-wide intertidal MIS composite	3/3	100	µg/kg dw	540	1,590	770	970	na	na	na
	public access intertidal MIS composite	1/1	100	µg/kg dw	370	370	na	na	na	na	na
Total PCBs (OC-normalized)[d]	grab	224/235	95	mg/kg OC	0.58 J	840	19	32	0.51 – 6.3	12	65

[a] Calculated mean and median concentrations were calculated with detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

[b] RLs are based only on non-detect samples.

[c] Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest RL.

[d] Summary statistics for OC-normalized PCB concentrations were calculated using only samples with TOC contents ≥ 0.5% and ≤ 4.0%. TOC values were not measured in the MIS samples and therefore there are no OC-normalized values for these samples.

CSL – cleanup screening level
dw – dry weight
J – estimated concentration
MIS – multi-increment sampling
na – not applicable
nc – not calculated
nv – no value
OC – organic carbon
PCB – polychlorinated biphenyl
RL – reporting limit
SQS – sediment quality standards
TOC – total organic carbon

Table 4-24

Percentiles of Total PCB Aroclor Concentrations in Surface Sediment

Method	Total PCB Concentration (µg/kg dw)[a]				
	Entire Dataset	25th Percentile	50th Percentile	75th Percentile	95th Percentile
Area-based	460 (SWAC)	120	300	590	1,300
Numerical[b]	490 (mean)	110	270	590	1,800

[a] Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest RL.

[b] Numerical percentiles were calculated using detected results and one-half the RL for non-detected results. Subtidal composite and intertidal MIS composite samples were not included in the calculation of numerical percentiles or in the calculation of the mean for the entire dataset. Data presented in this table were averaged by location (i.e., field duplicates were averaged to create a single result per sampling location).

dw – dry weight
EW – East Waterway
MIS – multi-increment sampling
PCB – polychlorinated biphenyl
RL – reporting limit
SWAC – spatially weighted average concentration

Area-based and numerical percentiles were calculated for surface sediment total PCB concentrations, and the percentile values were found to be similar, which is consistent with well-distributed surface sediment samples throughout the EW, with no bias resulting from the more intensive sampling of areas with higher concentrations. Five percent of the EW area is estimated to have total PCB concentrations > 1,300 µg/kg dw (Table 4-24).

The maximum total PCB concentration (8,400 µg/kg dw), as well as some other concentrations greater than the numerical 95th percentile (1,800 µg/kg dw), were detected on the west side of the EW, off of the northern portion of T-18 (Map 4-17). Other areas that had surface sediment total PCB concentrations greater than the numerical 95th percentile were the east side of the deep main body in the vicinity of T-25 and the Hanford #2 CSO and two SD outfalls (Station 4800), Slip 27, the mound area outside of Slip 27, and one location in the Junction/Sill Reach near Station 7000 and Slip 27 (Maps 4-17 and 4-18). Total PCB Aroclor concentrations for the area-wide intertidal MIS composite samples were greater than the mean of the site-wide grab samples (490 µg/kg dw) with concentrations ranging from 540 to 1,590 µg/kg dw (Table 4-23) Patterns of total PCB concentrations in surface sediment relative to subsurface sediment concentrations are discussed in greater detail in Section 4.2.3.3.

Total PCB concentrations expressed on an organic carbon-normalized basis exceeded the SQS but not the CSL in 134 surface sediment samples (56%) representing 124 sampling

locations (55%) and exceeded the CSL in 23 surface sediment samples (9.6%) representing 21 sampling locations (9.3%) (Map 4-19 and Figure 4-1).[59]

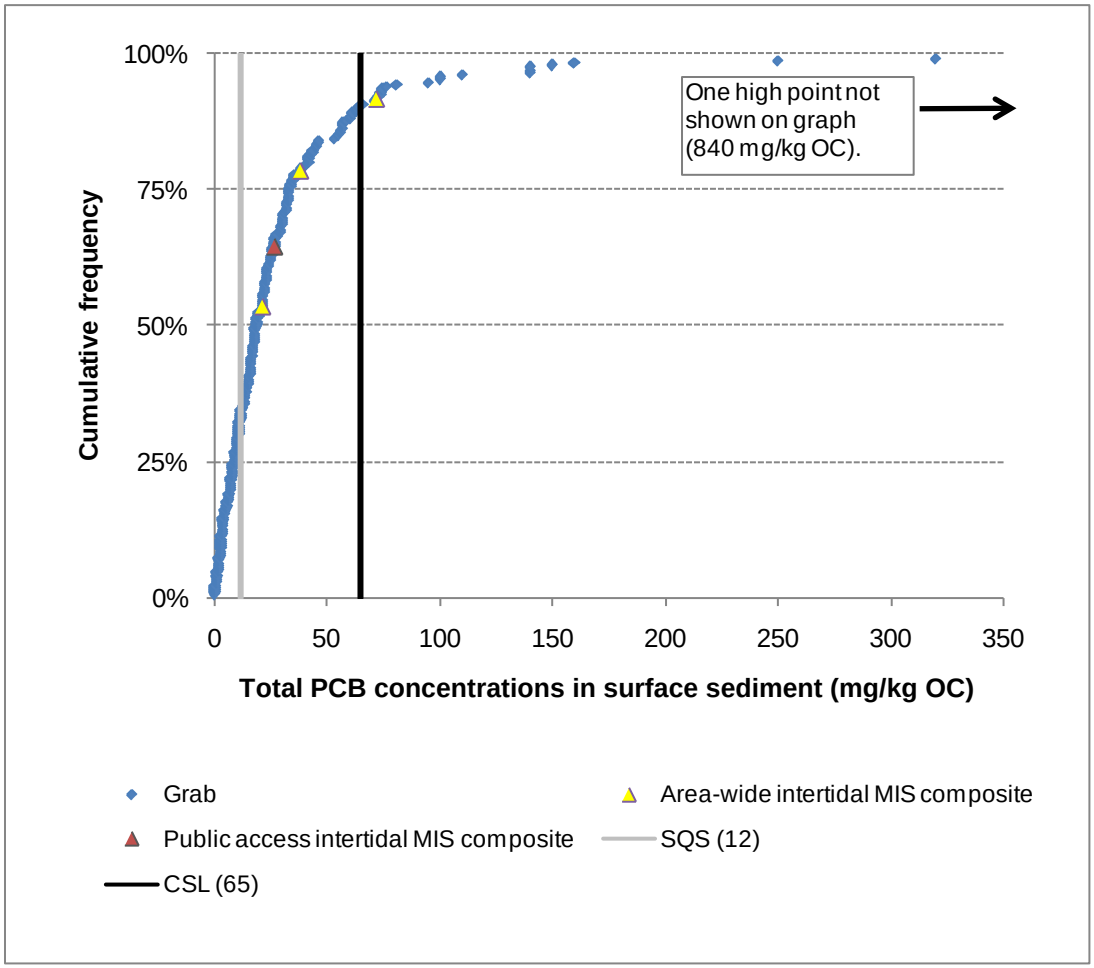


Figure 4-1
Cumulative Frequency of organic carbon-Normalized Total PCB Concentrations in Surface Sediment

The 13 subtidal surface sediment composite samples and the 4 intertidal MIS composite samples were analyzed for PCB congeners (Map 4-20). Total PCB congener concentrations for subtidal composite samples ranged from 168 to 2,860 µg/kg dw, with a mean value of 782 µg/kg dw. The mean of the total PCB sum of Aroclors in the same samples was 593 µg/kg dw.

[59] Ten of the 134 samples that had total PCB concentrations that exceeded the SQS were field duplicates.

Total PCBs measured as the sum of congeners and total PCBs measured as the sum of PCB Aroclors were generally comparable.

The analysis of the subtidal composite samples for total PCBs as the sum of Aroclors provided an opportunity to compare the IDW SWAC concentrations calculated using total PCB concentrations associated with the grab samples for these areas with the subtidal composite concentrations. However, the methods are not directly comparable because the spatial distribution of samples affects the calculation of the IDW SWAC and the composite sample concentrations are analogous to an arithmetic mean concentration because all locations are represented equally with no consideration of the spatial distribution.

The subtidal composite area IDW SWACs are compared with the measured total PCB (sum of Aroclors) concentrations in Table 4-25 and Figure 4-2. In general, throughout the EW, the IDW SWAC and the composite concentrations are consistent with one another. For two areas in the southern portion of the waterway, CS-002 and CS-003, SWAC concentrations were less than half of the measured concentration. The differences observed in composite areas 2 and 3 may reflect the influence of historical data that was included in the IDW SWAC calculation or heterogeneity in the sediment analyzed as both grab samples and as components of the composite samples. The overall agreement between the PCB IDW SWACs and the composite PCB concentrations is consistent with the fact that the dataset is well distributed throughout the waterway, with no bias resulting from more intensive sampling in areas with higher concentrations.

Table 4-25

Comparison of IDW SWAC and Measured Total PCB Values for Subtidal Composite Areas

Composite Location ID	Total PCB concentrations (µg/kg dw)		
	Calculated PCB IDW SWAC	Sum of PCB Aroclors (measured composite value)	No. of Samples in Composite
EW09-CS-001	325	410	14
EW09-CS-002	175	670	10
EW09-CS-003	266	820	8
EW09-CS-004	172	290	7
EW09-CS-005	703	740	8
EW09-CS-006	768	1,080	7
EW09-CS-007	602	590	9
EW09-CS-008	372	630	7

Composite Location ID	Total PCB concentrations (µg/kg dw)		
	Calculated PCB IDW SWAC	Sum of PCB Aroclors (measured composite value)	No. of Samples in Composite
EW09-CS-009	999	910	9
EW09-CS-010	605	380	9
EW09-CS-011	611	640	8
EW09-CS-012	182	146	13
EW09-CS-013	297	400	8

dw – dry weight
ID – identification
PCB – polychlorinated biphenyl
IDW – inverse distance weighting
SWAC – spatially weighted average concentration

Blue highlight identifies areas where the difference between the SWAC and the measured total PCB values is greater than the analytical variance that is considered acceptable for the Aroclor method (i.e., 50 to 150%).

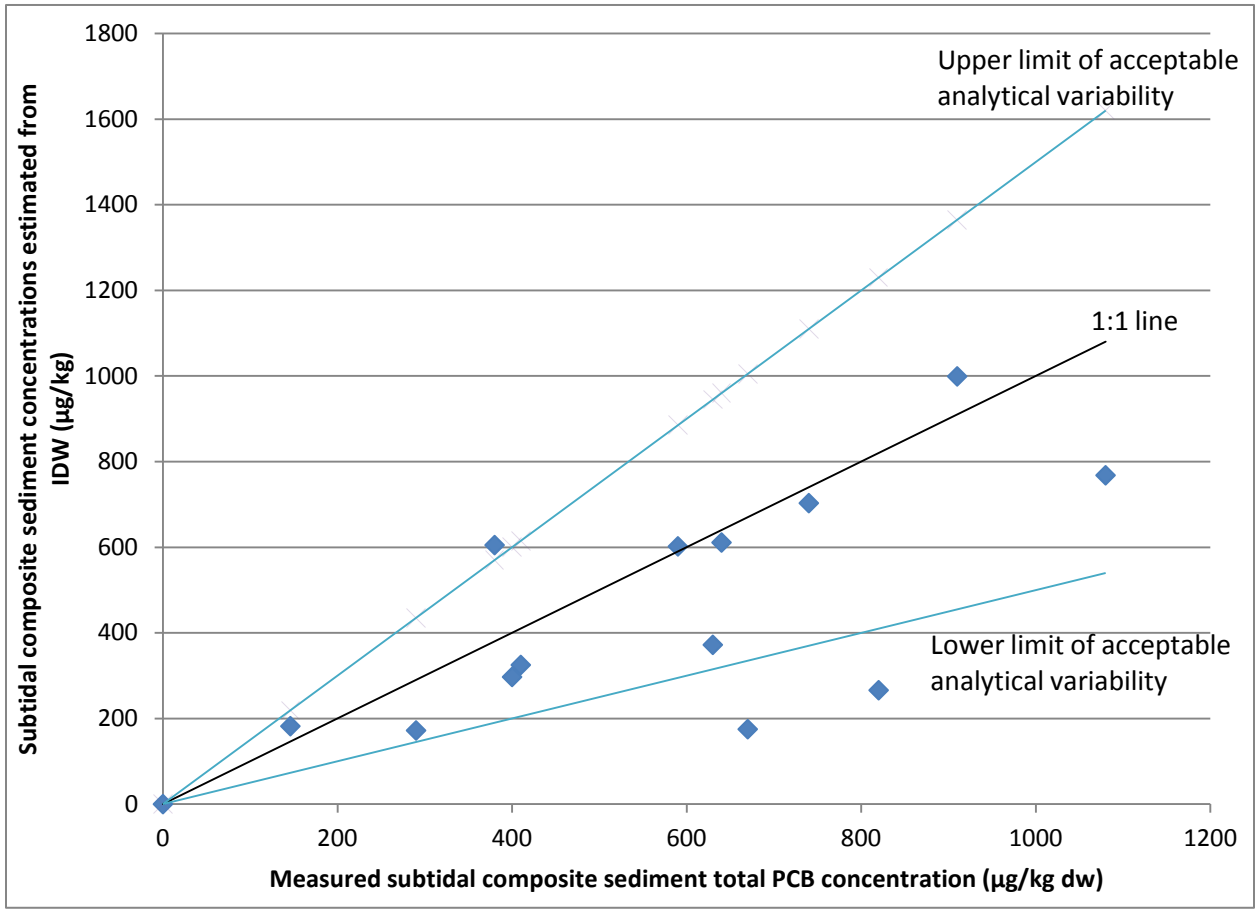


Figure 4-2.

Comparison of IDW SWAC and Measured Total PCB Values for Subtidal Composite Areas

Total PCB congener concentrations for the intertidal MIS composite samples ranged from 451 to 1,120 µg/kg dw. The public access intertidal MIS composite sample (PAMIS-01) had a total PCB congener concentration of 433 µg/kg dw.

Data for the 12 dioxin-like PCB congeners (i.e., PCB 77, PCB 81, PCB 105, PCB 114, PCB 118, PCB 123, PCB 126, PCB 156, PCB 157, PCB 167, PCB 169, and PCB 189) were used to calculate the PCB TEQ for each composite sample (as described in Table 4-26, Footnote a). PCB TEQ values for subtidal composite samples ranged from 1.08 to 9.50 ng TEQ/kg dw, with a mean value of 4.37 ng TEQ/kg dw (Table 4-26 and Map 4-20). PCB TEQ values for area-wide intertidal MIS composite samples ranged from 3.30 to 6.31 ng TEQ/kg dw (Table 4-26 and Map 4-20). The public access intertidal MIS composite sample had a total TEQ value of 1.40 ng TEQ/kg dw (Table 4-26 and Map 4-20).

Table 4-26

Total PCB (Sum of PCB Congeners) Concentrations and PCB TEQs for Surface Sediment

Contaminant	Sample Type	Detection Frequency		Unit	Lowest Value	Highest Value	Calculated Median	Calculated Mean
		Ratio	%					
Total PCBs	subtidal composite	13/13	100	µg/kg dw	168 J	2,860 J	819	782
	area-wide intertidal MIS composite	3/3	100	µg/kg dw	451 J	1,130 J	792	790
	public access intertidal MIS composite	1/1	100	µg/kg dw	433 J	433 J	na	na
PCB TEQ[a]	subtidal composite	13/13	100	ng TEQ/kg dw	1.08	9.50 J	3.42	4.37
	area-wide intertidal MIS composite	3/3	100	ng TEQ/kg dw	3.30 J	6.31 J	3.86	4.49
	public access intertidal MIS composite	1/1	100	ng TEQ/kg dw	1.40 J	1.40 J	na	na

[a] PCB TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). PCB TEQs were calculated for each sample by summing the TEQs for each dioxin-like PCB congener. PCB individual congener TEQs were calculated as the product of individual PCB congener concentrations and PCB congener-specific TEFs. If an individual PCB congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

dw – dry weight
EW – East Waterway
MIS – multi-increment sampling
na – not applicable
PCB – polychlorinated biphenyl
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent

The sum of the individual PCB congener concentrations in surface sediment samples were compared with the sum of the PCB Aroclor concentrations analyzed in the same samples (Figure 4-3). Both methods have analytical variability, although PCB Aroclors tend to have greater variability because of uncertainties associated with the identification and quantification of chemical patterns of multiple analytical peaks as compared with the identification and quantification of single analytical peaks for individual PCB congeners. Total PCBs based on the sum of PCB Aroclors and the sum of PCB congeners were generally similar among the various sediment sample types (i.e., close to the 1:1 line).The relative percent difference (RPD) between the two PCB sums ranged from 0.11 to 128%. The average RPD between the two PCB sums was 24%, excluding the sample with the highest RPD (128%). The two PCB sums are generally similar, within the acceptable range of analytical variability (50 to 150%), and have no consistent bias. This supports the use of the sum of PCB Aroclors to represent total PCBs for all purposes in the SRI and FS for the EW.

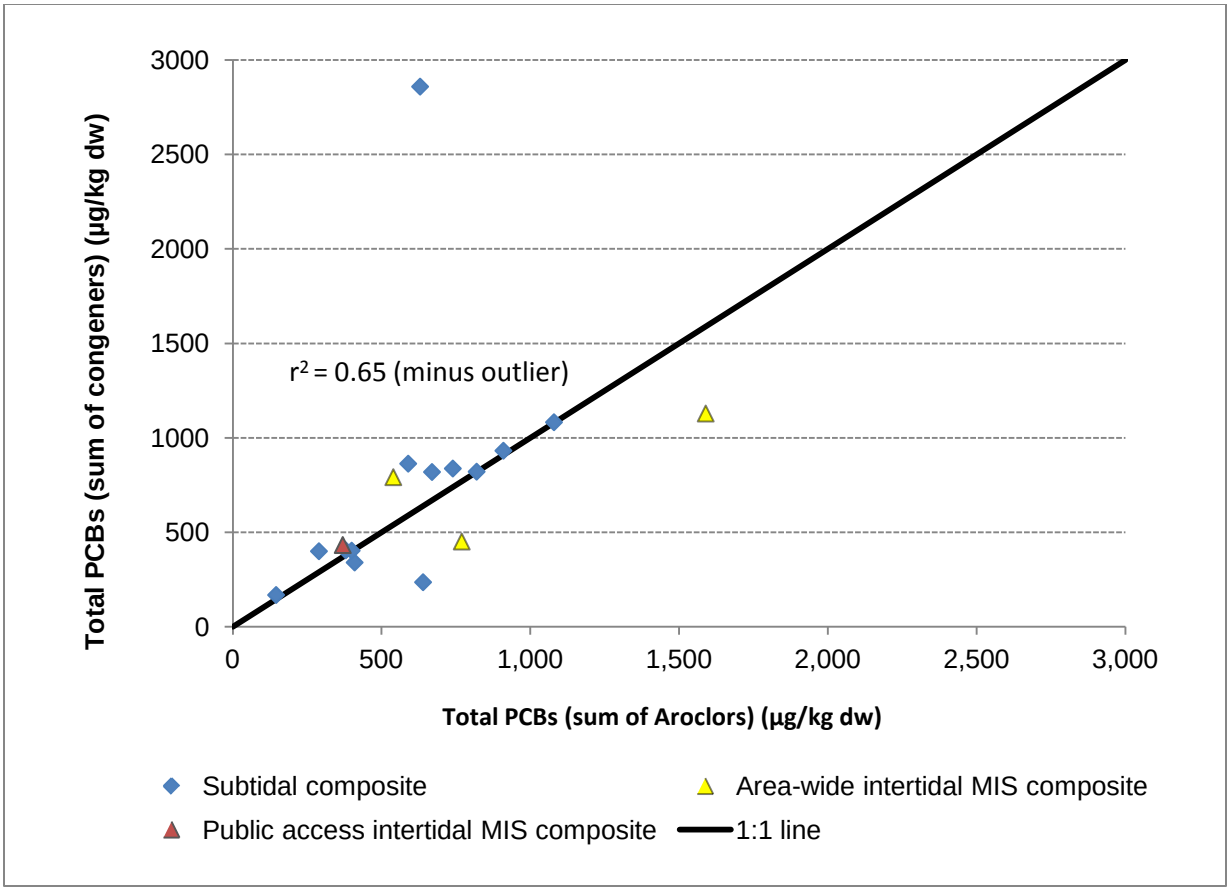


Figure 4-3
Total PCB Concentrations (Sum of PCB Congeners) Compared with Total PCB Concentrations (Sum of Aroclors) in Surface Sediment Samples

4.2.3.2 Subsurface Sediment

Total PCBs Aroclors were detected in 71% of the subsurface sediment samples at concentrations that ranged from 5.5 to 17,600 µg/kg dw (Table 4-27). Most of the subsurface sediment samples analyzed for total PCB Aroclors were from the top 4 ft of the sediment cores. All PCB concentrations above the 95th percentile were collected in this interval.

Table 4-27

Total PCB (sum of Aroclors) Concentrations in Subsurface Sediment

Sampling Interval (ft)	Detection Frequency		Total PCB Concentration (µg/kg dw)[a]		
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[b]
All Data					
Any interval	207/290	71	5.5	17,600	3.8 – 52
2-ft Intervals					
0 – 2	76/90	84	11.6	10,000	3.8 – 39
2 – 4	60/88	68	5.5	17,600	3.8 – 39
4 – 6	12/19	63	9.8	450	3.8 – 3.9
6 – 8	3/15	20	700	1,720	3.9 – 20
8 – 10	0/6	0	nd	nd	3.8 – 20
> 10	0/6	0	nd	nd	3.9 – 39
4-ft Intervals					
0 – 4	46/49	94	14 J	5,400 J	36 – 52
> 4	10/17	59	11 J	3,900	37 – 47

[a] Total PCBs were calculated as the sum of the detected concentrations of the individual Aroclors.If none of the individual Aroclors were detected in a given sample, then the sample was reported as undetected and the highest RL for an individual Aroclor was used for that sample.

[b] RLs are based only on non-detect samples.

dw – dry weight
EW – East Waterway
J – estimated concentration
nd – not detected
PCB – polychlorinated biphenyl
RL – reporting limit

Total PCB Aroclor concentrations in subsurface sediment samples collected entirely from within the lower alluvium unit were detected in 10 of 46 samples, with detected concentrations ranging from 9.8 to 480 µg/kg dw and concentrations in five samples above the SQS.

4.2.3.3 Total PCB Patterns in Surface and Subsurface Sediment Samples

This section presents the spatial and vertical patterns of total PCB concentrations in surface and subsurface sediment. These patterns were assessed to identify areas with relatively high concentrations in surface and subsurface sediment, to evaluate the spatial relationships between the two, and to identify areas and depths where maximum total PCB concentrations were detected. There were very few locations at which subsurface cores and surface sediment samples were collected within 10 ft of one another (Maps 4-21a through 4-21c); therefore, the interpolated surface sediment layer using all locations was used for the

comparison. The interpolated surface sediment total PCB concentrations are presented with the subsurface sediment total PCB concentrations on Maps 4-22a through 4-22c. The relationships for total PCBs are presented based on dry-weight concentrations. The relationships are also applicable to the organic carbon-normalized PCB concentrations because the surface and subsurface sediment TOC values are fairly consistent both throughout the EW, with a mean surface sediment TOC content of 1.61% and a mean subsurface TOC content of 1.84%, and at depth, with mean TOC values of 2.2% (0 to 2 ft), 2.1% (2 to 4 ft), 1.0% (4 to 6 ft), and 1.23% (6 to 8 ft). In both the surface and subsurface sediment samples, the vast majority had TOC values between 0.5 and 5% dw (i.e., 99% of surface sediment samples and 77% of the subsurface sediment samples).

It is important to note that the certainty and scale of the analyses presented in this section (and in Sections 4.2.6 and 4.2.7 for cPAHs and arsenic, respectively) are dependent on the availability of surface and subsurface sediment data. Sources of uncertainty include:

- Uncertainty in the interpretation of subsurface data resulting from the size of the sampling interval within each core, which is variable across the site
- Uncertainty with regard to distinguishing vertical patterns in locations with larger sampling intervals
- Uncertainty in the comparison of surface sediment data with subsurface core data because samples may have been collected at different times and conditions; interpolated surface sediment data are particularly uncertain

4.2.3.3.1 Junction/Sill Reach

Total PCB concentrations in surface and subsurface sediment samples collected within the Junction/Sill Reach (Station 7700 to Station 6850) were highly variable (Map 4-22a). No cores were collected in the Junction Reach because of the difficulty in penetrating the rocky substrate in this area with the sampling equipment. Concentrations of total PCBs in the surface sediment samples in the junction area were all less than the numerical 50th percentile of the site-wide surface sediment total PCB concentrations (270 µg/kg dw).

One surface sediment sample collected on the west side of the sill near Station 7000 was greater than the numerical 95th percentile (1,800 µg/kg dw). This sample (EW-128) was collected in 1995, and a more recent sample collected in the vicinity as part of the SRI

sampling in 2009 (EW09-SS-011) had a total PCB concentration below the 50th percentile. Both samples are included in the SRI dataset because the sampling locations are greater than 10 ft apart (see Appendix D for the data rules governing co-located samples). One core (EW10-SC-04) in this reach had total PCB concentrations > 1,800 µg/kg dw in the 0-to-2-ft interval. Surface total PCB concentrations under the bridges, in this reach are interpolated to be between the 50th and 95th percentile concentrations. The surface sediment south of the bridges was generally less than the 25th percentile.

4.2.3.3.2 Shallow Main Body

Sediment in the shallow main body (from Station 6850 to Station 5000) has not been dredged since the 1960s; as a result, the shallow main body section of the channel is at a higher mudline elevation than the deep main body (from Station 5000 to Station -600), which is maintained at depths > 50 ft below MLLW.

The surface sediment total PCB concentrations in the shallow main body are generally less than the numerical 75th percentile (590 µg/kg dw). The highest surface sediment concentrations were detected on the east side of the channel, off of T-25. Subsurface total PCB concentrations within the 0-to-4-ft sediment intervals are consistently higher than the surface sediment total PCB concentrations. Thirteen of 53 cores located throughout the shallow main body had concentrations above the numerical 95th percentile (1,800 µg/kg dw) (Maps 4-22a and 4-22b).

4.2.3.3.3 Deep Main Body

The majority of this area was dredged in the 2005-2006 Phase 1 removal action, so the surface sediment data are predominantly monitoring data from 3 years of recontamination monitoring that was conducted after the completion of dredging. Generally, the surface and subsurface sediment total PCB concentrations are below the 50th percentile within the Phase 1 dredge area.

Within the deep main body, surface sediment total PCB concentrations were greater than the numerical 95th percentile (1,800 µg/kg dw) in five areas. The first small area was on the east side of the EW near Station 4800 (Map 4-22a). Only one surface sediment sample (EW-RM-02) had a total PCB concentration of 4,500 µg/kg dw. Samples from three cores (S48, EW10-SC19, and EW10-SC21) collected in the vicinity, but outside of the Phase 1

removal action dredge boundary, had subsurface sediment total PCB concentrations > 1,800 µg/kg dw at depths of 0-2 ft and 2-4 ft, depending on the core. One core collected near these locations but within the dredge prism (EW10-SC20) had no detected PCBs in the subsurface samples.

The second small area was also within the Phase 1 removal action dredge boundary, in the vicinity of the mound at the mouth of Slip 27 (Map 4-22a). Two surface sediment samples, EW-RM-15 and EW-RM-34 had total PCB concentrations of 2,400 and 2,500µg/kg dw. Nearby subsurface sediment sample at EW10-SC28 was > 1,800 µg/kg dw in the 2-to-4-ft interval. Generally, the surface and subsurface sediment total PCB concentrations are below the 50th percentile (270 µg/kg dw) within the Phase 1 dredge area.

The third area was the mound area outside Slip 27, total PCB concentrations in subsurface sediment samples from the 0-to-2-ft interval of eight cores exceeded 1,800 µg/kg dw. The surface sediment interpolated concentration in this area was generally greater than the numerical 75th percentile (590 µg/kg dw) with one location above the 95th percentile (2,000 µg/kg dw in EW09-SS113). This area has not been dredged and total PCB concentrations are elevated in the surface and subsurface sediment samples.

The fourth area was located in the northern portion of the deep main body, in the center of the channel between Station 1500 and Station 1200 (Map 4-22c). Two surface sediment samples (EW09-SS-201 and EW-118) had concentrations > 1,800 µg/kg dw, with concentrations of 2,400 and 3,800 µg/kg dw, respectively. The most recent core collected from this area (EW10-SC47) had a total PCB concentration > 1,800 µg/kg dw in the 0-to-2-ft interval. This area has not been dredged in a recent dredge event. The fifth area was along the northern end of T-18 (from Station 1200 to Station 600), where three surface sediment samples (EW-109, EW-116, and EW-112) had concentrations > 1,800 µg/kg dw, with concentrations of 1,900, 2,300, and 8,400 µg/kg dw, respectively (Map 4-22c). None of the subsurface sediment samples in this area exceeded 1,800 µg/kg dw. Subsurface sediment cores were co-located with both EW-116 and EW-112. The core co-located with EW-112 was EW10-SC-51 with no detected PCBs. The core co-located with EW-116 was EW-163 collected in 2001 with total PCB concentration greater than the 75th percentile (590µg/kg dw) in the 0-to-4-ft interval.

Finally, subsurface sediment concentrations above the 95th percentile were observed in the cores collected on the east side of the waterway between Station 300 and Station 1000 in the vicinity of the former Rabanco barge loading facility and the former GATX facility. Four cores collected in this area had sediment concentrations above the 95th percentile (1,800 µg/kg dw) in the 0-to-4-ft intervals (Map 4-22c). The surface sediment concentrations in this area were lower than the subsurface sediment concentrations and were generally below the 75th percentiles (590 µg/kg dw).

Subsurface and surface sediment concentrations in the deep main body were all less than the 75th percentile for locations north of station 500.

4.2.3.3.4 Slip 27

Total PCB concentrations in surface sediment samples collected within Slip 27 were highly variable (Map 4-22a). Surface sediment total PCB concentrations were > 1,800 µg/kg dw at the head of the slip (3,200 µg/kg dw in EW09-SS104) but below 95th in the rest of the slip. Subsurface sediment total PCB concentrations in both of these areas exceeded 1,800 µg/kg dw in the 0-to-2- and 2-to-4-ft intervals. In addition, total PCB concentrations in one core collected from the middle of the slip (EW10-SC27) were > 1,800 µg/kg dw in both the 0-to-2- and 2-to-4-ft intervals.

4.2.3.3.5 Slip 36

The total PCB concentrations in the surface and subsurface sediment samples in Slip 36 were all below the numerical 75th percentile (590 µg/kg dw), with the exception of one surface sediment sample near the mouth of the slip that had a concentration of 750 µg/kg dw (Map 4-22c). Portions of Slip 36 were dredged in 2006, and total PCBs were generally not detected in subsurface sediment, except for one location (EW10-SC58) located outside of the 2006 dredge area, which had a total PCB concentration > 590 µg/kg dw in the 0-to-2-ft interval.

4.2.3.4 Tissue

4.2.3.4.1 Aroclor Data

Total PCB Aroclors were detected in all tissue samples that were analyzed for PCBs, except for one sand sole whole-body composite sample and three mussel whole-body composite

samples (Table 4-28). English sole whole-body composite samples had the highest mean total PCB concentration (3,200 µg/kg wet weight [ww]) of all tissue types, and individual geoduck edible meat samples had the lowest mean total PCB concentration (19 µg/kg ww). Total PCB Aroclor concentrations for individual brown rockfish ranged from 400 to 6,200 µg/kg ww (Map 4-23), with a mean of 2,000 µg/kg ww. Mean total PCB Aroclor concentrations in shiner surfperch whole-body composite samples and English sole fillet composite samples were 1,500 and 1,700 µg/kg ww, respectively. Sand sole whole-body composite and crab hepatopancreas composite samples had relatively similar mean total PCB concentrations (540 and 590 µg/kg ww, respectively). Crab hepatopancreas composite concentrations were consistently higher than the crab edible meat concentrations. Mean total PCB concentrations for juvenile Chinook salmon whole-body composite samples, striped perch fillet composite samples, and all other invertebrate samples ranged from 19 to 300 µg/kg ww. The greatest variances in total PCB concentrations were observed in individual brown rockfish, clams, and benthic invertebrates. These organisms have small home ranges and would be expected to reflect spatial variance due to their specific exposure locations The other species (i.e., English sole, shiner surfperch, crab) have home ranges larger than the EW and were composited on a site-wide basis; therefore, the reduced variance in those samples reflects the compositing of individuals and their exposure over the larger home ranges of these species.

Table 4-28

Total PCB (Aroclor Sum) Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency		Total PCB Concentration (µg/kg ww)[a]				
	Ratio	%	Lowest Value	Highest Value	Calculated Median[b]	Calculated Mean[b]	RL[c]
Fish							
Brown rockfish, whole body	15/15	100	400 J	6,200	2,000	2,000	na
English sole, whole body	13/13	100	1,460	7,900 J	2,800	3,200	na
Juvenile Chinook salmon, whole body	12/12	100	7.4	91.5	56	59	na
Sand sole, whole body	5/6	83	167	1,310	340	540	20
Shiner surfperch, whole body	11/11	100	380 JN	5,400	1,100	1,500	na
English sole, fillet	20/20	100	409 [d]	5,700 [d]	1,180	1,700	na
Striped perch, fillet	6/6	100	104.0	203 J	157	155	na

Tissue Type	Detection Frequency		Total PCB Concentration (µg/kg ww)[a]				
	Ratio	%	Lowest Value	Highest Value	Calculated Median[b]	Calculated Mean[b]	RL[c]
Invertebrates							
Crab, whole body[e, f]	9/9	100	180 J	860	240	300	na
Crab, edible meat[f]	12/12	100	48 J	210 J	120	130	na
Crab, hepatopancreas[f]	9/9	100	310 J	1,900	490	590	na
Clam, whole body[g,h]	11/11	100	4.7 JN	82	66	56	na
Mussel, whole body[h]	14/17	82	19 JN	44 J	28.4	26	13
Coonstripe shrimp, whole body	1/1	100	460 J	460 J	na	na	na
Geoduck clam,whole body[e]	4/4	100	25 J	34 JN	27	28	na
Geoduck clam, edible meat	6/6	100	14	24 JN	18	19	na
Geoduck clam, gutball	3/3	100	51 J	78	70	66	na
Benthic invertebrates, whole body	13/13	100	93	380	210	210	na

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] Total PCB concentrations represents the sum of detected Aroclors results for each sample. If none of the individual Aroclors were detected in a given sample, non-detect values represent the highest RL.

[b] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[c] RLs are based only on non-detect samples.

[d] The lowest concentrations were skin-off fillet samples collected, in 1999 and the highest concentrations were the skin-on composites analyzed in 2005.

[e] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck. The shell was not included in the analysis for either crabs or geoduck.

[f] Two species of crab (red rock and one Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[g] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[h] The clam and mussel whole body samples include all soft tissues. Shells were not included in these samples.

J – estimated concentration
N – tentative identification
na – not applicable
RL – reporting limit
ww – wet weight

In general, the highest PCB concentrations were measured in fish, which may reflect the trophic status of these organisms. Brown rockfish are a high-trophic-level species that has a limited home range, so the brown rockfish likely had a higher duration of exposure in the EW than did other species.[60] Juvenile Chinook salmon use the EW as a migration corridor and are not believed to be present in the waterway for extended periods of time (see Section 2.8.3), which may be reflected in the relatively low PCB concentrations in these fish. Clams and mussels also had relatively low PCB concentrations when compared with those in other species; this may be due to their filter-feeding behavior, which results in surface water exposure, and the fact they are low-trophic-level feeders (see Section 2.8.2).

Mean lipid contents ranged from 0.207% ww in crab edible-meat composite samples to 4.73% ww in shiner surfperch whole-body composite samples (Table 4-29). For fish samples, mean lipid content was highest in shiner surfperch whole-body composite samples, lowest in juvenile Chinook salmon whole-body composite samples (1.90% ww) and sand sole whole-body composite samples (0.61% ww), and relatively similar (3.00 to 3.40% ww) in other types of fish samples. For invertebrates, crab hepatopancreas samples (2.14% ww) and geoduck gutball samples (1.54 % ww) had the highest mean lipid content, and mean lipid contents ranged from 0.207 to 0.965% ww in other invertebrate samples.

Table 4-29
Lipid Content in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency		Lipid Content (% ww)			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Fish						
Brown rockfish, whole body	15/15	100	2.42	4.41	3.23	3.23
English sole, whole body	16/16	100	1.93	5.03	3.16	3.40
Juvenile Chinook salmon, whole body	12/12	100	0.758	2.60	1.80	1.90
Sand sole, whole body	6/6	100	0.304	1.20	0.565	0.61
Shiner surfperch, whole body	14/14	100	2.36	5.66	5.18	4.73

[60] The relationship between the brown rockfish PCB concentrations and the PCB concentrations in the sediment in the vicinity of the rockfish was investigated using nearest surface sediment samples and the interpolated sediment PCB concentrations. No significant relationship was observed between the rockfish tissue and sediment concentrations.

Tissue Type	Detection Frequency		Lipid Content (% ww)			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
English sole, fillet	23/23	100	0.915	10.6[a]	1.86	3.00
Invertebrates						
Crab, whole body[b,c]	12/12	100	0.430	1.85	0.939	0.965
Crab, edible meat[c]	12/12	100	0.140	0.319	0.203	0.207
Crab, hepatopancreas[c]	12/12	100	0.699	4.22	2.16	2.14
Clam, whole body[d,e]	10/10	100	0.353	0.943	0.658	0.647
Mussel, whole body[e]	17/17	100	0.292	1.19	0.474	0.596
Coonstripe shrimp, whole body	1/1	100	0.825	0.825	na	na
Geoduck clam, whole body[b]	4/4	100	0.634	0.726	0.687	0.683
Geoduck clam, edible meat	6/6	100	0.413	0.560	0.466	0.471
Geoduck clam, gutball	3/3	100	1.13	1.87	1.63	1.54
Benthic invertebrates, whole body	13/13	100	0.260	0.891	0.591	0.616

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] The highest lipid contents (8.8, 10.0, and 10.6%) were associated with the three skin-off fillet composite samples collected in 1995.

[b] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[c] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[d] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[e] The clam and mussel whole body samples include all soft tissues. Shells were not included in these samples.

J – estimated concentration ww – wet weight

na – not applicable

Mean lipid-normalized total PCB concentrations in tissue ranged from 3.0 to 90 mg/kg-lipids (Table 4-30). The highest mean lipid-normalized total PCB concentrations were in English sole, with relatively similar concentrations in whole-body (90 mg/kg-lipids) and fillet (83 mg/kg-lipids) composite samples. The lowest mean lipid-normalized total PCB concentration was in juvenile Chinook salmon whole-body composite samples (3.0 mg/kg-lipids) followed by various bivalve species collected (4.1 to 8.5 mg/kg-lipids).

Table 4-30

Lipid-Normalized Total PCB (Aroclor Sum) Concentrations for Fish and Invertebrate Tissues

Tissue Type	Detection Frequency[a]		Lipid-Normalized Total PCB Concentration (mg/kg lipids)[b]				
	Ratio	%	Lowest Value	Highest Value	Calculated Median[c]	Calculated Mean[c]	Range of RLs[d]
Fish							
Brown rockfish, whole body	15/15	100	11 J	150	65	63	na
English sole, whole body	13/13	100	42.8	160 J	81	90	na
Juvenile Chinook salmon, whole body	12/12	100	0.98	4.0	3.3	3.0	na
Sand sole, whole body	5/6	83	43	187	68	76	6.1
Shiner surfperch, whole body	11/11	100	7.1 JN	230	20.1	43	na
English sole, fillet	20/20	100	4.64	310	63	83	na
Invertebrates							
Crab, whole body[e, f]	9/9	100	15	70 J	35	40	na
Crab, edible meat[f]	9/9	100	20 J	81 J	49	48	na
Crab, hepatopancreas[f]	9/9	100	13	58 J	37	32	na
Clam, whole body[g]	10/10	100	1.3 JN	19	8.0	8.5	na
Mussel, whole body	14/17	82	3.30	15 J	5.7	5.7	1.1 – 1.2
Coonstripe shrimp, whole body	1/1	100	56 J	56 J	na	na	na
Geoduck clam, whole body[e]	4/4	100	3.7 J	4.8 JN	4.0	4.1	na
Geoduck clam, edible meat	6/6	100	3.1	5.6 J	3.7	4.1	na
Geoduck clam, gutball	3/3	100	4.2	4.5 J	4.3	4.3	na
Benthic invertebrates, whole body	13/13	100	14	55 J	34	34	na

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] A calculated total PCB result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Total PCB concentrations represents the sum of detected Aroclors results for each sample. If none of the individual Aroclors were detected in a given sample, non-detect values represent the highest RL.

[c] Median and mean concentrations were calculated using detected concentrations and one-half the RL for non-detected results.

[d] RLs are based only on non-detect samples.

[e] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck. No shells were included in these samples.

[f] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[g] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined. The whole body clam samples included all soft tissues and did not include shells.

J – estimated concentration
N – tentative identification
na – not applicable
RL – reporting limit
ww – wet weight

4.2.3.4.2 PCB Congener Data

A subset of the tissue samples (i.e., brown rockfish, English sole, shiner surfperch, crab, clams, and geoduck) were analyzed for all 209 PCB congeners (Table 4-31). The highest mean total PCB congener concentrations were in brown rockfish whole-body samples (2,350 µg/kg ww) and English sole whole-body composite samples (2,212 µg/kg ww). The lowest mean total PCB congener concentration was in geoduck edible meat samples (21 µg/kg ww). Crab hepatopancreas samples had consistently higher PCB congener concentrations than the crab edible meat samples. Fish samples had higher mean total PCB congener concentrations (ranging from 713 to 2,350 µg/kg ww) than did invertebrate samples (ranging from 21 to 570 µg/kg ww). An individual brown rockfish sample, collected from the southern portion of the deep main body, along the shoreline of T-18, had the highest sample-specific total PCB congener concentration (5,970 µg/kg ww). This concentration was relatively high as compared with the second highest total PCB congener concentration (2,438 µg/kg ww), which was detected in an individual rockfish whole-body sample collected from Slip 27.

Table 4-31
Total PCB (Sum of PCB Congeners) Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency[a]		Total PCB Concentration (µg/kg ww)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Fish						
Brown rockfish, whole body	6/6	100	618	5,970 J	1,980	2,350
English sole, whole body	3/3	100	2,010 J	2,365 J	2,260	2,212
Shiner surfperch, whole body	3/3	100	644	762	733	713
English sole, fillet	3/3	100	1,007	1,243	1,072	1,107
Invertebrates						
Crab, whole body[c, d]	3/3	100	272	304	286	287
Crab, edible meat[d]	3/3	100	96	115	104	105
Crab, hepatopancreas[d]	3/3	100	546	597	567	570
Intertidal Clam, whole body[e,f]	3/3	100	28	73	30	44

Tissue Type	Detection Frequency[a]		Total PCB Concentration (µg/kg ww)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Geoduck clam, whole body[d]	1/1	100	32	32	na	na
Geoduck clam, edible meat	3/3	100	13	26	24	21
Geoduck clam, gutball	2/2	100	53	72	na	62

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] A calculated total PCB result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Total PCB concentration represents the sum of detected PCB congener results.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[d] Two species of crab (red rock and one Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[e] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[f] The claml whole body samples include all soft tissues. Shells were not included in these samples.

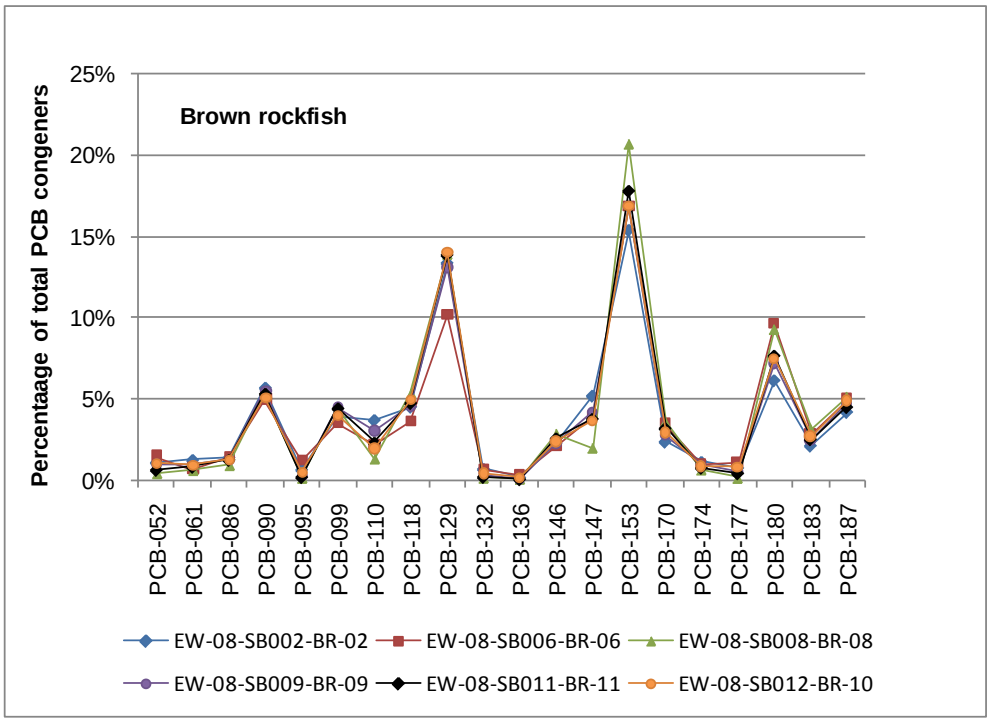
J – estimated concentration
na – not applicable
PCB – polychlorinated biphenyl
RL – reporting limit
ww – wet weight

The relative abundances of PCB congeners in each tissue type were calculated to determine if PCB patterns were different among species and tissue types. The first step in examining the relative abundance of individual PCB congeners within a tissue type was to condense the list of 209 PCB congeners to a smaller list based on the PCB congeners that contributed most to the total PCB concentration in each sample. These PCB congeners were identified by calculating the percentage of total PCB concentration represented by each PCB congener.

Then, a series of plots were generated to show the relative abundances of individual PCB congeners within a sample. A PCB congener was selected for inclusion in a plot if it was detected in every sample across all tissues types and if the concentration made up at least 2% of the total PCB concentration in any single sample. Twenty PCB congeners were identified using these criteria, and the sum of these 20 PCB congeners represented 62 to 98% of the total PCB concentrations for the subset of tissue samples analyzed for PCB congeners.

The PCB congener patterns in individual brown rockfish and shiner surfperch composite samples were relatively similar (Figures 4-4 and 4-5). The brown rockfish were analyzed as 15 individual fish samples, which results in more variability in the patterns compared to shiner surfperch, which were analyzed as three replicate supercomposite samples with little

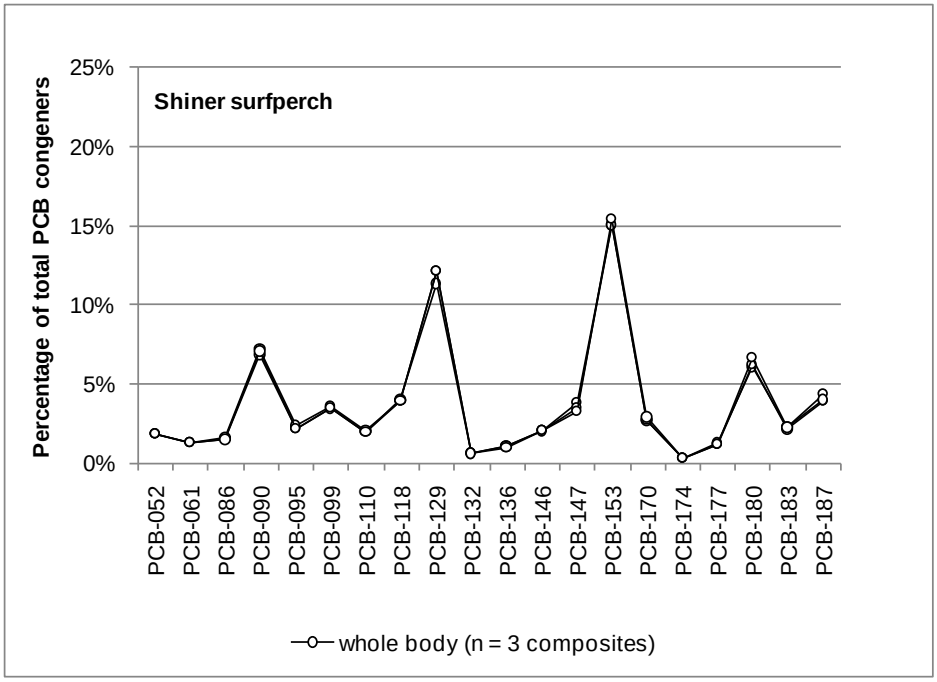
variability expected. The dominant congeners the patterns for all tissue types were PCB 90, PCB 129, PCB 153 and PCB 180. The PCB congener patterns for all the fish and crab tissues were similar (Figures 4-6 through 4-8). Finally, clams and geoduck (edible meat and gutball) had relatively similar PCB congener patterns, as shown in Figure 4-9. The congeners with the highest relative abundance for clams and geoduck were PCB 090, PCB 129, PCB 147, and PCB 153.



Note: Each line represents a sample.

Figure 4-4

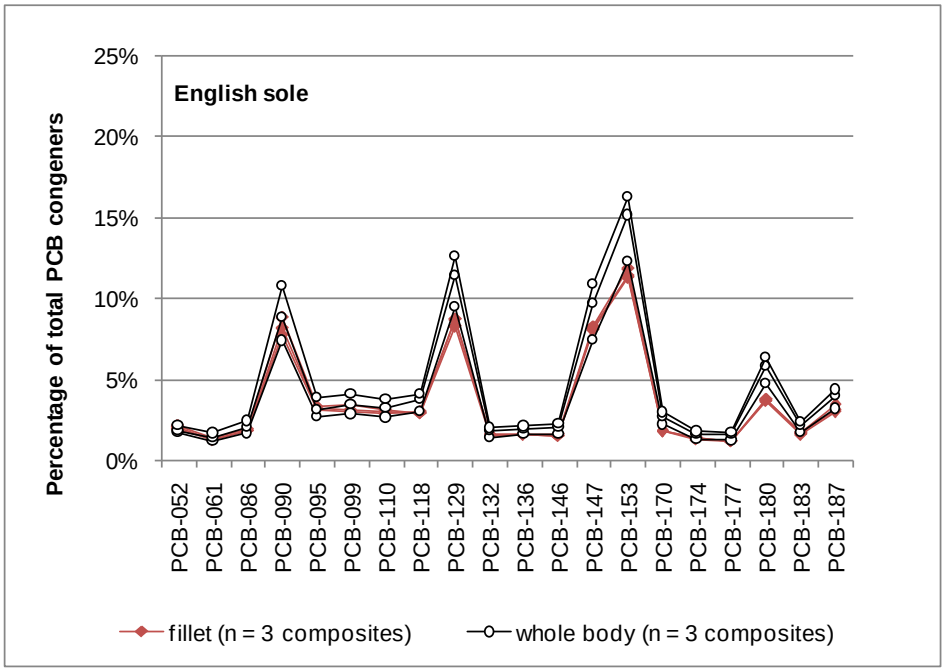
PCB Congener Patterns for Individual Brown Rockfish (Whole-Body) Samples



Note: Each line represents a sample.

Figure 4-5

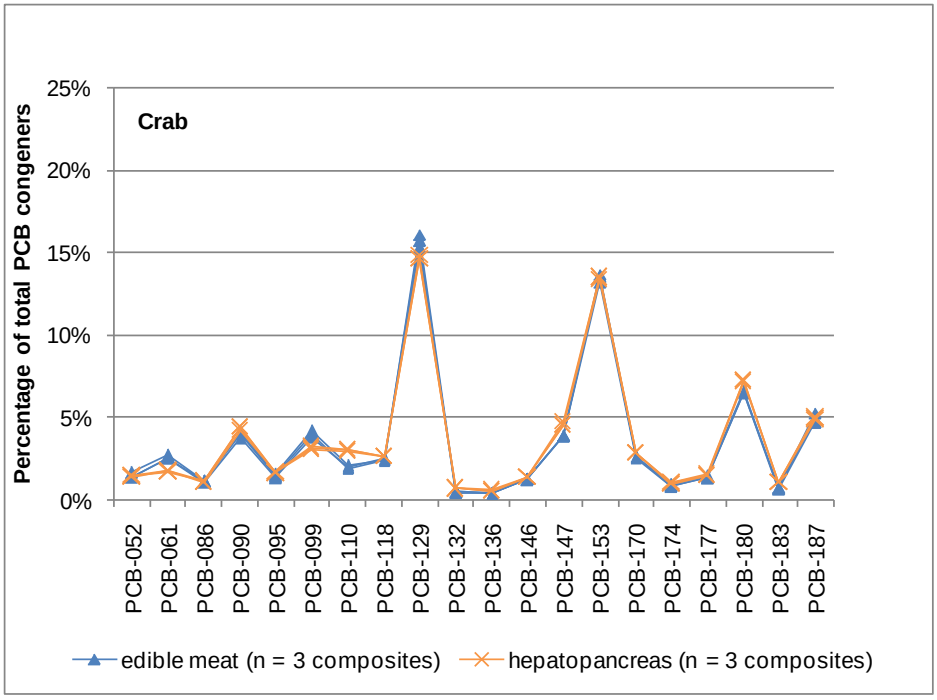
PCB Congener Patterns for Shiner Surfperch (Whole-Body) Composite Samples



Note: Each line represents a sample.

Figure 4-6

PCB Congener Patterns for English Sole (Whole-Body and Fillet) Composite Samples



Note: Each line represents a sample.

Figure 4-7

PCB Congener Patterns for Crab (Edible-Meat and Hepatopancreas) Composite Samples

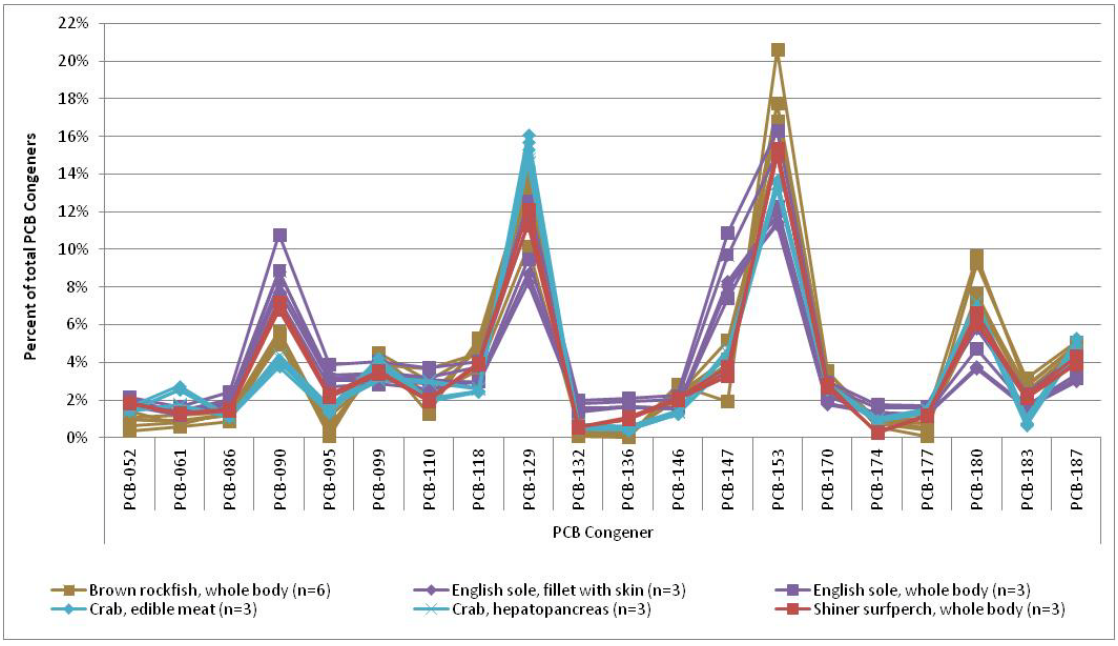
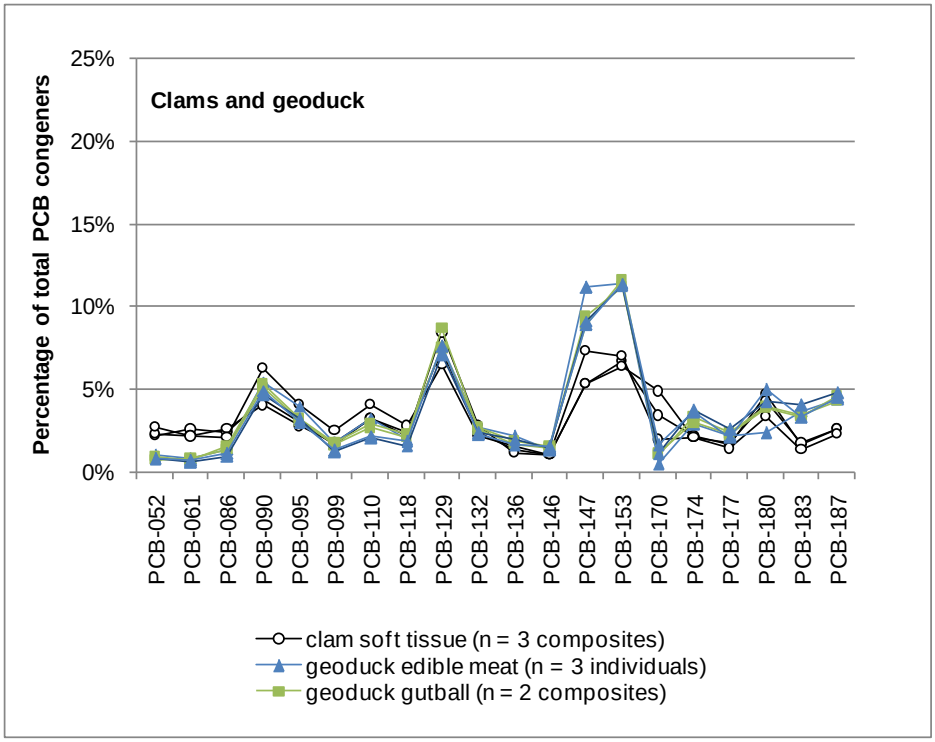


Figure 4-8

PCB Congener Patterns for All Fish and Crab Samples



Note: Each line represents a sample.

Figure 4-9
PCB Congener Patterns for Intertidal Clam (Whole body) Composite and Geoduck (Edible-Meat and Gutball) Samples

4.2.3.4.3 Comparison of Total PCB Aroclor Sums and Total PCB Congener Sums

For the subset of tissue samples analyzed for both PCB congeners and PCB Aroclors, the total PCB concentration based on the sum of detected individual congeners was compared with the total PCB concentration based on the sum of detected individual Aroclors. The sum of PCB congener concentrations is generally believed to provide the most accurate estimate of the total PCB concentrations in samples. Both methods have analytical variability, although Aroclors tend to have greater variability because of uncertainties associated with the identification and quantification of PCB patterns based on the analysis of a limited number of congeners as compared with the identification and quantification of all the individual PCB congeners.

Figures 4-10 and 4-11 show total PCB concentrations as the sum of PCB congeners plotted against total PCBs as the sum of Aroclors for the subset of EW tissue samples analyzed for both PCB Aroclors and PCB congeners. The gray line indicates a 1:1 relationship between

the two sums (points would fall along this line if the sums based on Aroclors and congeners were equal for a given sample). Points above this line identify samples with higher sums based on congeners, and points below this line identify samples with higher sums based on Aroclors. Total PCBs based on the sum of PCB Aroclors and the sum of PCB congeners were generally similar among the various tissue types (i.e., close to the 1:1 line). The RPD between the two PCB sums for fish and crab hepatopancreas tissues, which have the highest total PCB concentrations, ranged from 3 to 76%, with an average RPD of 32%. For the tissues with the lowest total PCB concentrations (i.e., crab edible meat, clam, and geoduck tissues), the RPD between the two PCB sums ranged from 2 to 92%, with an average RPD of 34. The relationships between the two sums were significant for both the higher concentration tissues and the lower concentration tissues with r^2 values of 0.84 and 0.55, respectively. The greater variance observed for the clam and crab edible meat tissues may be due to the fact that these samples represent specific species and locations, and thus they would be expected to be more variable than the site-wide composite samples that were analyzed for all the fish species (except for brown rockfish).

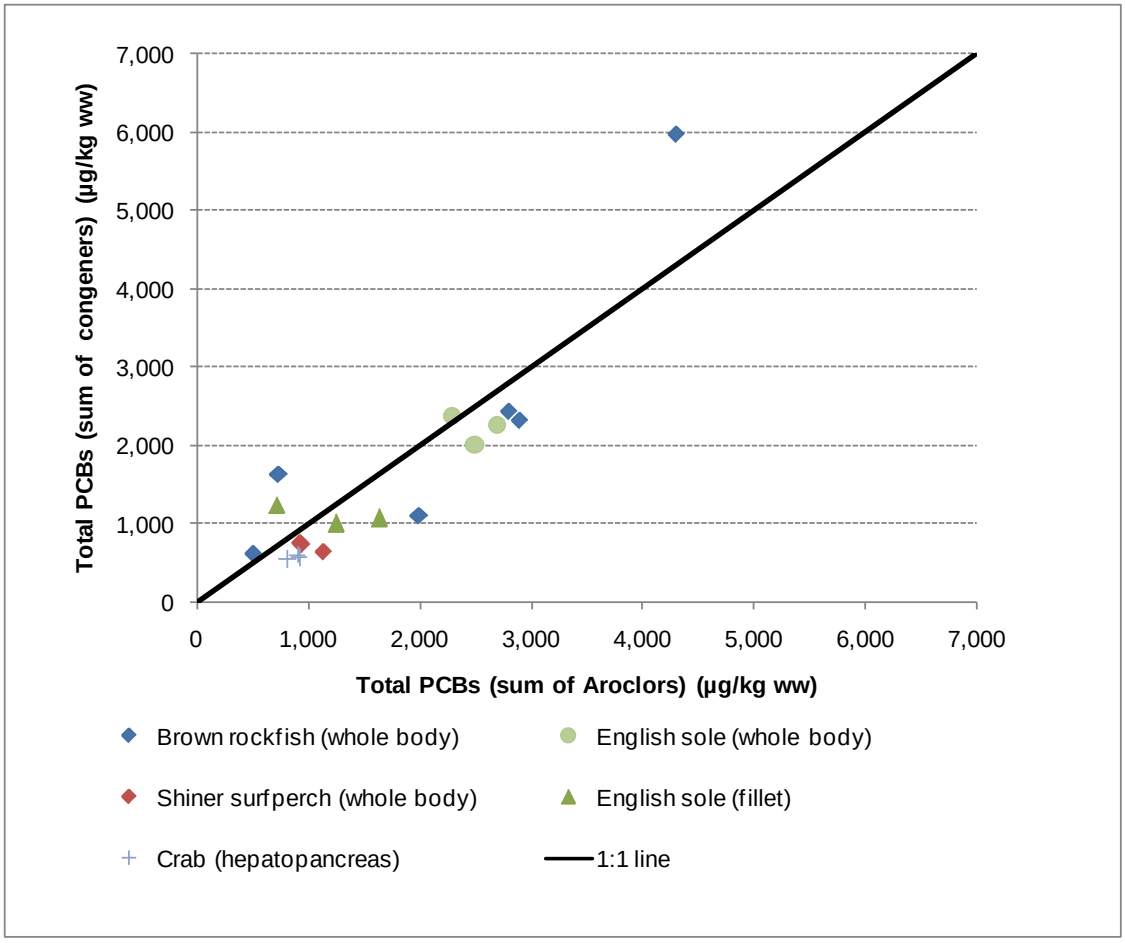


Figure 4-10

Total PCB Concentration (Sum of PCB Congeners) Compared with Total PCB Concentrations (Sum of Aroclors) in Brown Rockfish, English Sole, Shiner Surfperch, and Crab Hepatopancreas Samples

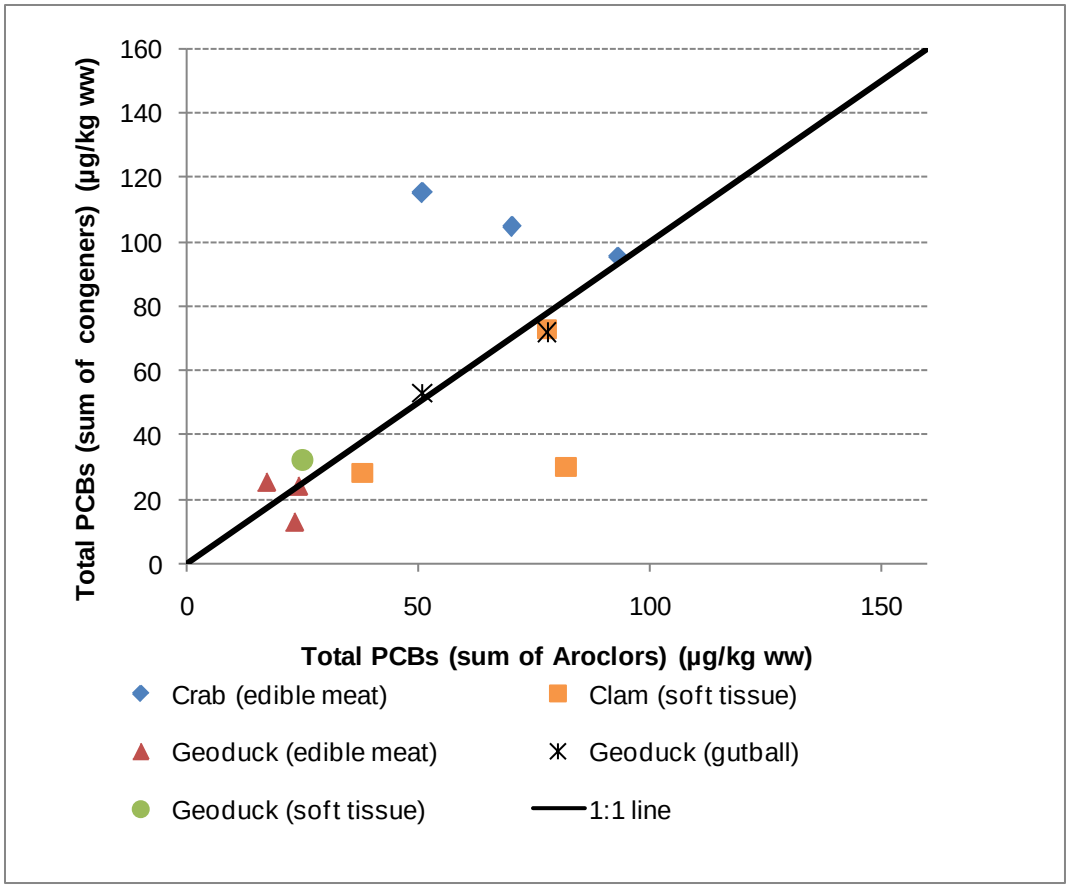


Figure 4-11
Total PCB Concentration (Sum of PCB Congeners) Compared with Total PCB Concentrations (Sum of Aroclors) in Geoduck and Crab (Edible Meat) Samples

4.2.3.4.4 PCB TEQs

Table 4-32 presents the detection frequencies and ranges of PCB TEQs for tissue. Mean PCB TEQ values were higher for fish than for invertebrates. For fish, the mean PCB TEQ value was highest (35.0 ng TEQ/kg ww) for English sole whole-body composite samples and lowest for English sole fillet composite samples (12.9 ng TEQ/kg ww) and shiner surfperch whole body composite samples (13.1 ng TEQ/kg ww). For invertebrates, the mean PCB TEQ value was highest (9.92 ng/kg ww) for crab hepatopancreas composite samples and lowest (0.141 ng/kg ww) for geoduck edible-meat composite samples.

Table 4-32
PCB TEQs for Fish and Invertebrate Tissues

Tissue Type	Detection Frequency[a]		PCB TEQ (ng TEQ/kg ww)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Fish						
Brown rockfish, whole body	6/6	100	5.05	59.5 J	20.8	24.8
English sole, whole body	3/3	100	32.4 J	37.4 J	35.1	35.0
Shiner surfperch, whole body	3/3	100	11.4	14.3	13.7	13.1
English sole, fillet	3/3	100	10.1	15.4	13.2	12.9
Invertebrates						
Crab, whole body[c, d]	3/3	100	3.67	5.61	5.22	4.83
Crab, edible meat[d]	3/3	100	1.53	1.71	1.66	1.63
Crab, hepatopancreas	3/3	100	8.06	11.0	10.7	9.92
Clam, whole body[e,f]	3/3	100	0.212	0.734	0.271	0.406
Geoduck clam, whole body[b]	1/1	100	0.228	0.228	na	na
Geoduck clam, edible meat	3/3	100	0.0910 J	0.192	0.140	0.141
Geoduck clam, gutball	2/2	100	0.378	0.544	na	0.461

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] A calculated PCB TEQ value was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated PCB TEQ value was considered not detected.

[b] PCB TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). PCB TEQs were calculated for each sample by summing the TEQs for each dioxin-like PCB congener. Individual PCB congener TEQs were calculated as the product of individual PCB congener concentrations and PCB congener-specific TEFs. If an individual PCB congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[d] Two species of crab (red rock and one Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown consist of results for all crab samples combined.

[e] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[f] The clam whole body samples include all soft tissues. Shells were not included in these samples.

EW – East Waterway
J – estimated concentration
na – not applicable
PCB – polychlorinated biphenyl
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent
ww – wet weight

An individual brown rockfish sample, collected from the southern portion of the deep main body, along the shoreline of T-18, had the highest sample-specific PCB TEQ value

(59.5 ng/kg ww) consistent with fact that the same fish the highest total PCB congener and total PCB Aroclor concentrations. The next highest PCB TEQ value (37.4 ng/kg ww) was for an English sole whole-body composite sample. The PCB TEQ values and total PCB concentrations were highest in the brown rockfish and English sole. The shiner surfperch had PCB TEQ and total PCB concentrations that were less than the brown rockfish and English sole but higher than the invertebrate tissues. The crab tissues had the higher PCB TEQ and total PCB concentrations than the other invertebrate tissues with the highest concentrations in the crab hepatopancreas samples. Intertidal clams and geoducks had the lowest PCB TEQ and total PCB concentrations.

4.2.3.5 Surface Water

PCB congeners were detected in all 57 surface water samples that were collected and analyzed for PCB congeners during the five SRI sampling events. Concentrations of total PCBs (as sum of detected congeners) ranged from 67.7 to 5,838 pg/L, with a mean concentration of 1,310 pg/L (Table 4-33). Data for the 12 dioxin-like PCB congeners were used to calculate PCB TEQs for each sample (as described in Appendix D). PCB TEQ values for surface water samples ranged from 0.447 to 0.689 pg TEQ/L, with a mean concentration of 0.582 pg TEQ/L. Surface water total PCB concentrations are compared with WQC in Section 4.2.2 (Table 4-21).

Table 4-33

Total PCB (as Sum of PCB Congeners) Concentrations and PCB TEQ for Surface Water

Chemical	Detection Frequency[a]		Concentration (pg/L)			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Total PCBs[b]	57/57	100	67.7 J	5,838 J	922	1,310
PCB TEQ[c]	57/57	100	0.447 J	0.689 J	0.559	0.582

[a] A calculated PCB TEQ value was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated PCB TEQ value was considered not detected.

[b] Total PCB concentration represents the sum of detected PCB congener results.

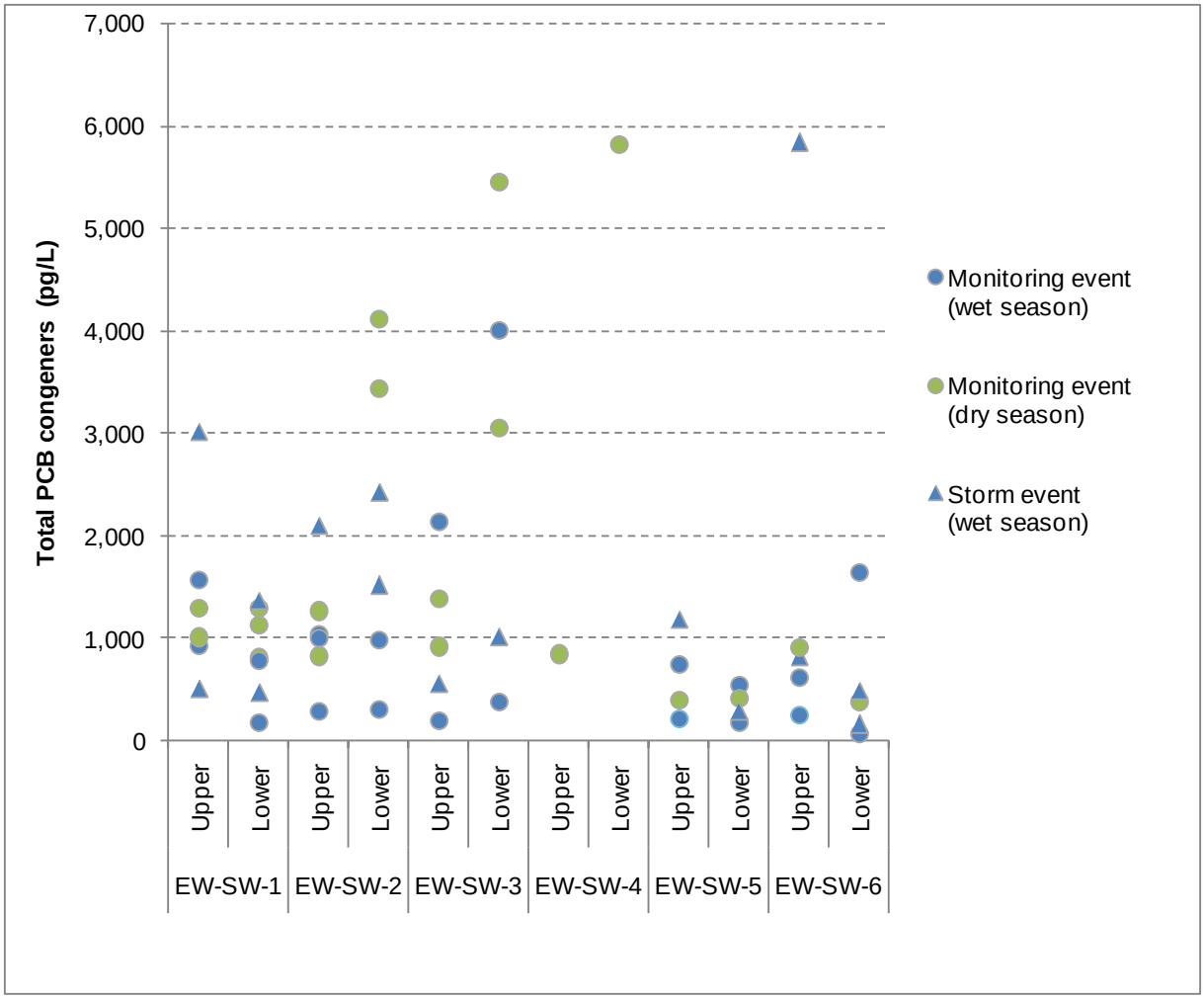
[c] PCB TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). PCB TEQs were calculated for each sample by summing the TEQs for each dioxin-like PCB congener. Individual PCB congener TEQs were calculated as the product of individual PCB congener concentrations and PCB congener-specific TEFs. If an individual PCB congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

J – estimated concentration

PCB – polychlorinated biphenyl

TEQ – toxic equivalent

Figure 4-12 shows the range of total PCB congener concentrations for each surface water sampling location at two depths. Approximately 47% (i.e., 27 of 57) of the samples were collected from 1 m below the water surface (i.e., upper water column) and 53% (i.e., 30 of 57) were from 1 m above the sediment surface (i.e., lower water column). Of the 27 samples from the upper water column, approximately 26% (i.e., 7 of 27) were collected during a storm event in January 2009. Of the 30 samples collected in the lower water column, 30% (i.e., 9 of 30) were collected during a storm event in January 2009. The highest total PCB congener concentration (5,838 pg/L) was from a water sample collected from the upper water column at location ES-SW-6 during a storm event in January 2009 (Map 4-7). The next highest concentrations were 5,083 pg/L collected from EW-SW-4 and 5,439 pg/L collected from EW-SE-3. Both samples were collected from the lower water column in September 2008. PCB surface water concentrations are whole-water concentrations, and much of the variability in the measured concentrations is consistent with that of the TSS concentrations in the sample. PCBs are strongly associated with particulates, and higher PCB concentrations tend to be associated with higher TSS concentrations (Figure 4-13).



Note: Upper water column samples were collected from 1 m below the water surface. Lower water column samples were collected from 1 m above the sediment surface.

Figure 4-12

Total PCB Concentrations (Sum of PCB Congeners) in Surface Water for Each Sampling Location

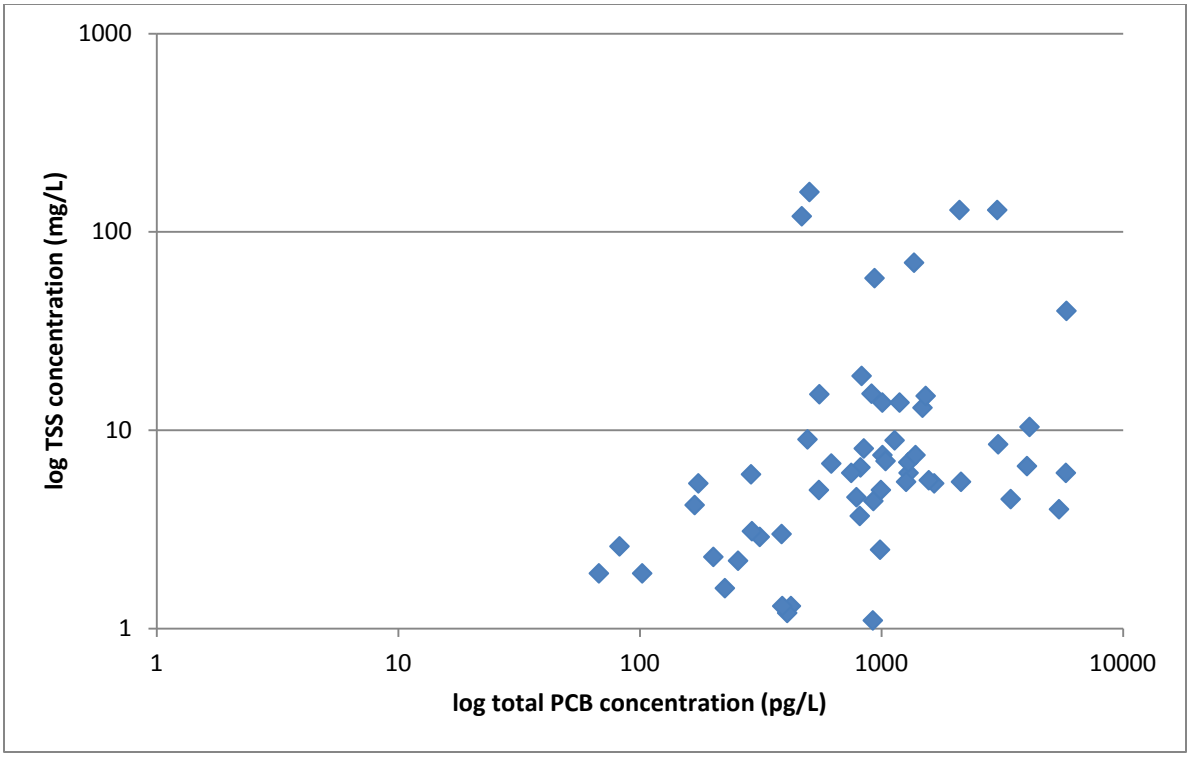


Figure 4-13
Total PCB Concentrations (Sum of PCB Congeners) and TSS Concentration for Each Surface Water Sample

4.2.3.6 Summary of PCB Data

Surface sediment, subsurface sediment, tissue, and surface water samples from throughout the EW were collected and analyzed for PCBs. These data were used to describe the nature and extent of PCB concentrations in the EW.

In surface sediment, total PCBs were detected in 95% of the samples, with concentrations ranging from 6.0 to 8,400 µg/kg dw; the area-based 95th and 50th percentiles were 1,300 and 300 µg/kg dw, respectively. The spatially weighted average concentration (SWAC) for the entire EW was 460 µg/kg dw. The calculation of the SWAC is based on the IDW interpolated PCB concentrations throughout the waterway. The SWAC and the arithmetic mean total PCB concentrations are similar in the EW, which reflects the fact that samples are evenly distributed throughout the waterway, with no bias resulting from the more intensive sampling of areas with higher concentrations.

The highest total PCB concentrations were in samples collected from the southeast and northwest portions of the deep main body, from Slip 27, and from one location in Sill Reach. Total PCB concentrations expressed on an organic carbon-normalized basis exceeded the SQS but not the CSL in 134 surface sediment samples (56%) and exceeded the CSL in 23 surface sediment samples (9.6%). Surface sediment total PCB concentrations in the Junction Reach and at the mouth of the waterway were less than the SQS and below the 25th percentile.

In several areas of the EW, the highest concentrations of total PCB in subsurface sediment samples were detected in the same areas that had higher concentrations of total PCBs in surface sediment samples (i.e., the area near Hanford # 2 CSO and two storm drains, and the head of Slip 27). Subsurface sediment total PCB concentrations were generally higher than surface sediment total PCB concentrations in the shallow main body and in the deep main body outside the areas that have been dredged (i.e., the mound area outside Slip 27 and the area south of Slip 36 near the former Rabanco barge loading facility and GATX) and subsurface sediment total PCB concentrations were generally less than surface sediment total PCB concentrations in the dredged areas in both the deep main body and along the pier face in the northern portion of T-18.

The fish and invertebrate tissue dataset provides good spatial coverage of the EW and represents species with a range of life histories, including a variety of dietary regimes and home ranges, as well as the species of interest for the ecological risk assessment (as either receptors or prey for receptors) and the human health risk assessment (as species and size classes consumed by people). PCBs were analyzed as Aroclors in all samples and as PCB congeners in a subset of samples. Total PCBs (Aroclor sum) were detected in almost all of the tissue samples. Mean total PCB concentrations (Aroclor sum) across the tissue types were highest in English sole whole-body composite samples (3,200 µg/kg ww) and lowest in geoduck edible meat samples from individual clams (19 µg/kg ww). Similarly, the highest mean lipid-normalized PCB concentration was in English sole whole-body composite samples (90 mg/kg-lipids). The mean lipid-normalized PCB concentration in geoduck edible meat samples was also low (4.1 mg/kg-lipids) but was lowest in juvenile Chinook salmon whole-body composite samples (3.0 mg/kg- lipids). The lipid-normalized concentrations are more similar than the wet weight concentrations because of the higher lipid content in fish compared to the invertebrate tissues.

In general, the PCB congener patterns for samples within each tissue type were similar. The two congeners with the highest percentage of total congeners were PCB 153 and PCB 129 in all tissue types. For tissue types that were analyzed for both PCB Aroclors and PCB congeners, a comparison was made between the two sums. Results were generally similar, with an RPD of 33% between the two sums. Mean PCB TEQ and total PCB values were highest for English sole whole-body composite samples and brown rockfish and lowest for geoduck edible meat samples from individual clams (0.141 ng TEQ/kg ww). Brown rockfish had the most variable tissue congener patterns, and PCB TEQ and total PCB concentrations. A large portion of this variability is likely due to the fact that rockfish were analyzed individually rather than as composites.

PCB congeners were analyzed in 57 surface water samples collected during the five SRI sampling events. Concentrations of total PCBs (as a sum of congeners) in surface water ranged from 67.7 to 5,838 pg/L, with a mean concentration of 1,310 pg/L. PCB TEQ values for surface water ranged from 0.447 to 0.689 pg TEQ/L, with a mean value of 0.582 pg TEQ/L.

4.2.4 Dioxins and Furans

This section summarizes the nature and extent of dioxin and furan concentrations in surface, subsurface sediment, and tissue samples. Surface water and porewater samples collected from the EW were not analyzed for dioxins and furans. Dioxin and furan TEQs were calculated by summing the products of concentrations and compound-specific TEFs for mammals (Van den Berg et al. 2006) for the seven dioxin and 10 furan congeners.

4.2.4.1 Surface Sediment

There were no historical surface sediment dioxin and furan data for the EW. In order to achieve a spatially representative estimate of mean dioxin and furan concentrations for the risk assessments, the subtidal area of the EW was divided into 13 sampling areas, and composite samples were created for each sampling area by combining grab samples collected in each area (Map 4-2). The compositing approach resulted in dioxin and furan concentrations that are representative of the mean dioxin and furan concentrations for each of the sampling areas. However, the spatial resolution of the data is limited to the spatial scale of the composites because of the compositing method. Therefore, the distribution of

surface sediment dioxin and furan concentrations within each sampling area cannot be determined from the analysis of composite samples.

The 13 composite samples were analyzed for dioxins and furans. Dioxins and furans were also analyzed in 11 surface sediment grab samples (Map 4-24).[61] All four of the intertidal MIS composite samples collected for the SRI in 2009 were also analyzed for dioxins and furans. For the surface sediment composite samples, dioxin and furan TEQ values ranged from 4.02 to 30.6 ng TEQ/kg dw with a mean value of 15.7 ng TEQ/kg dw (Table 4-34). The highest dioxin and furan TEQ values were from Slip 27 (30.6 ng TEQ/kg dw), the shallow main body (18.1 and 24.2 ng TEQ/kg dw) and the Junction/sill reach (17.4 ng TEQ/kg dw). The lowest TEQ values were from composites collected at the mouth of the waterway (4.02 and 5.69 ng TEQ/kg dw).

Table 4-34

Dioxin and Furan TEQs for EW Surface Sediment

Sample Type	Detection Frequency[a]		Dioxin and Furan TEQ (ng TEQ/kg dw)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Subtidal composite	13/13	100	4.02 J	30.6	15.6	15.7
Grab[c]	11/11	100	2.78 J	49.7 J	16.6	19.3
Area-wide intertidal MIS composite	3/3	100	9.19 J	13.8 J	13.2	12.1
Public access intertidal MIS composite	1/1	100	8.52 J	8.52 J	na	na

[a] A calculated dioxin and furan TEQ value was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated dioxin and furan TEQ value was considered not detected.

[b] Dioxin and furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQs were calculated for each sample by summing the TEQs for each dioxin and furan congener. Dioxin and furan individual congener TEQs for were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[c] Two grab samples were composites, each created from two adjacent grab samples.

EW – East Waterway
dw – dry weight
J – estimated concentration
na – not applicable
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent

[61] Two of the 11 grab samples were composites, each of these composites were created from two adjacent grab samples.

For surface sediment grab samples, dioxin and furan TEQ values ranged from 2.78 to 49.7 ng/kg dw. For the area-wide intertidal MIS composite samples, dioxin and furan TEQ values ranged from 9.19 to 13.8 ng TEQ/kg dw. The public access intertidal MIS composite sample had a dioxin and furan TEQ value of 8.52 ng TEQ/kg dw. The maximum dioxin and furan TEQ value (49.7 ng TEQ/kg dw) was for a grab sample collected from a location in the shallow main body (Station 6200), near the Hinds CSO/SD (Map 4-24).

4.2.4.2 Subsurface Sediment

Sixteen subsurface sediment samples representing 13 locations were analyzed for dioxins and furans (Map 4-25).[62] The subsurface sediment samples were all analyzed for SMS chemicals prior to the selection of samples for dioxin and furan analysis. The subsurface sediment samples selected for the analysis of dioxins and furans were primarily thosesamples with no SQS exceedances in order to determine whether or not dioxin concentrations were elevated in subsurface sediment samples that had no other elevated contaminant concentrations. A summary of the results is provided in Table 4-35. Dioxin and furan TEQ values generally ranged from 0.75 to 20.5 ng TEQ/kg dw, with the exception of the highest value of 184 ng TEQ/kg dw reported in the 2-to-4-ft interval of EW10-SC23 in Slip 27. Seven subsurface sediment samples collected entirely from within the lower alluvium unit had very low detected concentrations of dioxins and furans, with TEQ values ranging from 1.10 to 2.80 ng TEQ/kg dw.

Table 4-35
Dioxin and Furan TEQs for Subsurface Sediment

	Detection Frequency[a]		Dioxin and Furan TEQ (ng TEQ/kg dw)[b]	
Sampling Interval (ft)	Ratio	%	Lowest Value	Highest Value
All Data				
Any interval	16/16	100	0.748 J	184 J
2-ft Intervals				
0 – 2	1/1	100	20.5 J	20.5 J
2 – 4	3/3	100	1.97 J	184 J
4 – 6	5/5	100	1.10 J	2.80 J

[62] Three of the sixteen subsurface sediment samples analyzed for dioxins and furans were field duplicates; 13 unique sample locations had subsurface sediment samples analyzed for dioxins and furans.

Sampling Interval (ft)	Detection Frequency[a]		Dioxin and Furan TEQ (ng TEQ/kg dw)[b]	
	Ratio	%	Lowest Value	Highest Value
6 – 8	5/5	100	2.37 J	2.74
8 – 10	2/2	100	0.748 J	2.64 J

[a] A calculated dioxin and furan TEQ value was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected.

[b] Dioxin and furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQs were calculated for each sample by summing the TEQs for each dioxin and furan congener. Dioxin and furan individual congener TEQs were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

dw – dry weight
EW – East Waterway
J – estimated concentration
na – not applicable
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent

4.2.4.3 Tissue

Table 4-36 presents the detection frequencies and ranges of dioxin and furan TEQs for tissue. The mean dioxin and furan TEQ value was highest for crab hepatopancreas composite samples (2.28 ng TEQ/kg ww). However, mean dioxin and furan TEQ values were relatively similar for crab hepatopancreas composite, individual brown rockfish, and English sole whole-body composite samples, with mean values ranging from 1.77 to 2.28 ng TEQ/kg ww. Mean dioxin and furan TEQ values for shiner surfperch whole-body, English sole fillet, and crab whole body composite samples ranged from 0.752 to 1.22 ng TEQ/kg ww. The lowest mean dioxin and furan TEQ values were for crab edible meat, clam, and geoduck (whole body, edible meat, and gutball) composite samples, with mean values ranging from 0.234 to 0.470 ng TEQ/kg ww

Table 4-36
Dioxin and Furan TEQs for Fish and Invertebrate Tissues

Tissue Type	Detection Frequency[a]		Dioxin and Furan TEQ (ng TEQ/kg ww)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Fish						
Brown rockfish, whole body	6/6	100	0.658 J	3.00 J	2.15	2.11
English sole, whole body	3/3	100	1.54 J	1.89 J	1.89	1.77
Shiner surfperch, whole body	3/3	100	1.01 J	1.35 J	1.30	1.22
English sole, fillet	3/3	100	0.728 J	0.793 J	0.736	0.752

Tissue Type	Detection Frequency[a]		Dioxin and Furan TEQ (ng TEQ/kg ww)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Invertebrates						
Crab, whole body[c,]	3/3	100	1.17 J	1.25 J	1.19	1.20
Crab, edible meat[d]	3/3	100	0.451 J	0.488 J	0.471	0.470
Crab, hepatopancreas[d]	3/3	100	2.22 J	2.35 J	2.26	2.28
Clam, whole body[e]	3/3	100	0.234[f] J	0.379[f] J	0.237	0.283[f]
Geoduck clam, whole body[c]	1/1	100	0.204[f] J	0.204[f] J	na	na
Geoduck clam, edible meat	3/3	100	0.218[f] J	0.246[f] J	0.239	0.234[f]
Geoduck clam, gutball	2/2	100	0.303[f] J	0.536[f] J	na	0.420[f]

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] A calculated dioxin and furan TEQ value was considered detected if one or more of the components of the sum were detected.

[b] Dioxin and furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQs were calculated for each sample by summing the TEQs for each congener. Dioxin and furan individual congener TEQs were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[d] Two species of crab (red rock and one Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[e] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined. The clam l whole body samples include all soft tissues. Shells were not included in these samples.

[f] TEQ values for clam and geoduck tissues were based largely on TEQs calculated using RL values for non-detected results due to the high number of non-detected dioxin and furan congeners for these samples.

EW – East Waterway
J – estimated concentration
na – not applicable
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent
ww – wet weight

4.2.4.4 Summary of Dioxin and Furan Data

Surface sediment, subsurface sediment, and tissue samples from throughout the EW were collected and analyzed for dioxins and furans. These data were used to describe the nature and extent of dioxin and furan TEQs in the EW.

In order to achieve a spatially representative estimate of mean dioxin and furan concentrations for use in the risk assessments, especially for assessing risk due to direct contact with sediment in the HHRA, composite samples were analyzed for dioxins and

furans. The compositing approach resulted in dioxin and furan concentrations that were representative of the mean dioxin and furan concentrations for each sampling area. However, the spatial resolution of the data is limited. The distribution of surface sediment dioxin and furan concentrations within each sampling area cannot be determined from the analysis of composite samples.

Generally dioxins and furans concentrations in surface sediment composite and grabs were similar throughout waterway. Concentrations sediment composites collected in the mouth of the waterway are lower than sediment composites from the rest of waterway. Concentrations in composites ranged from 4.02 to 30.6 ng TEQ/kg dw, with a mean value of 15.7 ng TEQ/kg dw. For the surface sediment grab samples, dioxin and furan TEQ values ranged from 2.78 to 49.7 ng TEQ/kg dw; the highest concentration was collected from a location in the shallow main body (Station 6200), near the Hinds CSO/storm drain. The highest surface sediment dioxin concentrations were measured in the composite samples collected from Slip 27, the shallow main body and the Junction/Sill reach. Concentrations in the four intertidal MIS composite samples were in the same range as the surface sediment composite samples (8.52 to 13.8 ng TEQ/kg dw). Sixteen subsurface sediment samples were analyzed for dioxin. Dioxin TEQ values ranged from 0.75 to 20.5 ng TEQ/kg dw, except for one value of 184 ng TEQ/kg dw reported for the 2-to-4-ft interval of SC23 in Slip 27.

Mean dioxin and furan TEQ values were highest for crab hepatopancreas composite samples, individual brown rockfish, and English sole whole-body composite samples, with mean values ranging from 1.77 to 2.28 ng TEQ/kg ww. The lowest mean dioxin and furan TEQ values were for crab edible meat, clam whole body, and geoduck (whole body, edible meat, and gutball) composite samples, with mean values ranging from 0.234 to 0.470 ng TEQ/kg ww.

4.2.5 Total TEQ

This section summarizes the nature and extent of total TEQs (sums of both PCB TEQ and dioxins/furans TEQ values) in surface sediment and tissue samples. Subsurface sediment samples were not analyzed for PCB congeners and surface water samples were not analyzed for dioxins and furans, therefore, total TEQ could not be calculated for either of these media.

4.2.5.1 Surface Sediment

Total TEQ was calculated for the 13 surface sediment composite samples and the 4 intertidal MIS surface sediment composite samples (Table 4-37). Total TEQ values for surface sediment composite samples ranged from 5.10 to 40.1 ng TEQ/kg dw, with a mean value of 20.1 ng TEQ/kg dw. Total TEQ values for the area-wide intertidal MIS composite samples ranged from 15.5 to 17.6 ng TEQ/kg dw. The public access intertidal MIS composite sample had total TEQ of 9.92 ng TEQ/kg dw. The highest total TEQ value (40.1 ng TEQ/kg dw) was for a composite sample collected from Slip 27 (Map 4-26).

Table 4-37
Total TEQs for Surface Sediment

Sample Type	Detection Frequency[a]		Total TEQ (ng TEQ/kg dw)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Subtidal composite	13/13	100	5.10 J	40.1 J	20.6	20.1
Area-wide intertidal MIS composite	3/3	100	15.5 J	17.6 J	16.5	16.5
Public access intertidal MIS composite	1/1	100	9.92 J	9.92 J	na	na

[a] A calculated total TEQ value was considered detected if one or more of the components of the sum were detected.

[b] Total TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Total TEQs were calculated for each sample by summing the TEQs for each congener. TEQs for individual congeners were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

dw – dry weight
EW – East Waterway
J – estimated concentration
na – not applicable
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent

As shown in Figure 4-14, the relative proportion of dioxin and furan TEQ was greater than the PCB TEQ proportion for each surface sediment composite sample. The dioxin and furan TEQ ranged from 66 to 84% of the total TEQ for the 13 subtidal composite samples, and ranged from 59 to 80% of the total TEQ for the area-wide intertidal MIS composite samples. The dioxin and furan TEQ was 86% of the total TEQ for the public access intertidal MIS composite sample.

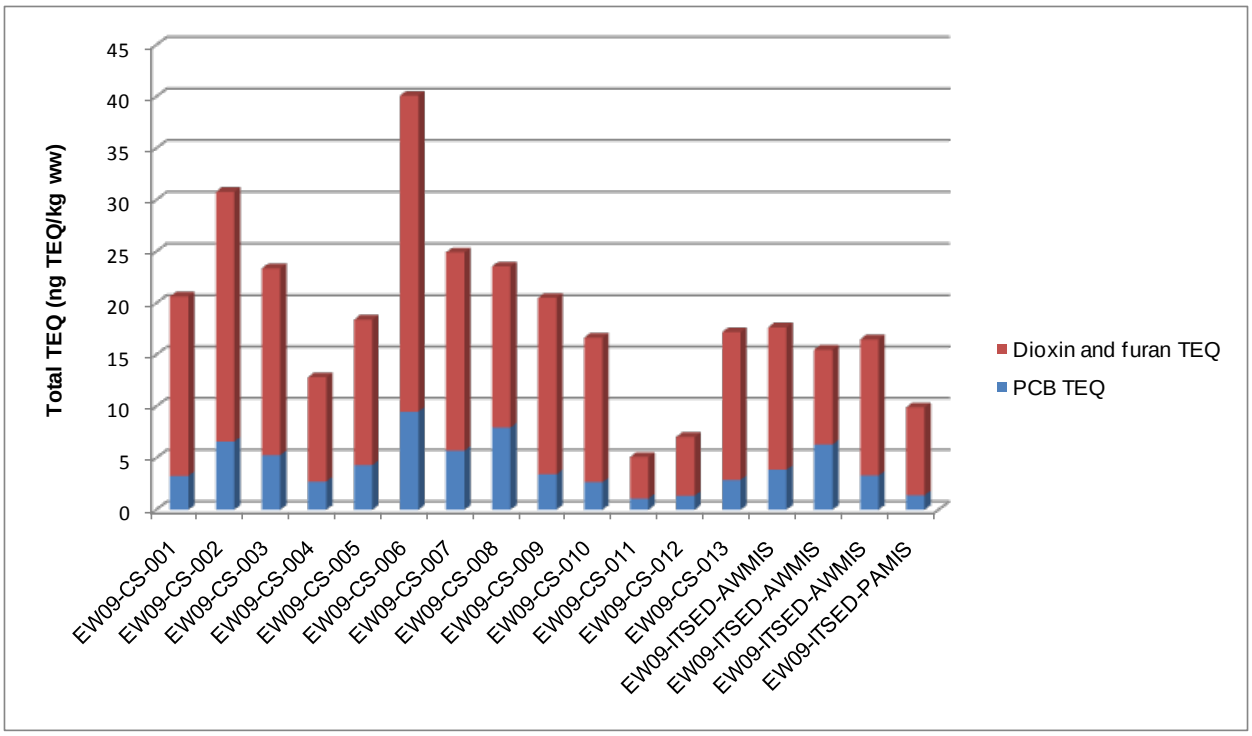


Figure 4-14
Total TEQ in Surface Sediment Composite Samples

4.2.5.2 Tissue

Table 4-38 presents the detection frequencies and ranges of total TEQs for tissue. Mean total TEQ values were higher for fish than for invertebrates. For fish, the mean total TEQ value was highest for English sole whole-body composite samples (36.8 ng TEQ/kg ww) and lowest for English sole fillet composite samples (13.6 ng TEQ/kg ww). For invertebrates, mean total TEQ value was highest for crab hepatopancreas composite samples (12.2 ng TEQ/kg ww) and lowest for geoduck edible meat composite samples (0.375 ng TEQ/kg ww). As shown in Figure 4-15, the relative proportion of PCB TEQ was generally greater than that of the dioxin and furan TEQ, particularly in samples with highest TEQs. The PCB TEQ ranged from 86 to 96% of the total TEQ across all fish samples and 27 to 82% of the total TEQ across all invertebrate samples.

Table 4-38
Total TEQs for Fish and Invertebrate Tissues

Tissue Type	Detection Frequency[a]		Total TEQ (ng TEQ/kg ww)[b]			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Fish						
Brown rockfish, whole body	6/6	100	5.71 J	61.8 J	23.3	26.9
English sole, whole body	3/3	100	34.3 J	39.0 J	37.1	36.8
Shiner surfperch, whole body	3/3	100	12.4 J	15.6 J	15.0	14.3
English sole, fillet	3/3	100	10.8 J	16.1 J	14.0	13.6
Invertebrates						
Crab, whole body[c, d]	3/3	100	4.84 J	6.80 J	6.46	6.03
Crab, edible meat[d]	3/3	100	1.98 J	2.18 J	2.15	2.10
Crab, hepatopancreas[d]	3/3	100	10.3 J	13.4 J	13.0	12.2
Clam, whole body[e]	3/3	100	0.446 J	1.11 J	0.508	0.688
Geoduck clam, whole body[c]	1/1	100	0.433 J	0.433 J	na	na
Geoduck clam, edible meat	3/3	100	0.337 J	0.431 J	0.357	0.375
Geoduck clam, gutball	2/2	100	0.681 J	1.08 J	na	0.881

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] Calculated dioxin and furan TEQ and PCB congener TEQ values were considered detected if one or more of the components of the sum were detected.

[b] Total TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Total TEQs were calculated for each sample by summing the TEQs for each congener. TEQs for individual congeners were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[d] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[e] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined. The clam whole body samples include all soft tissues. Shells were not included in these samples.

EW – East Waterway
J – estimated concentration
na – not applicable
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent
ww – wet weight

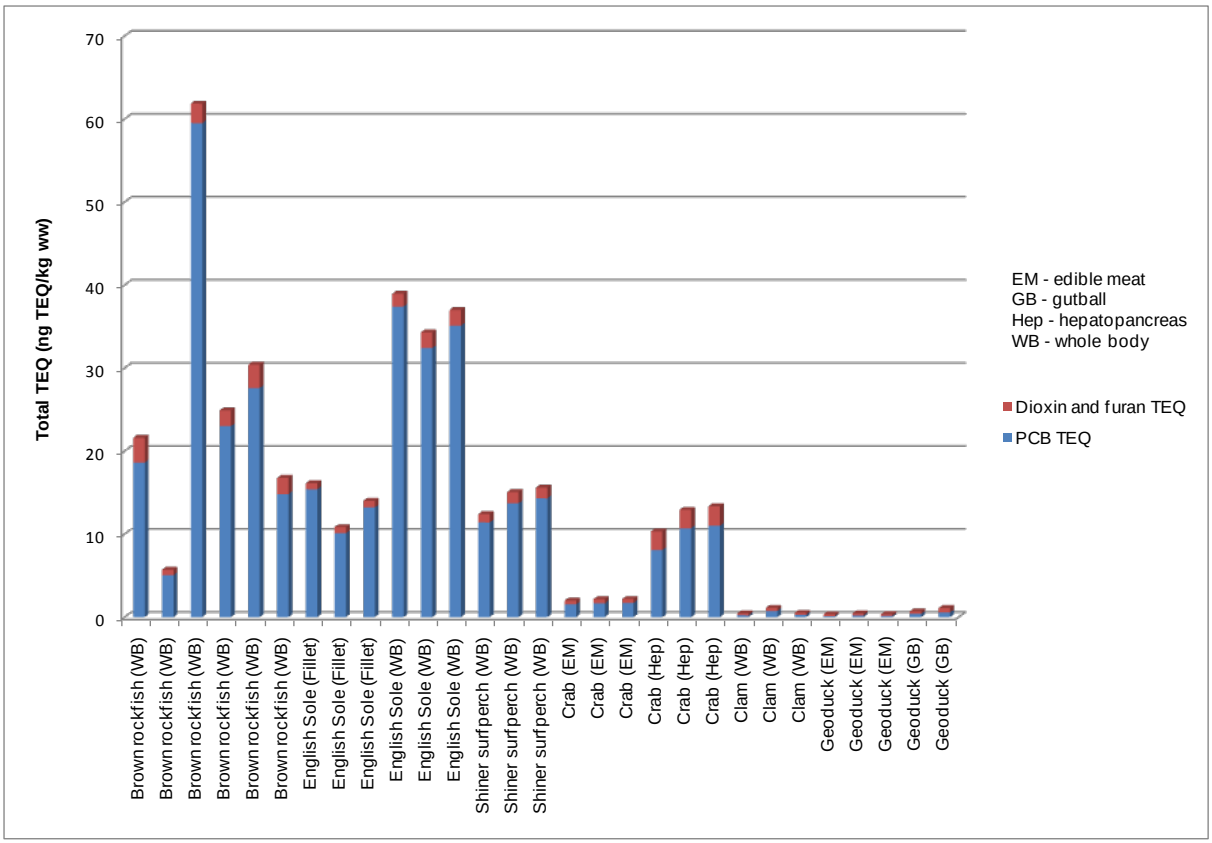


Figure 4-15
Total TEQ for Fish and Crab Tissue Samples

4.2.6 cPAHs

This section summarizes the nature and extent of cPAH concentrations in surface sediment, subsurface sediment, tissue, and surface water samples. cPAHs are hydrophobic organic contaminants with a strong tendency to be associated with particulate organic carbon in both sediment and surface water. Therefore, cPAH concentrations in sediment are critical to the evaluation of the nature and extent of cPAHs in the EW. cPAHs were not analyzed in porewater samples collected from the EW because porewater concentrations of cPAHs are a component of the measured bulk sediment concentration, and risks to human health were evaluated using cPAH sediment and tissue data (see Section 6.3)

cPAH concentrations in sediment, tissue, and surface water samples were calculated based on concentrations of seven individual PAHs (i.e., benzo(a)pyrene, benzo(b)fluoranthene, benzo(a)anthracene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, dibenz(a,h)anthracene, and chrysene) and their carcinogenic potency relative to benzo(a)pyrene, using PEFs from

the California Environmental Protection Agency (California EPA) (1994) as described in Appendix D. Data for individual and total PAHs are summarized in Section 4.2.11.

4.2.6.1 Surface Sediment

cPAH compounds were analyzed in 240 surface sediment grab samples and all four of the intertidal MIS composites collected.[63] Detected total cPAH concentrations in sediment grab samples ranged from 15 to 10,000 µg TEQ/kg dw and a mean concentration of 460 µg TEQ/kg dw (Table 4-39). In addition, cPAHs were detected in all four of the intertidal MIS composite samples. The area-wide intertidal MIS composite samples had cPAH concentrations that ranged from 450 to 1,900 µg TEQ/kg dw. The public access intertidal MIS composite had a cPAH concentration of 390 µg TEQ/kg dw.

Table 4-39
cPAH Concentrations in Surface Sediment

Sample Type	Detection Frequency[a]		Concentration (µg TEQ/kg dw)[b]				
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean	Range of RLs[c]
Intertidal composite	15/15	100	18 J	17,000 J	230	1,900	na
Grab	233/240	97	15 J	10,000	230	460	15 – 48
Area-wide intertidal MIS composite	3/3	100	450 J	1,900	780	1,000	na
Public access intertidal MIS composite	1/1	100	390	390	na	na	na

[a] A calculated cPAH result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated cPAH concentration was considered not detected.

[b] Total cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual PAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

[c] RLs were calculated as equivalent cPAH values for samples with no detected cPAH compounds. RLs for non-detect values were calculated as the sum of one-half the RL multiplied by the PEF for each compound.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
J – estimated concentration
MIS – multi-increment sampling
na – not applicable
PEF – potency equivalency factor
RL – reporting limit

[63] Fifteen of the 240 surface sediment grab samples were field duplicates; 225 unique sample locations had surface sediment grab samples analyzed for cPAHs.

One of the three area-wide intertidal MIS replicate samples contained substantially higher concentrations of cPAHs than the other two area-wide MIS samples and had higher cPAH concentrations than the single public access intertidal sediment sample. This variance suggested that one or more sediment grab samples within the MIS composite contained elevated cPAH concentrations relative to the grab samples that went into the other replicate MIS samples. In order to identify the area with elevated cPAH concentrations, sediment volume from discrete sampling points used to create the MIS samples were combined by geographic subarea to create 15 intertidal composites to represent beach areas (Map 4-27). These 15 intertidal composite were subsequently analyzed for PAHs. cPAH concentrations in these 15 intertidal surface sediment composite samples ranged from 18 to 17,000 µg TEQ/kg dw, a mean of 1,900 µg TEQ/kg dw. The maximum intertidal composite sample cPAH concentration (17,000 µg TEQ/kg dw) was located on the southeast side of the shallow main body near the historic Pier 24 location (Station 6200; Map 4-27). The area-wide intertidal MIS composite samples had a mean cPAH concentration of 1,000 µg TEQ/kg dw. cPAH TEQ concentrations in the intertidal MIS samples were all greater than the numerical 50th percentile (220 µg TEQ/kg dw) of the surface sediment dataset(Figure 4-16).

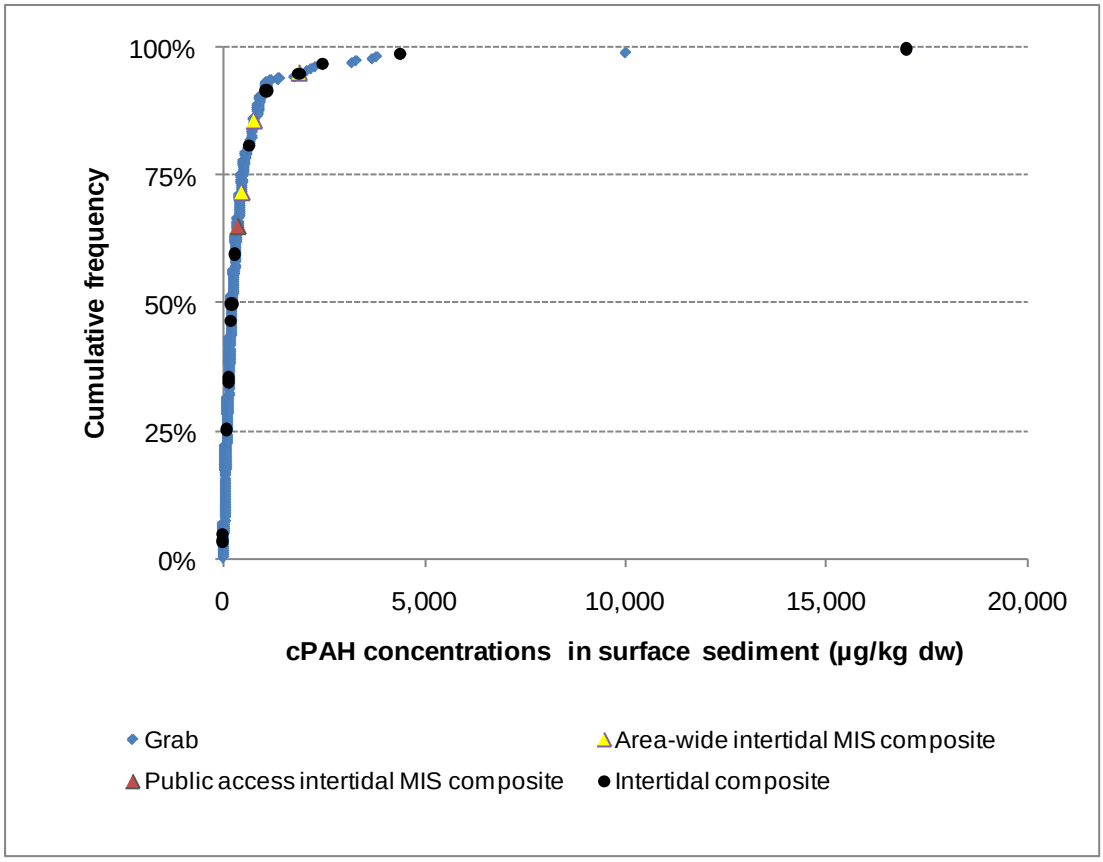


Figure 4-16
Cumulative Frequency of cPAH Concentrations in Surface Sediment

The maximum surface sediment cPAH concentration (10,000 µg TEQ/kg dw) was in a grab sample collected from the southeast side of the shallow main body near the historic Pier 24 location (Map 4-27). The numerical 95th percentile of cPAH concentrations in the surface sediment grab sample dataset was 1,200 µg TEQ/kg dw (Table 4-40), and the area-based 95th percentile calculated using IDW interpolation was 1,100 µg TEQ/kg dw (Table 4-40). Area-based and numerical percentiles were calculated for surface sediment cPAH concentrations, and the percentile values were found to be similar, which is consistent with well-distributed surface sediment samples throughout the EW, with no bias resulting from the more intensive sampling of areas with higher concentrations. Surface sediment cPAH concentrations were greater than the 95th percentile (1,200 µg TEQ/kg dw) at the head of Slip 27, Slip 36, south of Slip 36 near the former T-30/former GATX, and on southeast side of the shallow main body near the historic Pier 24 location (Map 4-28).

Table 4-40

Percentiles of cPAH Concentrations for Surface Sediment

Method	cPAH Concentration (µg TEQ/kg dw)[a]				
	Entire Dataset	25th Percentile	50th Percentile	75th Percentile	95th Percentile
Area-based	420 (SWAC)	120	230	440	1,100
Numerical[b]	440 (mean)	95	220	480	1,200

[a] Total cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as discussed in detail in Appendix D. If an individual PAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound. If none of the cPAH compounds were detected in a given sample, non-detect values represent the sum of one-half the RL multiplied by the PEF for each cPAH compound.

[b] Numerical percentiles were calculated using detected results and one-half the RL for non-detected results. Intertidal composite and MIS samples were not included in the calculation of numerical percentiles or in the calculation of the mean for the entire dataset. Data presented in this table were averaged by location (i.e., field duplicates were averaged to create a single result per sampling location).

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EW – East Waterway
RL – reporting limit
SWAC – spatially weighted average concentration

4.2.6.2 Subsurface Sediment

cPAHs were detected in 81% of the subsurface sediment samples, at concentrations that ranged from 15 to 23,000 µg TEQ/kg dw (Table 4-41). Most of the subsurface samples analyzed for cPAHs were from the top 4 ft of the sediment cores. Concentrations of cPAHs generally decreased with depth, with detected concentrations in samples collected entirely from within the lower alluvium unit ranging from 15 to 160 µg TEQ/kg dw.

Table 4-41

cPAH Concentrations in Subsurface Sediment

Sampling Interval (ft)	Detection Frequency[a]		cPAH Concentration (µg TEQ/kg dw)[b]		
	Ratio	%	Lowest Value	Highest Value	RL or Range of RLs[c]
All Data					
Any interval	218/269	81	15	23,000	4.1 – 120
2-ft Intervals					
0 – 2	77/90	86	19 J	16,000	14 – 17
2 – 4	63/88	72	15 J	23,000	14 – 120
4 – 6	4/8	50	29 J	1,300 J	4.1 – 17
6 – 8	6/8	75	15	3,600	17
8 – 10	3/6	50	71	220 J	14 – 16
> 10	6/7	86	23 J	310	16

Sampling Interval (ft)	Detection Frequency[a]		cPAH Concentration (µg TEQ/kg dw)[b]		
	Ratio	%	Lowest Value	Highest Value	RL or Range of RLs[c]
4-ft Intervals					
0 – 4	44/45	98	100	2,900 J	17
> 4	15/17	88	31	700 J	17

[a] A calculated cPAH result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated cPAH concentration was considered not detected.

[b] cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual cPAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

[c] RLs were calculated as equivalent cPAH values for samples with no detected cPAH compounds. RLs for non-detect values were calculated as the sum of one-half the RL multiplied by the PEF for each compound.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
J – estimated concentration
RL – reporting limit

4.2.6.3 cPAH Patterns in Surface and Subsurface Sediment Samples

cPAH concentrations in surface and subsurface sediment were evaluated to determine trends in distribution (Maps 4-29a through 4-29c). The percentiles of cPAH concentrations in sediment presented in this section were calculated on a numerical basis using the method described in Section 4.2. Subsurface sediment cPAH concentrations and interpolated surface sediment cPAH concentrations are presented on Maps 4-30a through 4-30c.

4.2.6.3.1 Junction/Sill Reach

Surface sediment cPAH concentrations in samples from the sill area under the bridges were greater than the numerical 75th percentile (480 TEQ µg/kg dw) (Map 4-30a). The subsurface core in this area with the highest cPAH concentrations was EW10-SC04 with cPAH concentrations above the 75th percentile in both the 0-to-2-ft interval and 2-to-4-ft interval.

4.2.6.3.2 Shallow Main Body

cPAH concentrations in surface and subsurface sediment samples from the shallow main body were generally less than the 95th percentile, with the highest surface and subsurface concentrations detected in samples collected off of the historic Pier 24 location near the Hinds CSO/SD. The highest cPAH subsurface sediment concentration (3,600 µg TEQ/kg dw) was in the 6-to-7.2-ft interval of EW10-SC09; the nearest surface sediment concentration (10,000 µg TEQ/kg dw in sample EW09-SS018) was higher than the subsurface concentration (Map 4-30a).

4.2.6.3.3 Deep Main Body

cPAH concentrations in the deep main body were generally less than the 50th percentile in the surface and subsurface sediments, particularly within the recently dredged areas. The three areas of the deep main body with elevated cPAH concentrations were both outside of the dredge areas.

Two cores in the southeastern Deep Main body, south of Slip 27 and near Hanford #2 CSO and two storm drains had cPAH concentrations above the 95th percentile (1,200 µg TEQ/kg dw) with concentrations of 1,900 µg TEQ/kg dw (S48) and 2,900 µg TEQ/kg dw (S50) in the 0-to4-ft intervals.

Four cores in the mound area outside of Slip 27 had cPAH concentrations above the numerical 95th percentile (Map 4-30a). The highest cPAH concentrations in these cores ranged from 1,500 to 16,000 µg TEQ/kg dw in the 0-to-2-ft interval of EW10-SB01 and EW10-SC29 and the 0-to-4-ft interval of S50 and S51. The surface sediment concentration in this area was above the numerical 75th percentile (480 ng TEQ/kg dw).

Surface and subsurface sediments collected south of Slip 36 near the former Rabanco barge loading facility and GATX (Maps 4-30c) had surface and subsurface cPAH concentrations greater than the numerical 95th percentile (1,200 µg TEQ/kg dw). The highest subsurface concentrations ranged from 4,600 to 7,200 µg TEQ/kg dw, with the exception of EW-159, which had a peak cPAH concentration of 23,000 µg TEQ/kg dw in the 1.5-to-2.5-ft interval (Map 4-30c). The surface sediment cPAH concentrations in this area generally exceeded the numerical 95th percentile (1,200 µg TEQ/kg dw) with a maximum concentration of 3,300 µg TEQ/kg dw.

4.2.6.3.4 Slip 27

Surface sediment cPAH concentrations were only greater than the numerical 95th percentile (1,200 ng/kg dw) in a small area at the head of Slip 27 (Map 4-30a). The maximum surface sediment concentration in this area was 2,200 µg TEQ/kg dw (EW-S27-9G). Subsurface concentrations above the 95th percentile were detected in the 0-to-4-ft interval of EW-S27-C, EW-S27-2C, EW-S27-3C, and EW-10-SC27. The highest cPAH concentration was detected in EW-S27-3C in the 3-to-3.5-ft interval sample (9,200 µg TEQ/kg dw).

4.2.6.3.5 Slip 36

The highest surface and subsurface sediment cPAH concentrations in Slip 36 were detected in samples collected from the area at the head of the slip, outside of the 2005 dredge area (Map 4-30c). The highest surface sediment cPAH concentration was 3,800 µg TEQ/kg dw (EW09-SS-215), and the highest subsurface sediment cPAH concentration was 4,800 µg TEQ/kg dw (in the 0-to-2-ft interval of EW10-SC58). Throughout the rest of the slip, subsurface sediment cPAH concentrations were generally lower than surface sediment interpolated cPAH concentrations, with the exception of the 0-to-2-ft interval of EW10-SC57, which had a cPAH concentration of 1,600 µg TEQ/kg dw.

4.2.6.4 Tissue

Table 4-42 presents the detection frequencies and ranges of cPAH concentrations in tissue. cPAHs were detected in all clam, geoduck, and benthic invertebrate samples and were frequently detected (67 to 94%) in fish whole-body, crab (all tissue types), and mussel whole body samples. Benthic invertebrate composite samples had the highest mean detected cPAH concentration (170 µg TEQ/kg ww), which reflects the fact that benthic invertebrates are poor metabolizers of cPAH relative to other organisms, such as fish and crab (Varanasi and Gmur 1980). Crab edible meat (0.60 µg TEQ/kg ww) and English sole fillet (0.29 µg TEQ/kg ww) composite samples had the two lowest mean detected cPAH concentrations. One English sole whole body composite sample cPAH concentration was higher (11 µg TEQ/kg ww) than the other six English sole whole body composite samples with detected cPAH concentrations (0.45 to 2.6 µg TEQ/kg ww). cPAHs were not detected in the coonstripe shrimp whole-body composite sample, individual brown rockfish whole-body composite samples, or juvenile Chinook salmon whole-body composite samples. RLs for cPAHs were slightly elevated (ranging from 29 to 300 µg TEQ/kg ww) in the following samples: one individual brown rockfish whole-body sample, one English sole whole-body composite sample, all six juvenile Chinook salmon whole-body composite samples, one mussel whole body composite sample, and the single coonstripe shrimp whole-body composite sample. These samples were analyzed by the SVOC method (EPA 8270) and did not have sufficient sample mass for the more sensitive PAH-specific analysis that was conducted with all other tissue samples.

Table 4-42
cPAH Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency[a]		cPAH Concentration (µg TEQ/kg ww)[b]				
	Ratio	%	Lowest Value	Highest Value	Calculated Median[c]	Calculated Mean[c]	RLs or Range of RLs[d]
Fish							
Brown rockfish, whole body	0/13	0	na	na	0.23	12 U	high res: 0.44 –0.67 (n=12) low res: 300 (n=1)
English sole, whole body	9/11	82	0.45 J	11	2.1	11	high res: 0.44 – 0.72 (n=10) low res: 180 (n=1)
Juvenile Chinook salmon, whole body	0/6	0	na	na	55	56 U	91 – 140
Shiner surfperch, whole body	6/8	75	0.76 J	2.2	0.96	1.2	1.0 – 3.3
English sole, fillet	3/11	27	0.32 J	0.42 J	0.24	0.29	0.44 – 0.67
Invertebrates							
Crab, whole body[e, f]	7/7	100	0.71 J	1.2 J	0.97	0.96	na
Crab, edible meat[f]	6/9	67	0.40 J	2.4 J	0.45	0.60	0.45
Crab, hepatopancreas[f]	7/7	100	0.96 J	2.4 J	1.3	1.3	na
Clam, whole body[g]	11/11	100	2.4	63	9.8	16	na
Mussel, whole body	16/17	94	3.8 J	110	13	20	29
Coonstripe shrimp, whole body	0/1	0	na	na	na	na	300
Geoduck clam, whole body[e]	4/4	100	2.1 J	4.1 J	3.0	3.1	na
Geoduck clam, edible meat[e]	6/6	100	0.99 J	2.8 J	1.5	1.6	na
Geoduck clam, gutball	3/3	100	6.3	11 J	7.2	8.2	na
Benthic invertebrates, whole body	13/13	100	45	420	120	170	na

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] A calculated cPAH result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated cPAH concentration was considered not detected.

[b] cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual cPAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound. If none of the cPAH compounds were detected in a given sample, non-detect values represent the sum of one-half the RL multiplied by the PEF for each cPAH compound.

[c] Calculated mean and median concentrations were based on detected concentrations and one-half the RL for non-detected results.

[d] RLs were calculated as the equivalent cPAH values for samples with no detected cPAH compounds. RLs for non-detect values were calculated as the sum of one-half the RL multiplied by the PEF for each compound. Where tissue samples were analyzed by both the high resolution and low resolution method the RLs and number of samples (n) are provided separately.

[e] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[f] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[g] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
J – estimated concentration
na – not applicable
PEF – potency equivalency factor
RL – reporting limit
ww – wet weight

The primary component of the cPAH concentration in tissue was benzo(a)pyrene, which accounted for an average of 56% of the carcinogenic potency of PAHs in tissue. Dibenzo(a,h)anthracene accounted for an average of 13% of the carcinogenic potency of PAHs in tissue. Benzo(a)anthracene and benzo(b)fluoranthene each accounted for an average of 10% of the carcinogenic potency of PAHs in tissue. The remaining three individual cPAHs each accounted for an average of 6% or less of the carcinogenic potency of PAHs.

4.2.6.5 Surface Water

At least one cPAH compound was detected in 4 of 59 surface water samples that were collected and analyzed for cPAHs during the five SRI surface water sampling events. Chrysene was detected in all four samples, and benz(a)anthracene was detected in one sample. The other five cPAH compounds (i.e., benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, and indeno(g,h,i)pyrene) were never detected. Detected concentrations of cPAHs in the four samples ranged from 0.0091 to 0.011 µg TEQ/L (Table 4-43). The highest detected cPAH concentration (0.011 µg TEQ/L) was from a water sample collected from 1 m below the water surface (i.e., upper water column) at location EW-SW-5 located in Slip 36 during a storm event in January 2009 (Map 4-7). The other three water samples with detected cPAH concentrations each had a concentration of 0.0091 µg TEQ/L. The TEQ values were calculated using one-half the RL for the non-detected cPAH compounds. Two of these water samples were collected from 1 m below the water surface (i.e., upper water column) at location EW-SW-6 during a storm event in January 2009 and during a monitoring event in February 2009 at location EW-SW-1 (Map 4-7). The third sample with a detected cPAH concentration of 0.0091 µg TEQ/L was

collected from 1 m above the sediment surface (lower water column) at location EW-SW-5 during a monitoring event in December 2008 (Map 4-7).

Table 4-43

cPAH Concentrations in Surface Water

Detection Frequency[a]		cPAH Concentration (µg TEQ/L)[b]				
Ratio	%	Lowest Value	Highest Value	Calculated Median[c]	Calculated Mean[d]	Range of RLs[e]
4/59	6.8	0.0091	0.011	0.0046	0.038	0.0091 – 0.50[f]

[a] A calculated cPAH result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated cPAH concentration was considered not detected.

[b] cPAHs were calculated by summing the products of individual cPAH concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual cPAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound. If none of the cPAH compounds were detected in a given sample, non-detect values represent the sum of one-half the RL multiplied by the PEF for each cPAH compound.

[c] The calculated median concentration is the average of detected concentrations and one-half the RL for non-detected results.

[d] The calculated mean concentration is higher than the maximum detected value because of the calculation included non-detected values at half the RL.

[e] RLs were calculated as equivalent cPAH values for samples with no detected cPAH compounds. RLs for non-detected values were calculated as the sum of one-half the RL multiplied by the PEF for each compound.

[f] The high RLs reflects elevated RLs for benzo(a)pyrene in a subset of samples (n = 2).

cPAH – carcinogenic polycyclic aromatic hydrocarbon
PEF – potency equivalency factor
RL – reporting limit
TEF – toxic equivalency factor

4.2.6.6 Summary of cPAH Data

cPAH concentrations in surface sediment grab samples ranged from 15 to 10,000 µg TEQ/kg dw; the area-based 95th percentile was 1,100 µg TEQ/kg dw. Areas with sediment cPAH concentrations greater than the area-based 95th percentile were Slip 36, the area just outside of and to the south of Slip 36, just outside and at the head of Slip 27, and the south eastern corner of the shallow main body (historic Pier 24 location near the Hinds CSO/SD). Throughout the EW, surface and subsurface sediment cPAH concentrations from the same areas were generally similar. The only area in which subsurface sediment cPAH concentrations were higher than surface sediment cPAH concentrations was the mound area outside of Slip 27.

For tissue, benthic invertebrate composite samples had the highest mean cPAH concentration (170 µg TEQ/kg ww), and English sole fillet composite samples had the lowest

mean cPAH concentration (0.29 µg TEQ/kg ww). cPAHs were not detected in the single shrimp whole-body composite sample, individual rockfish whole-body samples, or juvenile Chinook salmon whole-body composite samples. However, RLs were elevated in the shrimp and juvenile Chinook salmon samples because of the reduced sensitivity of the analytical method used for the analysis of these samples.

cPAHs were infrequently detected in surface water samples (4 out of 59 samples). cPAH concentrations in surface water ranged from 0.0091 to 0.011 µg TEQ/L.

4.2.7 Arsenic

This section summarizes the nature and extent of arsenic concentrations in surface sediment, subsurface sediment, tissue, and surface water samples. Arsenic exposures in the HHRA and ERA were evaluated using sediment and tissue arsenic concentrations. Porewater samples collected from the EW were not analyzed for arsenic; however, porewater arsenic is included as a component of bulk sediment concentrations.

4.2.7.1 Surface Sediment

Total arsenic was analyzed in 231 surface sediment grab samples.[64] All four of the intertidal MIS composite samples collected were also analyzed for total arsenic. Arsenic was detected in 70% of the surface sediment grab samples analyzed for arsenic, with concentrations ranging from 2.3 to 241 mg/kg dw and a mean concentration of 9.0 mg/kg dw (Table 4-44). Arsenic was detected in 100% of the intertidal MIS composite samples, with concentrations ranging from 7.9 to 13.3 mg/kg dw for the area-wide intertidal MIS composite (Table 4-44). The public access intertidal MIS composite had a total arsenic concentration of 7.7 mg/kg dw.

[64] Fifteen of the 231surface sediment grab samples were field duplicates; 216unique sampling locations had surface sediment grab samples analyzed for total arsenic.

Table 4-44

Total Arsenic Concentrations in Surface Sediment

Sample Type	Detection Frequency		Total Arsenic Concentration (mg/kg dw)					SQS	CSL
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]		
Grab	162/231	70	2.3	241	6.2	9.0	5 – 20	57	93
Area-wide intertidal MIS composite	3/3	100	7.9	13.3	9.1	10	na	57	93
Public access intertidal MIS	1/1	100	7.7	7.7	na	na	na	57	93

[a] Calculated mean and median concentration is the mean of detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

[b] RLs are based only on non-detect samples.

CSL – cleanup screening level
dw – dry weight
MIS – multi-increment sampling
na – not applicable
RL – reporting limit
SQS – sediment quality standards

Percentiles calculated on an area-basis using IDW interpolation were similar to those calculated on a numerical basis (Table 4-45), which is consistent with well-distributed surface sediment samples throughout the EW with no spatial bias. The concentration range between the 25th and 75th percentile were narrow for both the area-based and numerical percentiles and ranged from 4.0 to10 mg/kg dw. Both the numerical and area-based 95th percentiles of arsenic in surface sediment were 17 mg/kg dw (Table 4-45). Because the percentile values were so similar to one another, percentiles were not used to map the sediment concentrations (Maps 4-31, 4-32, 4-33).

Table 4-45

Percentiles of Arsenic Concentrations in Surface Sediment

Method	Arsenic Concentration (mg/kg dw)				
	Entire Dataset	25th Percentile	50th Percentile	75th Percentile	95th Percentile
Area-based	8.8 (SWAC)	4.0	6.5	10	17
Numerical[a]	9.3 (mean)	4.0	6.2	10	17

[a] Numerical percentiles were calculated using detected results and one-half the RL for non-detected results. Intertidal MIS composite samples were not included in the calculation of numerical percentiles or in the calculation of the mean for the entire dataset. Data presented in this table were averaged by location (i.e., field duplicates were averaged to create a single result per sampling location).

dw – dry weight
EW – East Waterway
RL – reporting limit
SWAC – spatially weighted average concentration

MIS – multi-increment samples

The two highest surface sediment arsenic concentrations (163 mg/kg and 241 mg/kg) were detected in samples collected from locations along the shoreline just south of Slip 36 (Map 4-31). These locations are the only two locations in the EW with arsenic concentrations above the CSL (Figure 4-17; Map 4-31). No samples had arsenic concentrations that exceeded the SQS but were less than CSL (Figure 4-17). In general, surface sediment arsenic concentrations in the deep main body of EWwere less than 7 mg/kg dw (Map 4-32). The surface sediment arsenic concentrations in the shallow main body, the slips, and the area off of the former GATX facility were generally greater than 7 mg/kg dw (Map 4-32).

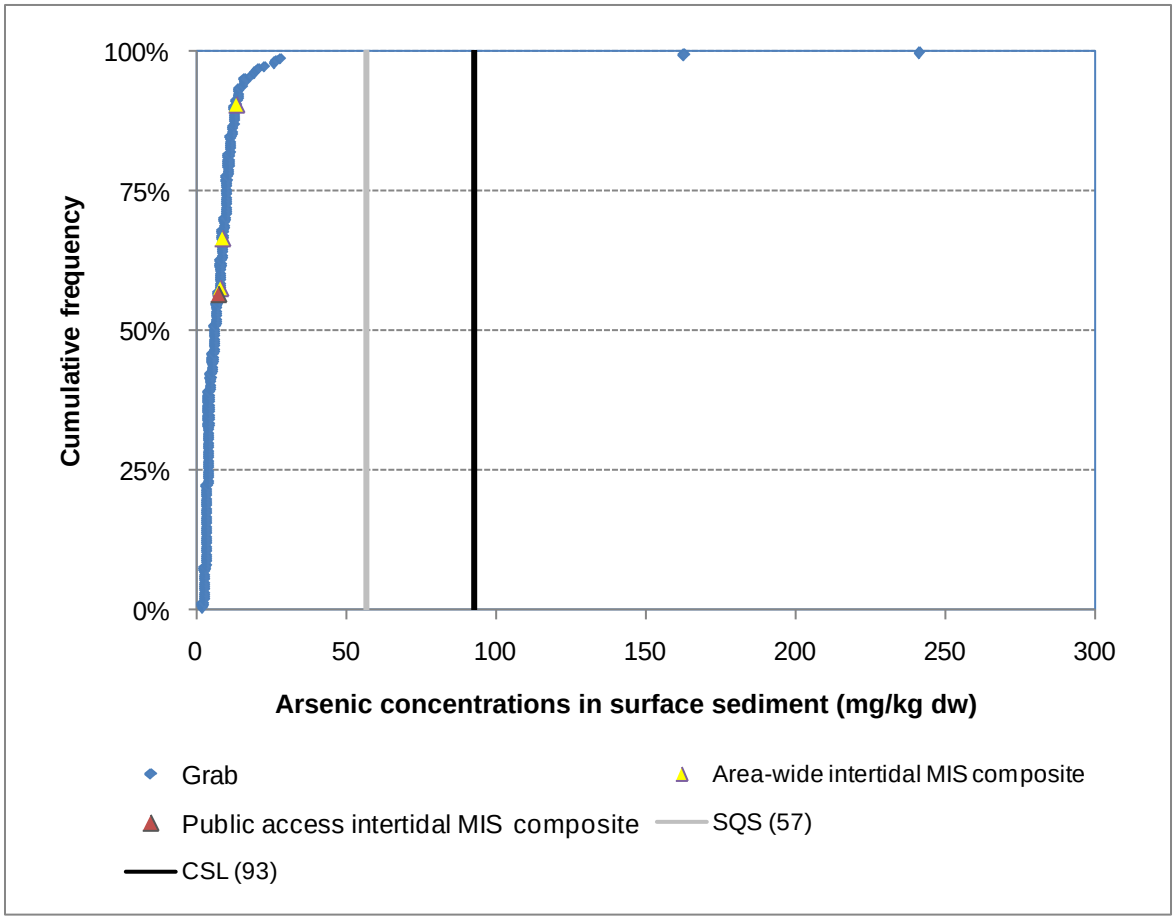


Figure 4-17

Cumulative Frequency of Arsenic Concentrations in Surface Sediment

4.2.7.2 Subsurface Sediment

Arsenic was detected in 98% of the subsurface sediment samples at concentrations that ranged from 1.2 to 96 mg/kg dw (Table 4-46). Most of the subsurface sediment samples analyzed for arsenic were from the top 4 ft of the sediment core. One subsurface sediment sample had an arsenic concentration that exceeded the CSL. The sample (EW 159-01) was located in the vicinity of the former Rabanco barge loading facility and GATX. Arsenic was detected in all 30 subsurface sediment samples collected entirely from within the lower alluvium unit, with concentrations ranging from 1.4 to 9.0 mg/kg dw. Highest concentrations were detected in the upper 4 ft.

Table 4-46
Total Arsenic Concentrations in Subsurface Sediment

Sampling Interval (ft)	Detection Frequency		Total Arsenic Concentration (mg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	RL or Range of RLs[a]
All Data					
Any interval	250/255	98	1.2	**96**	0.3 – 7.0
2-ft Intervals					
0 – 2	89/90	99	1.8	**96**	7.0
2 – 4	85/88	97	1.4	35.8	6.0 – 7.0
4 – 6	2/2	100	7.8	11.5	na
6 – 8	2/2	100	1.5	8.4	na
8 – 10	3/4	75	3.5	5.7	0.3
> 10	5/5	100	3.1	5.6	na
4-ft Intervals					
0 – 4	47/47	100	1.7	31	na
> 4	17/17	100	1.2	11	na

[a] RLs are based only on non-detect samples.
dw – dry weight
na – not applicable
RL – reporting limit
Bold underline identifies concentrations greater than the CSL (93 mg/kg dw).

4.2.7.3 Arsenic Patterns in Surface and Subsurface Sediment Samples

Arsenic concentrations in surface and subsurface sediment were evaluated to assess patterns (Maps 4-34a through 4-34c). Subsurface sediment arsenic concentrations and interpolated surface sediment arsenic concentrations are presented on Maps 4-35a through 4-35c.

4.2.7.3.1 Junction/Sill Reach

Most surface sediment concentrations were below 7 mg/kg dw in this area. Only two samples in this area had surface sediment arsenic concentrations greater than the 15 mg/kg dw (Map 4-35a). Surface sediment concentrations in nearby core (EW10-SC03) were 13.2 mg/kg dw in the 0-to-2-ft interval. On the east side of the sill, the highest arsenic concentration was 18.6 mg/kg dw (in the 0-to-2-ft interval of EW10-SC04).

4.2.7.3.2 Shallow Main Body

In the shallow main body, the interpolated surface sediment concentrations in this area were between 7 mg/kg dw and 15 mg/kg dw. The highest subsurface sediment arsenic concentrations were in the 0-to-2- and 2-to-4-ft intervals of cores EW10-SC08, EW10-SC09, and EW10-SC10, with concentrations ranging from 18.5 to 22.5 mg/kg dw. Although very few samples from intervals below 4 ft were analyzed for arsenic, arsenic concentrations in samples from the > 4-ft interval of seven cores collected from the shallow main body were all less than the 7mg/kg dw (Map 4-35b). In general, the surface sediment arsenic concentrations in the shallow main body were less than the subsurface sediment arsenic concentrations in the 0-to-4-ft sediment interval.

4.2.7.3.3 Deep Main Body

The surface and subsurface sediment arsenic concentrations in the deep main body were generally less than 7 mg/kg dw in the areas that have been recently dredged (Maps 4-35a and 4-35c). Outside of the dredged areas, three areas with sediment arsenic concentrations above 7 mg/kg dw were the mound area outside of Slip 27, T-18 between Stations 3500 and 3900, and the area south of Slip 36 near the former Rabanco barge loading facility and GATX.

In the mound area outside of Slip 27, subsurface sediment arsenic concentrations were generally greater than interpolated surface sediment concentrations (Map 4-35a). Subsurface sediment arsenic concentrations in the 0-to-2-, 2-to-4- and 1-to-4-ft intervals were greater than the 15 mg/kg dw. Interpolated surface sediment concentrations in the mound area were greater than 7 mg/kg dw) and less than the 15 mg/kg dw.

One surface sediment sample located along T-18 between Stations 3500 and 3900 was greater than 15 mg/kg dw. There are no subsurface sediment cores in the vicinity of this location.

Surface and subsurface sediment samples collected from the area south of Slip 36 near the former Rabanco barge loading facility and GATX had arsenic concentrations that were greater than 15mg/kg dw, with two of the surface sediment concentrations exceeding the CSL (93 mg/kg dw) (Map 4-35c). Surface sediment sample EW-110 had the highest arsenic concentration in the EW (241 mg/kg dw). Arsenic concentrations in five of the six cores from this area were above 15 mg/kg dw in the samples collected within the 0-to-4-ft sediment interval. The 0.5-to-1.5ft interval of EW-159 had the highest subsurface sediment arsenic concentration in EW (96 mg/kg dw).

4.2.7.3.4 Slip 27

Subsurface sediment arsenic concentrations within Slip 27 were consistently higher than interpolated surface sediment concentrations (Map 4-35a). The highest concentrations were associated with the 2-to-4-ft interval in EW-S27-3C (35.8 mg/kg dw) and EW10-SC27 (31.9 mg/kg dw). Surface sediment concentrations were generally less than 15 mg/kg dw in this area.

4.2.7.3.5 Slip 36

Surface and subsurface sediment arsenic concentrations in Slip 36 were highest at the head of the slip, with surface sediment concentrations of 26.2 and 27.0 mg/kg dw and a peak subsurface sediment concentration of 56.7 mg/kg dw (in the 0-to-2-ft interval of EW10-SC58) (Map 4-35c).

4.2.7.4 Tissue

Total arsenic was detected in all tissue samples that were analyzed for arsenic (Table 4-47). The mean total arsenic concentration was highest in English sole fillet composite samples (5.24 mg/kg ww). However, mean total arsenic concentrations were similar in English sole (both whole-body and fillet), crab (whole body, edible meat, and hepatopancreas), Coonstripe shrimp (whole-body), and benthic invertebrate composite samples, with mean concentrations that ranged from 3.52 to 5.24 mg/kg ww. Other fish (i.e., brown rockfish, juvenile Chinook salmon, and shiner surfperch), clam (including geoduck), and mussel composite samples had mean total arsenic concentrations that ranged from 0.441 to 2.12 mg/kg ww.

Table 4-47

Total Arsenic Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency		Total Arsenic Concentration (mg/kg ww)			
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median	Calculated Mean
Fish						
Brown rockfish, whole body	13/13	100	0.531 J	1.24 J	0.831	0.847
English sole, whole body	11/11	100	2.97 J	4.18 J	3.42	3.52
Juvenile Chinook salmon, whole body	6/6	100	0.203	0.552	0.482	0.441
Shiner surfperch, whole body	8/8	100	0.493 J	1.24 J	1.15	1.07
English sole, fillet	11/11	100	3.43 J	8.23 J	5.14	5.24
Invertebrates						
Crab, whole body[a,b]	9/9	100	3.78 J	6.81 J	4.43	4.64
Crab, edible meat[c]	9/9	100	4.33 J	7.30 J	4.79	5.05
Crab, hepatopancreas[b]	9/9	100	2.93 J	6.04 J	3.90	3.99
Clam, whole body[c,d]	12/12	100	0.916 J	2.83 J	2.03	1.97
Mussel, whole body[d]	17/17	100	0.616 J	1.85 J	0.871	0.936
Coonstripe shrimp, whole body	1/1	100	4.42	4.42	na	na
Geoduck clam, whole body[b]	4/4	100	1.15 J	1.38 J	1.25	1.26
Geoduck clam, edible meat	6/6	100	0.950 J	1.29 J	1.04	1.08
Geoduck clam, gutball	3/3	100	1.79 J	2.73 J	1.84	2.12
Benthic invertebrates, whole body	13/13	100	2.61	7.67	4.04	4.12

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[b] Two species of crab (red rock and one Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[c] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[d] The clam and mussel whole body samples include all soft tissues. Shells were not included in these samples.

J – estimated concentration
RL – reporting limit
na – not applicable
ww – wet weight

Inorganic arsenic is the most toxic form of arsenic to humans and is a known carcinogen, so a subset of tissue types, those consumed by humans (i.e., fish, crab, clam, mussel, and geoduck tissue), were analyzed for inorganic arsenic (Table 4-48). The concentration patterns of inorganic arsenic were different than those of total arsenic, with the highest mean inorganic

arsenic concentration (0.166 mg/kg ww) detected in clam whole body composite samples. Inorganic arsenic was not detected in any English sole fillet samples; mean concentrations for all other tissue types ranged from 0.008 to 0.087 mg/kg ww.

Table 4-48

Inorganic Arsenic Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency		Inorganic Arsenic Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	Range of RLs[b]
Fish							
Brown rockfish, whole body	13/13	100	0.004 J	0.023 J	0.007	0.008	na
English sole, whole body	11/11	100	0.023 J	0.059 J	0.031	0.032	na
Shiner surfperch, whole body	8/8	100	0.012 J	0.037 J	0.022	0.021	na
English sole, fillet	0/11	0	na	na	0.005	0.005 U	0.007 – 0.009
Invertebrates							
Crab, whole body[c, d]	9/9	100	0.031 J	0.057 J	0.042	0.042	na
Crab, edible meat[d]	9/9	100	0.020 J	0.043 J	0.033	0.032	na
Crab, hepatopancreas[d]	9/9	100	0.038 J	0.089 J	0.055	0.058	na
Clam, whole body[e,f]	12/12	100	0.074 J	0.443	0.148	0.166	na
Mussel, whole body[f]	11/11	100	0.040 J	0.133 J	0.068	0.078	na
Geoduck clam, whole body[c]	4/4	100	0.027 J	0.049 J	0.035	0.036	na
Geoduck clam, edible meat	6/6	100	0.012 J	0.063 J	0.024	0.029	na
Geoduck clam, gutball	3/3	100	0.075 J	0.110 J	0.075	0.087	na

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[b] RLs are based only on non-detect samples.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[d] Two species of crab (red rock and one Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[e] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[f] The clam and mussel whole body samples include all soft tissues. Shells were not included in these samples.

J – estimated concentration
na – not applicable
RL – reporting limit
ww – wet weight

The amount of inorganic arsenic in fish, crab, intertidal clam, mussel, and geoduck samples as a percentage of total arsenic is presented in Table 4-49 and shown in Figure 4-18. The mean percentage of inorganic relative to total arsenic ranged from 0.095 to 4.3% in fish, crab, and geoduck samples. The mean percentage of inorganic arsenic relative to total arsenic in mussel whole body composite samples (9.1%) was similar to that in intertidal clam whole body composite samples (11%). However, the percentage of inorganic relative to total arsenic was less variable across composite mussels samples than across composite intertidal clam samples (i.e., the maximum percentage was 16% in mussels and 47% in clams). The percentage of inorganic arsenic for each clam species were calculated and are discussed subsequently.

Table 4-49

Inorganic Arsenic as a Percentage of Total Arsenic for Fish and Invertebrate Tissues

Tissue Type	No. of Samples[a]	Inorganic Arsenic as a Percentage of Total Arsenic		
		Minimum (%)	Maximum (%)	Mean (%)
Fish				
Brown rockfish, whole body	13	0.65	2.1	0.98
English sole, whole body	11	0.59	1.6	0.92
Shiner surfperch, whole body	8	1.0	3.2	2.0
English sole, fillet[b]	11	0.058	0.15	0.095
Invertebrates				
Crab, whole body[c, d]	9	0.65	1.3	0.93
Crab, edible meat[d]	9	0.43	0.83	0.64
Crab, hepatopancreas[d]	9	0.76	2.2	1.5
Clam, whole body[e,f]	12	3.4	47	11
Mussel, whole body[f]	11	4.5	16	9.1
Geoduck clam, whole body[c]	4	2.0	4.3	3.0
Geoduck clam, edible meat	6	1.3	4.9	2.6
Geoduck clam, gutball	3	2.7	6.1	4.3

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] The sample number includes only those samples with both inorganic and total arsenic results.

[b] One-half the RL was used for the inorganic arsenic results because inorganic arsenic was not detected in any of the English sole fillet samples.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[d] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[e] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[f] The clam and mussel whole body samples include all soft tissues. Shells were not included in these samples.

EW – East Waterway

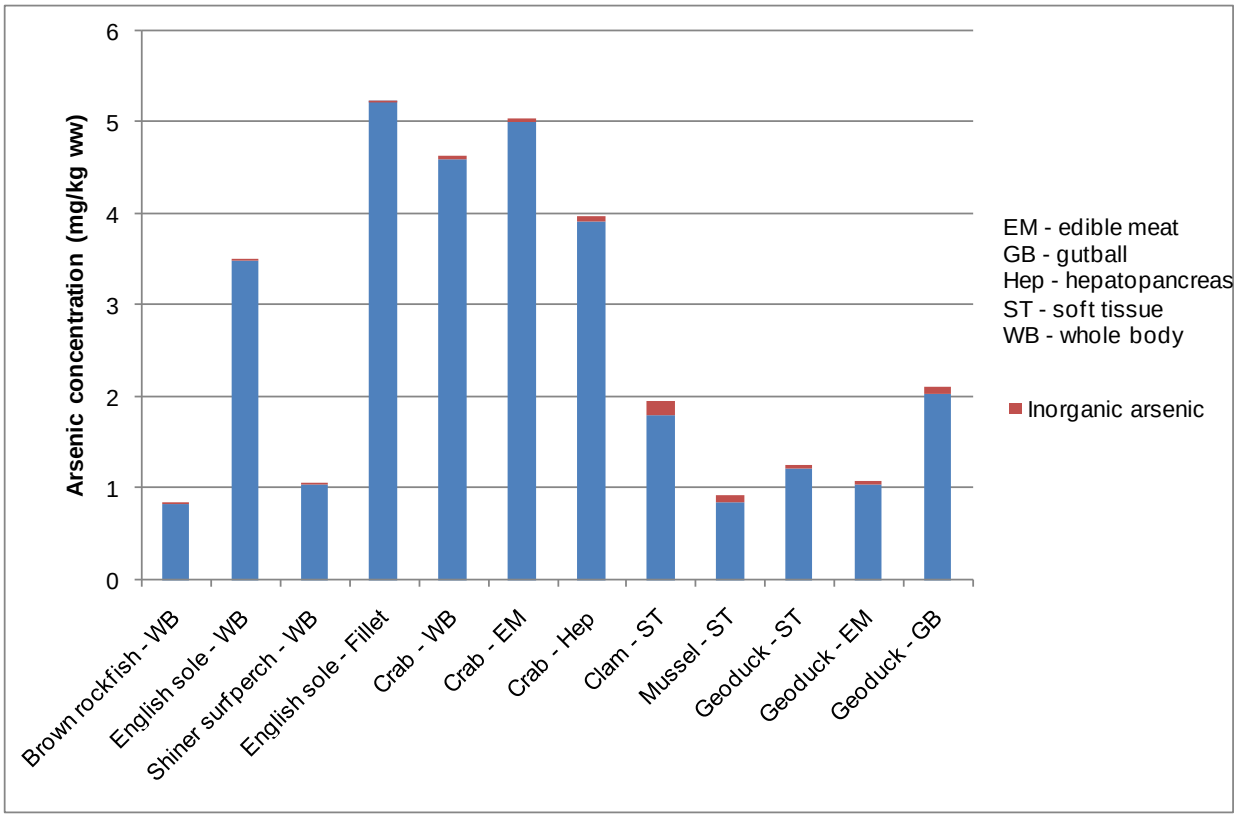


Figure 4-18
Inorganic Arsenic and Total Arsenic Concentrations in Tissue

The Eastern soft-shell clam (*Mya arenaria*) composite sample from the east side of the Junction Reach near T-104 (Map 4-5) had the maximum percentage of inorganic arsenic relative to total arsenic (47%) as shown in Table 4-50 and Figure 4-19.[65] The percentage of inorganic relative to total arsenic in the two cockle clam (*Clinocardium nuttali*) composite samples (18 and 22%) from the south end of the EW, underneath the West Seattle and Spokane Street Bridges on the east and west side of the sill, were approximately half that of the Eastern soft-shell clam composite sample (47%). Two native little neck clam composite

[65] Eastern soft-shell clams were only found in this one small area in EW. By comparison, this is the predominant clam of harvestable size in the LDW.

samples (*Protothaca staminea*) from the same locations as the cockle clam composite samples had relatively lower percentages of inorganic relative to total arsenic (6.1 and 8.5%). Butter clams (*Saxidomus giganteus*), which were collected at four locations throughout EW, had the lowest percentages of inorganic arsenic to total arsenic, which ranged from 3.4 to 7.1%.

Table 4-50
Inorganic Arsenic as a Percentage of Total Arsenic for Intertidal Clam Composite Tissues

Clam Species	No. of Composite Samples	Inorganic Arsenic as a Percentage of Total Arsenic		
		Minimum (%)	Maximum (%)	Mean (%)
Butter clam	7	3.4	7.1	5.0
Cockle clam	2	18	22	20
Eastern soft-shell clam	1	47	47	na
Native little neck clam	2	6.1	8.5	7.3

EW – East Waterway
na – not applicable

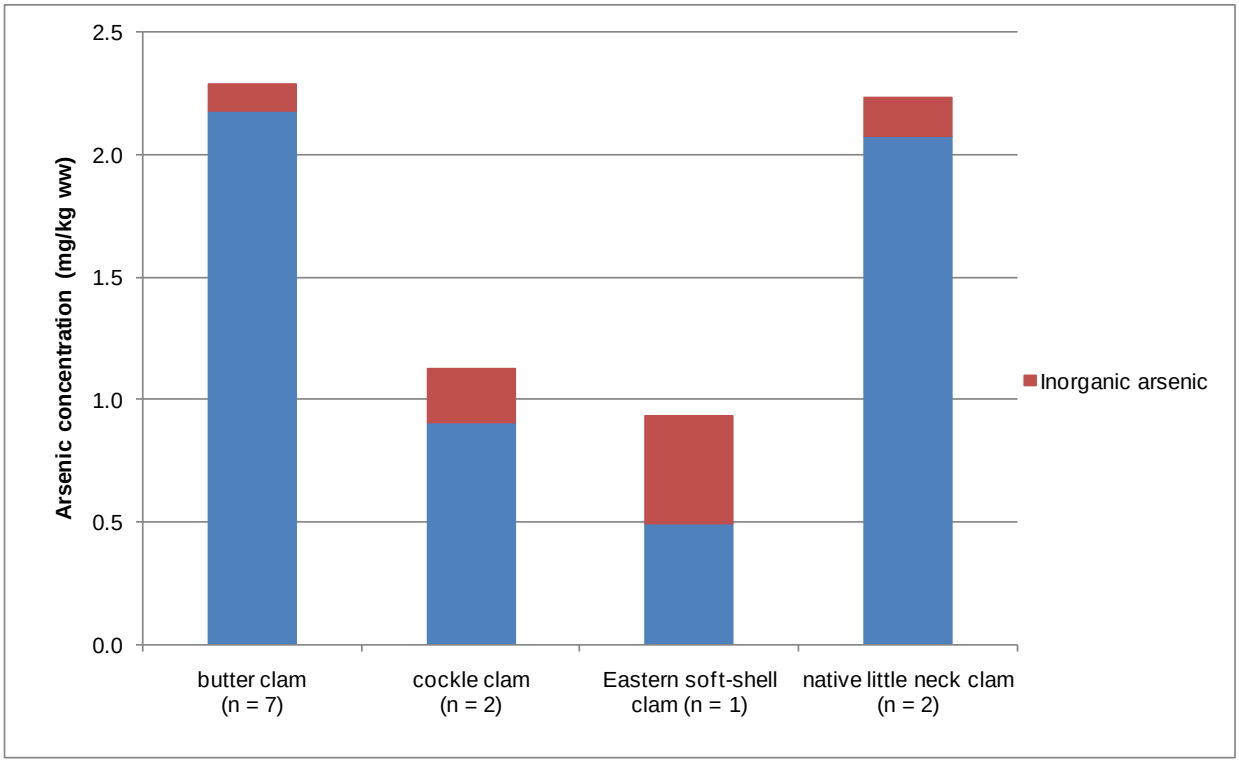


Figure 4-19
Inorganic Arsenic Concentrations and Total Arsenic Concentrations for Intertidal Clam Composite Tissue Samples

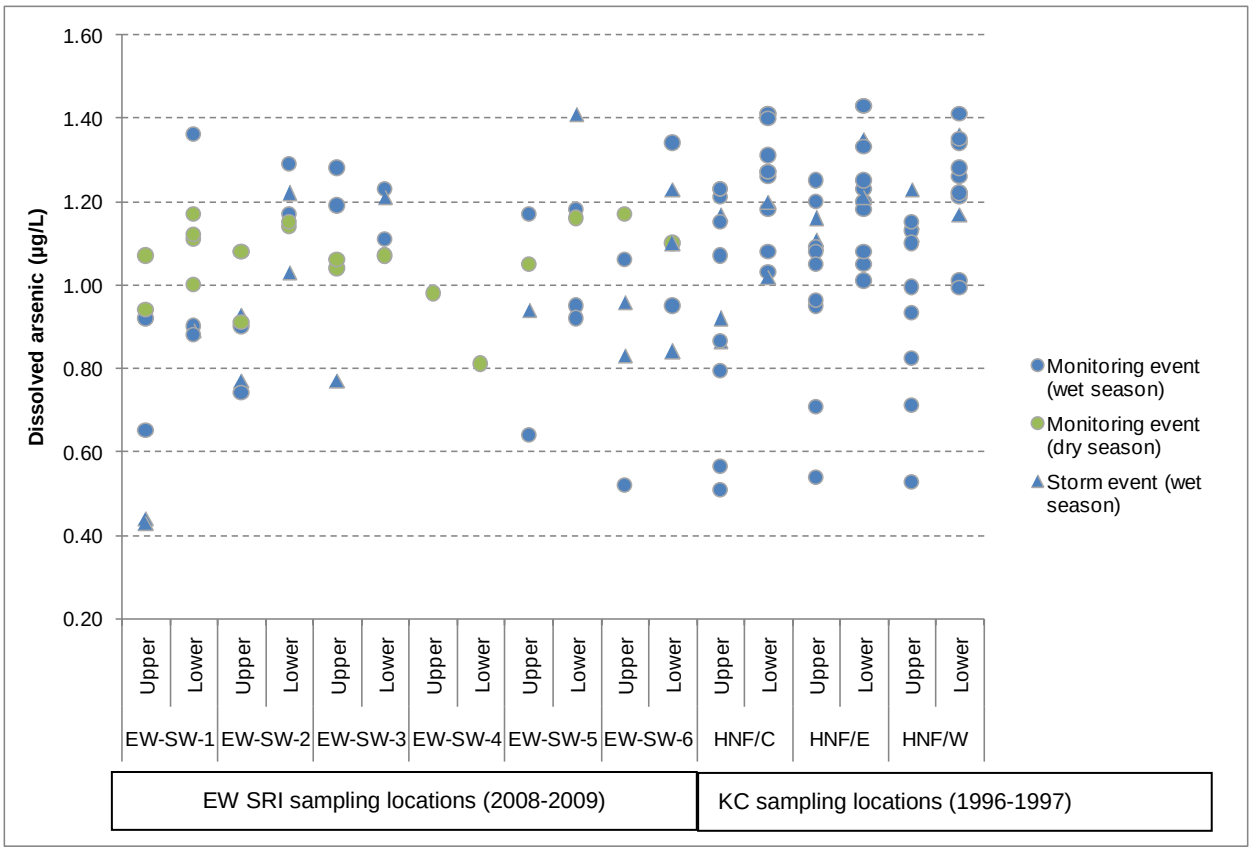
4.2.7.5 *Surface Water*

Arsenic was detected in every surface water sample collected and analyzed for either dissolved or total arsenic during the King County WQA and SRI sampling events. The results for both sampling events are compared in Appendix A, Attachment 1. The arsenic concentrations in the two datasets were consistent. Detected concentrations of dissolved arsenic ranged from 0.43 to 1.43 µg/L, and detected concentrations of total arsenic ranged from 0.23 to 1.89 (Table 4-51). The total and dissolved arsenic concentrations were generally consistent across the two datasets. Figure 4-20 shows the range of dissolved arsenic concentrations for each surface water sampling location at two depths. The dissolved arsenic concentrations are fairly consistent across sampling locations and sampling events. The calculated mean concentration for both dissolved arsenic and total arsenic was 1.1 µg/L. Arsenic concentrations in surface water samples are compared with WQC in Section 4.2.2 (Table 4-21). All surface water arsenic concentrations were below the state and federal marine WQC for the protection of aquatic life.

Table 4-51
Arsenic Concentrations in Surface Water

Chemical	Detection Frequency		Concentration (µg/L)			
	Ratio	%	Lowest Value	Highest Value	Calculated Median	Calculated Mean
Arsenic (dissolved)	130/130	100	0.43	1.43	1.10	1.1
Arsenic (total)	227/227	100	0.23	1.89	1.16	1.1

Note: State and federal marine WQC for the protection of aquatic life are 36 µg/L (chronic) and 69 µg/L (acute) for dissolved arsenic.
WQC – water quality criteria



Note: Upper water column samples were collected from 1 m below the water surface. Lower water column samples were collected from 1 m above the sediment surface. Sampling locations are shown on Map 4-7.

Figure 4-20

Detected Dissolved Arsenic Concentrations in Surface Water for Each Sampling Location

4.2.7.6 Summary of Arsenic Data

Arsenic concentrations in surface sediment ranged from 2.3 to 241 mg/kg dw; the area-based 95th and 50th percentile concentrations were 17 and 6.5 mg/kg dw, respectively. The highest surface sediment arsenic concentrations were just south of Slip 36. Arsenic concentrations exceeded the CSL in surface sediment samples from only two locations south of Slip 36. No surface sediment samples had arsenic concentrations between the SQS and the CSL. Throughout the EW, surface and subsurface sediment arsenic concentrations from the same area were generally similar. Two areas with subsurface arsenic concentrations that were generally higher than the surface sediment arsenic concentrations were the mound area outside Slip 27 and the head of Slip 27. The range of sediment arsenic concentrations throughout EW was narrow relative to other contaminants as evidenced by the range between the 25th and 75th percentile values (4.0 to 10 mg/kg dw).

Arsenic was detected in all tissue samples. Mean total arsenic concentrations across tissue types ranged from 0.441 to 5.24 mg/kg ww, with the highest mean concentration in English sole fillet composite samples. The mean percentage of inorganic arsenic relative to total arsenic in various tissue types ranged from 0.095 to 11%, with the highest percentage in clam whole body composite samples.

Arsenic was detected in 100% of the surface water samples. Dissolved arsenic concentrations ranged from 0.43 to 1.43 µg/L (mean of 1.1 µg/L), and total arsenic concentrations ranged from 0.23 to 1.89 (mean of 1.1 µg/L).

4.2.8 Mercury

This section summarizes the nature and extent of mercury concentrations in surface sediment, subsurface sediment, tissue, and surface water samples Mercury exposure in the HHRA and ERA was evaluated using sediment, tissue, and surface water mercury concentrations. Porewater samples collected in the EW were not analyzed for mercury. However, porewater mercury is a component of bulk sediment concentrations.

4.2.8.1 Surface Sediment

Total mercury was analyzed in 239 surface sediment grab samples.[66] All four of the intertidal MIS composite samples were also analyzed for total mercury. Mercury was detected in 98% of the surface sediment grab samples analyzed for mercury, with concentrations ranging from 0.02 to 1.07 mg/kg dw and a mean concentrations of 0.30 mg/kg dw (Table 4-52). Mercury was detected in 100% of the MIS composite samples, with concentrations ranging from 0.06 to 0.10 mg/kg dw in the area-wide intertidal MIS composite samples (Table 4-52). The public access intertidal MIS composite sample had a mercury concentration of 0.08 mg/kg dw.

[66] Fifteen of the 239 surface sediment grab samples were field duplicates; 224 unique sample locations had surface sediment grab samples analyzed for total mercury.

Table 4-52

Mercury Concentrations in Surface Sediment

Sample Type	Detection Frequency		Mercury Concentration (mg/kg dw)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Grab	233/239	98	0.02 J	**1.07 J**	0.24	0.30	0.04 – 0.070
Area-wide intertidal MIS composite	3/3	100	0.06	0.10	0.08	0.08	na
Public access intertidal MIS composite	1/1	100	0.08	0.08	na	na	na

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

[b] RLs are based only on non-detect samples.

CSL – cleanup screening level
dw – dry weight
J – estimated concentration
MIS – multi-increment sampling
na – not applicable
RL – reporting limit

Underlined bold identifies concentrations that exceed the CSL (0.59 mg/kg dw).

The numerical 95th percentile of mercury in the surface sediment dataset was 0.59 mg/kg dw (Table 4-53). The area-based 95th percentile calculated using IDW interpolation was 0.54 mg/kg dw (Table 4-53). Surface sediment mercury concentrations are shown on Map 4-36, and the results of the IDW interpolation for mercury are shown on Map 4-37. Area-based and numerical percentiles were calculated for surface sediment mercury concentrations, and the percentile values were found to be similar, which is consistent with well-distributed surface sediment samples throughout the EW, with no bias resulting from the more intensive sampling of areas with higher concentrations.

Table 4-53

Percentiles of Mercury Concentrations for Surface Sediment

Method	Concentration (mg/kg dw)				
	Entire Dataset	25th Percentile	50th Percentile	75th Percentile	95th Percentile
Area-based	0.28 (SWAC)	0.14	0.26	0.40	0.54
Numerical[a]	0.27 (mean)	0.12	0.24	0.37	0.59

[a] Numerical percentiles were calculated using detected results and one-half the RL for non-detected results. Intertidal MIS composite samples were not included in the calculation of numerical percentiles or in the calculation of the mean for the entire dataset. Data presented in this table were averaged by location (i.e., field duplicates were averaged to create a single result per sampling location).

dw – dry weight

EW – East Waterway
RL – reporting limit
SWAC – spatially weighted average concentration

Surface sediment grab samples with mercury concentrations above 95th percentile, including the two highest concentrations, were collected from four locations within 600 ft of one another in the deep main channel between Station 3400 and Station 2800 (Maps 4-37 and 4-38). Five other samples throughout the waterway had surface sediment mercury concentrations greater than the numerical 95th percentile (0.59 mg/kg dw) (Maps 4-36 and 4-37). Mercury concentrations in the intertidal MIS composite samples were all below the numerical 25th percentile.

Mercury concentrations exceeded the SQS but not the CSL in 36 surface sediment grab samples (representing 34 sampling locations) and exceeded the CSL in 10 surface sediment grab samples (representing 9 sampling locations) (Map 4-38; Figure 4-21).[67] The locations with mercury concentrations that exceeded the CSL (Map 4-38) were the same locations with mercury concentrations above the 95th percentile (Map 4-36). Surface sediment samples with mercury concentrations above the SQS were located between Station 5600 and Station 4800 (10 sampling locations), near the mouth and within Slip 27 (10 sampling locations), near two outfalls along T-30 (Station 3200), in the deep main channel between Station 3000 and Station 1600 (9 sampling locations), and south of Slip 36 near the former Rabanco barge loading facility and GATX (4 sampling locations) (Map 4-38).

[67] Two of the surface sediment grab samples that exceeded the SQS but not the CSL were field duplicates. One surface sediment grab sampled that exceeded the CSL was a field duplicate.

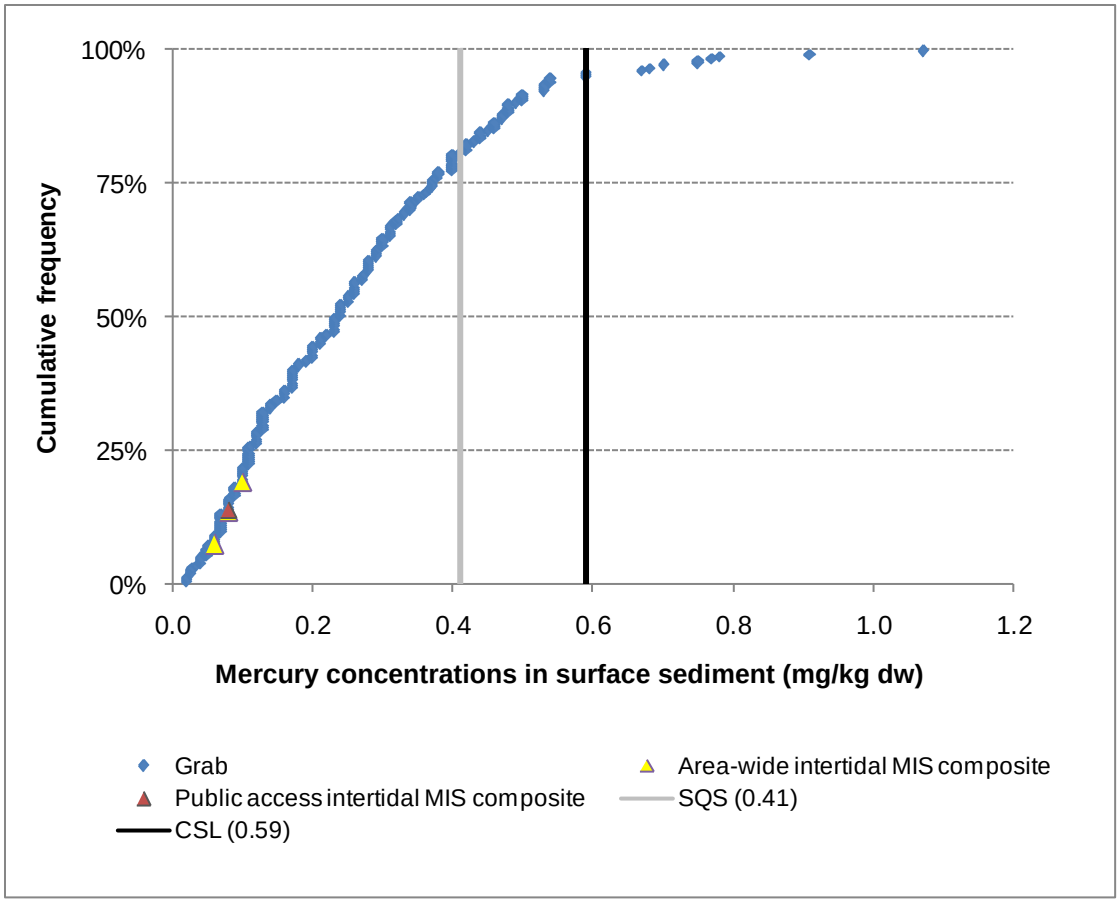


Figure 4-21

Cumulative Frequency of Mercury Concentrations in Surface Sediment

4.2.8.2 Subsurface Sediment

Mercury was detected in 82% of the subsurface sediment samples, at concentrations that ranged from 0.01 to 3.37 mg/kg dw (Table 4-54). Forty-eight of the 305 subsurface samples exceeded only the SQS, and 87 samples exceeded both the SQS and the CSL. Most of the subsurface samples analyzed for mercury were from the top 4 ft of the sediment cores. Mercury was detected in 20 of 56 subsurface sediment samples collected entirely from within the lower alluvium unit and analyzed for mercury, with concentrations ranging from 0.02 to 0.53 mg/kg dw and one sample above the SQS value of 0.41 mg/kg dw.

Table 4-54

Mercury Concentrations in Subsurface Sediment

Sampling Interval (ft)	Detection Frequency		Mercury Concentration (mg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	RL or Range of RLs[a]
All Data					
Any interval	249/305	82	0.01 J	**3.37**	0.02 – 0.06
2-ft Intervals					
0 – 2	79/91	87	0.03	**3.37**	0.02 – 0.050
2 – 4	66/89	74	0.01 J	**3.20**	0.02 – 0.06
4 – 6	12/13	92	0.02	**1.07**	0.03
6 – 8	12/20	60	0.03	**2.54**	0.02 – 0.03
8 – 10	8/14	57	0.03	**0.80**	0.02 – 0.03
> 10	9/13	69	0.053	0.23	0.03
4-ft Intervals					
0 – 4	46/47	98	0.063	**1.16**	0.028
> 4	17/18	94	0.028	**0.755**	0.06

[a] RLs are based only on non-detect samples.

dw – dry weight

J – estimated concentration

RL – reporting limit

Underlined bold identifies concentrations that exceed the CSL (0.59 mg/kg dw).

4.2.8.3 Mercury Patterns in Surface and Subsurface Sediment Samples

Mercury concentrations in surface and subsurface sediment samples were evaluated to assess patterns (Maps 4-39a through 4-39c). The percentiles of mercury concentrations in sediment presented in this section were calculated on a numerical basis using the method described in Section 4.2. Subsurface sediment mercury concentrations and interpolated surface sediment mercury concentrations are presented on Maps 4-40a through 4-40c. There is some uncertainty in the interpretation of patterns and spatial relationships between mercury concentrations in surface and subsurface sediment data because the differences between the percentile concentrations are small and within the range of acceptable analytical variance in most cases. For example, the difference between the 50th percentile (0.24 mg/kg dw) and the 75th percentile (0.37 mg/kg dw) is less than the acceptable analytical variance for mercury at those concentrations.

4.2.8.3.1 Junction/Sill Reach

The highest mercury concentrations in the Junction/Sill Reach were detected in samples from the 0-to-2-ft interval of cores EW10-SC03 (0.52 mg/kg dw) and EW10-SC04 (0.40 mg/kg dw), with concentrations greater than the numerical 75th percentile (0.37 mg/kg dw) (Map 4-40a). The interpolated surface sediment concentrations for samples collected from this area were all less than the 75th percentile and were generally less than the 50th percentile (0.24 mg/kg dw).

4.2.8.3.2 Shallow Main body

Subsurface sediment samples from 15 cores collected from throughout the shallow main body in the southern portion of the EW had mercury concentrations greater than the numerical 95th percentile and the CSL value (0.59 mg/kg dw) (Maps 4-40a and 4-40b). The highest mercury concentration was measured in EW10-SC17 (2.54 mg/kg dw) in the 6-to-8-ft sediment interval. Surface sediment mercury concentrations in this area were generally less than subsurface sediment mercury concentrations.

4.2.8.3.3 Deep Main body

In general, both the surface and subsurface sediment mercury concentrations were less than the 50th percentile (0.24 mg/kg dw) in the dredged areas within the deep main body (Maps 4-40a and 4-40c). However, in the center of the deep main body between Station 2700 and Station 3400, which is within the dredged area, surface sediment mercury concentrations were above the numerical 95th percentile and the CSL value (0.59 mg/kg dw) in four sediment samples. Within the Phase 1 dredge area between Station 3000 and Station 5000, the surface sediment mercury concentrations were generally below the 50th percentile. Higher concentrations were measured in subsurface sediment collected from two cores (EW10-SC31 and EW10 SC28). In addition, the surface sediment mercury concentrations in samples collected prior to the placement of sand cover material in this area ranged from 0.09 to 10.9 mg/kg dw, with mercury concentrations at 26 locations exceeding the SQS (Map 4-16 and Section 4.2.1.5).

Outside of the dredged areas surface and subsurface mercury concentrations were elevated in several locations. In the main channel between Stations 1600 and 2700 subsurface mercury concentrations were above the 95th percentile in the 0-to-4-ft intervals of seven cores that

were collected in areas that were not dredged (Map 4-40c). In the T-25 area near Hanford #2 CSO outfall and two SDs, four subsurface sediment cores had mercury concentrations greater than the numerical 95th percentile (Map 4-40a). The highest mercury concentrations were detected in samples from the 0-to-4-ft interval of cores S48 (0.937 mg/kg dw) and S49 (1.16 mg/kg dw). Both the surface and subsurface mercury concentrations were elevated in this area.

Subsurface sediment samples from eight cores collected from the vicinity of the mound at the mouth of Slip 27 had mercury concentrations above the numerical 95th percentile (Map 4-40a). The highest mercury concentrations were in samples from the 0-to-2-ft interval of EW10-SC28 (3.37 mg/kg dw), the 2-to-4-ft interval of EW10-SC32 (3.03 mg/kg dw), and the 0-to-2-ft interval of EW10-SB01 (2.48 mg/kg dw). The subsurface mercury concentrations were generally greater than the surface sediment mercury concentrations in this area.

Finally, subsurface sediment samples from eight cores collected from the area off of T-30/former GATX had mercury concentrations greater than the CSL (Map 4-40c), with the highest concentrations in the 0-to-2-ft interval of EW10-SC59 (2.09 mg/kg dw), the 2-to-4-ft interval of EW158 (1.96 mg/kg dw), and the 2-to-4-ft interval of EW10-SC54 (1.83mg/kg dw). The subsurface sediment mercury concentrations were consistently higher than the surface sediment mercury concentrations in this area.

4.2.8.3.4 Slip 27

The highest mercury concentrations in Slip 27 were detected in subsurface sediment samples from cores collected from the head of the slip (EW-S27-2C, EW-S27-3C, EW10-SC23) and the center of the slip (EW10-SC27) (Map 4-40a). Subsurface sediment mercury concentrations were > 1 mg/kg dw at each of these locations, with a maximum concentration of 2.03 mg/kg dw (in the 2-to-4-ft interval of EW-S27-3C). Subsurface sediment mercury concentrations were greater than the numerical 95th percentile and the CSL (0.59 mg/kg dw) in samples collected from the 6-to-8-ft interval of two cores (EW10-SC23 and EW10-SC27). Surface sediment mercury concentrations within Slip 27 were consistently less than the highest subsurface sediment mercury concentrations.

4.2.8.3.5 Slip 36

The highest surface sediment mercury concentration (0.7 mg/kg dw) in Slip 36 was detected at EW09-SS215, at the head of the slip (Map 4-40c). The highest subsurface sediment mercury concentrations were in the 0-to-2-ft interval of EW10-SC58 (1.28 mg/kg dw) in the head of the slip and EW10-SC60 (0.69 mg/kg dw) at the mouth of the slip.

4.2.8.4 Tissue

Total mercury was detected in all tissue samples that were analyzed for mercury, except for a few of the striped perch fillet, mussel whole body, and geoduck edible meat samples (Table 4-55). In addition, three of the English sole fillet samples were analyzed for methyl mercury. The methyl mercury concentrations were equal to the total mercury concentrations. The highest mean mercury concentration was for whole-body brown rockfish samples (0.15 mg/kg ww). Mercury concentrations in brown rockfish whole-body samples ranged from 0.04 to 0.418 mg/kg ww. The brown rockfish sample (EW-08-SB008-BR-08) with the highest concentration (0.418 mg/kg ww) was located in the southern portion of the deep main body on the west side of the EW near Station 4800 (Map 4-23). Crab edible-meat composite samples had the second highest mean mercury concentration (0.07 mg/kg ww); mean mercury concentrations for all other sample types ranged from 0.008 to 0.05 mg/kg ww.

Table 4-55

Mercury Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency		Mercury Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[s]	Calculated Mean[a]	RL or Range of RLs[b]
Fish							
Brown rockfish, whole body	15/15	100	0.04	0.418	0.12	0.15	na
English sole, whole body	13/13	100	0.02 J	0.042	0.033	0.03	na
Juvenile Chinook salmon, whole body	12/12	100	0.010 J	0.043 J	0.025	0.022	na
Sand sole, whole body	6/6	100	0.03 J	0.119 J	0.04	0.05	na
Shiner surfperch	11/11	100	0.02 J	0.05	0.04	0.04	na
English sole, fillet[c]	20/20	100	0.0259	0.07	0.04	0.04	na
Striped perch, fillet	2/6	33	0.06 J	0.07 J	0.01	0.03	0.02

Tissue Type	Detection Frequency		Mercury Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[s]	Calculated Mean[a]	RL or Range of RLs[b]
Invertebrates							
Crab, whole body[d, e]	9/9	100	0.038	0.12	0.04	0.05	na
Crab, edible meat[e]	12/12	100	0.042	0.15	0.058	0.07	na
Crab, hepatopancreas[e]	9/9	100	0.02	0.077	0.028	0.03	na
Intertidal Clam, whole body[f,g]	10/10	100	0.01	0.03	0.015	0.02	na
Mussel, whole body[g]	7/17	41	0.0098	0.015	0.005	0.008	0.009 – 0.01
Coonstripe shrimp, whole body	1/1	100	0.03	0.03	na	na	na
Geoduck clam, whole body[d]	4/4	100	0.01	0.01	0.01	0.01	na
Geoduck clam, edible meat	4/6	67	0.01	0.011	0.01	0.009	0.01
Geoduck clam, gutball	3/3	100	0.02	0.02	0.02	0.02	na
Benthic invertebrates, whole body	13/13	100	0.024	0.06	0.04	0.04	na

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[b] RLs are based only on non-detect samples.

[c] Three English sole fillet samples were analyzed for methylmercury, and the total mercury and methylmercury concentrations were the same (EVS unpublished). The mercury concentrations in these samples, which were collected in 1999, were consistent with concentrations in the other two datasets collected in 2005 and 2008.

[d] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[e] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[f] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal area and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[g] The clam and mussel whole body samples include all soft tissues. Shells were not included in these samples.

J – estimated concentration
na – not applicable
RL – reporting limit
ww – wet weight

4.2.8.5 Surface Water

Dissolved and total mercury were detected in 34% and 74%, respectively of the surface water samples collected during the King County WQA and SRI sampling events combined. The results for both sampling events are compared in Appendix A, Attachment 1. In general, the

mercury concentrations in the two datasets were consistent. Mean concentrations were 0.0003 and 0.01 µg/L for dissolved and total mercury, respectively (Table 4-56). Mercury concentrations in surface water samples are compared with WQC in Section 4.2.2 (Table 4-21).

Table 4-56
Mercury Concentrations in Surface Water

Chemical	Detection Frequency		Concentration (µg/L)				Range of RLs[b]
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	
Mercury (dissolved)	23/68	34	0.000130	0.00146	0.00021	0.0003	0.0001 – 0.00054
Mercury (total)	55/74	74	0.000100	0.0277	0.00084	0.01	0.0001 – 0.20

Note: Federal marine WQC for the protection of aquatic life are 0.94 µg/L (chronic) and 1.8 µg/L (acute) for dissolved mercury. State WQS for the protection of aquatic life are 0.025 µg/L (chronic) and 1.8µg/L (acute) for dissolved mercury.

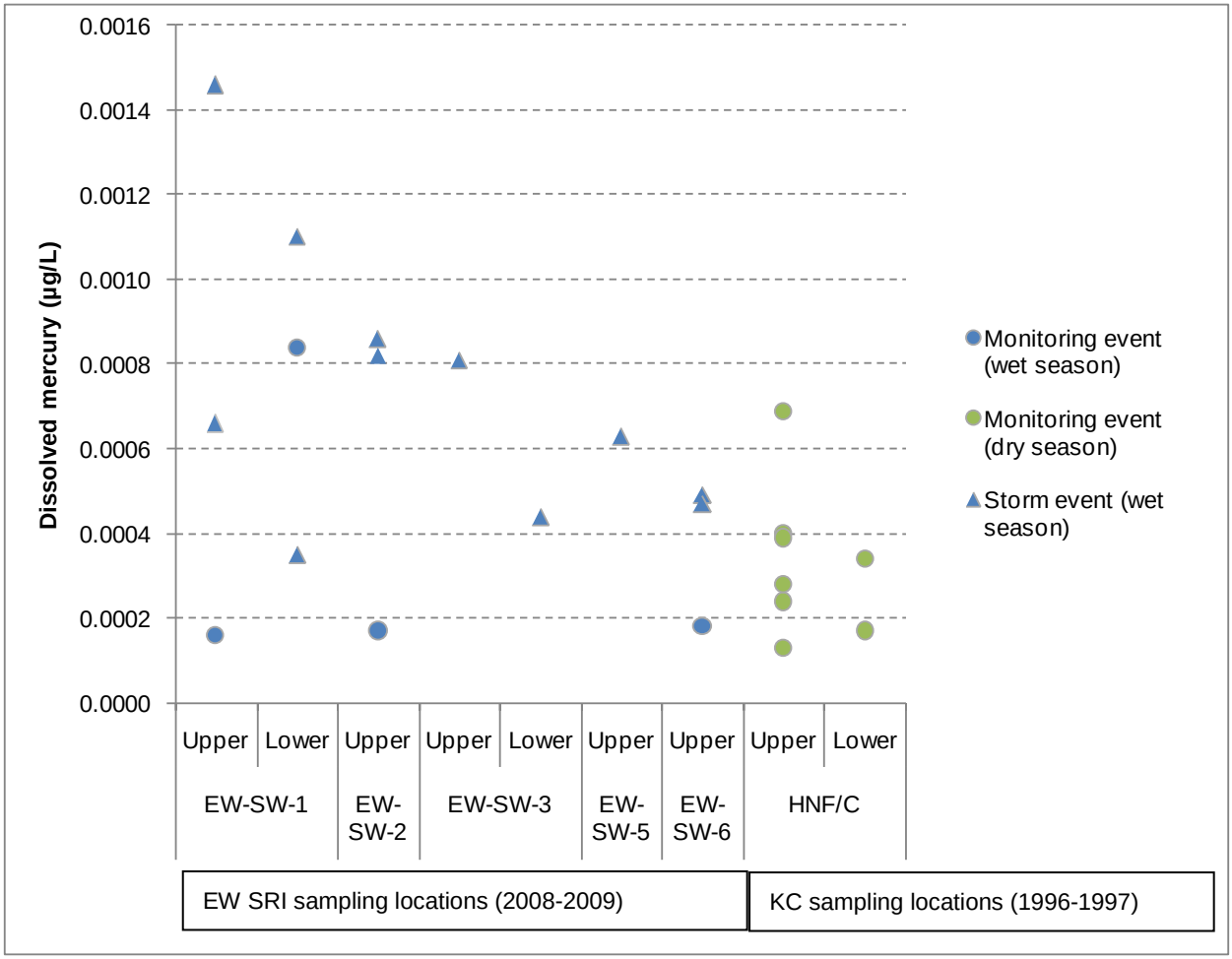
[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results for the SRI samples. The non-detected results were included as one half the MDL for KC samples.

[b] RLs are based only on non-detect samples.

KC – King County
MDL – method detection limit
RL – reporting limit
SRI – supplemental remedial investigation
WQC – water quality criteria
WQS – water quality standards

The majority of the data (87% of dissolved mercury and 80% of the total mercury) were collected as part of the EW SRI sampling. Total mercury was frequently detected in both King County and SRI sampling events, with the highest concentrations reported for the SRI sampling events. Dissolved mercury was less frequently detected in the SRI sampling events as compared with the King County sampling events. However, the highest dissolved mercury concentrations were reported for samples collected during a storm event during the SRI sampling at sampling locations in the southern portion of the waterway. Figure 4-22 shows the range of detected dissolved mercury concentrations for each surface water sampling location at two depths. Approximately 74% (i.e., 17 of 23) of the detected dissolved mercury concentrations were from 1 m below the water surface (i.e., upper water column) and 26% (i.e., 6 of 23) were from 1 m above the sediment surface (i.e., lower water column). Of the 17 samples with detected dissolved mercury concentrations in the upper water column, approximately 47% (i.e., 8 of 17) were collected during a storm event in January 2009. Of the six samples with detected dissolved mercury concentrations in the lower water column, 50%

(i.e., 3 of 6) were collected during a storm event in January 2009. The highest detected dissolved mercury concentration (0.00146 µg/L) was from a water sample collected from the upper water column at location EW-SW-1 during a storm event in January 2009 (Map 4-7). In general, the storm event samples were associated with the highest concentrations for all sampling locations.



Note: Upper water column samples were collected from 1 m below the water surface. Lower water column samples were collected from 1 m above the sediment surface. Sampling locations are shown on Map 4-7.

Figure 4-22

Detected Dissolved Mercury Concentrations in Surface Water for Each Sampling Location

4.2.8.6 Summary of Mercury Data

Mercury was detected in 98% of the surface sediment samples analyzed for mercury. Mercury concentrations ranged from 0.02 to 1.07 mg/kg dw, and the area-based 95th and 50th percentile concentrations were 0.54 and 0.26 mg/kg dw, respectively. Areas with mercury

concentrations greater than the numerical 75th percentile (0.37 mg/kg dw) were located in Slip 36, just outside of Slip 36, and along the eastern shoreline to the south of Slip 36 near the former Rabanco barge loading facility and GATX, in the central portion of the deep main body between Station 4900 and Station 1600, in Slip 27, near the mound area at the mouth of Slip 27, and in the shallow main body between Station 6200 and Station 5000. Mercury concentrations exceeded the SQS but not the CSL in 36 surface sediment samples and exceeded the CSL in 10 surface sediment samples. In general, subsurface sediment mercury concentrations were higher than the surface sediment mercury concentrations. Subsurface sediment mercury concentrations were higher than the surface sediment mercury concentrations in the shallow main body, and portions of the deep main body that have not been dredged including the mound area outside of Slip 27, the head of Slip 27, and the area off of T-30/former GATX.

Mercury was frequently detected in tissue samples. Mean mercury concentrations in tissue samples ranged from 0.008 to 0.15 mg/kg ww, with the highest mean concentration in brown rockfish samples.

In surface water, dissolved and total mercury were detected in 34 and 74% of the samples. Mean concentrations were 0.0003 and 0.01 µg/L for dissolved and total mercury, respectively.

4.2.9 TBT

This section summarizes the nature and extent of TBT concentrations in surface sediment, subsurface sediment, tissue, surface water, and porewater samples collected from the EW.

4.2.9.1 Surface Sediment

TBT was analyzed in 67 surface sediment grab samples (Map 4-41).[68] The analysis of TBT in surface sediment occurred throughout the EW, with the greatest number of samples located along T-18 on the western side of the waterway. The analysis of sediment TBT concentrations has not been required for either SMS characterization or the characterization of dredged materials. Therefore, fewer sediment samples have been characterized for TBT.

[68] Three of the 67 surface sediment grab samples were field duplicates; 64 unique sample locations had surface sediment grab samples analyzed for TBT.

The analysis of TBT in sediment samples has been focused in areas with historically elevated sediment or porewater TBT concentrations. All four of the intertidal MIS composite samples were analyzed for TBT. TBT was detected in 90% of the surface sediment grab samples, with concentrations ranging from 1.6 to 6,000 µg/kg dw and a mean concentration of 180 µg/kg dw (Table 4-57). TBT was detected in 100% of the intertidal MIS composite samples, with concentrations ranging from 7.9 to 8.9 µg/kg dw for the area-wide intertidal MIS composite samples. The public access intertidal MIS composite sample had a TBT concentration of 11 µg/kg dw.

Table 4-57

TBT Concentrations in Surface Sediment

Sample Type	Detection Frequency		TBT Concentration (µg/kg dw)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs
Grab	60/67	90	1.6 J	6,000	31	180	3.4 – 3.7
Area-wide intertidal MIS composite	3/3	100	7.9 J	8.9 J	8.8	8.5	na
Public access intertidal MIS composite	1/1	100	11 J	11 J	na	na	na

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

dw – dry weight
J – estimated concentration
MIS – multi-increment sampling
na – not applicable
RL – reporting limit
TBT – tributyltin

The numerical 95th percentile of TBT concentrations in the surface sediment dataset was 560 µg/kg dw and the 50th percentile was 31 µg/kg dw (Table 4-58). Area-based percentiles were not calculated using IDW interpolation because the sample density was not sufficient for IDW methods. Therefore, the TBT surface sediment data were not interpolated (Map 4-41).

Table 4-58

Percentiles of TBT Concentrations for Surface Sediment

Method	TBT Concentration (µg/kg dw)				
	Entire Dataset	25th Percentile	50th Percentile	75th Percentile	95th Percentile
Numerical[a]	190 (mean)	10	31	79	560

[a] Numerical percentiles were calculated using detected results and one-half the RL for non-detected results. Intertidal MIS composite samples were not included in the calculation of numerical percentiles or in the calculation of the mean for the entire dataset. Data presented in this table were averaged by location (i.e., field duplicates were averaged to create a single result per sampling location).

dw – dry weight
EW – East Waterway
MIS – multi-increment sampling
RL – reporting limit
TBT – tributyltin

The three highest surface sediment TBT concentrations (6,000, 1,600, and 610 µg/kg dw) were detected in samples collected from locations along the shoreline of T-18 near Station 4400, Station 1800, and Station 800 (Map 4-41). TBT concentrations in the intertidal MIS composite samples (7.9 to 11 µg/kg dw) were similar to the numerical 25th percentile (10 µg/kg dw) (Figure 4-23).

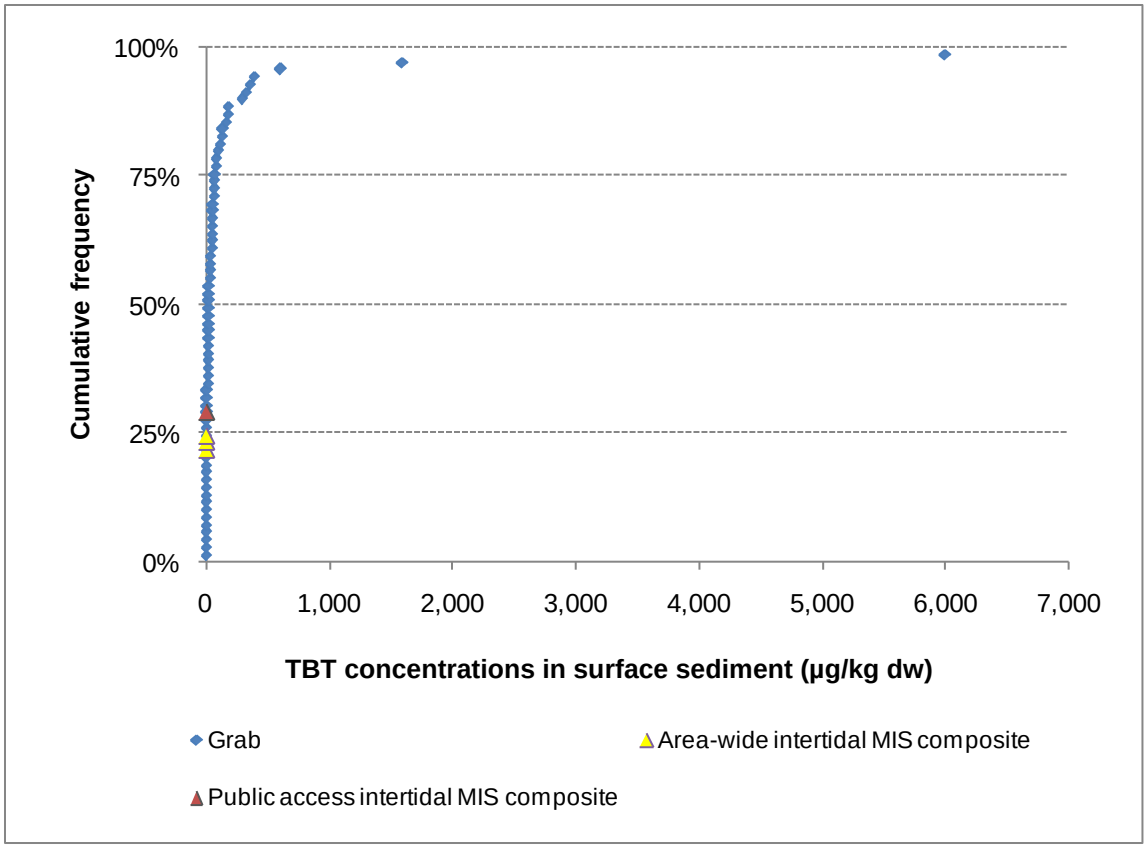


Figure 4-23
Cumulative Frequency of TBT Concentrations in Surface Sediment

4.2.9.2 Subsurface Sediment

TBT was analyzed in 97 subsurface sediment samples, and was detected in 55% of the samples, at concentrations ranging from 0.4 to 21,000 µg/kg dw (Table 4-59). All of the subsurface sediment samples analyzed for TBT were from the 0-to-2-, 2-to-4-, and 0-to-4-ft intervals, except for one sample from the > 4-ft sediment interval. Subsurface sediment sample TBT concentrations are shown on Maps 4-42a and 4-42b. One subsurface sediment sample collected entirely from within the lower alluvium unit and analyzed for TBT had a detected TBT concentration of 39 µg/kg dw.

Table 4-59

TBT Concentrations in Subsurface Sediment

Sampling interval (ft)	Detection Frequency		TBT Concentration (µg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	RL or Range of RLs[a]
All Data					
Any interval	53/97	55	0.40 JN	21,000	0.482 – 36
2-ft Intervals					
0 – 2	32/41	78	5.3	21,000	3.2 – 36
2 – 4	14/47	30	0.40 JN	110	3.0 – 16
4-ft Intervals					
0 – 4	7/8	88	1.63	74.6	0.482
> 4	0/1	0	na	na	0.482

[a] RLs are based only on non-detect samples.

dw – dry weight
J – estimated concentration
N – tentative identification
RL – reporting limit

A limited number of subsurface sediment cores (46 cores) were analyzed for TBT. Subsurface and surface sediment TBT concentrations are shown on Maps 4-43a and 4-43b. There is a higher level of uncertainty associated with the nature and extent evaluation of TBT due to the limited number of sediment samples analyzed for TBT.

Surface sediment samples with TBT concentrations above the numerical 95th percentile (560 µg/kg dw) were all collected from locations on the west side of EW, along T-18. Surface sediment sample EW09-SS133, which was collected near Station 4400, had a TBT concentration of 610 µg/kg dw. Surface sediment samples EW09-SS129 and PDM-15, which were both collected from the northern section of T-18, had TBT concentrations of 1,600 and 6,000 µg/kg dw, respectively. Sample PDM-15 was collected following the Stage 1 navigational dredging that concluded in 2000. The highest subsurface sediment TBT concentration (21,000 µg/kg dw) was detected in a sample from the 0-to-2-ft interval of core EW163, which was collected from the vicinity of samples EW09-129 and PDM-15. TBT was only detected in the 0-to-4-ft sediment intervals and was much more frequently detected in the 0-to-2-ft intervals (78% detection) relative to the 2-to-4-ft intervals (30% detection)

4.2.9.3 Tissue

With the exception of crab, juvenile Chinook salmon and English sole fillet, TBT was detected in 94 to 100% of the tissue samples analyzed (Table 4-60). TBT was detected in 50%

of English sole fillet composite samples but was not detected in crab edible-meat samples or juvenile Chinook salmon whole-body samples, and was detected in only one of the nine crab hepatopancreas composite samples. Mean TBT concentrations were highest in rockfish whole-body (160 µg/kg ww) and benthic invertebrate (110 µg/kg ww) composite samples. Mean TBT concentrations were relatively lower in shiner surfperch whole-body (58 µg/kg ww), clam whole body(47 µg/kg ww), mussel whole body(33 µg/kg ww), and English sole whole-body (26 µg/kg ww) composite samples. The lowest mean TBT concentrations were in crab hepatopancreas, English sole and striped perch fillet, and geoduck (whole body, edible meat, and gutball) samples, with mean detected TBT concentrations ranging from 5.7 to 20 µg/kg ww.

Table 4-60

TBT Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency		TBT Concentration (µg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Fish							
Brown rockfish, whole body	13/13	100	38	420	120	160	na
English sole, whole body	11/11	100	17	38	25	26	na
Juvenile Chinook salmon, whole body	0/5	0	na	na	3.6 U	3.6 U	6.7 – 7.4
Shiner surfperch, whole body	8/8	100	30 J	67	61	58	na
English sole, fillet	7/14	50	1.63	14	3.9	5.7	0.68 – 7.7
Striped perch, fillet	6/6	100	5 J	31 J	23	20	na
Invertebrates							
Crab, whole body[c, d]	1/9	11	13	13	2	3.2	3.8 – 3.9
Crab, edible meat[d]	0/12	0	na	na	3.9 U	3 U	2 – 7.7
Crab, hepatopancreas[d]	1/9	11	23	23	3.9	6.0	7.6 – 7.7
Clam, whole body[e,f]	10/10	100	15	140	38	47	na
Mussel, whole body[f]	16/17	94	7.5	92.8	12	33	7.7
Geoduck clam, whole body[c]	4/4	100	8.1 J	12	9.7	9.9	na
Geoduck clam, edible meat	6/6	100	5.1 J	9.8	7.6	7.6	na
Geoduck clam, gutball	3/3	100	14	29	15	19	na

Tissue Type	Detection Frequency		TBT Concentration (µg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Benthic invertebrates, whole body	12/12	100	20	390	92	110	na

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[b] RLs are based only on non-detect samples.

[c] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck.

[d] Two species of crab (red rock and one Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[e] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined.

[f] The clam and mussel whole body samples include all soft tissues. Shells were not included in these samples.

J – estimated concentration
na – not applicable
RL – reporting limit
U – not detected at given concentration
ww – wet weight

The highest sample-specific TBT concentration (420 µg/kg ww) was detected in a brown rockfish whole-body sample collected from T-18 (Station 200), on the western side of the EW, close to the EW study area boundary. Two brown rockfish collected in the southern portion of T-18 had TBT concentrations of 290 and 300 µg/kg ww. Surface sediment TBT concentrations were also elevated along T-18. The second highest sample-specific TBT concentration (390 µg/kg ww) was detected in a benthic invertebrate composite tissue sample collected from the southern end of the deep main body (Stations 3600 to 5000) along the shoreline of T-18. The corresponding composite sediment sample TBT concentration[69] was not elevated relative to the other composite sediment samples.

4.2.9.4 Surface Water

TBT was detected in 1 of 59 surface water samples (Table 4-61). The single detected concentration of TBT was 0.010 µg/L from the lower depth sample collected at Station 2 (Map 4-7), which is equal to the maximum RL in another sample where TBT was not

[69] It is important to note that all sampling locations that contributed tissue to the tissue composite were represented equally in the sediment composite. The amount of tissue obtained from each varied considerably, so the tissue and sediment composites are not consistent in their weighting of individual locations.

detected. It should be noted that all of the RL values were above the chronic marine AWQC value of 0.0074 µg/L. The surface water samples were analyzed by the most sensitive, commercially available analytical method. The TBT MDL values were below the chronic marine AWQC, and the laboratory was required to report values between the MDL and the RL as estimated. For non-detected results with RLs above the criterion, there is uncertainty as to whether the sample would actually exceed the criterion. TBT concentrations in surface water samples are compared with WQC in Section 4.2.2 (Table 4-21).

Table 4-61
TBT Concentrations in Surface Water

Detection Frequency		TBT Concentration (µg/L)				
Ratio	%	Minimum Detect	Maximum Detect	Calculated Median	Calculated Mean[a]	Range of RLs[b]
1/59	1.7	0.010 J	0.010 J	0.004	0.0044	0.0080 – 0.010

Note: Federal marine WQC for the protection of aquatic life for TBT are 0.42 µg/L (acute) and 0.0074 µg/L (chronic).

[a] Calculated mean concentration is the average of detected concentrations and one-half the RL for non-detected results.

[b] RLs are based only on non-detect samples.

J – estimated concentration
RL – reporting limit
TBT – tributyltin
WQC –water quality criteria

4.2.9.5 Porewater

Numerous historical porewater samples from the EW were analyzed for TBT because the DMMP for TBT requires porewater TBT concentration data rather than bulk sediment concentration data (USACE et al. 2000). The measurement of TBT in porewater was required as part of post-dredge monitoring events, and the subsurface sediment porewater samples were collected for dredge material characterization studies.

TBT was analyzed in 44 porewater samples collected from surface sediment from the 0-to-10-cm depth, 39 subsurface sediment samples collected from various depths between 0 and 4 ft, and 16 subsurface sediment samples collected from depths > 4 ft (Table 4-62). TBT was detected in 96% of the samples from 0-to-10-cm depth at a mean concentration of 0.81 µg/L. TBT was detected in 92% of samples collected within the 0-to-4-ft interval, with a mean concentration of 0.15 µg/L and in 31% of samples collected at depths > 4 ft, with a mean concentration of 0.06 µg/L. Porewater TBT concentrations were greater than the DMMP screening level (SL) of 0.15 µg/L in 19 samples from the 0-to-10-cm depth; the

highest 0-to-10-cm porewater TBT concentration (28 µg/L) was at EW-116 collected of T-18 at Station 1100 (Map 4-41). The sediment from this location was not analyzed for TBT. The nearest (within 75 ft) surface sediment sample analyzed for TBT was EW-SS202, which had a sediment TBT concentration of 180 µg/kg dw. The 0-to-4-ft porewater concentrations were greater than the DMMP SL for 17 samples. The highest porewater 0-to-4-ft TBT concentration was 0.83 µg/L for S47 located in the shallow main body. None of the detected TBT concentrations from the > 4 ft samples were greater than the DMMP SL.

Table 4-62

TBT Concentrations in Porewater

Depth Category	Detection Frequency		TBT Concentration (µg/L)			Range of RLs
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Mean[a]	
0 to 10 cm	42/44	96	0.019 J	28	0.81	0.037 – 0.038
0 to 4 ft[b]	36/39	92	0.040	0.83	0.15	0.046 – 0.15
> 4 ft	5/16	31	0.028 J	0.098 J	0.06	0.0062 – 1

Note: The DMMP screening level for porewater TBT concentrations is 0.15 µg/L.

[a] Calculated mean concentration is the average of detected concentrations and one-half the RL for non-detected results.

[b] Samples were collected at various depth intervals between 0 and 4 ft; these samples do not include those collected from 0 to 10 cm.

DMMP – Dredged Material Management Program
J – estimated concentration
RL – reporting limit
TBT – tributyltin

4.2.9.6 Summary of TBT Data

TBT was frequently detected in surface sediment samples, with concentrations ranging from 1.6 to 6,000 µg/kg dw. The numerical 95th and 50th percentiles were 560 and 31 µg/kg dw, respectively. The three highest concentrations were detected in surface sediment samples collected from along the shoreline of T-18. There are no SQS or CSL criteria for TBT. The highest TBT concentrations in surface and subsurface sediment were detected along the northern section of T-18.

TBT was frequently detected in all tissue types, with the exception of whole-body juvenile Chinook salmon (no detections) and crab (one detection in hepatopancreas and no detections in edible meat). Mean TBT concentrations ranged from 3.2 to 160 µg/kg ww, with the highest concentrations detected in brown rockfish whole-body samples collected along T-18. These areas also had the highest concentrations of TBT in sediment.

TBT was detected in only 1 of 59 surface water samples. The single detected TBT concentration in surface water was 0.010 µg/L collected from the lower water depth at Station 2. The RLs for the 58 non-detected results were all greater than the marine chronic AWQC value for TBT; however, the MDL values for these results were below the AWQC value.

TBT was detected in 42 of 44 porewater samples from 0-to-10-cm sediment depth, with a mean concentration of 0.81 µg/L. In addition, porewater samples from subsurface sediment depths (0 to 4 ft and > 4 ft) were analyzed. The highest porewater TBT concentrations were associated with the porewater samples collected from 0-to-10-cm depth, with the two highest concentrations in samples collected in the vicinity of the northern portion of T-18. TBT porewater concentrations in samples from the 0-to-4-ft sediment intervals were greater than those from the > 4-ft sediment intervals.

4.2.10 Metals

This section summarizes the nature and extent of metals (other than arsenic and mercury) concentrations in surface sediment, subsurface sediment, tissue, and surface water samples. Arsenic and mercury are discussed separately in Sections 4.2.7 and 4.2.8, respectively.

4.2.10.1 Surface Sediment

Cadmium, chromium, copper, lead, silver, and zinc were analyzed in 231 surface sediment grab samples.[70] Cobalt, molybdenum, and vanadium were analyzed in 111 surface sediment grab samples.[71] Nickel was analyzed in 220 surface sediment grab samples, and antimony was analyzed in 187 surface sediment grab samples.[72] All four of the intertidal MIS composites were analyzed for these 11 metals (i.e., antimony, cadmium, cobalt, copper, lead,

[70] Fifteen of the 231 surface sediment grab samples were field duplicates; 216 unique sample locations had surface sediment grab samples analyzed for cadmium, chromium, copper, lead, silver, and zinc.

[71] Six of the 111 surface sediment grab samples were field duplicates; 105 unique sample locations had surface sediment grab samples analyzed for cobalt, molybdenum, and vanadium.

[72] Fourteen of the 220 surface sediment grab samples analyzed for nickel were field duplicates; 206 unique sample locations had surface sediment grab samples analyzed for nickel. Twelve of the 187 surface sediment grab sampls were field duplicates analyzed for antimony; 175 unique sample locations had surface sediment grab samples analyzed for antimony.

molybdenum, nickel, silver, vanadium, and zinc). Table 4-63 presents the detection frequencies and a summary of concentrations for the 11 metals other than arsenic and mercury, that were detected in surface sediment, (arsenic and mercury, were described in Sections 4.2.7.1 and 4.2.8.1, respectively). The surface sediment SMS exceedances for metals are provided in Table 4-16.

Table 4-63
Metals Concentrations in Surface Sediment

Chemical	Sample Type	Detection Frequency		Concentration (mg/kg dw)					SQS	CSL
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]		
Antimony	grab	4/187	2.1	7 J	44 J	4	5.0	0.3 – 30	na	na
	area-wide intertidal MIS composite	0/3	0	na	na	3	3 U	6	na	na
	public access intertidal MIS composite	0/1	0	na	na	na	na	6	na	na
Cadmium	grab	155/231	67	0.126	**6.76**	0.5	0.70	0.2 – 1	5.1	6.7
	area-wide intertidal MIS composite	3/3	100	0.5	0.6	0.6	0.6	na	5.1	6.7
	public access intertidal MIS composite	0/1	0	na	na	na	na	0.3		
Chromium	grab	231/231	100	8	82 J	25.4	30	nc	260	270
	area-wide intertidal MIS composite	3/3	100	21.5	44.8	27.3	31.2	na	260	270
	public access intertidal MIS composite	1/1	100	20.5	20.5	na	na	na	260	270
Cobalt	grab	111/111	100	4	16	7.1	7.0	na	na	na
	area-wide intertidal MIS composite	3/3	100	5.7	6.8	6.2	6.2	na	na	na
	public access intertidal MIS composite	1/1	100	5.0	5.0	na	na	na	na	na
Copper	grab	231/231	100	11.3	272 J	52.6	59	nc	390	390
	area-wide intertidal MIS composite	3/3	100	36.2	41.4	40.8	39.5	na	390	390
	public access intertidal MIS composite	1/1	100	28.0	28.0	na	na	na	390	390
Lead	grab	228/231	99	3	208	34	50	3 – 10	450	530
	area-wide intertidal MIS composite	3/3	100	49	60	50	50	na	450	530
	public access intertidal MIS composite	1/1	100	23	23	na	na	na	450	530
Molybdenum	grab	71/111	64	0.7	5	1.2	2.0	0.6 – 2	na	na
	area-wide intertidal MIS composite	3/3	100	1.5	2.2	2	1.9	na	na	na
	public access intertidal MIS composite	1/1	100	1.3	1.3	na	na	na	na	na

Chemical	Sample Type	Detection Frequency		Concentration (mg/kg dw)					SQS	CSL
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]		
Nickel	grab	219/220	100	7.0	56	19	20	6	na	na
	area-wide intertidal MIS composite	3/3	100	21	27	24	24	na	na	na
	public access intertidal MIS composite	1/1	100	20	20	na	na	na	na	na
Silver	grab	97/231	42	0.110	6[c]	0.3	0.60	0.3 – 2	6.1	6.1
	area-wide intertidal MIS composite	0/3	0	na	na	0.2	0.2 U	0.4	6.1	6.1
	public access intertidal MIS composite	0/1	0	na	na	na	na	0.4	6.1	6.1
Vanadium	grab	111/111	100	24	94.1	54.6	57	na	na	na
	area-wide intertidal MIS composite	3/3	100	34.3 J	45.5 J	43.4	41.1	na	na	na
	public access intertidal MIS composite	1/1	100	30.6 J	30.6 J	na	na	na	na	na
Zinc	grab	231/231	100	25.3 J	**1,230 J**	89	100	na	410	960
	area-wide intertidal MIS composite	3/3	100	100	117	113	100	na	410	960
	public access intertidal MIS composite	1/1	100	57	57	na	na	na	410	960

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

[b] RLs are based only on non-detect samples.

[c] Value reported (based on ICP Method) with insufficient accuracy to determine whether or not the SQS value of 6.1 has been exceeded. However, the ICP-MS result for this sample included silver, which was not detected at 0.28 mg/kg dw.

CSL – cleanup screening level
dw – dry weight
ICP – inductively coupled plasma
J – estimated concentration
MIS – multi-increment sampling
MS – mass spectrometry
na – not applicable
RL – reporting limit
SQS – sediment quality standards

Underlined bold identifies concentrations that exceed the CSL value.

Antimony, silver, and molybdenum were the least frequently detected chemicals in surface sediment grab samples, detected in 2.1, 42, and 64% of the samples, respectively Table 4-63). Of these three chemicals, only silver has SQS and CSL criteria. None of the silver concentrations exceeded the SQS or CSL.

The remaining eight metals (i.e., cadmium, chromium, cobalt, copper, lead, nickel, vanadium, and zinc) were detected relatively frequently in surface sediment grab samples (67 to 100%) (Table 4-63). Six of these eight metals have SMS criteria; there are no SMS criteria for cobalt or vanadium. Of the six chemicals with SMS criteria, only cadmium and zinc had surface sediment concentrations that exceeded the SQS or CSL. Surface sediment cadmium concentrations are shown on Map 4-44. Cadmium concentrations exceeded the SQS but not the CSL in one surface sediment sample and exceeded CSL in another surface sediment sample (Map 4-45). Surface sediment zinc concentrations are shown on Map 4-46. Zinc concentrations exceeded the SQS but not the CSL in four surface sediment samples and exceeded the CSL in one surface sediment sample. The exceedances were located at the head of Slip 36, off of the Former Rabanco barge loading facility and GATX and the mound area off of Slip 27 (Map 4-47).

4.2.10.2 Subsurface Sediment

Subsurface sediment samples collected from 205 cores (326 samples) prior to dredging were analyzed for at least one metal. All of the subsurface samples that were analyzed for chromium, cobalt, copper, vanadium, and zinc had detected concentrations of these chemicals. Table 4-64 presents a summary of subsurface metals data for samples collected from any interval.

Table 4-64
Metals Concentrations in Subsurface Sediment

Chemical	Detection Frequency		Concentration (mg/kg dw)				
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[a]	SQS	CSL
Antimony	31/223	14	0.49	18 J	0.5 – 20	na	na
Cadmium	199/258	77	0.007	**91.9**	0.2 – 0.39	5.1	6.7
Chromium	190/190	100	8.9	155	na	260	270
Cobalt	148/148	100	3.7	16.4	na	na	na
Copper	255/255	100	7.9	**730**	na	390	390

Chemical	Detection Frequency		Concentration (mg/kg dw)				
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[a]	SQS	CSL
Lead	220/255	86	0.19	**1,450**	2 – 6.4	450	530
Molybdenum	117/144	81	0.7	28	0.5 – 0.7	na	na
Nickel	253/255	99	6.8	86	6 – 19	na	na
Selenium	13/160	8.1	0.8	2	0.12 – 4	na	na
Silver	150/251	60	0.12	**10**	0.07 – 1.9	6.1	6.1
Thallium	16/148	11	0.3	0.6	0.03 – 0.5	na	na
Vanadium	148/148	100	31.7	89.6	na	na	na
Zinc	255/255	100	19	**16,100**	na	410	960

[a] RLs are based only on non-detect samples.
dw – dry weight
na – not applicable
RL – reporting limit
Underlined bold identifies concentrations that exceed the CSL value.

Over 90% of the subsurface sediment samples summarized in Table 4-64 were collected from the top 4 ft of sediment. Relatively few subsurface sediment samples from depths > 4 ft below the mudline were analyzed; approximately half of those samples were collected and analyzed as part of the SRI from locations with SMS exceedances for metals in the upper intervals, and the other half of the samples were collected from > 4 ft and analyzed as composite samples for dredging characterization.

Cadmium and zinc were the only metals with surface sediment concentrations that exceeded CSL. The highest cadmium and zinc concentrations were detected in a subsurface sediment sample collected from the head of Slip 27 and the mound area outside of Slip 27; maximum concentrations of both metals were detected in samples from the 0-to-2-ft interval of core SB-01 and the 2-to-4-ft interval of core S27C3. In addition to cadmium and zinc, copper, lead and silver concentrations in subsurface sediments exceeded their CSL values. The cores with CSL exceedances for metals were located in Slip 27 (Maps 4-14e and 4-14k).and the area south of Slip 36 off of the former Rabanco barge loading facility and GATX (Maps 4-14h, 4-14i and 4-14k).

4.2.10.3 Tissue

Table 4-65 presents the detection frequencies and ranges of metals concentrations in tissue. Fish fillet composite samples generally had the lowest mean metal concentrations, while

benthic invertebrates, crab, clams, and geoducks had the highest mean metal concentrations. Benthic invertebrate composite samples had the highest mean antimony, chromium, cobalt, lead, nickel, thallium, and vanadium concentrations. Crab hepatopancreas composite samples had the highest mean cadmium, copper, selenium, and silver concentrations; and crab edible-meat composite samples had the highest zinc concentrations. Geoduck gutball composite samples had the highest mean molybdenum concentration.

Table 4-65
Metals Concentrations in Fish and Invertebrate Tissues

Tissue Type	Detection Frequency		Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Antimony							
Clam, whole body[c]	8/10	80	0.009 J	0.061	0.012	0.02	0.008
Crab, edible meat[d, e]	1/9	11	0.004	0.004	0.002	0.002	0.004 – 0.008
Crab, hepatopancreas[d]	8/9	89	0.006	0.016	0.007	0.008	0.008
Crab, whole body[d]	8/9	89	0.005	0.009	0.005	0.006	0.004
Fish, fillet[f]	0/11	0	na	na	0.002	0.002 U	0.004
Fish, whole body[g]	4/38	11	0.004	0.005	0.003	0.003	0.004 – 0.008
Geoduck clam, edible meat	0/6	0	na	na	0.004	0.004 U	0.008
Geoduck clam, gutball	3/3	100	0.008	0.011	0.008	0.009	na
Geoduck clam, whole body[e]	4/4	100	0.008	0.009	0.008	0.008	na
Benthic invertebrates, whole body	13/13	100	0.04 J	0.45 J	0.07	0.10	na
Mussel, whole body[h]	9/17	53	0.004 J	0.010 J	0.006	0.007	0.004 – 0.02
Shrimp, whole body	0/1	0	na	na	na	na	0.008
Cadmium							
Clam, whole body[c]	10/10	100	0.04	0.11	0.085	0.08	na
Crab, edible meat[d, e]	9/9	100	0.09	0.98	0.77	0.7	na
Crab, hepatopancreas[d]	9/9	100	0.37	6.85	4.65	4.8	na
Crab, whole body[d]	9/9	100	0.2	3.1	2.2	2.0	na
Fish, fillet[f]	1/11	9	0.11	0.11	0.02	0.03	0.04
Fish, whole body[g]	1/38	3	0.04	0.04	0.03	0.03	0.04 – 0.08
Geoduck clam, edible meat	6/6	100	0.07	0.38	0.16	0.20	na

Tissue Type	Detection Frequency		Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Geoduck clam, gutball	3/3	100	0.12	0.19	0.15	0.15	na
Geoduck clam, whole body[e]	4/4	100	0.1	0.27	0.15	0.2	na
Benthic invertebrates, whole body	6/13	46	0.2	0.5	0.2	0.3	0.4 – 0.8
Mussel, whole body[h]	17/17	100	0.19	0.66	0.43	0.45	na
Shrimp, whole body	1/1	100	0.17	0.17	na	na	na
Chromium							
Clam, whole body[c]	10/10	100	0.3 J	1.0	0.5	0.6	na
Crab, edible meat[d, e]	7/9	78	0.1	0.1	0.1	0.09	0.1
Crab, hepatopancreas[d]	8/9	89	0.1	0.2	0.2	0.2	0.1
Crab, whole body[d]	8/9	89	0.1	0.1	0.1	0.09	0.05
Fish, fillet[f]	5/11	46	0.1	0.1	0.05	0.07	0.1
Fish, whole body[g]	36/38	95	0.2	0.6	0.3	0.3	0.2
Geoduck clam, edible meat	3/6	50	0.1	0.5	0.075	0.2	0.1
Geoduck clam, gutball	3/3	100	0.3	0.5	0.4	0.4	na
Geoduck clam, whole body[e]	4/4	100	0.1	0.2	0.15	0.2	na
Benthic invertebrates, whole body	13/13	100	2.0	10.6	2.7	4.0	na
Mussel, whole body[h]	17/17	100	0.1	0.934	0.2	0.2	na
Shrimp, whole body	1/1	100	0.5	0.5	na	na	na
Cobalt							
Clam, whole body[c]	10/10	100	0.12 J	0.36 J	0.14	0.17	na
Crab, edible meat[d, e]	9/9	100	0.09	0.17	0.11	0.10	na
Crab, hepatopancreas[d]	9/9	100	0.21	0.40	0.28	0.29	na
Crab, whole body[d]	9/9	100	0.14	0.23	0.2	0.20	na
Fish, fillet[f]	0/11	0	na	na	0.03	0.03 U	0.06
Fish, whole body[g]	5/38	13	0.08	0.12	0.05	0.05	0.06 – 0.1
Geoduck clam, edible meat	1/6	17	0.08	0.08	0.03	0.04	0.06
Geoduck clam, gutball	3/3	100	0.12	0.17	0.14	0.14	na
Geoduck clam, whole body[e]	4/4	100	0.07	0.08	0.07	0.07	na
Benthic invertebrates, whole body	5/13	39	0.5	0.6	0.5	0.40	0.6 – 1

Tissue Type	Detection Frequency		Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Mussel, whole body[h]	12/14	86	0.06	0.08	0.07	0.06	0.06
Shrimp, whole body	0/1	0	na	na	na	na	0.1
Copper							
Clam, whole body[c]	10/10	100	1.52 J	9.67 J	6.09	5.81	na
Crab, edible meat[d, e]	9/9	100	10.8	15.9	15	14.6	na
Crab, hepatopancreas[d]	9/9	100	31.1	58.5	47.6	47.5	na
Crab, whole body[d]	9/9	100	21.8	31.3	27.5	27.5	na
Fish, fillet[f]	11/11	100	0.28	1.47	0.33	0.48	na
Fish, whole body[g]	38/38	100	0.43	3.16	1.08	1.3	na
Geoduck clam, edible meat	6/6	100	3.93	15.0	6.88	7.76	na
Geoduck clam, gutball	3/3	100	19.2	28.1	28.1	25.1	na
Geoduck clam, whole body[e]	4/4	100	7.55	11.5	10.1	9.80	na
Benthic invertebrates, whole body	13/13	100	15.8	36.4	21.4	22.9	na
Mussel, whole body[h]	17/17	100	1.22	2.63	1.67	1.76	na
Shrimp, whole body	1/1	100	26.4	26.4	na	na	na
Lead							
Clam, whole body[c]	7/10	70	0.4 J	1.2 J	0.55	0.6	0.4
Crab, edible meat[d, e]	0/9	0	na	na	0.2	0.2 U	0.4
Crab, hepatopancreas[d]	0/9	0	na	na	0.2	0.2 U	0.4
Crab, whole body[d]	0/9	0	na	na	0.1	0.1 U	0.2
Fish, fillet[f]	0/11	0	na	na	0.2	0.2 U	0.4
Fish, whole body[g]	0/38	0	na	na	0.2	0.3 U	0.4 – 0.8
Geoduck clam, edible meat	1/6	17	0.5	0.5	0.2	0.3	0.4
Geoduck clam, gutball	3/3	100	0.4	0.6	0.6	0.5	na
Geoduck clam, whole body[e]	4/4	100	0.4	0.4	0.4	0.4	na
Benthic invertebrates, whole body	6/13	46	3.0	20.4	4	4.0	4 – 8
Mussel, whole body[h]	6/17	35	0.426	0.833	0.2	0.3	0.4
Shrimp, whole body	0/1	0	na	na	na	na	0.8
Molybdenum							
Clam, whole body[c]	10/10	100	0.3	0.6 J	0.45	0.5	na
Crab, edible meat[d, e]	9/9	100	0.3	0.4	0.4	0.4	na

Tissue Type	Detection Frequency		Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Crab, hepatopancreas[d]	9/9	100	0.3	0.5	0.5	0.4	na
Crab, whole body[d]	9/9	100	0.3	0.4	0.4	0.4	na
Fish, fillet[f]	11/11	100	0.2	0.3	0.2	0.2	na
Fish, whole body[g]	24/38	63	0.1	0.4	0.2	0.2	0.1 – 0.2
Geoduck clam, edible meat	6/6	100	0.8	1.4	1.1	1.0	na
Geoduck clam, gutball	3/3	100	1.6	1.7	1.6	1.6	na
Geoduck clam, whole body[e]	4/4	100	1.1	1.5	1.3	1.3	na
Benthic invertebrates, whole body	8/13	62	0.7	3	1	0.9	0.5 – 2
Mussel, whole body[h]	11/11	100	0.3	0.4	0.4	0.4	na
Shrimp, whole body	1/1	100	0.5	0.5	na	na	na
Nickel							
Clam, whole body[c]	10/10	100	0.6 J	1.2	0.8	0.8	na
Crab, edible meat[d, e]	5/9	56	0.2 J	0.4	0.2	0.2	0.2
Crab, hepatopancreas[d]	2/9	22	0.4	0.4	0.1	0.2	0.2
Crab, whole body[d]	5/9	56	0.2 J	0.3	0.2	0.2	0.1
Fish, fillet[f]	1/11	9.1	0.4 J	0.4 J	0.1	0.1	0.2
Fish, whole body[g]	8/38	21	0.2 J	1.0	0.2	0.2	0.2 – 0.4
Geoduck clam, edible meat	1/6	17	0.3	0.3	0.1	0.1	0.2
Geoduck clam, gutball	3/3	100	0.2	0.4	0.3	0.3	na
Geoduck clam, whole body[e]	4/4	100	0.2	0.2	0.2	0.2	na
Benthic invertebrates, whole body	6/13	46	1.0 J	3.0 J	1	1.0	2 – 4
Mussel, whole body[h]	6/17	35	0.106	0.230 J	0.1	0.1	0.2
Shrimp, whole body	1/1	100	2.3	2.3	na	na	na
Selenium							
Clam, whole body[c]	10/10	100	0.27 J	0.52	0.37	0.37	na
Crab, edible meat[d, e]	9/9	100	0.7	1.21	0.99	1.0	na
Crab, hepatopancreas[d]	9/9	100	1.07	1.60	1.33	1.4	na
Crab, whole body[d]	9/9	100	1.0	1.36	1	1.0	na
Fish, fillet[f]	11/11	100	0.47	0.67	0.54	0.55	na
Fish, whole body[g]	38/38	100	0.3	0.85	0.56	0.5	na

Tissue Type	Detection Frequency		Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Geoduck clam, edible meat	6/6	100	0.41	0.60	0.48	0.50	na
Geoduck clam, gutball	3/3	100	1.00	1.27	1.15	1.14	na
Geoduck clam, whole body[e]	4/4	100	0.55	0.62	0.59	0.59	na
Benthic invertebrates, whole body	13/13	100	0.5	1.2	0.69	0.7	na
Mussel, whole body[h]	11/11	100	0.37	0.60	0.51	0.49	na
Shrimp, whole body	1/1	100	0.5 J	0.5 J	na	na	na
Silver							
Clam, whole body[c]	7/10	70	0.11 J	0.26 J	0.13	0.10	0.06
Crab, edible meat[d, e]	9/9	100	0.11 J	0.18 J	0.14	0.14	na
Crab, hepatopancreas[d]	9/9	100	0.28 J	0.53 J	0.37	0.38	na
Crab, whole body[d]	9/9	100	0.18 J	0.32 J	0.23	0.24	na
Fish, fillet[f]	0/11	0	na	na	0.03	0.03 U	0.06
Fish, whole body[g]	0/38	0	na	na	0.035	0.04 U	0.06 – 0.1
Geoduck clam, edible meat	3/6	50	0.06 J	0.09 J	0.045	0.05	0.06
Geoduck clam, gutball	3/3	100	0.25 J	0.30 J	0.3	0.28	na
Geoduck clam, whole body[e]	4/4	100	0.09 J	0.1 J	0.1	0.1	na
Benthic invertebrates, whole body	1/13	7.7	0.1 J	0.1 J	0.3	0.3	0.3 – 1
Mussel, whole body[h]	0/17	0	na	na	0.03	0.02 U	0.01 – 0.06
Shrimp, whole body	1/1	100	0.2 J	0.2 J	na	na	na
Thallium							
Clam, whole body[c]	0/10	0	na	na	0.004	0.003 U	0.004 – 0.008
Crab, edible meat[d, e]	0/9	0	na	na	0.002	0.002 U	0.004 – 0.008
Crab, hepatopancreas[d]	0/9	0	na	na	0.002	0.002 U	0.004 – 0.008
Crab, whole body[d]	0/9	0	na	na	0.001	0.001 U	0.002 – 0.004
Fish, fillet[f]	0/11	0	na	na	0.002	0.002 U	0.004
Fish, whole body[g]	0/38	0	na	na	0.002	0.003 U	0.004 – 0.008
Geoduck clam, edible meat	0/6	0	na	na	0.004	0.004 U	0.008

Tissue Type	Detection Frequency		Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Geoduck clam, gutball	0/3	0	na	na	0.004	0.004 U	0.008
Geoduck clam, whole body[e]	0/4	0	na	na	0.002	0.002 U	0.004
Benthic invertebrates, whole body	8/13	62	0.005	0.012	0.01	0.009	0.008 – 0.02
Mussel, whole body[h]	0/11	0	na	na	0.002	0.002 U	0.004
Shrimp, whole body	0/1	0	na	na	na	na	0.008
Vanadium							
Clam, whole body[c]	10/10	100	0.25	0.82 J	0.36	0.45	na
Crab, edible meat[d, e]	3/9	33	0.06	0.08	0.03	0.04	0.06
Crab, hepatopancreas[d]	9/9	100	0.11	0.62	0.22	0.26	na
Crab, whole body[d]	9/9	100	0.08	0.3	0.1	0.1	na
Fish, fillet[f]	0/11	0	na	na	0.03	0.03 U	0.06
Fish, whole body[g]	17/38	45	0.06	0.49	0.05	0.20	0.06 – 0.1
Geoduck clam, edible meat	4/6	67	0.06	0.34	0.065	0.10	0.06
Geoduck clam, gutball	3/3	100	0.46	0.69	0.47	0.54	na
Geoduck clam, whole body[e]	4/4	100	0.1	0.2	0.15	0.2	na
Benthic invertebrates, whole body	13/13	100	2.8	7.2	3.8	4.0	na
Mussel, whole body[h]	11/11	100	0.16	0.42	0.34	0.32	na
Shrimp, whole body	1/1	100	0.3	0.3	na	na	na
Zinc							
Clam, whole body[c]	10/10	100	13.3 J	20.9 J	17.8	17.7	na
Crab, edible meat[d, e]	9/9	100	39.4	59.5	54.1	51.6	na
Crab, hepatopancreas[d]	9/9	100	23.5	58.1	44.1	43.6	na
Crab, whole body[d]	9/9	100	34.0	59.0	47.3	48.5	na
Fish, fillet[f]	11/11	100	8.6	13.0	9.4	9.7	na
Fish, whole body[g]	38/38	100	13.7	46.2	17.1	21.4	na
Geoduck clam, edible meat	6/6	100	7.8	15.0	9.5	10.0	na
Geoduck clam, gutball	3/3	100	20.6	27.1	25.1	24.3	na
Geoduck clam, whole body[e]	4/4	100	11.0	16.1	12	13.0	na
Benthic invertebrates, whole body	13/13	100	17.0	79.7	32	40.0	na

Tissue Type	Detection Frequency		Concentration (mg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Mussel, whole body[h]	17/17	100	11.5	49.1	19	25.4	na
Shrimp, whole body	1/1	100	16.9	16.9	na	na	na

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[b] RLs are based only on non-detect samples.

[c] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined. The clam whole body samples include all soft tissues. Shells were not included in these samples.

[d] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[e] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck. No shells were included in these samples.

[f] English sole was the only species analyzed as species-specific fillet composite samples.

[g] Four fish species (brown rockfish, juvenile Chinook salmon, English sole, and shiner surfperch) were collected. Whole body fish were collected and composited into species-specific samples for juvenile Chinook salmon, English sole, and shiner surfperch. The data shown include results for all whole-body fish samples combined.

[h] Mussel whole body samples include all soft tissues. Shells were not included in these samples.

J – estimated concentration
na – not applicable
RL – reporting limit
U – not detected at given concentration
ww – wet weight

4.2.10.4 Surface Water

Table 4-66 presents a summary of detected metals concentrations in EW surface water samples collected as part of the King County WQA and the SRI sampling events.[73] The results for both sampling events are compared in Appendix A, Attachment 1. In general, the metals concentrations in the two datasets were consistent. However, dissolved cobalt was more frequently detected in the King County WQA dataset and was detected only once in the SRI dataset. The one detected result from the SRI sampling was more than four times higher than the dissolved cobalt concentrations in the King County WQA dataset. In addition, dissolved zinc concentrations tended to be higher in the EW SRI dataset compared with the King County WQA dataset.

[73] Arsenic and mercury data are presented in Sections 4.2.7.5 and 4.2.8.5, respectively.

Table 4-66
Metals Concentrations in Surface Water

Chemical	Detection Frequency		Concentration (µg/L)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
Antimony (dissolved)	89/124	72	0.0340 J	0.156 J	0.0776	0.076	0.022 – 0.191
Antimony (total)	194/227	86	0.0150	0.150 J	0.067	0.064	0.025 – 0.193
Beryllium (total)	1/163	0.6	0.0150	0.0150	0.0075	0.0075	0.014 – 0.016
Cadmium (dissolved)	126/130	97	0.009 J	0.091[c]	0.0667	0.064	0.088
Cadmium (total)	230/233	99	0.0320	1.45	0.0677	0.071	0.088
Chromium (dissolved)	98/118	83	0.10 J	1.15 J	0.307	0.35	0.70 – 2.36
Chromium (total)	195/215	91	0.15 J	3.61 J	0.367	0.46	0.70 – 2.36
Cobalt (dissolved)	72/130	55	0.0180	0.40	0.0492	0.052	0.10 – 0.25
Cobalt (total)	164/215	76	0.0140	2.13	0.07	0.12	0.10 – 0.35
Copper (dissolved)	125/125	100	0.23	2.44	0.581	0.66	na
Copper (total)	228/228	100	0.26	8.11 J	0.934	1.1	na
Lead (dissolved)	78/130	60	0.00740 J	0.814 J	0.049	0.29	0.150 – 6.80
Lead (total)	213/233	9	0.0200 J	8.04 J	0.197	0.43	0.150 – 6.80
Nickel (dissolved)	81/125	65	0.27 J	0.855 J	0.395	0.36	0.23 – 1.00
Nickel (total)	181/222	82	0.25 J	3.37	0.473	0.52	0.23 – 1.00
Selenium (dissolved)	58/130	45	0.06 J	0.38 J	0.075	0.10	0.13 – 0.20
Selenium (total)	59/221	27	0.06 J	0.44 J	0.075	0.10	0.13 – 0.16
Silver (dissolved)	1/130	0.8	0.019	0.019	0.055	0.039	0.025 – 0.13
Thallium (dissolved)	108/130	83	0.004 J	0.012	0.0091	0.009	0.0046 – 0.020
Thallium (total)	211/233	90.6	0.00500	0.021	0.0096	0.009	0.0048 – 0.021
Vanadium (dissolved)	112/112	100	0.029 J	1.68	1.29	1.20	na
Vanadium (total)	190/191	99.5	0.029 J	9.29	1.41	1.50	0.080
Zinc (dissolved)	109/129	84.5	0.60	7.79	1.51	2.40	0.950 – 116[d]
Zinc (total)	213/233	91.4	0.620 J	15.8	1.85	2.60	0.610 – 65.0[d]

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[b] RLs are based only on non-detect samples.

[c] The maximum dissolved cadmium concentration of 37.8 µg/L was excluded because this value appears to be anomalous because the total cadmium concentration of 1.45 µg/L in the same sample was more than an order of magnitude lower than the dissolved concentration of 37.8 µg/L. In addition, a field duplicate sample collected at the same location on the same date had dissolved and total cadmium concentrations of 0.076 and 0.074 µg/L, respectively. These data indicate that there are analytical concerns with the dissolved cadmium concentration of 37.8 µg/L and that this value is anomalous and unlikely representative of conditions in EW.

[d] Maximum RLs are elevated due to blank contamination associated with two samples. For dissolved zinc, the maximum RLs associated with the affected samples were 116 µg/L and 17.4 µg/L. For total zinc, the maximum RLs were 65.0 µg/L and 32.8 µg/L.

EW – East Waterway
J – estimated concentration
na – not applicable
RL – reporting limit

The surface water metals concentrations were compared with WQC, as presented in Table 4-21. One anomalous dissolved cadmium concentration (37.8 mg/L) exceeded the marine chronic AWQC for the protection of aquatic life. However, the whole water concentration (1.45 µg/L) for this sample did not exceed the AWQC, nor did the field replicate sample (0.076 µg/L) collected with the original sample. The AWQC is based on dissolved metals concentrations. These other data indicate that this anomalous dissolved cadmium concentration is not likely representative of conditions in EW. No other metals exceeded WQC for the protection of aquatic life. In addition, the whole water concentrations of antimony, nickel, selenium, thallium, and zinc did not exceed the federal WQC based on the protection of human health.

Beryllium and silver were least frequently detected in surface water samples; only one sample had a detected concentration in either the total or dissolved fraction for each of these metals (Table 4-66). All other metals were detected in at least 55% of the samples, with the exception of selenium, which was detected in 45 and 27% of the samples for the dissolved and total fractions, respectively. Concentrations of metals in surface water samples are compared with WQC in Section 4.2.2 (Table 4-21). It should be noted that only a subset of the surface water samples were analyzed for both total and dissolved metals. There were approximately twice as many results for total metals as compared with dissolved metals.

4.2.10.5 Summary of Metals Data

Eleven metals in addition to arsenic and mercury, which are described separately in Sections 4.2.7.1 and 4.2.8.1, respectively, were detected in surface sediment. SMS criteria are available for 7 of these 11 metals, and only two metals had concentrations that exceeded the SQS or CSL. Cadmium concentrations exceeded the SQS but not the CSL in one surface sediment sample and exceeded the CSL in another surface sediment sample. Zinc concentrations exceeded the SQS but not the CSL in four surface sediment samples and exceeded the CSL in one surface sediment sample. The highest cadmium and zinc concentrations were detected in subsurface sediment samples collected from the head of Slip 27 and the mound area outside of Slip 27. The highest cadmium and zinc concentrations were detected in a subsurface sediment sample collected from the head of Slip 27 and the

mound area outside of Slip 27; maximum concentrations of both metals were detected in samples from the 0-to-2-ft interval of core SB-01 and the 2-to-4-ft interval of core S27C3. In addition to cadmium and zinc, copper, lead, and silver concentrations in subsurface sediment samples exceeded their CSL values. The cores with CSL exceedances for metals were collected from Slip 27 (Maps 4-14e and 4-14k) the area south of Slip 36 off of the former Rabanco barge loading facility and GATX (Maps 4-14h, 4-14i, and 4-14k).

For tissue, fish fillet composite samples generally had the lowest mean metals concentrations, and four invertebrate tissue types (i.e., benthic invertebrates, crab, clams, and geoducks) had the highest mean metal concentrations.

Thirteen metals were detected in surface water samples. Beryllium and silver were each detected in only one sample. Dissolved and total selenium were detected at frequencies of 45 and 27%, respectively. The remaining metals (i.e., antimony, cadmium, chromium, cobalt, copper, lead, nickel, thallium, vanadium, and zinc) were each detected in at least 55% of the samples in either the dissolved or total form.

4.2.11 SVOCs and VOCs

This section summarizes the nature and extent of SVOC concentrations (PAHs, phthalates, and other SVOCs) in surface sediment, subsurface sediment, tissue, surface water, and porewater samples. The VOC concentrations in porewater samples are also provided. The nature and extent of cPAHs are presented in Section 4.2.6.

4.2.11.1 Surface Sediment

Table 4-67 presents detection frequencies and surface sediment SVOC concentrations that were detected in at least one sample type (i.e., composite, surface sediment grab, or intertidal MIS composite samples). Two SVOCs had sediment concentrations that exceeded the SQS or CSL on a dry-weight basis: 2,4-dimethylphenol (one sample exceeded the CSL), and phenol (five samples exceeded the SQS but not the CSL). Table 4-68 presents the detection frequencies and a summary of organic carbon-normalized concentrations for SVOCs, with SMS criteria expressed in units of mg/kg OC. A total of 240 surface sediment grab samples were analyzed for all PAH compounds, with the exception of 1-methylnaphthalene;

141 surface sediment grab samples[74] were analyzed for 1-methylnaphthalene. A total of 231 surface sediment grab samples[75] were analyzed for phthalates; 231 surface sediment grab samples[76] were analyzed for other SVOCs. All four of the intertidal MIS composite samples were analyzed for PAHs, phthalates, and other SVOCs. In addition, 15 composite samples were created from discrete samples collected from the MIS intertidal areas to characterize each of the intertidal sampling areas for PAHs as described in Section 4.2.6.1.

[74] Fifteen of the 240 surface sediment grab samples analyzed for PAHs (except 1-methylnaphthalene) were field duplicates; 225 unique sampling locations had surface sediment grab samples analyzed for PAHs (except for 1-methylnaphthalene). Nine of the 141 surface sediment grab samples analyzed for 1-methylnaphthalene were field duplicates; 132 unique sampling locations had surface sediment grab samples analyzed for 1-methylnaphthalene.

[75] Fifteen of the 231surface sediment grab samples analyzed were field duplicates; 216 unique sampling locations had surface sediment grab samples analyzed for phthalates.

[76] Seven to 15 of the 133 to 231 surface sediment grab samples analyzed were field duplicates; 126 to 216 unique sampling locations had surface sediment grab samples analyzed for other SVOCs.

Table 4-67
SVOC Concentrations Detected in Surface Sediment

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
PAHs								
1-Methylnaphthalene	intertidal composite	8/15	53	10 J	4,400 J	12	330	19 – 24
	grab	36/141	26	9.9 J	2,700	10	37	19 – 59
	area-wide intertidal MIS composite	3/3	100	35	640	57	240	na
	public access intertidal MIS composite	1/1	100	690	690	na	na	na
2-Methylnaphthalene	intertidal composite	9/15	60	15 J	5,200 J	16	390	19 – 24
	grab	87/240	36	9.7 J	2,800	15	38	9.8 – 190
	area-wide intertidal MIS composite	3/3	100	35	740	61	280	na
	public access intertidal MIS composite	1/1	100	11 J	11 J	na	na	na
Acenaphthene	intertidal composite	10/15	67	16 J	5,600 J	27	480	19 – 24
	grab	126/240	53	10 J	3,000	24	97	18 – 120
	area-wide intertidal MIS composite	3/3	100	40	62	74	37	20
	public access intertidal MIS composite	1/1	100	19 J	19 J	na	na	na
Acenaphthylene	intertidal composite	7/15	47	20 J	130 J	20	34	19 – 80
	grab	109/240	45	4.4 J	630	20	35	18 – 190
	area-wide intertidal MIS composite	2/3	67	40	62	40	37	20
	public access intertidal MIS composite	1/1	100	19 J	19 J	na	na	na
Anthracene	intertidal composite	12/15	80	32 J	11,000 J	72	1,000	20 – 21
	grab	209/240	87	10 J	6,500	77	200	19 – 62
	area-wide intertidal MIS composite	3/3	100	170 J	1,100	240	500	na
	public access intertidal MIS composite	1/1	100	140	140	na	na	na

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
Benzo(a)anthracene	intertidal composite	12/15	80	82 J	16,000 J	150	1,500	20 – 21
	grab	226/240	94	9.8 J	9,000	140	330	19 – 61
	area-wide intertidal MIS composite	3/3	100	320	1,500	480	770	na
	public access intertidal MIS composite	1/1	100	290	290	na	na	na
Benzo(a)pyrene	intertidal composite	13/15	87	11 J	12,000 J	160	1,400	20
	grab	225/240	94	15 J	7,800	170	320	19 – 61
	area-wide intertidal MIS composite	3/3	100	320	1,400	550	760	na
	public access intertidal MIS composite	1/1	100	270	270	na	na	na
Benzo(b)fluoranthene	grab	228/240	95	14 J	6,600	220	430	19 – 61
	area-wide intertidal MIS composite	3/3	100	300	1,000	550	620	na
	public access intertidal MIS composite	1/1	100	310	310	na	na	na
Benzo(g,h,i)perylene	intertidal composite	12/15	80	27 J	2,200 J	62	320	20 – 21
	grab	212/240	88	10 J	1,800	57	110	18 – 61
	area-wide intertidal MIS composite	3/3	100	110	440	170	240	na
	public access intertidal MIS composite	1/1	100	58	58	na	na	na
Benzo(k)fluoranthene	grab	222/240	93	14 J	5,400	190	330	19 – 61
	area-wide intertidal MIS composite	3/3	100	300	1,000	550	620	na
	public access intertidal MIS composite	1/1	100	310	310	na	na	na
Total benzofluoranthenes[d]	intertidal composite	15/15	100	22 J	20,000 J	360	2,500	na
	grab	228/240	95	14 J	10,800	400	750	19 – 61
	area-wide intertidal MIS composite	3/3	100	600	2,000	1,100	1,200	na
	public access intertidal MIS composite	1/1	100	620	620	na	na	na

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
Chrysene	intertidal composite	15/15	100	13 J	17,000 J	230	2,000	na
	grab	230/240	96	12 J	13,000	220	520	19 – 61
	area-wide intertidal MIS composite	3/3	100	450 J	1,500	740	900	na
	public access intertidal MIS composite	1/1	100	440	440	na	na	na
Dibenzo(a,h) anthracene	intertidal composite	11/15	73	16 J	1,300 J	34	170	19 – 21
	grab	156/240	65	3.0 J	690	21	39	6.0 – 120
	area-wide intertidal MIS composite	3/3	100	60	260	110	140	na
	public access intertidal MIS composite	1/1	100	45	45	na	na	na
Dibenzofuran	intertidal composite	9/15	60	14 J	2,100 J	16	200	19 – 24
	grab	107/240	45	7.1 J	1,700	20	57	18 – 190
	area-wide intertidal MIS composite	3/3	100	27	340	44	140	na
	public access intertidal MIS composite	1/1	100	10 J	10 J	na	na	na
Fluoranthene	intertidal composite	15/15	100	15 J	44,000 J	380	4,600	na
	grab	233/240	97	12 J	75,000	300	1,100	20 – 61
	area-wide intertidal MIS composite	3/3	100	790	3,700	850	1,800	na
	public access intertidal MIS composite	1/1	100	580	580	na	na	na
Fluorene	intertidal composite	10/15	67	11 J	8,300 J	21	660	19 – 24
	grab	144/240	60	8.6 J	3,800	29	94	18 – 120
	area-wide intertidal MIS composite	3/3	100	74	940	100	370	na
	public access intertidal MIS composite	1/1	100	20	20	na	na	na
Indeno(1,2,3-cd)pyrene	intertidal composite	12/15	80	30 J	2,500 J	69	340	20 – 21
	grab	210/240	88	11 J	1,800	60	120	19 – 62
	area-wide intertidal MIS composite	3/3	100	120	480	200	270	na
	public access intertidal MIS composite	1/1	100	71	71	na	na	na

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
Naphthalene	intertidal composite	10/15	67	12 J	5,600 J	19	470	19 – 24
	grab	118/240	49	9.5 J	3,000	24	52	18 – 190
	area-wide intertidal MIS composite	3/3	100	28	850	85	320	na
	public access intertidal MIS composite	1/1	100	14 J	14 J	na	na	na
Phenanthrene	intertidal composite	12/15	80	62 J	62,000 J	150	5,000	20 – 21
	grab	230/240	96	12 J	24,000	140	520	19 – 61
	area-wide intertidal MIS composite	3/3	100	560	5,100	800	2,200	na
	public access intertidal MIS composite	1/1	100	180	180	na	na	na
Pyrene	intertidal composite	15/15	100	16 J	52,000 J	390	5,100	na
	grab	235/240	98	18 J	41,000	300	900	20 – 61
	area-wide intertidal MIS composite	3/3	100	690	3,900	720	1,800	na
	public access intertidal MIS composite	1/1	100	510	510	na	na	na
Total HPAHs[e]	intertidal composite	15/15	100	67 J	167,000 J	1,720	18,000	na
	grab	237/240	99	3.0 J	148,000 J	1,700	4,200	20
	area-wide intertidal MIS composite	3/3	100	3,550 J	15,200	4,830	7,860	na
	public access intertidal MIS composite	1/1	100	2,880	2,880	na	na	na
Total LPAHs[f]	intertidal composite	12/15	80	94 J	93,000 J	350	7,600	20 – 21
	grab	230/240	96	12 J	41,000	270	960	19 – 61
	area-wide intertidal MIS composite	3/3	100	1,010	8,800	1,270	3,700	na
	public access intertidal MIS composite	1/1	100	400 J	400 J	na	na	na
Total PAHs[g]	intertidal composite	15/15	100	67 J	260,000 J	2,120	25,000	na
	grab	237/240	99	3.0 J	155,000 J	2,000	5,100	20
	area-wide intertidal MIS composite	3/3	100	4,820 J	24,000	5,840	11,600	na
	public access intertidal MIS composite	1/1	100	3,290 J	3,290 J	na	na	na

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
Phthalates								
BEHP	grab	207/231	90	18 J	37,000	170	410	19 – 1,400
	area-wide intertidal MIS composite	0/3	0	na	na	170	170 U	280 – 410
	public access intertidal MIS composite	0/1	0	na	na	na	na	330
BBP	grab	101/231	44	4.8 J	290	17	26	6.0 – 190
	area-wide intertidal MIS composite	3/3	100	18	82	31	44	na
	public access intertidal MIS composite	1/1	100	17	17	na	na	na
Diethyl phthalate	grab	19/231	8.2	17 J	74	10	16	9.8 – 190
	area-wide intertidal MIS composite	1/3	33	12 J	12 J	9.5	9.7	15 – 19
	public access intertidal MIS composite	0/1	0	na	na	na	na	15
Dimethyl phthalate	grab	15/231	6.5	3.1 J	73	7.5	12	6.0 – 190
	area-wide intertidal MIS composite	1/3	33	11 J	11 J	7.5	8.7	15
	public access intertidal MIS composite	0/1	0	na	na	na	na	15
Di-n-butyl phthalate	grab	32/231	14	11 J	48,000	10	230	9.8 – 190
	area-wide intertidal MIS composite	1/3	33	17 J	17 J	10	12	19 – 20
	public access intertidal MIS composite	0/1	0	na	na	na	na	20
Di-n-octyl phthalate	grab	9/231	3.9	14 J	83	10	16	9.8 – 190
	area-wide intertidal MIS composite	0/3	0	na	na	10	9.8 U	19 – 20
	public access intertidal MIS composite	0/1	0	na	na	na	na	20
Other SVOCs								
1,2,4-Trichlorobenzene	grab	7/231	3.0	4.3 J	9.3	3.1	4.8	3.0 – 100
	area-wide intertidal MIS composite	0/3	0	na	na	3	3.0 U	5.8 – 6.0
	public access intertidal MIS composite	0/1	0	na	na	na	na	6.0

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
1,2-Dichlorobenzene	grab	2/231	0.9	6.2	11	3.1	4.2	0.90 – 100
	area-wide intertidal MIS composite	0/3	0	na	na	3	3.0 U	5.8 – 6.0
	public access intertidal MIS composite	0/1	0	na	na	na	na	6.0
1,3-Dichlorobenzene	grab	2/214	0.9	1.5 J	20 J	10	14	0.90 – 190
	area-wide intertidal MIS composite	0/3	0	na	na	10	9.8 U	19 – 20
	public access intertidal MIS composite	0/1	0	na	na	na	na	20
1,4-Dichlorobenzene	grab	146/231	63	1.9	15,000	10	120	0.90 – 50
	area-wide intertidal MIS composite	1/3	50	12	12	3	6.0	5.8 – 6.0
	public access intertidal MIS composite	1/1	100	13 J	13 J	na	na	na
2,4-Dimethylphenol	grab	14/231	6.1	6.1	**90 J**	3.1	13	5.8 – 500
	area-wide intertidal MIS composite	0/3	0	na	na	3	3.0 U	5.8 – 6.0
	public access intertidal MIS composite	0/1	0	na	na	na	na	6.0
2,4-Dinitrotoluene	grab	1/176	0.6	340	340	49	65	96 – 310
	area-wide intertidal MIS composite	0/3	0	na	na	49	49 U	96 – 98
	public access intertidal MIS composite	0/1	0	na	na	na	na	99
2-Methylphenol	grab	6/231	2.6	3.7 J	38 J	3.1	8.4	5.8 – 190
	area-wide intertidal MIS composite	0/3	0	na	na	3	3.0 U	5.8 – 6.0
	public access intertidal MIS composite	0/1	0	na	na	na	na	6.0
4-Methylphenol	grab	48/231	21	9.6 J	200	10	24	9.8 – 190
	area-wide intertidal MIS composite	2/3	67	11 J	24	11	15	20
	public access intertidal MIS composite	0/1	0	na	na	na	na	20
Aniline	grab	1/142	0.7	90	90	10	14	19 – 62
	area-wide intertidal MIS composite	0/2	0	na	na	na	10 U	20
	public access intertidal MIS composite	0/1	0	na	na	na	na	20

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
Benzoic acid	grab	3/231	1.3	230	340 J	100	160	180 – 2,000
	area-wide intertidal MIS composite	0/3	0	na	na	100	98 U	190 – 200
	public access intertidal MIS composite	0/1	0	na	na	na	na	200
Benzyl alcohol	grab	2/220	0.9	19 J	38 J	10	14	9.8 – 190
	area-wide intertidal MIS composite	0/3	0	na	na	10	9.8 U	19 – 20
	public access intertidal MIS composite	0/1	0	na	na	na	na	20
Bis(2-chloroisopropyl) ether	grab	1/176	0.6	38 J	38 J	10	13	19 – 62
	area-wide intertidal MIS composite	0/3	0	na	na	10	9.8 U	19 – 20
	public access intertidal MIS composite	0/1	0	na	na	na	na	20
Carbazole	grab	85/133	64	9.8 J	2,200	20	66	19 – 39
	area-wide intertidal MIS composite	3/3	100	84	980	110	390	na
	public access intertidal MIS composite	1/1	100	82	82	na	na	na
n-Nitroso-di-n-propylamine	grab	1/176	0.6	44 JN	44 JN	15	19	29 – 200
	area-wide intertidal MIS composite	0/3	0	na	na	15	15 U	29 – 30
	public access intertidal MIS composite	0/1	0	na	na	na	na	30
n-Nitrosodiphenyl-amine	grab	2/231	0.9	160 J	180	3.1	9.8	5.8 – 190
	area-wide intertidal MIS composite	0/3	0	na	na	4.2	4.4 U	8.3 – 9.8
	public access intertidal MIS composite	0/1	0	na	na	na	na	6.0
Pentachlorophenol	grab	10/231	4.3	59	110 J	16	49	29 – 1,000
	area-wide intertidal MIS composite	1/3	33	42 J	42 J	15	24	30
	public access intertidal MIS composite	0/1	0	na	na	na	na	30
Phenol	grab	94/231	41	13 J	**630**	22	55	18 – 300
	area-wide intertidal MIS composite	3/3	100	110	210	140	150	na
	public access intertidal MIS composite	1/3	100	98	98	na	na	na

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Calculated median and mean concentrations are based on the detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

[c] RLs are based only on non-detect samples.

[d] Total benzofluoranthenes were calculated as the sum of detected benzo(b)fluoranthene and benzo(k)fluoranthene. If none of the benzofluoranthenes were detected in a given sample, non-detect values represent the highest RL.

[e] Total HPAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene. If none of the individual HPAH compounds were detected in a given sample, non-detect values represent the highest RL.

[f] Total LPAHs were calculated as the sum of detected acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. If none of the individual LPAH compounds were detected in a given sample, non-detect values represent the highest RL.

[g] Total PAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, pyrene, acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. If none of the individual PAH compounds were detected in a given sample, non-detect values represent the highest RL.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
J – estimated concentration
MIS – multi-increment sampling
na – not applicable
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SQS – sediment quality standards
SVOC – semivolatile organic compound
U – not detected at given concentration

Bold identifies concentrations above the SQS and below the CSL value.
Underlined bold identifies concentrations above the CSL value.

Table 4-68

Comparison of OC-Normalized SVOC Concentrations in Surface Sediment Grab Samples with OC-Normalized SMS Criteria

Chemical	Detection Frequency[a]		Concentration (mg/kg OC)[b]					SMS Criteria (mg/kg OC)	
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[c]	Calculated Mean[c]	RL or Range of RLs[d]	SQS	CSL
PAHs									
2-Methylnaphthalene	85/235	36	0.39 J	**85**	1.2	2.2	0.59 – 12	38	64
Acenaphthene	123/235	52	0.45 J	**230**	1.6	6.1	0.69 – 12	16	57
Acenaphthylene	107/235	46	0.45 J	53	1.4	2.3	0.59 – 12	66	66
Anthracene	207/235	88	0.77 J	**230**	5	12	1.2 – 12	220	1,200
Benzo(a)anthracene	223/235	95	1.3	**350**	9.4	19	2.5 – 12	110	270
Benzo(a)pyrene	223/235	95	1.0	**240**	11	19	2.5 – 12	99	210
Benzo(g,h,i)perylene	210/235	89	0.41 J	**55**	4.1	6.4	1.2 – 12	31	78
Total benzofluoranthenes[e]	226/235	96	2.5 J	**915**	27	44	2.5 – 12	230	450
Chrysene	227/235	97	2.0	**1,100**	15	31	2.5 – 12	110	460
Dibenzo(a,h)anthracene	154/235	66	0.25 J	**21**	1.6	2.3	0.34 – 9.5	12	33
Dibenzofuran	105/235	45	0.53 J	**160**	1.45	3.9	0.69 – 12	15	58
Fluoranthene	230/235	98	2.1 J	**6,400**	19	74	2.5 – 11	160	1,200
Fluorene	142/235	60	0.45 J	**220**	1.85	6.0	0.89 – 12	23	79
Indeno(1,2,3-cd)pyrene	208/235	89	0.38 J	**58 J**	4.2	6.9	1.4 – 12	34	88
Naphthalene	116/235	49	0.45 J	91	1.6	3.3	0.59 – 12	99	170
Phenanthrene	227/235	97	1.7 J	**780**	9.1	31	2.5 – 12	100	480
Pyrene	231/235	98	2.6	**3,500**	20	57	2.6 – 11	1,000	1,400
Total HPAHs[f]	233/235	99	0.37 J	**12,500 J**	111	260	2.6 – 3.5	960	5,300
Total LPAHs[g]	227/235	97	1.7 J	**1,330**	18	58	2.5 – 12	370	780
Phthalates									

Chemical	Detection Frequency[a]		Concentration (mg/kg OC)[b]					SMS Criteria (mg/kg OC)	
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[c]	Calculated Mean[c]	RL or Range of RLs[d]	SQS	CSL
BEHP	205/226	91	1.3	**1,900**	11	24	1 – 130	47	78
BBP	99/226	44	0.56 J	**14**	1.2	1.6	0.44 – 9.5	4.9	64
Diethyl phthalate	17/226	7.5	0.72	5.3	0.75	1.2	0.45 – 12	61	110
Dimethyl phthalate	15/226	6.6	0.22 J	4.2	0.55	0.85	0.23 – 9.5	53	53
Di-n-butyl phthalate	31/226	14	0.79	**2,600**	0.96	13	0.6 – 18	220	1,700
Di-n-octyl phthalate	9/226	4.0	0.49 J	5.8	0.8	1.2	0.59 – 12	58	4,500
Other SVOCs									
1,2,4-Trichlorobenzene	7/226	3.1	0.29 J	0.67	0.23	0.35	0.18 – 7.5	0.81	1.8
1,2-Dichlorobenzene	2/226	0.9	0.37	0.78	0.18	0.31	0.045 – 7.5	2.3	2.3
1,4-Dichlorobenzene	144/226	64	0.18	**1,100**	0.84	8.6	0.056 – 4	3.1	9
n-Nitrosodiphenylamine	1/226	0.4	11 J	11 J[h]	0.28	0.66	0.18 – 9.5	11	11

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Summary statistics for OC-normalized SVOC concentrations were calculated using only samples with TOC contents ≥ 0.5% and ≤ 4.0%. At very low or very high TOC contents, OC-normalization is not appropriate for comparison to SMS (Michelsen and Bragdon-Cook 1993).

[c] Calculated median and mean concentrations are based on the detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

[d] RLs are based only on non-detect samples.

[e] Total benzofluoranthenes were calculated as the sum of detected benzo(b)fluoranthene and benzo(k)fluoranthene. If none of the benzofluoranthenes were detected in a given sample, the non-detect value represents the highest RL.

[f] Total HPAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene. If none of the individual HPAH compounds were detected in a given sample, the non-detect value represents the highest RL.

[g] Total LPAHs were calculated as the sum of detected acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. If none of the individual LPAH compounds were detected in a given sample, the non-detect value represents the highest RL.

[h] Sample exceeded dry-weight-based 2LAET value. The concentration was not organic carbon-normalized for comparison with SMS because the TOC value (10.1%) was greater than the limit for normalization (4%).

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
2LAET – second lowest apparent effects threshold
LPAH – low-molecular-weight polycyclic aromatic
nv – no value
OC – organic carbon

CSL – cleanup screening level
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated concentration
na – not applicable
nc – not calculated
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SQS – sediment quality standards
SVOC – semivolatile organic compound

Bold identifies concentrations above the SQS and below the CSL value.
Underlined bold identifies concentrations above the CSL value.

Individual PAHs were frequently detected in all surface sediment samples. Total PAH concentrations in surface sediment grab samples ranged from 3.0 to 155,000 µg/kg dw, with a mean concentration of 5,100 µg/kg dw. Total PAH concentrations in intertidal MIS composite samples ranged from 3,290 to 24,000 µg/kg dw, with a mean concentration of 9,490 µg/kg dw. Total PAH concentrations in composite samples ranged from 67 to 260,000 µg/kg dw, with a mean concentration of 25,000 µg/kg dw.

High-molecular-weight PAH (HPAH) concentrations in all samples ranged from 3 to 167,000 µg/kg dw, with mean concentrations across the three types of samples ranging from 4,200 to 18,000 µg/kg dw. The maximum HPAH concentration (167,000 µg/kg dw) was detected in a composite sample from the intertidal area on the southeastern side of the shallow main body (Map 4-48). HPAH concentrations exceeded the SQS but not the CSL in eight surface sediment grab samples (3.3% of the samples). The majority of the samples with HPAH SQS exceedances were from locations either within Slip 36 or just outside and to the south of Slip 36 (Map 4-49).

Low-molecular-weight PAH (LPAH) concentrations in all surface sediment grab samples ranged from 12 to 93,000 µg/kg dw, with mean concentrations for the three sample types ranging from of 960 to 7,600 µg/kg dw. The maximum LPAH concentration (93,000 µg/kg dw) was detected in the same composite sample that had the maximum HPAH concentration (from the intertidal area on the southeastern side of the shallow main body) (Map 4-50). LPAH concentrations exceeded the SQS but not the CSL in five surface sediment grab samples (2.1% of the samples) and the CSL in three surface sediment grab samples (1.3% of the samples).The majority of the samples with LPAH SQS and CSL exceedances were from locations either within Slip 36 or just outside and to the south of Slip 36 (Map 4-51). In addition, two surface sediment grab samples collected from the same location, north of Slip 36 had LPAH concentrations that were greater than SQS.

BEHP and BBP were the two most frequently detected phthalates (Table 4-67). BEHP was detected in 90% of the surface sediment grab samples but was not detected in the four intertidal MIS composite samples. The maximum BEHP concentration (37,000 µg/kg dw) was detected in a grab sample collected from a location just north of Slip 27, near the eastern shoreline of the EW (near the Lander CSO/storm drain) (Map 4-52). Detected concentrations of BEHP exceeded the SQS but not the CSL in four surface sediment grab samples (1.7% of

the samples) that represent three surface sediment locations (1.4% of the locations). Detected concentrations of BEHP exceeded the CSL in five surface sediment grab samples (2.2% of the samples). Samples with BEHP SQS and CSL exceedances were located in three areas: just outside of and to the south of Slip 27 near Hanford # 2 CSO and two SD outfalls, T-30 near the Lander CSO and SD and the northern portion of T-18 at Station 200 (Map 4-53).

BBP was detected in 44% of the surface sediment grab samples and in all four intertidal MIS composite samples. The maximum BBP concentration (290 µg/kg dw) was detected in a grab sample from a location just outside and to the south of Slip 36 (Map 4-54). Detected concentrations of BBP in nine surface sediment grab samples (3.9% of the samples) exceeded the SQS but not the CSL (Map 4-55). Samples with BBP exceedances were in six areas located south of Slip 27 near Hanford #2 CSO and two SD outfalls, near the mouth of Slip 27, T-25 at Station 5900, on the west side of the deep main body near Station 4800 and Station 1200, and south of Slip 36 (Map 4-55).

Among the 17 chemicals in the "other SVOC" category in Table 4-67, carbazole and 1,4-dichlorobenzene were detected most frequently. Carbazole was detected in 64% of the surface sediment grab samples and in all four intertidal MIS composite samples. The maximum carbazole concentration (2,200 µg/kg dw) was detected in a surface sediment grab sample collected from near the historic Pier 24 location. There are no SMS criteria for carbazole.

1,4-Dichlorobenzene was detected in 63% of the surface sediment grab samples and in 50% of the intertidal MIS composite samples. The maximum 1,4-dichlorobenzene (15,000 µg/kg dw) was detected in a surface sediment grab sample collected from a location near Hanford # 2 CSO and two SD outfalls (Map 4-56). Detected concentrations of 1,4-dichlorobenzene exceeded the SQS but not the CSL in 20 surface sediment grab samples (8.7% of the samples) and the CSL in 9 surface sediment grab samples (3.9% of the samples). Eight of the nine surface sediment grab samples that had 1,4-dichlorobenzene concentrations that exceeded the CSL were collected from locations between Stations 5000 and 4200 (Map 4-57). Discussion of the source control activities for 1,4-dichlorobenzene associated with the Hanford #2 CSO is provided in Appendix F.

Other chemicals that are not discussed above but had surface sediment concentrations that exceeded the SQS or CSL are 2,4-dimethylphenol (one sample exceeded the CSL), and phenol (five samples exceeded the SQS but not the CSL),

4.2.11.2 Subsurface Sediment

Table 4-69 presents detection frequencies and subsurface sediment SVOC concentrations that were detected in at least one subsurface sediment sample. Four SVOCs had sediment concentrations that exceeded the SQS or CSL on a dry-weight basis: phenol (1 detected result above the SQS), 2-methyl phenol (1 detected result above the CSL), 4-methyl phenol (2 detected results above the CSL), and 2,4-dimethylphenol (12 detected results above the CSL). Table 4-68 presents the detection frequencies and a summary of organic carbon-normalized concentrations for SVOCs with SMS criteria expressed in units of mg/kg OC. A total of 326 subsurface sediment samples from 205 cores collected prior to dredging were analyzed for SVOCs. Tables 4-69 and 4-70 present summaries of subsurface SVOC data for samples collected from any interval. The subsurface sediment SVOC concentrations were compared with SMS criteria, as presented in Table 4-18. All of the SVOC compounds exceeded the SQS in at least one subsurface sediment sample, except for diethylphthalate, benzoic acid, hexachlorobenzene, hexachlorobutadiene, and pentachlorophenol. The greatest number of exceedances were associated with PAH compounds.

Table 4-69
SVOC Concentrations Detected in Subsurface Sediment

Chemical	Detection Frequency[a]		Concentration (µg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[b]
PAHs					
1-Methylnaphthalene	67/172	39	9.6	8,900	4.8 – 93
2-Methylnaphthalene	123/269	46	5.3 J	7,200	4.8 – 780
Acenaphthene	157/269	58	7.7	11,000	4.8 – 460
Acenaphthylene	98/269	36	10 J	5,100	4.8 – 780
Anthracene	204/269	76	8.7 J	17,000	4.8 – 130
Benzo(a)anthracene	211/269	78	12	20,000	4.8 – 130
Benzo(a)pyrene	213/269	79	10	17,000	4.8 – 130
Benzo(b)fluoranthene	97/109	89	22	18,000	19 – 130
Benzo(g,h,i)perylene	198/269	74	6.8	7,200	4.8 – 390

Chemical	Detection Frequency[a]		Concentration (µg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[b]
Benzo(k)fluoranthene	98/109	90	22	13,000	19 – 130
Total benzofluoranthenes[c]	217/269	81	17 J	31,000	4.8 – 130
Chrysene	210/268	78	14 J	20,000	4.8 – 130
Dibenzo(a,h)anthracene	165/269	61	6.5 J	1,200	4.8 – 780
Dibenzofuran	141/269	52	5.0 J	9,600	4.8 – 870
Fluoranthene	222/269	83	11 J	54,000	4.8 – 120
Fluorene	174/269	65	9.7	12,000	4.8 – 460
Indeno(1,2,3-cd)pyrene	194/269	72	5.8	4,400	4.8 – 390
Naphthalene	170/269	63	3.0 J	24,000	4.8 – 780
Phenanthrene	216/269	80	4.0 J	73,000	4.8 – 390
Pyrene	226/269	84	9.8 J	57,000	4.8 – 130
Total HPAHs[d]	231/269	86	9.8 J	212,000	4.8 – 120
Total LPAHs[e]	219/269	81	4.0 J	139,000	4.8 – 120
Total PAHs[f]	233/269	87	9.8 J	350,000	4.8 – 120
Phthalates					
BEHP	197/265	74	13 J	13,000 J	18 – 3,800
BBP	97/265	37	7.0 J	350	9.2 – 780
Diethyl phthalate	11/265	4.2	10 J	86	14 – 780
Dimethyl phthalate	14/265	5.3	10 J	880	9.2 – 780
Di-n-butyl phthalate	44/265	17	4.0 J	190	18 – 780
Di-n-octyl phthalate	3/264	1.1	31	190 J	18 – 780
Other SVOCs					
1,2,4-Trichlorobenzene	10/266	3.8	6.0	62	4.4 – 780
1,2-Dichlorobenzene	3/265	1.1	4.0 J	83	0.90 – 780
1,3-Dichlorobenzene	6/265	2.3	2.1 J	100	0.90 – 780
1,4-Dichlorobenzene	76/265	29	0.90	540	0.90 – 780
2,4-Dimethylphenol	16/265	6.0	6.0	**1,400**	5.8 – **780**
2-Methylphenol	8/264	3.0	7.4	**620**	5.8 – **780**
4-Methylphenol	69/265	26	11 J	**2,000**	18 – 460
4-Nitroaniline	1/171	0.60	140 J	140 J	95 – 2,100
Benzoic acid	3/250	1.2	47 J	71 J	97 – 7,800
Carbazole	67/160	42	11 J	2,500	19 – 140
Hexachlorobenzene	2/265	0.80	0.65	1.7	0.074 – 140
Hexachlorobutadiene	2/265	0.80	1.3	1.3	0.89 – 140

Chemical	Detection Frequency[a]		Concentration (µg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[b]
Hexachloroethane	1/235	0.40	35	35	19 – 420
n-Nitroso-di-n-propylamine	5/172	2.9	34 J	350	29 – 480
n-Nitrosodiphenylamine	2/265	0.80	12	160	5.8 – 780
Pentachlorophenol	4/238	1.7	52	120	20 – 3,900
Phenol	46/265	17	16 J	**620**	18 – **780**
Retene	1/4	25	28 J	28 J	120 – 140

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] RLs are based only on non-detect samples.

[c] Total benzofluoranthenes were calculated as the sum of detected benzo(b)fluoranthene and benzo(k)fluoranthene. If none of the benzofluoranthenes were detected in a given sample, the non-detect value represents the highest RL.

[d] Total HPAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene. If none of the individual HPAH compounds were detected in a given sample, the non-detect value represents the highest RL.

[e] Total LPAHs were calculated as the sum of detected acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. If none of the individual LPAH compounds were detected in a given sample, the non-detect value represents the highest RL.

[f] Total PAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, pyrene, acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. If none of the individual PAH compounds were detected in a given sample, the non-detect value represents the highest RL.

BEHP – bis(2-ethylhexyl phthalate
BBP – butyl benzyl phthalate
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SVOC – semivolatile organic compound

Bold identifies concentrations above the SQS and below the CSL value.
Underlined bold identifies concentrations above the CSL value.

Table 4-70
OC-Normalized SVOC Concentrations Detected in Subsurface Sediment

Chemical	Detection Frequency		SVOC Concentration (mg/kg OC)				
	Ratio	%	Minimum Detect	Maximum Detect	RL or Range of RLs	SQS	CSL
PAHs							
2-Methylnaphthalene	103/200	52	0.49	**560**	0.70 – 13	38	64
Acenaphthene	129/200	65	0.64	**1,300**	0.70 – 11	16	27
Acenaphthylene	79/200	40	0.44	**42**	0.56 – 13	66	66

Chemical	Detection Frequency		SVOC Concentration (mg/kg OC)				
	Ratio	%	Minimum Detect	Maximum Detect	RL or Range of RLs	SQS	CSL
Anthracene	172/200	86	0.82	**520**	0.95 – 6.0	220	1,200
Benzo(a)anthracene	179/200	90	1.2	**610**	1.9 – 5.9	110	270
Benzo(a)pyrene	180/200	90	1	**430**	1.9 – 6.0	99	210
Benzo(g,h,i)perylene	167/200	84	0.59	**75**	0.95 – 6.0	31	78
Total benzofluoranthenes	182/200	91	1.1	**600**	1.9 – 3.8	230	450
Chrysene	178/199	89	1.4	**720**	1.9 – 5.9	110	460
Dibenzo(a,h)anthracene	138/200	69	0.43	**49**	0.45 – 13	12	33
Dibenzofuran	115/200	58	0.58	**760**	0.70 – 25	15	58
Fluoranthene	185/200	93	1.8	**1,800**	2.1 – 3.8	160	1,200
Fluorene	147/200	74	0.36	**820**	0.79 – 6.0	23	79
Indeno(1,2,3-cd)pyrene	163/200	82	0.59	**80**	0.95 – 13	34	88
Naphthalene	143/200	72	0.37	**2,800**	0.95 – 11	99	170
Phenanthrene	183/200	92	1.3	**2,700**	1.9 – 3.8	100	480
Pyrene	187/200	94	1.3	**1,400**	2.2 – 4.7	1,000	1,400
Total HPAHs	188/200	94	1.3	**5,590**	2.2 – 3.8	960	5,300
Total LPAHs	184/200	92	1.3	**8,200**	1.9 – 3.8	370	780
Phthalates							
BEHP	154/198	78	0.79	**190**	1.1 – **110**	47	78
BBP	84/198	42	0.58	**7.3**	0.35 – 13	4.9	64
Diethyl phthalate	9/198	4.5	0.74	11	0.50 – 13	61	110
Dimethyl phthalate	12/198	6.1	0.43	24	0.35 – 13	53	53
Di-n-butyl phthalate	28/198	14	0.74	22	0.63 – 13	220	1,700
Di-n-octyl phthalate	1/197	0.50	4.4	4.4	0.50 – 13	58	4,500
Other SVOCs							
1,2,4-Trichlorobenzene	6/199	3.0	0.37	**2.2**	0.15 – **13**	0.81	1.8
1,2-Dichlorobenzene	1/198	0.50	0.81	0.81	0.037 – 13	2.3	2.3
1,4-Dichlorobenzene	64/198	32	0.039	**16**	0.037 – **13**	3.1	9.0
Hexachlorobenzene	2/198	1.0	0.033	0.047	0.0074 – **13**	0.38	2.3
Hexachlorobutadiene	1/198	0.50	0.081	0.081	0.026 – **13**	3.9	6.2
n-Nitrosodiphenylamine	2/198	1.0	0.4	**21**	0.20 – **13**	11	11
Total PCBs	168/215	78	0.31	**400**	0.17 – 7.5	12	65

BEHP – bis(2-ethylhexyl) phthalate
BBP – butyl benzyl phthalate
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
OC – organic carbon
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SVOC – semivolatile organic compound

Bold identifies concentrations above the SQS and below the CSL value.
Underlined bold identifies concentrations above the CSL value.

Over 90% of the subsurface sediment samples in Table 4-69 were collected from the top 4 ft of sediment. Relatively few samples from depths > 4 ft below the mudline were analyzed; most of those samples were collected and analyzed as part of the SRI at locations with SMS exceedances in upper intervals, and some samples were analyzed as > 4-ft composite samples for dredging characterizations.

Total LPAHs, total HPAHs, and BEHP were the SVOCs with the greatest number of surface sediment concentrations above SQS values. Subsurface sediment LPAH concentrations are shown on Maps 4-58a through 4-58c, HPAH concentrations are shown on Maps 4-59a through 4-59c, BEHP concentrations are shown on Maps 4-60a through 4-60c, and BBP concentrations are shown on Maps 4-61a through 4-61c. The highest LPAH and HPAH concentrations were co-located and detected in subsurface sediment samples collected from the head of Slip 27 (Maps 4-58a and 4-59a), the mound area outside of Slip 27 (Maps 4-58a and 4-59a), the T-30/former Rabanco barge loading facility and GATX (Maps 4-58c and 4-59c), and the head of Slip 36 (Maps 4-58c and 4-59c). Subsurface sediment LPAH concentrations above the CSL were detected in samples from the deepest intervals of core EW10-SB01 located in the mound outside of Slip 27, including the 12-to-14-, 16-to-18-, and 24-to-26-ft intervals. In addition, subsurface sediment LPAH concentrations above the SQS value were detected in samples from the10-to-12-ft interval of EW10-SC29, which was collected from the vicinity of core EW10-SB01on the mound area outside of Slip 27.

Subsurface sediment BEHP concentrations are shown on Maps 4-59a through 4-59c. Subsurface sediment BEHP concentrations that exceeded the numeric 95th percentile (760 µg/kg) were found in various locations throughout the EW. The highest BEHP concentrations were detected in the 0-to-4-ft interval of core S48 (13,000 µg/kg) collected from near T25/Hanford # 2 CSO and the head of Slip 27, the 2-to-4-ft interval of core SC23 (5,800 µg/kg),the 2-to-4-ft interval of core S27-C3 (5,500 µg/kg), and the 0-to-2-ft interval of core EW10-SC27 (4,700 µg/kg).

4.2.11.3 Tissue

Table 4-71 presents the detection frequencies and ranges of SVOC concentrations in tissue. Of the SVOCs listed in Table 4-71, PAHs, benzoic acid, and phenol were the only compounds detected in 14% or more of the tissue samples.

Table 4-71
SVOC Concentrations Detected in Fish and Invertebrate Tissues

Chemical	Detection Frequency[a]		Concentration (µg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	Range of RLs[c]
PAHs							
1-Methylnaphthalene	67/125	54	0.28 J	16	0.96	11	0.24 – 330
2-Methylnaphthalene	64/131	49	0.50 J	43	1.4	12	0.48 – 330
Acenaphthene	99/131	76	0.45 J	130 J	2.9	14	0.25 – 330
Acenaphthylene	99/131	76	0.074 J	11	0.48	10	0.48 – 330
Anthracene	110/131	84	0.29 J	350	2.3	20	0.50 – 330
Benzo(a)anthracene	66/131	50	0.35 J	350	2.9	24	0.47 – 330
Benzo(a)pyrene	71/131	54	0.12 J	290	1.4	25	0.47 – 330
Benzo(b)fluoranthene	82/131	63	0.15 J	290	3	28	0.47 – 330
Benzo(g,h,i)perylene	83/131	63	0.067 J	130 J	0.92	17	0.47 – 330
Benzo(k)fluoranthene	81/131	62	0.11 J	290	1.5	25	0.48 – 330
Total benzofluoranthenes[d]	83/131	63	0.18 J	580	4.2	43	0.48 – 330
Chrysene	69/131	53	0.31 J	510	3.3	34	0.47 – 330
Dibenzo(a,h)anthracene	65/131	50	0.071 J	130 J	0.39	14	0.25 – 330
Dibenzofuran	105/131	80	0.12 J	130	2	14	4.6 – 330
Fluoranthene	83/131	63	0.39 J	760	12	49	0.49 – 330
Fluorene	109/131	83	0.19 J	130	2.4	15	4.8 – 330
Indeno(1,2,3-cd)pyrene	79/131	60	0.10 J	130 J	1.1	16	0.48 – 330
Naphthalene	28/131	21	1.0	130	2	13	0.52 – 330
Perylene	47/99	48	0.11 J	21	0.4	1.2	0.47 – 3.7
Phenanthrene	101/131	77	0.38 J	220	6.6	23	0.85 – 330
Pyrene	81/131	62	0.23 J	900	6	49	0.49 – 330
Total HPAHs[e]	105/131	80	0.37 J	3,210	29.8	190	0.49 – 330
Total LPAHs[f]	117/131	89	1.00 J	550	16.6	48	43 – 330
Total PAHs[g]	120/131	92	3.14 J	3,760	45.4	200	100 – 330
Phthalates							
Diethyl phthalate	1/117	0.9	410	410	100	150	27 – 1,300
Other SVOCs							
1,4-Dichlorobenzene	1/117	0.9	4,800	4,800	100	190	16 – 1,300
2-Methylphenol	6/117	5.1	44	87.9	100	150	43 – 1,300
Benzoic acid	37/115	32	530 J	13,000 J	1,700	2,400	1,000 – 13,000

Chemical	Detection Frequency[a]		Concentration (µg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	Range of RLs[c]
Pentachlorophenol	2/70	2.9	6.0 J	8.2 J	2.1	55	2.0 – 1,600
Phenol	16/117	14	310	1,400	150	230	43 – 1,300

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Calculated median and mean concentrations are based on the detected concentrations and one-half the RL for non-detected results.

[c] RLs are based only on non-detect samples.

[d] Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene. If none of the benzofluoranthenes were detected in a given sample, the non-detect value represents the highest RL.

[e] Total HPAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene. If none of the individual HPAH compounds were detected in a given sample, the non-detect value represents the highest RL.

[f] Total LPAHs were calculated as the sum of detected acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. If none of the individual LPAH compounds were detected in a given sample, the non-detect value represents the highest RL.

[g] Total PAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, pyrene, acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. If none of the individual PAH compounds were detected in a given sample, the non-detect value represents the highest RL.

HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated concentration
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SVOC – semivolatile organic compound
ww – wet weight

In general, 20 individual PAHs were frequently detected in all tissue types except brown rockfish whole-body samples, in which only 8 individual PAH compounds were detected, and juvenile Chinook salmon whole-body composite sample and the single coonstripe shrimp whole-body composite sample, in which no PAHs were detected (Table 4-72). Detected individual PAH concentrations ranged from 0.067 to 900 µg/kg ww, and RLs for non-detected results ranged from 0.24 to 330 µg/kg ww. The highest mean total PAH, total LPAH, and total HPAH concentrations (1,500, 170, and 1,300 µg/kg ww, respectively) were detected in benthic invertebrate composite samples. The lowest mean total PAH and total LPAH concentrations (7.2 µg/kg ww and 1.4 µg/kg ww, respectively) were detected in individual geoduck edible-meat samples, and the lowest mean total HPAH concentration (1.3 µg/kg ww) was detected in fish fillet composite samples.

Table 4-72
Detection Frequencies for SVOCs in Tissue Samples

Chemical	Detection Frequency (%)[a]														
	Fish					Invertebrates									
	Brown Rockfish, Whole Body (n = 13)	English Sole, Whole Body (n = 11)	Juvenile Chinook Salmon, Whole Body (n = 6)	Shiner Surfperch, Whole Body (n = 8)	English Sole, Fillet (n = 11)	Crab, Whole body (n = 9)[b, c]	Crab, Edible Meat (n = 9)[c]	Crab, Hepatopancreas (n = 9)[c]	Clam, Soft Tissue (n = 11)[d]	Mussel, Whole body (n = 17)	Shrimp, Whole Body (n = 1)	Geoduck Clam, Whole body (n = 4)[b]	Geoduck Clam, Edible Meat (n = 6)	Geoduck Clam, Gutball (n = 3)	Benthic Invertebrates, Whole Body (n = 13)
PAHs															
1-Methylnaphthalene	92	36	0	100	64	67	11	56	100	100	0	0	0	0	15
2-Methylnaphthalene	92	36	0	100	55	67	11	56	91	53	0	0	0	0	23
Acenaphthene	92	91	0	100	100	100	100	78	100	71	0	50	0	33	54
Acenaphthylene	92	91	0	100	100	78	44	78	100	65	0	100	100	100	39
Anthracene	77	91	0	100	100	89	89	78	100	65	0	100	100	100	100
Benzo(a)anthracene	0	18	0	25	9.1	78	33	67	100	82	0	100	0	100	100
Benzo(a)pyrene	0	46	0	13	9.1	78	33	67	100	65	0	100	100	100	100
Benzo(b)fluoranthene	0	73	0	75	18	89	33	78	100	65	0	100	100	100	100
Benzo(g,h,i)perylene	0	82	0	75	18	89	44	78	91	65	0	100	100	100	100
Benzo(k)fluoranthene	0	73	0	63	27	89	22	78	100	65	0	100	100	100	100
Total benzofluoranthenes[e]	0	73	0	75	27	89	33	78	100	65	0	100	100	100	100
Chrysene	0	18	0	25	0	78	56	67	100	94	0	100	0	100	100
Dibenzo(a,h)anthracene	0	73	0	38	0	78	11	67	27	65	0	100	100	100	100
Dibenzofuran	92	91	0	100	100	100	100	78	100	65	0	100	100	100	31
Fluoranthene	0	9	0	13	100	89	89	67	100	100	0	100	0	100	100

Table 4-72
Detection Frequencies for SVOCs in Tissue Samples (cont.)

Chemical	Detection Frequency (%)[a]														
	Fish					Invertebrates									
	Brown Rockfish, Whole Body (n = 13)	English Sole, Whole Body (n = 11)	Juvenile Chinook Salmon, Whole Body (n = 6)	Shiner Surfperch, Whole Body (n = 8)	English Sole, Fillet (n = 11)	Crab, Whole body (n = 9)[b, c]	Crab, Edible Meat (n = 9)[c]	Crab, Hepatopancreas (n = 9)[c]	Clam, Soft Tissue (n = 11)[d]	Mussel, Whole body (n = 17)	Shrimp, Whole Body (n = 1)	Geoduck Clam, Whole body (n = 4)[b]	Geoduck Clam, Edible Meat (n = 6)	Geoduck Clam, Gutball (n = 3)	Benthic Invertebrates, Whole Body (n = 13)
Fluorene	92	91	0	100	100	100	100	78	100	65	0	100	100	100	62
Indeno(1,2,3-cd)pyrene	0	82	0	63	18	89	22	78	82	65	0	100	100	100	100
Naphthalene	92	0	0	0	0	44	11	33	27	0	0	0	0	0	39
Perylene	0	10	na	0	0	86	11	86	100	100	na	100	67	100	na
Phenanthrene	0	73	0	100	100	89	89	78	100	82	0	100	100	100	100
Pyrene	0	9.1	0	13	100	89	89	67	100	88	0	100	0	100	100
Total HPAHs[f]	0	82	0	75	100	100	100	78	100	100	0	100	100	100	100
Total LPAHs[g]	92	91	0	100	100	100	100	78	100	82	0	100	100	100	100
Total PAHs[h]	92	91	0	100	100	100	100	78	100	100	0	100	100	100	100
Phthalates															
Diethyl phthalate	0	0	0	0	9	0	0	0	0	0	0	0	0	0	na
Other SVOCs															
1,4-Dichlorobenzene	0	9.1	0	0	0	0	0	0	0	0	0	0	0	0	na
2-Methylphenol	0	0	0	0	0	0	0	0	0	35	0	0	0	0	na
Benzoic acid	0	0	0	0	0	0	0	0	70	100	0	100	100	100	na
Pentachlorophenol[i]	0	0	0	0	0	0	0	0	20	0	0	0	0	0	na
Phenol	0	0	0	0	0	89	0	89	0	0	0	0	0	0	na

Table 4-72

Detection Frequencies for SVOCs in Tissue Samples (cont.)

Note: Brown rockfish whole-body samples and geoduck edible meat samples were analyzed as individual samples. All other tissue samples were analyzed as composite samples.

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Whole body concentrations were calculated from edible meat and hepatopancreas results for crab, and from edible meat and gutball results for geoduck. Shells were not included in these samples.

[c] Two species of crab (red rock and Dungeness) were collected and composited into species-specific and tissue-specific samples. The data shown include results for all crab samples combined.

[d] Four species of clams (butter, cockle, Eastern soft-shell, and native little neck) were collected in intertidal areas and composited into species-specific and location-specific samples. The data shown include results for all intertidal clam samples combined. The clam whole body samples include all soft tissues. Shells were not included in these samples.

[e] Total benzofluoranthenes were calculated as the sum of detected benzo(b)fluoranthene and benzo(k)fluoranthene.

[f] Total HPAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

[g] Total LPAHs were calculated as the sum of detected acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

[h] Total PAHs were calculated as the sum of detected benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, pyrene, acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

[i] The sample count for pentachlorophenol is lower for English sole (n = 3 for whole-body and fillet), surfperch shiner (n = 3), crab (n = 3 for edible meat, hepatopancreas, and whole body), and mussel (n = 9) samples, because samples were re-composited and re-analyzed using a more sensitive analytical method (EPA 8041) to achieve lower DLs.

HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated concentration
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
na – not applicable (not analyzed for phthalates or other SVOCs)
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SVOC – semivolatile organic compound
ww – wet weight

Benzoic acid, which was the second most frequently detected SVOC in tissue after the PAHs, was detected in all geoduck and mussel samples and in 70% of the clam composite samples. Detected benzoic acid concentrations ranged from 530 to 13,000 µg/kg ww. The highest mean benzoic acid concentration (7, 400 µg/kg ww) was detected in individual geoduck edible meat samples, and the lowest mean benzoic acid concentration (990 µg/kg ww) was detected in clam edible-meat composite samples. Benzoic acid was not detected in fish or crab samples, and associated RLs were elevated and ranged from 1,000 to 13,000 µg/kg ww. Elevated RLs were caused by analytical dilutions that were used to minimize matrix interferences. Shiner surfperch whole-body composite samples had the highest RLs (13,000 µg/kg ww). Shiner surfperch samples were analyzed with a higher analytical dilution because of a higher lipid content (4.73% ww) relative to that of other tissue types (0.207 to 3.4% ww).

4.2.11.4 Surface Water

Individual PAH compounds were detected in 12 of the 59 samples in the surface water dataset. The most frequently detected PAHs were acenapthene (20%), fluoranthene (25%), naphthalene (29%), phenanthrene (22%), and pyrene (25%). The remaining PAHs (i.e., 1-methylnaphthalene, 2-methylnaphthalene, anthracene, benzo(a)anthracene, chrysene, dibenzofuran, and fluorene) were detected at frequencies that ranged from 1.7 to 6. 8%. The majority of the detections were for samples collected during the two wet season events (49%) or the one storm event (41%). A much smaller number of detections (10%) were in samples collected during the two dry season events. Sixty-seven percent of the detections were for samples collected from 1 m below the water surface, and thirty-three percent were in samples collected from 1 m above the sediment surface.

Three SVOCs other than PAHs were detected in surface water samples: BEHP, diethyl phthalate, and 1,4-dichlorobenzene (Table 4-73). Detection frequencies of these three chemicals were very low, ranging from 1.7 to 5.1%. None of the surface water SVOC concentrations exceeded the chronic AWQC for the protection of aquatic life. Concentrations of SVOCs in surface water samples are compared with WQC in Section 4.2.2 (Table 4-21).

Table 4-73
SVOC Concentrations Detected in Surface Water

Chemical	Detection Frequency		Concentration (µg/L)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL or Range of RLs[b]
PAHs							
1-Methylnaphthalene	3/59	5.1	0.015	0.091	0.0050	0.0068	0.010
2-Methylnaphthalene	4/59	6.8	0.010	1.0 J	0.0050	0.025	0.010 – 0.028
Acenaphthene	12/59	20	0.010	0.20	0.0050	0.011	0.010
Anthracene	2/59	3.4	0.011 J	0.057	0.0050	0.0060	0.010
Benzo(a)anthracene	1/59	1.7	0.020	0.020	0.0050	0.0053	0.010
Chrysene	4/59	6.8	0.010	0.024	0.0050	0.0056	0.010
Dibenzofuran	1/59	1.7	0.13	0.13	0.0050	0.0071	0.010
Fluoranthene	15/59	25	0.010	0.19	0.0050	0.012	0.010 – 0.018
Fluorene	3/59	5.1	0.015 J	0.16	0.0050	0.0080	0.010
Naphthalene	17/59	29	0.011	12	0.0090	0.26	0.010 – 0.042
Phenanthrene	13/59	22	0.010	0.9 J	0.0050	0.03	0.010 – 0.036
Pyrene	15/59	25	0.010	0.12	0.0050	0.0096	0.010
Phthalates							
BEHP	3/59	5.1	2.3	7.8	0.50	1.2	1.0 – 54
Diethyl phthalate	2/59	3.4	1.4	2.2	0.50	0.54	1.0
Other SVOCs							
1,4-Dichlorobenzene	1/59	1.7	3.1	3.1	0.50	0.54	1.0

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[b] RLs are based only on non-detected samples.

BEHP – bis(2-ethylhexyl) phthalate
J – estimated concentration
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SVOC – semivolatile organic compound

4.2.11.5 Porewater

Intertidal porewater samples were collected and analyzed for VOCs (Maps 4-9a and 4-9b). The VOC method includes the analysis of contaminants that are also classified as SVOCs. Two of the three detected chemicals were SVOCs: naphthalene and cis-1,2 dichloroethene.[77] The other detected chemical was benzene which is a VOC. These chemicals were infrequently detected in the 13 porewater samples (Table 4-74). Naphthalene was detected in two samples, benzene was detected in two samples, and cis-1,2-dichloroethene was detected in one sample. The mean concentration of naphthalene was 4.2 µg/L, and the mean concentration of benzene was 0.12 µg/L. Porewater concentrations of benzene and cis-1,2-dichloroethene did not exceed the chronic AWQC values for these compounds. There is no aquatic life AWQC value for naphthalene.

Table 4-74
SVOC and VOC Concentrations Detected in Porewater

Chemical	Detection Frequency		Concentration (µg/L)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[a]	Calculated Mean[a]	RL[b]
Naphthalene	2/13	15	3.4	48	0.25	4.2	0.50
Benzene	2/13	15	0.20	0.30	0.1	0.12	0.20
cis-1,2-Dichloroethene	1/13	7.7	0.30	0.30	0.1	na	0.20

[a] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.
[b] RLs are based only on non-detect samples.
na – not applicable
RL – reporting limit
VOC – volatile organic compound

4.2.11.6 Summary of SVOC and VOC Data

PAHs and BEHP were the most frequently detected SVOCs in surface sediment. Mean concentrations of total PAHs and BEHP in surface sediment grab samples were 5,100 and 410 µg/kg dw, respectively. The surface sediment samples with the highest PAH concentrations were collected from located either within Slip 36, just south of Slip 36 off of T-30/former Rabanco barge loading facility and GATX, and off of the historic Pier 24

[77] Naphthalene and cis-1,2 dichloroethene results were from the VOC analysis (EPA 8260).

location. Samples with BEHP SQS and CSL exceedances were located in three areas: just outside of and to the south of Slip 27 near Hanford # 2 CSO and two SD outfalls, T-30 near the Lander CSO and SD and the northern portion of T-18 at Station 200. Most of the samples with the highest BEHP concentrations were collected from locations off of T-25 near the Hanford # 2 CSO and two SD outfalls. Other SVOCs most frequently detected in surface sediment included carbazole, 1,4-dichlorobenzene, BBP, and phenol. The remaining SVOCs had detection frequencies < 41% for surface sediment grab samples.

PAHs and BEHP were also the most frequently detected SVOCs in subsurface sediment. The highest PAH concentrations were detected in subsurface sediment samples collected from the head of Slip 27, the mound area outside of Slip 27, and the T-30/former GATX area. Subsurface sediment BEHP concentrations above the 95th percentile were detected throughout EW.

PAHs were the most frequently detected SVOCs in tissue samples. Benzoic acid was detected in 32% of the tissue samples. The five remaining detected SVOCs (i.e., diethyl phthalate, 1,4-dichlorobenzene, 2-methylphenol, pentachlorophenol, and phenol) were infrequently detected in tissue samples (i.e., ≤ 14% of the samples). Twelve individual PAHs were detected in surface water samples at frequencies that ranged from 1.7 to 29%. Three other SVOCs were detected in surface water: BEHP, diethyl phthalate, and 1,4-dichlorobenzene, at detection frequencies of 5.1, 3.4, and 1.7%, respectively. Twelve porewater samples were analyzed for VOCs and SVOCs. Naphthalene was detected in two samples, benzene was detected in two samples, and cis-1,2-dichloroethene was detected in one sample.

4.2.12 Organochlorine Pesticides

This section summarizes the nature and extent of organochlorine pesticide concentrations in surface sediment, subsurface sediment, and tissue samples. None of the surface water or porewater samples collected from the EW were analyzed for organochlorine pesticides. Organochlorine pesticides are hydrophobic and lipophilic organic contaminants that tend to be strongly associated with sediment and tissue. Because these contaminants have been rarely detected in sediment and tissues in the EW, the analysis of organochlorine pesticides in surface water was not required by EPA. Porewater was evaluated as a component of the analysis of bulk sediment samples.

Some of the pesticide data are uncertain because of analytical interference from the presence of PCB congeners, as identified by both the analytical laboratory and the data validators during the analyses of benthic invertebrate, fish, and crab tissue. Samples with this probable interference were assigned a JN-qualifier, indicating that analytical interference has resulted in values that are highly uncertain and biased high. The tissue samples analyzed as part of the SRI were analyzed by a gas chromatography/mass spectrometry/mass spectrometry (GC/MS/MS) method that was developed to resolve the issues associated with PCB interference in the analysis of pesticides. Therefore, the JN-qualifiers are associated with older data that were not collected for the SRI.

4.2.12.1 Surface Sediment

Surface sediment grab samples collected from up to 143 locations were analyzed for organochlorine pesticides (Table 4-75).[78] All four of the intertidal MIS composite samples were analyzed for organochlorine pesticides. Table 4-75 presents detection frequencies and concentrations of organochlorine pesticides that were detected in at least one surface sediment sample type (i.e., surface sediment grab or intertidal MIS composite). Organochlorine pesticides were not detected in the intertidal MIS composite samples and were detected in 5.6% or fewer of the surface sediment grab samples analyzed for organochlorine pesticides.

[78] Nine of the 143 surface sediment grab samples analyzed for DDT-related compounds were field duplicates; 134 unique sample locations had surface sediment grab samples analyzed for DDT-related compounds. Seven of the 91 surface sediment grab samples analyzed for aldrin, dieldrin, and total chlordane were field duplicates; 84 unique sample locations had surface sediment grab samples analyzed for aldrin, dieldrin, and total chlordane. Seven of the 79 surface sediment grab samples analyzed for trans-nonachlor were field duplicates; 72 unique sample locations had surface sediment grab samples analyzed for trans-nonachlor.

Table 4-75

Organochlorine Pesticide Concentrations Detected in Surface Sediment

Chemical	Sample Type	Detection Frequency[a]		Concentration (µg/kg dw)				
		Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	RL or Range of RLs[c]
4,4′-DDD	grab	6/143	4.2	2.3	8.6 J	1.05	3.0	1.7 – 61
	area-wide intertidal MIS composite	0/3	0	na	na	1.6	1.7 U	2.7 – 4.2
	public access intertidal MIS composite	0/1	0	na	na	na	na	2.7
4,4′-DDE	grab	2/143	1.4	3.0	32	1.4	3.1	1.6 – 46
	area-wide intertidal MIS composite	0/3	0	na	na	1.4	1.5 U	1.7 – 4.2
	public access intertidal MIS composite	0/1	0	na	na	na	na	2.7
Total DDTs[c]	grab	8/143	5.6	2.3	32	4.3	8.3	1.8 – 270
	area-wide intertidal MIS composite	0/3	0	na	na	10	8.9 U	3.2 – 29
	public access intertidal MIS composite	0/1	0	na	na	na	na	2.7
Aldrin	grab	1/91	1.1	2.1	2.1	0.495	4.4	0.82 – 270
	area-wide intertidal MIS composite	0/3	0	na	na	0.7	0.74 U	0.86 – 2.1
	public access intertidal MIS composite	0/1	0	na	na	na	na	1.4
Total aldrin/ dieldrin	grab	1/91	1.1	2.1	2.1	3.15	8.0	1.6 – 270
	area-wide intertidal MIS composite	0/3	0	na	na	1.4	1.5 U	1.7 – 4.2
	public access intertidal MIS composite	0/1	0	na	na	na	na	2.7
trans-Nonachlor	grab	1/79	1.3	4.4	4.4	1	3.0	1.9 – 100
	area-wide intertidal MIS composite	0/3	0	na	na	1.4	1.5 U	1.7 – 4.2
	public access intertidal MIS composite	0/1	0	na	na	na	na	2.7
Total chlordane[d]	grab	1/91	1.1	4.4	4.4	1.95	4.0	0.96 – 100
	area-wide intertidal MIS composite	0/3	0	na	na	1.4	1.5 U	1.7 – 4.2
	public access intertidal MIS composite	0/1	0	na	na	na	na	2.7

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results. Data presented in this table were not averaged by location (i.e., each field duplicate was treated as a separate sample and was not averaged with the parent sample).

[c] RLs are based only on non-detect samples.

[d] Total DDT was calculated as the sum of 2,4′-DDD; 2,4′-DDE; 2,4′-DDT; 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT and one-half the RL for non-detected results. If none of the individual DDT-related compounds were detected in a given sample, the non-detect value represents the highest RL.

[d] Total chlordane was calculated as the sum of alpha-chlordane, gamma-chlordane, oxychlordane, cis-nonachlor, and trans-nonachlor and one-half the RL for non-detected results. If none of the individual chlordane compounds were detected in a given sample, the non-detect value represents the highest RL.

DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
dw – dry weight
J – estimated concentration
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent
U – not detected at given concentration

4,4′-DDD was the organochlorine pesticide most frequently detected in surface sediment grab samples (4.2% of the samples). 4,4′-DDE had a detection frequency of 1.4% in surface sediment grab samples, no other DDT-related compounds were detected. The highest total DDT concentration (32 µg/kg dw) was detected in a surface sediment grab sediment collected from a location (PDM-06) in the central portion of the deep main body near Station 2800. This sample had a total PCB concentration of 1,400 µg/kg, which may have contributed to the reported total DDT concentration due to the fact that PCB congeners can be misidentified as DDT isomers which results in elevated total DDT results. However, the total DDT result was not qualified during data validation on the basis of PCB interference.

4.2.12.2 Subsurface Sediment

Organochlorine pesticides were analyzed in a subset of subsurface sediment samples collected from the EW. Of the samples analyzed for organochlorine pesticides, 23% had one or more detected DDT compounds (Table 4-76). Other organochlorine pesticides were detected in < 10% of the samples in the subset. The maximum detected 4,4′-DDD concentration was JN-qualified, which indicates the presence of laboratory interference; this results in the tentative identification of this compound and a high bias in the result due to the presence of PCBs in the sample.

Table 4-76
Organochlorine Pesticide Concentrations Detected in Subsurface Sediment

Chemical	Detection Frequency[a]		Concentration (µg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[b]
2,4'-DDD	4/24	17	0.011 J	240	1.9 – 40
2,4'-DDE	1/24	4.2	120 J	120 J	0.035 – 40
4,4'-DDD	27/123	22	0.060	1,600 JN	0.61 – 84
4,4'-DDE	7/123	5.7	4.5	100 J	0.035 – 140
4,4'-DDT	2/123	1.6	190 JN	420 J	0.035 – 290
Total DDTs[c]	28/123	23	0.07 J	1,600 JN	0.61 – 210
Aldrin	4/90	4.4	5.7	10	0.30 – 42
Dieldrin	6/93	6.5	7.4	23	0.35 – 120
Total aldrin/dieldrin	6/93	6.5	7.4	33	0.35 – 120
alpha-Chlordane	4/90	4.4	0.54	33	0.035 – 52
beta-Chlordane	3/62	4.8	0.95	50	0.035 – 80

Chemical	Detection Frequency[a]		Concentration (µg/kg dw)		
	Ratio	%	Minimum Detect	Maximum Detect	Range of RLs[b]
Total chlordane[d]	6/91	6.6	1.6	50	0.14 – 200
cis-Nonachlor	1/24	4.2	0.11 J	0.11 J	0.14 – 200
trans-Nonachlor	1/24	4.2	0.27	0.27	0.035 – 64

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] RLs are based only on non-detect samples.

[c] Total DDT was calculated as the sum of 2,4′-DDD; 2,4′-DDE; 2,4′-DDT; 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT and one-half the RL for non-detected results. If none of the individual DDT-related compounds were detected in a given sample, the non-detect value represents the highest RL.

[d] Total chlordane was calculated as the sum of alpha-chlordane, gamma-chlordane, oxychlordane, cis-nonachlor, and trans-nonachlor and one-half the RL for non-detected results. If none of the individual chlordane compounds were detected in a given sample, the non-detect value represents the highest RL.

DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
dw – dry weight
J-qualifier – estimated concentration
N-qualifier – tentative identification
RL – reporting limit

4.2.12.3 Tissue

Table 4-77 presents the detection frequencies and ranges of organochlorine pesticide concentrations in tissue. 4,4′-DDD was the most frequently detected organochlorine pesticide (65% detection frequency). 2,4′-DDE and 2,4′-DDT were not detected, and other DDT compounds had a detection frequency that ranged from 10 to 45%. Chlordane compounds (i.e., alpha-chlordane, beta-chlordane, oxychlordane, cis-nonachlor, and trans-nonachlor) had detection frequencies that ranged from 6.7 to 56%. The remaining organochlorine pesticides were detected in 36% or less of tissue samples. Detected concentrations were reported for fish tissues (brown rockfish, English sole and shiner surfperch) were greater than the detected concentrations in the invertebrate tissues (crab, clam and mussels) for all the detected organochlorine pesticides.

Table 4-77

Organochlorine Pesticide Concentrations Detected in Fish and Invertebrate Tissues

Chemical	Detection Frequency[a]		Concentration (µg/kg ww)				
	Ratio	%	Minimum Detect	Maximum Detect	Calculated Median[b]	Calculated Mean[b]	Range of RLs[c]
2,4′-DDD	3/31	10	0.52 J	0.83 J	0.45	0.74	0.43 – 4.0
4,4′-DDD	20/31	65	0.16 J	5.6 J	1.8	1.9	0.82 – 4.0
4,4′-DDE	14/31	45	4.0 J	49 J	2	7.3	1.1 – 4.0
4,4′-DDT	10/31	32	0.50 J	1.4 J	0.5	0.84	0.43 – 4.0
Total DDTs[d]	20/31	65	0.16 J	54 J	2	8.9	2.1 – 4.0
alpha-Chlordane	13/31	42	0.25 J	1.4 J	0.62	0.61	0.22 – 2.0
beta-Chlordane	14/25	56	0.14 J	0.79 J	0.28	0.36	0.22 – 0.47
cis-Nonachlor	14/31	45	0.18 J	2.8 J	0.51	0.86	0.22 – 4.0
trans-Nonachlor	17/31	55	0.11 J	9.0 J	1.3	1.6	0.22 – 4.0
Oxychlordane	2/30	6.7	17 J	41 J	1.2	3.1	1.1 – 4.0
Total chlordane[e]	17/33	52	0.11 J	42 J	2.55	5.0	1.1 – 10
Dieldrin	11/31	36	0.24 J	0.76 J	0.44	0.72	0.43 – 4.0
alpha-BHC	4/31	13	0.31 J	1.2 J	0.45	0.58	0.43 – 2.0
beta-BHC	2/31	6.5	1.4 J	1.5 J	0.45	0.60	0.43 – 2.0
gamma-BHC	2/31	6.5	0.18 J	0.23 J	0.23	0.36	0.22 – 2.0
beta-Endosulfan	8/31	26	1.0 J	13 J	0.47	1.4	0.43 – 4.0
Heptachlor	1/31	3.2	0.10 J	0.10 J	0.22	0.36	0.22 – 2.0
Heptachlor epoxide	3/31	10	0.14 J	0.31 J	0.22	0.36	0.22 – 2.0
Mirex	10/31	32	0.11 J	0.76 J	0.22	0.56	0.22 – 4.0

[a] A calculated total concentration result was considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated total concentration was considered not detected.

[b] Calculated median and mean concentrations are based on detected concentrations and one-half the RL for non-detected results.

[c] RLs are based only on non-detect samples.

[d] Total DDT was calculated as the sum of 2,4′-DDD; 2,4′-DDE; 2,4′-DDT; 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT and one-half the RL for non-detected results. If none of the individual DDT-related compounds were detected in a given sample, the non-detect value represents the highest RL.

[e] Total chlordane was calculated as the sum of alpha-chlordane, gamma-chlordane, oxychlordane, cis-nonachlor, and trans-nonachlor and one-half the RL for non-detected results. If none of the individual chlordane compounds were detected in a given sample, the non-detect value represents the highest RL.

BHC – benzene hexachloride
DDD – dichlorodiphenyldichloroethane
DDE – dichlorodiphenyldichloroethylene
DDT – dichlorodiphenyltrichloroethane
J – estimated concentration
RL – reporting limit
ww – wet weight

4.2.12.4 Summary of Organochlorine Pesticide Data

Organochlorine pesticides were analyzed in a subset of surface sediment, subsurface sediment, and tissue samples from the EW. Analytical interference in the organochlorine pesticide analyses from the presence of PCBs in the sediment samples resulted in high uncertainty and high bias in some of the organochlorine pesticide data, particularly for samples with high PCB concentrations.

Pesticides were detected in only a small number of surface sediment samples. Four compounds (4,4′-DDD, 4,4′-DDE, aldrin, and trans-nonachlor) were detected at detection frequencies that ranged from 1.1 to 4.2%. The subsurface sediment data for pesticides was limited. DDT compounds were most commonly detected.

Seventeen individual pesticide compounds were detected in tissue samples. The most frequently detected compound was 4,4′-DDD, which was detected in 65% of the samples. Detection frequencies of other pesticides ranged from 3.2 to 56%.

4.3 Summary

This section provides a summary of the nature and extent of contamination in the EW based on a comprehensive chemical dataset for surface sediment, subsurface sediment, tissue, surface water, and porewater.

Surface sediment samples from 243 locations within the EW were used to evaluate the nature and extent of contamination. In addition, 13 subtidal composite samples were created for the analysis of dioxins and furans and PCB congeners. Finally, four MIS samples were used to characterize the intertidal sediments throughout EW.

Table 4-78 presents summary statistics for selected risk driver contaminants identified in the risk assessments and also lists locations with the highest concentrations. The sediment patterns of risk drivers are shown on Map 4-62.

Table 4-78
Summary of EW Surface Sediment Data

Chemical	Unit	50th Percentile[a]	95th Percentile[a]	Areas with Highest Concentrations[b]
Total PCBs	µg/kg dw	270	1,800	Northern Terminal25 near Hanford #2 CSO and two storm drain outfalls Mound outside Slip 27 Head of Slip 27 Deep Main body (Stations 600 to 1600)
Dioxin and furan TEQ	ng TEQ/kg dw	nc	nc	Southern Terminal 18 Slip 27
cPAHs	µg TEQ/kg dw	220	1,200	In vicinity of Pier 24 and Hinds CSO/SD South of Slip 36 near the former Rabanco Barge loading facility and GATX Head of Slip 36
Arsenic	mg/kg dw	6.2	17	South of Slip 36 near the former Rabanco Barge loading facility and GATX Head of Slip 36
TBT	µg/kg dw	31	560	Northern Terminal 18

[a] The percentiles are numerical percentiles of the surface sediment dataset which includes all the surface sediment grab samples.

[b] Areas with the highest concentrations are listed by location from north to south within the EW. These areas may not include all areas with concentrations greater than the 95th percentile; see individual maps for all locations.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EW – East Waterway
nc – not calculated
PCB – polychlorinated biphenyl
TBT – tributyltin

Surface sediment chemistry and toxicity data were compared with SMS criteria to evaluate the potential effects on benthic invertebrates throughout the EW. Discussions of the risks to benthic invertebrates are presented in Section 5 and Appendix A. The 29 chemicals with surface sediment SMS exceedances are listed in Table 4-79. The areal extent of potential effects was estimated using Thiessen polygons created from combined toxicity test results and SMS chemical criteria exceedances. Using this approach, approximately 21% (34 ac) of the EW area, exceed CSL criteria and approximately 39% (82 ac) of the EW area was between the SQS and CSL criteria. There were no exceedances of the SQS in the remaining 40% of EW.

Table 4-79
Summary of EW Surface Sediment SMS Exceedances

Chemical	No. of Samples	No. of Samples > SQS and < CSL	No. of Samples > CSL	Areas with Highest Concentrations[a]
Metals				
Arsenic	231	0	2	South of Slip 36 near the former Rabanco Barge loading facility and GATX
Cadmium	231	0	1	Terminal 30
Mercury	239	36	10	Shallow main body Pier 25 Head of Slip 36
Zinc	231	4	1	South of Slip 36 near the former Rabanco Barge loading facility and GATX Slip 27
PAHs				
2-Methylnaphthalene	240	0	1	In vicinity of Pier 24 and Hinds CSO/SD South of Slip 36 near the former Rabanco Barge loading facility and GATX Head of Slip 36
Acenaphthene	240	10	6	
Anthracene	240	1	0	
Benzo(a)anthracene	240	6	1	
Benzo(a)pyrene	240	6	1	
Benzo(g,h,i)perylene	240	4	0	
Total benzofluoranthenes	240	6	1	
Chrysene	240	7	1	
Dibenzo(a,h)anthracene	240	4	0	
Dibenzofuran	240	6	2	
Fluoranthene	240	12	2	
Fluorene	240	9	3	
Indeno(1,2,3-cd)pyrene	240	6	0	
Phenanthrene	240	12	3	
Pyrene	240	0	1	
Total HPAHs	240	8	1	
Total LPAHs	240	5	3	

Chemical	No. of Samples	No. of Samples > SQS and < CSL	No. of Samples > CSL	Areas with Highest Concentrations[a]
Phthalates				
BEHP	231	4	5	Northern Terminal25 near Hanford #2 CSO and two SD outfalls
BBP	231	9	0	
Di-n-butyl phthalate	231	0	1	
Other SVOCs				
1,4-Dichlorobenzene	231	20	9	Northern Terminal25 near Hanford #2 CSO and two SD outfalls
2,4-Dimethylphenol	231	0	1	
n-Nitrosodiphenylamine	231	0	1	
Phenol	231	5	0	
Total PCBs	240	134	23	Northern Terminal 25, near Hanford #2 CSO and two SD outfalls Mound outside Slip 27 Head of Slip 27 Deep Main body (Stations 600 to 1600)

[a] Areas with the highest concentrations are listed by location from north to south within EW. These areas may not include all areas with concentrations greater than the 95th percentile; see individual maps for all locations.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
CSO – combined sewer overflow
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl;
SD – storm drain
SQS – sediment quality standards
SVOC – semivolatile organic compound

Subsurface sediment contamination was also characterized by many studies within the EW. A summary of the EW subsurface data for select risk drivers is provided in Table 4-80. SMS exceedances in subsurface sediment data are summarized in Table 4-81. Some areas with high contaminant concentrations in surface sediment also had high concentrations in subsurface sediment, although some areas with less contaminated surface sediment had contamination in the subsurface, particularly in the shallow main body area and the portions of the deep main body that have not been recently dredged.

Table 4-80
Summary of EW Subsurface Sediment Data

Chemical	Unit	Minimum Conc.	Maximum Conc.	Areas with Highest Concentrations[a]
Total PCBs	µg/kg dw	5.5	17,600	Northern Terminal 25 near Hanford #2 CSO and two storm drain outfalls Mound outside Slip 27 Head of Slip 27 Shallow main body
Dioxin and furan TEQ	ng TEQ/kg dw	0.748	184	Southern Terminal 18 Slip 27
cPAHs	µg TEQ/kg dw	15	23,000	In vicinity of Pier 24 and Hinds CSO/SD South of Slip 36 near the former Rabanco barge loading facility and GATX Head of Slip 27
Arsenic	mg/kg dw	1.2	96	South of Slip 36 near the former Rabanco barge loading facility and GATX Head of Slip 36 Mound outside Slip 27
TBT	µg/kg dw	0.40 JN	21,000	Northern Terminal 18

[a] Areas with the highest concentrations are listed by location from north to south within EW. These areas may not include all areas with concentrations greater than the 95th percentile; see individual maps for all locations.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
EW – East Waterway
J – estimated concentration
N – tentative concentration
PCB – polychlorinated biphenyl
SD – storm drain
TBT – tributyltin
TEQ – toxic equivalent

Table 4-81
Summary of EW Subsurface Sediment SMS Exceedances

Chemical	No. of Samples	No. of Samples > SQS and < CSL	No. of Samples > CSL	Areas with Highest Concentrations[a]
Metals				
Arsenic	255	0	1	South of Slip 36 near the former Rabanco barge loading facility and GATX
Cadmium	258	11	13	Slip 27 South of Slip 36 near the former Rabanco barge loading facility and GATX
Copper	255	0	4	Head of Slip 36
Lead	255	2	5	Slip 27
Mercury	305	48	87	Shallow main waterway

Chemical	No. of Samples	No. of Samples > SQS and < CSL	No. of Samples > CSL	Areas with Highest Concentrations[a]
Silver	251	0	10	Slip 27 Northern Terminal 25 near Hanford #2 CSO and two SD outfalls
Zinc	255	24	9	Mound area outside Slip 27 Head of Slip 36 Slip 27
PAHs				
2-Methylnaphthalene	269	1	8	Slip 27 Slip 36 In vicinity of Pier 24 and Hinds CSO/SD
Acenaphthene	269	14	22	
Acenaphthylene	269	0	1	
Anthracene	269	2	15	
Benzo(a)anthracene	269	8	14	
Benzo(a)pyrene	269	1	15	
Benzo(g,h,i)perylene	269	6	8	
Total benzofluoranthenes[b]	269	5	13	
Chrysene	268	12	13	
Dibenzo(a,h)anthracene	269	3	12	
Dibenzofuran	269	9	12	
Fluoranthene	269	20	20	
Fluorene	269	9	19	
Indeno(1,2,3-cd)pyrene	269	4	11	
Naphthalene	269	0	7	
Phenanthrene	269	12	14	
Pyrene	269	3	17	
Total HPAHs[c]	269	15	16	
Total LPAHs[d]	269	5	18	
Phthalates				
BEHP	265	34	22	Slip 27 Northern Terminal 25 near Hanford #2 CSO and two SD outfalls Shallow main body Mound area outside Slip 27
BBP	265	15	0	
Dimethyl phthalate	265	0	1	

Chemical	No. of Samples	No. of Samples > SQS and < CSL	No. of Samples > CSL	Areas with Highest Concentrations[a]
Other SVOCs				
1,2,4-Trichlorobenzene	266	1	2	Northern Terminal 25 near Hanford #2 CSO and two SD outfalls Shallow main body Mound area outside Slip 27
1,2-Dichlorobenzene	265	0	1	
1,4-Dichlorobenzene	265	6	10	
2,4-Dimethylphenol	265	0	8	
2-Methylphenol	264	0	2	
4-Methylphenol	265	0	2	
n-Nitrosodiphenylamine	265	0	1	
Phenol	265	1	0	
PCBs				
Total PCBs[d]	290	86	78	Slip 27 South of Slip 36 near the former Rabanco barge loading facility and GATX

[a] Areas with the highest concentrations are listed by location from north to south within the EW. These areas may not include all areas with concentrations greater than the 95th percentile; see individual maps for all locations.

[b] Total benzofluoranthenes were calculated as the sum of benzo(b)fluoranthene and benzo(k)fluoranthene.

[c] Total HPAHs were calculated as the sum of benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, total benzofluoranthenes, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene.

[d] Total LPAHs were calculated as the sum of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
CSO – combined sewer overflow
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl;
SD – storm drain
SQS – sediment quality standards
SVOC – semivolatile organic compound

A large number of tissue composite samples have been collected in the EW for various fish, crab, and invertebrate species. In general, total PCB concentrations in invertebrates (except crab hepatopancreas samples) tended to be lower than in fish tissues except for juvenile Chinook salmon tissues which had concentrations comparable to the concentrations in clams and mussels. Mean total PCB concentrations in fish and crab tissue ranged from 59 to 3,200 µg/kg ww. Mean total PCB concentrations in benthic invertebrates, shrimp, clams, and mussels were generally lower than in fish and crab tissue, ranging from 19 to 460 µg/kg ww.

Dioxins and furans were analyzed in supercomposite tissue samples created by combining all existing composite samples separately for English sole, shiner surfperch and crab tissues.

Individual brown rockfish and clams, which were composited by species and location were also analyzed for dioxins and furans. The dioxin and furan TEQ concentrations in fish and crab tissue were generally higher than the concentrations in clam and geoduck tissues. The TEQ concentrations for fish and crab ranged from 0.451 to 3.00 ng TEQ/kg ww with the highest concentrations in brown rockfish and English sole whole body tissues. The TEQ concentrations for clam and geoduck tissues ranged from 0.204 to 0.536 ng TEQ/kg ww and had a significant contribution from non-detected congeners.

In general, the PCB and dioxin and furan congener patterns for each tissue type were similar. Of the three fish species analyzed for PCB congeners and dioxins and furans, brown rockfish had the greatest variability in congener patterns among the individual samples most likely due to the fact that these fish have small home ranges and were analyzed as individual fish rather than composites.

The highest cPAH concentrations in tissue were detected in clams, mussels, and benthic invertebrates at mean concentrations ranging from 1.6 to 170 µg TEQ/kg ww; cPAH concentrations in fish tissue were relatively low. Mean cPAH concentrations in fish tissues ranged from 0.24 to 34 µg TEQ/kg ww.

Tissue arsenic concentrations were reported as total arsenic and inorganic arsenic. Total arsenic concentrations were similar for all species with mean concentrations ranging from 0.441 to 5.24 mg/kg ww for the fish tissues compared to clam, mussel, shrimp, geoduck, and benthic invertebrate tissues with mean concentrations ranging from 0.936 to 4.12 mg/kg ww. However, the percentage of the arsenic present as inorganic arsenic was higher in clam tissues (11%) compared to the fish tissues (0.1-2%) and the other invertebrate tissues (2.6-9.1%). The composite tissue sample for soft-shell clam had the highest percentage of total arsenic present as inorganic arsenic concentration of all tissue types (47%). The mean inorganic arsenic concentration for clams was 0.166 mg/kg ww compared to mean concentrations from 0.008 to 0.078 for all other tissue types.

Tissue mercury concentrations were similar for fish and invertebrate tissue samples with the exception of the highest mean tissue concentration for brown rockfish. The mean tissue mercury concentration for brown rockfish was 0.16 mg/kg ww and the range of mean concentrations for all other species was 0.008 to 0.07 mg/kg ww.

TBT concentrations were similar for all tissue samples except for brown rockfish and the benthic invertebrate tissue samples which had the highest TBT concentrations. The mean TBT concentration for the brown rockfish was 160 µg/kg ww and the mean TBT concentration for benthic invertebrate tissues was 110 µg/kg ww. The mean TBT concentrations for all other tissue types ranged from not detected to 58 µg/kg ww.

Total PCB congener concentrations in surface water grab samples ranged from 0.068 to 5.8 ng/L. Surface water samples collected for the SRI were also analyzed for cPAHs. cPAHs were detected on only 4 of 59 samples with concentrations ranging from 0.0091 to 0.011 µg/L. Surface water arsenic concentrations were generally consistent across all sampling events and sampling locations with concentrations ranging from 0.43 to 1.43 for dissolved arsenic. Dissolved surface water mercury concentrations ranged from 0.00013 to 0.0015 µg/L. In general, the surface water total PCB, cPAH and mercury concentrations were higher in the storm event samples compared to the other monitoring events. TBT was detected in one of the 59 surface water samples.

Sediment porewater samples were analyzed from 44 samples representing 0-to-10cm sediment and 55 samples representing subsurface sediments. The TBT concentrations in porewater collected from surface sediments ranged from 0.019 to 20 µg/L and the TBT concentrations collected from subsurface sediments ranged from 0.028 to 0.83 µg/L.

In addition, as part of the EW SRI, 13 unfiltered porewater samples were collected from three intertidal areas in the EW and analyzed for VOCs. Benzene and naphthalene were detected in two porewater samples and cis-1,2-dichloroethene was detected in one porewater sample.

5 SUMMARY OF THE BASELINE ECOLOGICAL RISK ASSESSMENT

The baseline ERA estimated potential risks to benthic invertebrate, fish, and aquatic-dependent wildlife species that may be exposed to contaminants in sediment, water, and aquatic biota in the EW. This assessment was based on data collected since 1995, with the majority of the sediment and tissue chemistry data collected as part of this SRI. This section first summarizes the problem formulation of the ERA, which selects the receptors of concern (ROCs), identifies the contaminants of potential concern (COPCs) to be evaluated in the risk assessment, and presents a CSM for exposures of the ROCs. The problem formulation is followed by a summary of the risk assessments for benthic invertebrates, fish, and wildlife. These risk assessments characterize risks and determine the COCs by comparing exposure and effects data for each ROC; this comparison assesses the potential for sediment-associated contaminants to cause adverse effects to the ROCs. The risk assessments also include uncertainty analyses that describe uncertainties encountered with the data or risk evaluation process. Finally, this section summarizes the risk drivers for the ROCs for which COCs are identified. The complete ERA is included as Appendix A to this SRI.

5.1 Problem Formulation

The ERA problem formulation establishes the overall scope of the assessment. Because it is impractical to evaluate risks to every potentially exposed species at a site, it is standard ERA practice to focus on representative receptor species that typify groups of similar organisms with specific exposure pathways. One objective in selecting representative receptors is to choose species for which the risk conclusions will be protective of other species that are not explicitly evaluated. For example, an assessment of risks to osprey is assumed to be protective of all piscivorous birds because of the higher potential exposure of osprey than that of other piscivorous birds. In addition, risks to some species are analyzed because those species are highly valued by society, such as juvenile Chinook salmon, which is listed as a threatened species under the Endangered Species Act (ESA). Representative ROCs selected for the EW ERA were the benthic invertebrate community, crab, three fish species (juvenile Chinook salmon, English sole, and brown rockfish), and four aquatic-dependent wildlife species (pigeon guillemot, osprey, river otter, and harbor seal). The rationale for selecting each ROC, including its ecological and societal importance, site use, and sensitivity, is provided in Table 5-1.

Table 5-1

Receptors of Concern Selected for the EW and Summary of Rationale for Selection

ROC	Ecological Significance	Societal Significance	Site Use	Sensitivity
Benthic invertebrate community	food source for other invertebrates, fish, birds, and mammals; nutrient cycling; sediment oxygenation	valued as food source to other species of high societal value	present year-round; multiple life stages, diverse phyla	range of contaminant sensitivities represented
Cancrid crab	higher-trophic-level benthic invertebrate; food for other invertebrates, fish, birds, and mammals	recreational and commercial value	multiple life stages (gravid females, juveniles)	effects data available for decapods; sensitivity relative to other decapods unknown
Brown rockfish	higher-trophic-level fish; important prey item for fish, birds, and mammals	some commercial (though not in EW) and recreational value	adults and juveniles present year-round; may spawn in the EW	effects data available for other fish species; relative sensitivity of brown rockfish unknown; potential for elevated exposure via bioaccumulation because of trophic position; long-lived
English sole	important prey item for fish, birds and mammals; key benthic invertebrate predator	some commercial and recreational value (though not in EW)	juveniles present year-round; adults present except during spawning migration to Puget Sound	NMFS data suggest they are as sensitive as other flatfish species
Juvenile Chinook salmon	important prey item for fish, birds and mammals; seasonally one of the most abundant juvenile salmonids in the EW	T&E species; returning adults important to tribal, commercial, and sport fisheries	generally present April to July; individuals likely present in EW for a few days to couple of weeks; most estuary-dependent juvenile salmonid	sensitive to a wide range of contaminants
Osprey	high trophic level	highly valued and well-studied bird of prey; protected under the Migratory Bird Treaty Act	nests along the EW and likely forages in the EW	effects data available for other bird species; relative sensitivity of osprey unknown; potential for elevated exposure via bioaccumulation because of trophic position
Pigeon guillemot	high trophic level	valued in general as wildlife species; protected under the Migratory Bird Treaty Act	nests observed along the EW	effects data available for other bird species; relative sensitivity of pigeon guillemot unknown; potential for elevated exposure via bioaccumulation because of trophic position
River otter	high trophic level	highly valued by society	limited data, although anecdotal information indicates year-round presence of a river otter family on Kellogg Island	mink are sensitive to some contaminants, such as PCBs, although the relative sensitivity of river otter is unknown; potential for elevated exposure via bioaccumulation because of trophic position

ROC	Ecological Significance	Societal Significance	Site Use	Sensitivity
Harbor seal	high trophic level	protected under Marine Mammal Protection Act	occasional use based on a survey in the EW	pinnipeds suspected to be sensitive to some contaminants, such as PCBs, although the relative sensitivity of harbor seal is unknown; potential for elevated exposure via bioaccumulation because of trophic position

EW – East Waterway
NMFS – National Marine Fisheries Service
PCB – polychlorinated biphenyl
ROC – receptor of concern
T&E – threatened and endangered

The problem formulation also includes a discussion of the data available for conducting the ERA and the suitability of the data for risk assessment purposes, as well as the performance of a risk-based screening evaluation that allows the risk assessment to focus on COPCs and eliminate contaminants that do not pose risks to the ROCs.

Site-specific data used in the EW ERA consisted of:

- Surface sediment (uppermost 10 cm) chemistry data
- Sediment toxicity data
- Tissue chemistry data for benthic invertebrates (including benthic infauna and epifauna, crab, shrimp, clams, and mussels), English sole, brown rockfish, shiner surfperch, and juvenile Chinook salmon
- Surface water chemistry data
- Sediment porewater chemistry data (only VOCs)[79]

For each ROC selected, COPCs were identified through a conservative risk-based screening process, which consisted of a comparison of maximum contaminant concentrations with established criteria or literature-based toxicity reference values (TRVs). A detailed risk evaluation was conducted for these COPCs, which are identified as the following:

[79] Sediment porewater samples were analyzed only for VOCs because these chemicals do not have a strong affinity for sediment particles. Bulk sediment, which included sediment particles and associated porewater, was analyzed for all other analytes. Both exposure media were used to assess potential risk to benthic invertebrates.

- **Benthic invertebrate community –** 4 metals (arsenic, cadmium, mercury, zinc); 1 organometal (TBT); 16 PAHs; total PCBs; 7 other SVOCs; 1 VOC (naphthalene); and 1 pesticide (total DDTs)

- **Crab –** arsenic, cadmium, copper, mercury, zinc, TBT, and total PCBs

- **Fish –** arsenic, cadmium, chromium, copper, mercury, vanadium, TBT, benzo(a)pyrene, beta-endosulfan, and total PCBs (each contaminant was identified as a COPC for at least one but not necessarily all fish ROCs)

- **Wildlife –** mercury, selenium, total PCBs, PCB TEQ,[80] and total TEQ[81] (each contaminant was identified as a COPC for at least one but not necessarily all wildlife ROCs)

The problem formulation also included the development of CSMs for the ROCs (Figures 5-1 and 5-2). CSMs identify and describe pathways through which ROCs may be exposed to COPCs associated with EW sediment. The pathways evaluated in the EW ERA included both direct exposure through sediment and water and indirect exposure through the ingestion of prey from the EW (see Section 2.6 of Appendix A and Figure A.2-2 of Appendix A).

[80] PCB TEQ is calculated using TEFs, which relate the toxicity of the co-planar PCB congeners (i.e., those with dioxin-like properties) to the toxicity of 2,3,7,8- tetrachlorodibenzo-*p*-dioxin.

[81] Total TEQ is the sum of the PCB TEQ and the TEQ calculated for dioxin and furan congeners.

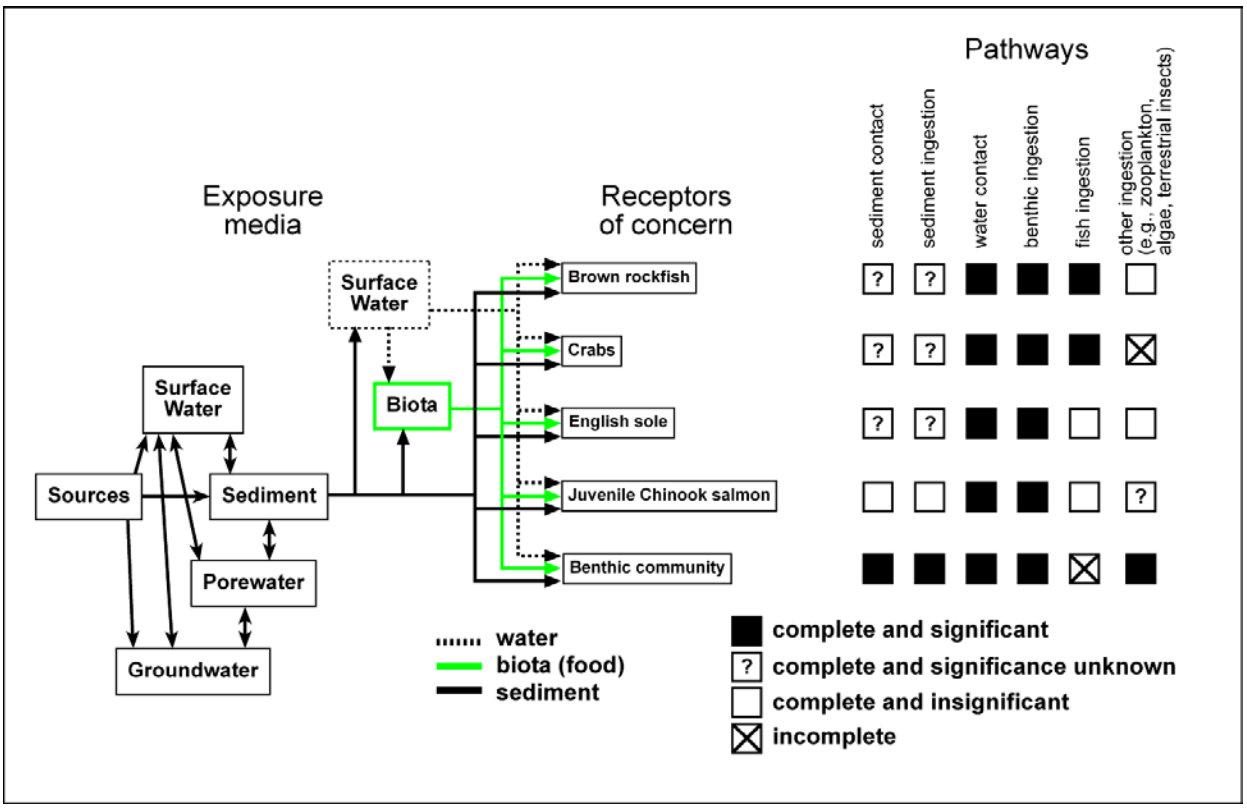


Figure 5-1.

Conceptual Site Model for Fish, the Benthic Invertebrate Community, and Crab

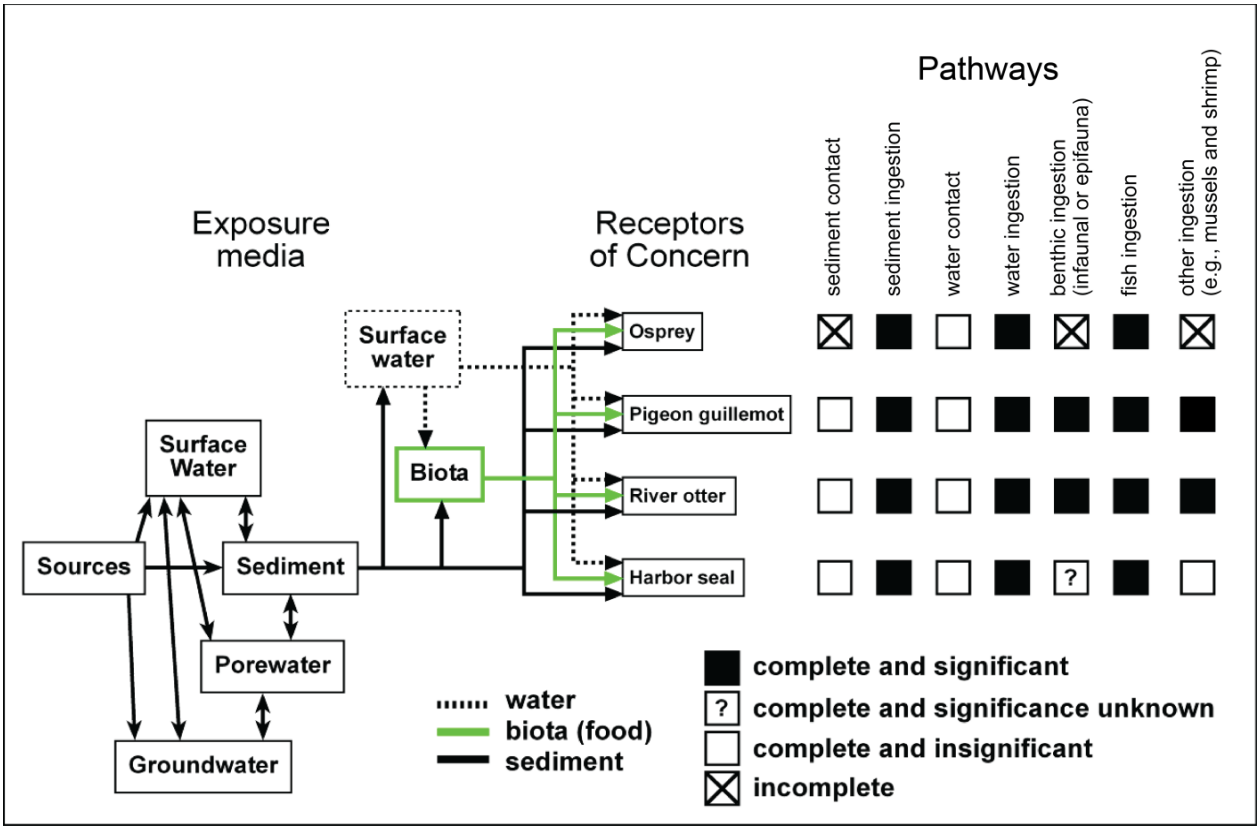


Figure 5-2.
Conceptual Site Model for Wildlife

Finally, the problem formulation identified the characteristics of the ROCs that are important to protect, and identified the means to measure the effects on these characteristics, called assessment and measurement endpoints, respectively. The key assessment endpoints were maintenance of EW ROC populations and the key measurement endpoints were evaluations of survival, growth, and reproduction of the EW ROCs. Table 5-2 identifies each EW ROC and its assessment and measurement endpoints. Each measurement endpoint is presented as: 1) the measure of exposure, 2) the measure of effect, and 3) the method by which the measure is evaluated to determine risk. The measurement endpoints are defined as lines of evidence because there are multiple measurement endpoints for some ROCs The representative ROCs, COPCs, exposure pathways, and endpoints formed the scope for the EW ERA.

Table 5-2.

Lines of Evidence and Methods of Risk Evaluation for the Selected Ecological Receptors of Concern

ROC	Assessment Endpoint	Line of Evidence		Method of Evaluation
		Measure of Exposure	Measure of Effect	
Benthic Invertebrates				
Benthic invertebrate community[a]	maintenance of the benthic invertebrate community in EW sediment	contaminant concentrations in surface sediment	Washington State SMS and toxicity-based regional guidelines (where no standards are available)	compare measured contaminant concentrations in sediment with SMS or DMMP guidelines
			site-specific sediment toxicity tests (survival, development, and growth) relative to reference area sediment toxicity tests	compare 10-day amphipod survival in site sediment with amphipod survival in reference area sediment
				compare 48-hour echinoderm embryo or bivalve larvae normal survival in site sediment elutriates with normal embryo/larval survival in reference area sediment
				compare 20-day polychaete growth in site sediment with polychaete growth in reference area sediment
		VOC concentrations in porewater	WQC or other water TRVs based on survival and growth	compare contaminant concentrations in porewater with WQC or other relevant TRVs
		PCB, mercury, and TBT concentrations in benthic invertebrate tissue (field-collected)	tissue-residue TRVs based on survival, growth, and reproduction	compare measured tissue burdens with tissue-residue TRV
		contaminant concentrations in surface water	WQC or other water TRVs based on survival, growth, and reproduction	compare contaminant concentrations in surface water with WQC or other relevant TRVs
Cancrid crab	maintenance of crab populations in the EW	concentrations of contaminants in cancrid crab whole-body tissue	tissue-residue TRVs based survival, growth, and reproduction	compare contaminant concentrations measured in tissue with tissue-residue-based TRVs for crab or other decapods
		contaminant concentrations in surface water	WQC or other water TRVs based on survival, growth, and reproduction	compare contaminant concentrations in surface water with WQC or other relevant TRVs

ROC	Assessment Endpoint	Line of Evidence		Method of Evaluation
		Measure of Exposure	Measure of Effect	
Fish				
Juvenile Chinook salmon	survival and growth of individual juvenile anadromous salmon in the EW	contaminant concentrations in juvenile Chinook salmon whole-body tissue	tissue-residue TRVs based on survival and growth	compare contaminant concentrations in juvenile Chinook tissue with fish tissue-residue TRVs
		contaminant concentrations in prey (benthic invertebrate) tissue	dietary prey tissue TRVs based on survival and growth	compare contaminant concentrations in juvenile Chinook salmon prey and juvenile Chinook salmon stomach contents with diet-based prey tissue TRVs for fish
		contaminant concentrations in juvenile Chinook salmon stomach contents		
		contaminant concentrations in surface water	WQC or other water TRVs based on survival and growth	compare contaminant concentrations in surface water with WQC or other relevant TRVs
English sole	maintenance of benthivorous and planktivorous fish populations in the EW	contaminant concentrations in English sole whole-body tissue	tissue-residue TRVs based on survival, growth, and reproduction	compare contaminant concentrations in English sole tissue with fish tissue-residue TRVs
		contaminant concentrations in prey (benthic invertebrate) tissue and surface sediment	dietary prey tissue TRVs based on survival, growth, and reproduction	compare contaminant concentrations in English sole prey and incidentally ingested surface sediment collected throughout the EW with diet-based prey tissue TRVs for fish
		contaminant concentrations in surface water	WQC or other water TRVs based on survival, growth, and reproduction	compare contaminant concentrations in surface water with WQC or other relevant TRVs
Brown rockfish	maintenance of upper-trophic-level fish populations in the EW	contaminant concentrations in brown rockfish whole-body tissue	tissue-residue TRVs based on survival, growth, and reproduction	compare contaminant concentrations in brown rockfish tissue with tissue-residue TRVs for fish
		contaminant concentrations in prey tissue (benthic invertebrate, shrimp, juvenile Chinook salmon, shiner surfperch) and surface sediment	dietary prey tissue TRVs based on survival, growth, and reproduction	compare contaminant concentrations in brown rockfish prey and incidentally ingested surface sediment collected throughout the EW with diet-based prey tissue TRVs for fish
		contaminant concentrations in surface water	WQC or other water TRVs based on survival, growth, and reproduction	compare contaminant concentrations in surface water with WQC or other relevant TRVs

ROC	Assessment Endpoint	Line of Evidence		Method of Evaluation
		Measure of Exposure	Measure of Effect	
Wildlife				
Osprey	maintenance of piscivorous bird populations in the EW	contaminant concentrations in prey fish tissue and surface water	dietary TRVs based on survival, growth, and reproduction of birds	compare dietary dose calculated from contaminant concentrations in fish, surface water, and incidentally ingested sediment with dietary dose-based TRVs for birds
Pigeon guillemot	maintenance of piscivorous/ benthivorous bird populations in the EW	contaminant concentrations in prey (fish tissue, shrimp, crab, and mussels), surface sediment, and surface water	dietary TRVs based on survival, growth, and reproduction of birds	compare dietary dose calculated from contaminant concentrations in fish, invertebrates, incidentally ingested surface sediment, and surface water with dietary dose-based TRVs for birds
River otter	maintenance of piscivorous semi-aquatic mammal populations in the EW	contaminant concentrations in prey (fish tissue, clams, crab, and mussels), surface sediment, and surface water	dietary TRVs based on survival, growth, and reproduction of mammals	compare dietary dose calculated from contaminant concentrations in fish, invertebrates, incidentally ingested surface sediment, and surface water with dietary dose-based TRVs for mammals
Harbor seal	maintenance of piscivorous marine mammal populations in the EW	contaminant concentrations in prey fish tissue, surface sediment, and surface water	dietary TRVs based on survival, growth, and reproduction of mammals	compare dietary dose calculated from contaminant concentrations in fish, incidentally ingested surface sediment, and surface water with dietary dose-based TRVs for mammals

[a] The benthic invertebrate community consists of both infaunal invertebrates (i.e., those that live within the sediment, including clams) and epifaunal invertebrates (i.e., those that live on the sediment surface).

DMMP – Dredge Material Management Program
EW – East Waterway
PCB – polychlorinated biphenyl
ROC – receptor of concern
SMS – Washington State Sediment Management Standards
TBT – tributyltin
TRV – toxicity reference value
VOC – volatile organic compound
WQC – water quality criteria

5.2 Benthic Invertebrate Assessment

This section presents an overview of the risk assessment for the benthic invertebrate community (which includes clams, polychaete worms, and amphipod crustaceans) and crab. The complete assessment is presented in Appendix A, Sections A.3 and A.6.1. Thirty-one COPCs were identified for the benthic invertebrate community; twenty-nine of these COPCs were selected based on sediment concentrations, one (TBT) was selected based on tissue-residue and surface water concentrations, and one (naphthalene) was selected based on porewater concentrations.

5.2.1 Exposure and Effects Assessment

This section presents the exposure and effects assessment for benthic invertebrates. The following approaches were used in the assessment for the benthic invertebrate community and crab:

- Risks to the benthic invertebrate community were evaluated by comparing surface sediment COPC concentrations and site-specific sediment toxicity test results with the SMS; when SMS were not available, DMMP guidelines were used.
- Risks to the benthic invertebrate community from VOC exposure were evaluated by comparing VOC concentrations in porewater with literature-based TRVs.
- Risks to the benthic invertebrate community from TBT exposure were evaluated by comparing TBT concentrations in EW benthic invertebrate tissue with tissue-based TRVs from the scientific literature. In addition, benthic invertebrate tissue mercury and total PCB concentrations were compared with tissue TRVs as an additional line of evidence for these two contaminants.
- Risks to benthic invertebrates were also evaluated by comparing surface water COPC concentrations with Washington State or federal chronic WQC.
- Risks to crab were evaluated by comparing COPC concentrations in EW crab tissue with tissue-based TRVs from the scientific literature.

- Risks to crab were also evaluated by comparing surface water COPC concentrations with Washington State or federal WQC.[82]

Each of these approaches is described in the following subsections.

5.2.1.1 Sediment Data and Toxicity Test Results

The exposure assessment for the benthic invertebrate community includes a summary of the available surface sediment chemistry data for each COPC. The potential for effects on the benthic invertebrate community was assessed by comparing the COPC concentrations in EW surface sediment with SQS and CSLs of the SMS (WAC 173-204). The SL and maximum level guidelines of the DMMP were used for DDTs, the only COPC without SMS criteria. The SMS numerical chemical criteria and DMMP guidelines are based on AETs developed for four different benthic endpoints by PSEP (Barrick et al. 1988). An AET is the highest "no effect" chemical-specific sediment concentration above which a significant adverse biological effect always occurred among the several hundred samples used in its derivation. In general, the lowest of the four AETs for each chemical was identified as the SQS; the second lowest AET was identified as the CSL. According to the SMS (WAC 173-204), chemical concentrations less than or equal to the SQS are defined as concentrations at which no acute or chronic adverse effects on biological resources are expected, chemical concentrations between the SQS and CSL are defined as having the potential for minor adverse effects, and chemical concentrations greater than the CSL are defined as concentrations above levels at which minor adverse effects are expected.

The effects assessment for the benthic invertebrate community also included the results of site-specific toxicity tests conducted using EW sediment samples. Three toxicity tests were conducted with surface sediment (0 to 10 cm) collected at each of 48 locations. The toxicity tests included:

- Acute 10-day amphipod (*Eohaustorius estuarius*) survival test
- Acute 48-hour bivalve larvae (*Mytilus galloprovincialis*) normal survival test

[82] For TBT, the final chronic value used to derive the federal WQC was used because the WQC is based on protection of a few sensitive species and is overly conservative when applied to crab (see Section A.3.4.2.1 of Appendix A).

- Chronic 20-day juvenile polychaete (*Neanthes arenaceodentata*) survival and growth test

Biological responses in these tests were evaluated based on the biological criteria from the SMS.

5.2.1.2 VOCs in Porewater

Naphthalene was the only COPC identified in porewater for the benthic invertebrate community. The effects assessment identified the TRVs as the no-observed-effect concentration (NOEC) and lowest-observed-effect concentration (LOEC) that were selected for naphthalene in water based on a review of the scientific literature.

5.2.1.3 Benthic Invertebrate Tissue Residues

TBT and total PCBs were identified as tissue-residue COPCs for the benthic invertebrate community. Benthic invertebrates are relatively stationary, so exposure was evaluated on an area-specific basis. The exposure point concentrations (EPCs) for TBT and total PCBs were represented by tissue concentrations in benthic invertebrate samples collected and composited from each area (i.e., one concentration for each COPC for each area). The effects assessment identified no-observed-adverse-effect levels (NOAELs) and lowest-observed-adverse-effect levels (LOAELs) as TRVs by searching the scientific literature for levels of contaminants in benthic invertebrate tissue associated with adverse effects (see Section A.2.5.1.2 of Appendix A for requirements to select acceptable toxicological data).

5.2.1.4 Benthic Invertebrate Surface Water

Three contaminants were identified as surface water COPCs for the benthic invertebrate community: cadmium, mercury, and TBT. Exposure was evaluated using EPCs calculated on a location-specific basis (i.e., samples were grouped by location) and using surface water data collected from the bottom of the water column. In addition, as a more conservative approach, exposure was evaluated based on EPCs for each individual water sample to represent the range of conditions at the time of sampling at each location. The effects assessment was based primarily on Washington State or federal chronic WQC.

5.2.1.5 Crab Tissue Residue

Five chemicals were identified as COPCs for the crab tissue-residue evaluation: arsenic, cadmium, copper, zinc, and total PCBs. EPCs for crab were calculated using data from nine composite crab samples collected throughout the EW during the SRI crab sampling event. Eight of the nine samples consisted of red rock crab, and one sample consisted of Dungeness crab. Crab composite samples were analyzed as edible meat and hepatopancreas tissues. Whole-body crab concentrations in each of the composite samples were calculated using the relative tissue weights and COPC concentrations in edible meat and hepatopancreas tissue. The EPCs were calculated as the 95% upper confidence limit on the mean (UCL) of the combined Dungeness crab and red rock crab data for each COPC. The effects assessment identified NOECs and LOECs as TRVs by searching the scientific literature for adverse effect levels for tissue concentrations in decapods.

5.2.1.6 Crab Surface Water

Three contaminants were identified as surface water COPCs: cadmium, mercury, and TBT. Dungeness and red rock crab are relatively mobile[83] so exposure was evaluated using EPCs in surface water calculated on a site-wide basis. In addition, as a more conservative approach, exposure was evaluated based on EPCs for individual water samples to represent conditions at each location at the time of sampling. The effects assessment was based on Washington State or federal chronic WQC.

5.2.2 Risk Characterization

Risks to the benthic invertebrate community were evaluated through four approaches: sediment data and toxicity test results, tissue residue, surface water, and porewater. Risks to crabs were evaluated through two approaches: tissue residue and surface water. Based on the results of the risk estimates and the uncertainty analysis, risk conclusions were made and COCs were identified.

[83] Dungeness crab in Oregon have been known to travel up to 91 km (Hildenbrand et al. 2011), and red rock crab were reported to have moved 3.1 km in 6 to 10 days (Carroll and Winn 1989).

5.2.2.1 Sediment Data and Toxicity Test Results

Comparison of sediment chemistry and site-specific toxicity test results with SMS indicated that no adverse effects on benthic invertebrates living in intertidal and subtidal sediments are predicted for approximately 40% of the EW area (i.e., the area in which contaminant concentrations were less than or equal to SQS chemical criteria and/or sediment was non-toxic according to SQS biological effects criteria) (Map 4-13). Adverse effects are predicted in approximately 21% of the EW area, which had contaminant concentrations or biological effects in excess of the CSL values. The remaining 39% of the EW area had contaminant concentrations or biological effects between the SQS and CSL values, indicating the potential for minor adverse effects to benthic invertebrate communities. Some uncertainty is associated with these area estimates because areas were calculated by interpolating from the individual locations at which sediment was sampled. Twenty-eight COPCs had at least one concentration that exceeded its respective SQS and one COPC, total DDTs, had at least one concentration that exceeded the SL; thus, twenty-nine COCs were identified for the benthic invertebrate community. The COCs include 4 metals, 16 individual PAHs or group of PAHs, 3 phthalates, 4 other SVOCs, total PCBs, and total DDTs.

5.2.2.2 VOCs in Porewater

VOCs in sediment porewater are unlikely to pose a risk to the benthic invertebrate community, except for naphthalene, which had a concentration that exceeded the LOEC TRV at one location. Naphthalene was identified as a COC based on the porewater evaluation.

5.2.2.3 Benthic Invertebrate Tissue Residues

Benthic invertebrates were identified as potentially being at risk from exposures to TBT in 2 of the 12 benthic invertebrate tissue sampling areas of the EW because the tissue-residue LOAEL TRV for TBT was exceeded in samples collected from those two areas (Map 5-1). Therefore, TBT was identified as a COC based on the tissue-residue evaluation. For total PCBs, risk was predicted to be low and uncertain because tissue concentrations were below LOAEL TRV but greater than the NOAEL TRV in 10 of the 13 sampling areas evaluated for total PCBs. In the remaining three sampling areas, total PCB tissue concentrations were below the NOAEL TRV.

5.2.2.4 Benthic Invertebrate Surface Water

Cadmium[84] and mercury are not expected to pose a risk to the benthic invertebrate community based on the comparison of surface water EPCs to the Washington State or federal chronic WQC. There is uncertainty in the risk posed to the benthic invertebrate community from exposure to TBT. One location-specific and one individual sample EPC for TBT exceeded the federal chronic WQC, each with a hazard quotient (HQ) of 1.4; TBT was undetected in the remaining 30 samples with RLs (0.01 µg/L) that slightly exceeded the WQC (0.066 µg/L). Because of the one-location specific exceedance and the RL exceedance of the WQC, TBT was selected as a COC for benthic invertebrates based on the surface water evaluation.

5.2.2.5 Crab Tissue Residue

Cadmium, copper, and zinc were identified as COCs because concentrations of these COPCs in crab tissue were greater than their LOAEL TRVs, indicating potential risks to crab. Arsenic and total PCBs, the two remaining COPCs, had concentrations in crab tissue below LOAEL TRVs but above NOAEL TRVs, indicating low but uncertain risks to crab. These two COPCs were not identified as COCs because concentrations were below LOAEL TRVs.

5.2.2.6 Crab Surface Water

Three chemicals (cadmium, mercury, and TBT) were identified as surface water COPCs for the crab ROCs. EPCs were calculated as the 95% UCLs using all of the site-wide surface water data for each COPC to represent exposure throughout the site, thus accounting for a variety of seasons and water flow conditions. In addition, as a more conservative analysis, EPCs based on detected COPC concentrations in individual water samples were used to represent conditions at each location at the time of sampling. Cadmium and mercury EPCs were based on the dissolved fraction because the TRVs were based on the dissolved fraction; TBT EPCs were based on total concentrations. The effects assessment was based on the Washington State chronic WQC for cadmium, the federal chronic WQC for mercury, and

[84] One anomalous detection of dissolved cadmium resulted in an HQ of 4.1 based on both the location-specific and individual sample EPCs. Details regarding this anomalous result are presented in Section A.6.1.1.3 of Appendix A.

the federal FCV for TBT.[85] No COCs were selected for crab based on the surface water evaluation.

5.3 Fish Assessment

This section presents an overview of the risk assessment for fish. The complete assessment is presented in Appendix A, Sections A.4 and A.6.2. Three ROCs were selected in the problem formulation to represent the different kinds of fish that use the EW and may be exposed to sediment-associated contaminants. COPCs were identified separately for each of those species, as follows:

- **Juvenile Chinook salmon –** arsenic, cadmium, chromium, copper, mercury, vanadium, and TBT
- **English sole –** arsenic, cadmium, chromium, copper, mercury, vanadium, benzo(a)pyrene, TBT, and PCBs
- **Brown rockfish –** arsenic, cadmium, mercury, chromium, copper, vanadium, benzo(a)pyrene, mercury, TBT, beta-endosulfan, and total PCBs

5.3.1 Exposure and Effects Assessment

Risks to fish were evaluated using three approaches – tissue residue, dietary, or surface water exposures. The tissue-residue approach was used for bioaccumulative COPCs: mercury, TBT, beta-endosulfan, and total PCBs. The dietary approach was used for arsenic, cadmium, chromium, copper, vanadium, and benzo(a)pyrene because these COPCs are metabolically regulated by fish. The surface water COPCs for fish were cadmium, mercury, and TBT.

COPCs were evaluated for each fish ROC under different approaches. To evaluate risks using a tissue-residue approach, the exposure assessment was based on the 95% UCL concentrations of TBT and total PCBs in English sole whole body tissue; and 95% UCL concentrations of mercury, total PCBs, beta-endosulfan and TBT in brown rockfish whole-body tissue collected from the EW. Brown rockfish data were also evaluated on an individual basis using COPC concentrations in each individual fish. No COPCs were identified for juvenile Chinook salmon using the tissue-residue approach. In the effects assessment for the

[85] The selection of the federal FCV for the TBT TRV for crab is discussed in Section A.3.4.2 of Appendix A.

tissue residue approach, toxicological studies from the scientific literature reporting fish tissue concentrations associated with adverse effects on growth, survival, and reproduction of fish were used to derive NOAEL and LOAEL TRVs. For PCBs in tissue, a range of NOAEL and LOAEL TRVs was used because of the uncertainty in the study from which the TRVs were derived (as discussed in both the effects section [Section A.4.2.1.3] and the uncertainty section [Section A.6.2.2.2]).

Estimated concentrations of arsenic, cadmium, chromium, copper, vanadium, and benzo(a)pyrene in fish diets were identified in the exposure assessment for all three fish ROCs. Concentrations of dietary COPCs were estimated using 95% UCL concentrations of COPCs in prey tissue (i.e., benthic invertebrates for all three ROCs plus crab, shiner surfperch, and shrimp[86] for brown rockfish) and in incidentally ingested sediment. For juvenile Chinook salmon, dietary concentrations were also estimated based on the chemical analysis of one composite sample of stomach contents of juvenile Chinook salmon[87] collected from the EW. In the effects assessment, toxicological studies from the scientific literature reporting dietary concentrations associated with adverse effects on growth, survival, and reproduction of fish were used to derive NOAEL and LOAEL TRVs.

Three chemicals (cadmium, mercury, and TBT) were identified as surface water COPCs for the fish ROCs. EPCs were calculated as the 95% UCLs using all of the site-wide surface water data for each COPC to represent exposure throughout the site, thus accounting for a variety of seasons and water flow conditions. In addition, as a more conservative analysis, EPCs based on detected COPC concentrations in individual water samples were used to represent conditions at each location at the time of sampling. Cadmium and mercury EPCs were based on the dissolved fraction because the TRVs were based on the dissolved fraction; TBT EPCs were based on total concentrations. The effects assessment was based on the Washington

[86] One composite sample was available for shrimp so a 95%UCL could not be calculated.

[87] A total of 165 fish were analyzed for stomach contents. Nineteen fish had no measurable stomach contents, and 146 fish contributed mass to the composite sample. The individual fish stomach content masses ranged from 0.01 to 0.502g, with an average of 0.05 g of stomach contents per fish.

State chronic WQC for cadmium, the federal chronic WQC for mercury, and the federal final chronic value (FCV) for TBT.[88]

5.3.2 Risk Characterization

Exposure and effects data were compared in the risk characterization to assess the potential for sediment-associated COPCs to cause adverse effects to fish ROCs. Based on the results of the risk estimates and the uncertainty analysis, risk conclusions were made and COCs were identified for each fish ROC.

5.3.2.1 Juvenile Chinook Salmon

Two lines of evidence were used to evaluate dietary exposures for juvenile Chinook salmon: composite samples of *in situ* benthic invertebrates and a single composite sample of salmon stomach contents. For the stomach contents data, only cadmium had a NOAEL HQ > 1.0; whereas for the benthic invertebrate data, four metals (i.e., cadmium, chromium, copper, and vanadium) had NOAEL HQs > 1.0 and three metals (i.e., cadmium, copper and vanadium) had LOAEL HQs > 1.0. The arsenic NOAEL HQ was = 1.0. The uncertainties associated with both lines of evidence are discussed below.

- There is uncertainty associated with the use of only benthic invertebrate prey data to represent COPC concentrations in the juvenile Chinook salmon diet. In addition to infaunal benthic invertebrates, juvenile Chinook salmon ingest water column organisms such as zooplankton, larval fish, and terrestrial insects that drift in the current (Cordell et al. 1996; 1997; 1999). Water column prey are less closely associated with sediment than are benthic invertebrates and are less likely to have contaminant body burdens that reflect sediment exposure.
- Another uncertainty associated with using benthic invertebrate data to estimate dietary concentrations of COPCs for juvenile Chinook salmon is that the benthic invertebrate samples were composites of specimens collected from subtidal areas (mostly in deep-water areas) within the EW, whereas juvenile Chinook salmon generally do not forage in deep-water habitats (Tabor et al. 2004). Lastly, the use of composite benthic invertebrate tissue samples is uncertain because preferential

[88] The selection of the Federal FCV for the TBT TRV for fish is discussed in Section A.4.2.3 of Appendix A.

feeding in one area or on a subset of the organisms included in the composites could result in exposures that are either overestimated or underestimated by the exposure based on the 95th UCL for the composite samples.

- Because Chinook salmon are a federally listed species, it is relevant to consider adverse effects at the level of the individual as well as the population. In this risk evaluation, HQs were determined using the 95th UCL as the EPC for the benthic invertebrate tissue samples. The most conservative estimate of the exposure of an individual would be the maximum measured concentration. Use of the maximum value from the benthic invertebrate tissue data would change the HQ exceedance conclusions only for arsenic because the EPCs based on the 95th UCL concentrations for the other trace metals already exceed their respective LOAELs. However, because the maximum concentration comes from a single sampling location, its use is based on the unlikely assumption that the entire diet is based on the consumption of subtidal infaunal benthic invertebrates in one portion of the waterway.
- Use of the stomach contents data to represent juvenile Chinook salmon exposure is uncertain inasmuch as the data represent the diet of juvenile Chinook salmon in the EW at one point in time. Only one composite sample of stomach contents was available for analysis because of the limited sample mass collected. Thus, the measured stomach content concentrations do not necessarily reflect the maximum concentration to which an individual could be exposed. However, this sample does provide a good representation of the average stomach contents for fish in the EW at the time of the collection event because of the large number of fish (n = 165) that were used to create this stomach content composite sample.
- In addition to the uncertainties associated with estimating dietary exposure of juvenile Chinook salmon, there is high uncertainty associated with the cadmium LOAEL TRV (0.5 mg/kg dw) because it is substantially lower than concentrations associated with observed adverse effects in eight other toxicity studies. Furthermore, there is uncertainty in the NOAEL TRV because it was extrapolated from the LOAEL TRV using a safety factor of five. Using the lowest reported NOAEL (55 mg/kg dw) from a salmonid study (instead of the extrapolated NOAEL), the HQ calculated using the stomach content data was 0.01 and the HQ calculated using the benthic invertebrate tissue data was 0.02.

These results indicate that risk to juvenile Chinook salmon from cadmium is likely to be lower than the risk estimated using the selected TRV.

The risk characterization for juvenile Chinook salmon for the surface water evaluation was based on both site-wide and individual EPCs. All HQs were < 1.0 based on site-wide EPCs with the exception of the cadmium HQ of 4.1, which was based on one sample with an anomalous cadmium concentration (see Section A.6.2.1.2 of Appendix A). No COCs were identified for juvenile Chinook salmon based on the surface water evaluation.

5.3.2.2 English Sole

For the tissue-residue evaluation, the estimated risk to English sole from exposure to TBT was low based on the LOAEL HQ of 0.1. PCB tissue residues indicate a potential risk to English sole based on LOAEL HQs of 1.6 and 7.9. Total PCBs was identified as a COC for English sole for the tissue-residue evaluation; TBT was not identified as a COC.

The highest LOAEL HQs calculated using the dietary evaluation were for cadmium and vanadium (2.4 and 1.9, respectively). These HQs indicate a potential risk to English sole from dietary exposure, although there was a high level of uncertainty associated with each of the TRVs for these COPCs. Cadmium and vanadium were identified as COCs for English sole for the dietary evaluation.

For chromium exposure based on the dietary evaluation, a LOAEL HQ could not be calculated because a LOAEL TRV was not available. There is significant uncertainty associated with forming risk conclusions using a NOAEL TRV when no effects data are available. Therefore, the risk to English sole from chromium exposure in the diet is unknown, and chromium was not identified as a COC for English sole for the dietary evaluation.

The LOAEL HQ of 1.1 for copper indicates there may be a risk to English sole because the estimated concentration of copper in the diet is slightly above the concentration associated with reduced growth in juvenile rockfish. Copper was identified as a COC for English sole.

LOAEL HQs were < 1.0 for arsenic and benzo(a)pyrene, with relatively low uncertainty, indicating a low risk to English sole from dietary exposure to these COPCs. Arsenic and benzo(a)pyrene were not identified as COCs.

No COCs were identified for English sole based on the surface water evaluation.

5.3.2.3 Brown Rockfish

Tissue-residue LOAEL HQs for mercury and beta-endosulfan were < 1.0 (with the exception of one individual rockfish sample for mercury that had an HQ of 1.1[89]). For the dietary approach, LOAEL HQs were < 1.0 for arsenic, copper, vanadium, and benzo(a)pyrene. Therefore, there is low risk to brown rockfish in the EW from exposure to these COPCs. None of these COPCs were identified as COCs for brown rockfish based on the tissue-residue or dietary evaluations.

For TBT, the site-wide tissue-residue LOAEL HQ was < 1.0, indicating there is a low risk to brown rockfish. However, three individual samples had LOAEL HQs > 1.0, indicating that there is some risk to individual brown rockfish from TBT exposure. The rockfish with tissue TBT concentrations above the LOAEL were collected from the west side of the EW along T-18, an area with elevated sediment TBT concentrations; therefore, TBT was identified as a COC for brown rockfish based on the tissue-residue evaluation.

For PCBs, tissue residue LOAEL HQs > 1.0 were calculated using both site-wide and individual EPCs, indicating some risk to brown rockfish from PCB exposure. Total PCBs was identified as a COC for brown rockfish based on the tissue-residue evaluation.

For cadmium, LOAEL HQs > 1.0 on both site-wide and individual bases indicate some risk to brown rockfish from cadmium exposure as measured in the diet. However, there is uncertainty associated with the cadmium TRV and when the second-lowest LOAEL TRV was used to estimate risks, the LOAEL HQ was 0.002. Because the site-wide LOAEL HQ was > 1.0, cadmium was identified as a COC for brown rockfish based on the tissue-residue evaluation.

For chromium, a LOAEL HQ could not be calculated because no LOAEL TRV for fish was available. Therefore, risk to brown rockfish from chromium exposure in the diet is unknown.

[89] The distribution of mercury concentrations in the vicinity of the rockfish sample was examined, and the mercury concentrations were between the 50th and 75th percentile concentrations for the waterway. This area did not have unusually high mercury concentrations relative to the rest of the EW.

Chromium was not identified as a COC for brown rockfish based on the tissue-residue evaluation.

No COCs were identified for brown rockfish based on the surface water evaluation.

5.4 Wildlife Assessment

This section presents a summary of the risk assessment for aquatic-dependent wildlife. The complete assessment is presented in Appendix A, Sections A.5 and A.6.3. In the problem formulation, four ROCs were selected to represent wildlife that use the EW and may be exposed to sediment-associated contaminants. The ROCs and associated COPCs were:

- **Pigeon Guillemot –** mercury, total PCBs, PCB TEQ, and total TEQ
- **Osprey –** total PCBs
- **River otter –** mercury, selenium, total PCBs, PCB TEQ, and total TEQ
- **Harbor seal –** mercury, total PCBs, PCB TEQ, and total TEQ

Risks to wildlife ROCs were evaluated by comparing estimated COPC concentrations as a dietary dose for each ROC with dietary doses associated with adverse effects from the scientific literature.

5.4.1 Exposure and Effects Assessment

For wildlife ROCs, the daily exposure doses of COPCs were estimated in the exposure assessment. Exposure doses were calculated using COPC concentrations in prey, water, and sediment; food, water, and sediment ingestion rates; site use factors; and body weight, with the resulting ingested dose expressed as mg COPC/kg body weight/day (see Section A.5.1.2 of Appendix A for the exposure factor values used and for the percentages of prey types ingested by each ROC).

Each wildlife ROC has a foraging range larger than EW. Therefore, site use factors for all the wildlife ROCs were less than 1.0. The site use factors used for the pigeon guillemot and river otter were based on data from the scientific literature whereas those for osprey and harbor seal were based on site-specific data. Concentrations of COPCs in prey, water, and sediment were calculated as the 95% UCL or the maximum concentration if fewer than six samples were available.

The effects assessment presents a review of the scientific literature for the dietary exposure doses associated with adverse effects on survival, growth, and reproduction in birds and mammals. NOAELs and LOAELs were selected as dose-based TRVs for each COPC based on these effects.

5.4.2 Risk Characterization

Risks to wildlife ROCs were evaluated based on a comparison of ingested doses of COPCs in aquatic prey, surface water, and sediment from EW with dose-based TRVs based on data from the scientific literature. From the results of the risk estimates and the uncertainty analysis, risk conclusions were made and COCs were identified.

Risks were evaluated for two bird ROCs (pigeon guillemot and osprey), which served as representative surrogates for all other aquatic-dependent bird species that may be exposed in the EW. Exposures were below NOAEL TRVs for all COPCs, and therefore risks to birds from exposures to contaminants in the EW are considered to be unlikely. Therefore, no COCs were identified for bird ROCs.

Risks were evaluated for two mammal ROCs (river otters and harbor seals), which served as representative surrogates for all other aquatic-dependent mammal species that may be exposed in the EW. Exposures were below NOAEL TRVs for all COPCs for harbor seals, and therefore risks to harbor seals from exposure to contaminants in the EW are considered to be unlikely. For river otter, exposure doses were below NOAEL TRVs for selenium and therefore risks from selenium are unlikely. For exposure of river otter to mercury, total PCBs, PCB TEQ, and total TEQ, the potential for adverse effects was considered low and uncertain because the NOAEL TRVs were exceeded but the LOAEL TRVs were not exceeded. No COCs were identified for the mammal ROCs.

5.5 Summary of Risk Drivers

COCs were identified as risk drivers for ROCs based on the risk estimates, uncertainties discussed in the ERA, and regional background concentrations in accordance with EPA guidance (1992a, 1997a, b, 1998) and consistent with the LDW ERA (Windward 2007c). Further details on the selection of risk drivers are presented in Section A.7 of Appendix A. The risk drivers from both the ERA and the HHRA will be the focus of remedial analyses in

the FS. COCs not selected as risk drivers in the EW ERA will be evaluated qualitatively in the EW FS.

COCs that were identified as risk drivers are noted in Table 5-3. Twenty-eight sediment COCs were selected as risk drivers for the benthic invertebrate community because the concentrations of these 28 COCs exceeded SQS of the SMS in one or more surface sediment sampling locations and SMS is a key regulation governing sediment remediation in the State of Washington. TBT was identified as a risk driver for the benthic invertebrate community because TBT concentrations in benthic invertebrate composite tissue samples collected from 2 out of 12 areas within the EW exceeded the LOAEL TRV. The three COCs identified for crab were not selected as risk drivers because site sediment concentrations were similar to regional background concentrations (cadmium and copper) and because of uncertainties in the effects data for all three COCs, including the lack of toxicity data for crabs. Naphthalene in porewater was not selected as a risk driver for benthic invertebrates because of uncertainties in effects data and because only one sample exceeded the TRV.

Table 5-3
COCs and Risk Drivers Identified for ERA Receptors

Receptor	Evaluation Type	COPCs	COCs	Risk Driver
Benthic invertebrate community	sediment	29 chemicals, including metals, PAHs, total PCBs, phthalates, other SVOCs, total DDTs[a]	29 COPCs[b]	28 SMS chemicals[c]
	tissue residue	TBT, total PCBs	TBT	TBT
	surface water	cadmium, mercury, TBT	TBT	none
	porewater	naphthalene	naphthalene	none
Crab	tissue residue	arsenic, cadmium, copper, zinc, total PCBs	cadmium, copper, zinc	none
	surface water	cadmium, mercury, TBT	none	none
Fish	dietary	arsenic, cadmium, chromium, copper, vanadium, benzo(a)pyrene	cadmium, copper, vanadium	none
	tissue residue	beta-endosulfan, total PCBs, TBT	total PCBs, TBT	total PCBs
	surface water	cadmium, mercury, TBT	none	none
Birds	dietary dose	mercury, total PCBs, PCB TEQ	none	none
Mammals	dietary dose	mercury, selenium, total PCBs, PCB TEQ	none	none

[a] The 29 COPCs were arsenic, cadmium, mercury, zinc, acenaphthene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, BEHP, BBP, di-n-butyl phthalate, 1,4-dichlorobenzene, 2-methylnaphthalene, 2,4-dimethylphenol, dibenzofuran, n-nitrosodiphenylamine, phenol, total PCBs, and total DDTs. All COPCs had exceedances of SMS chemical criteria except total DDTs, which was based on exceedances of the DMMP guideline.

[b] Anthracene was inadvertently omitted as a COC in the ERA. One sample had an anthracene concentration above the SQS, with an HQ of 1.03. Anthracene has been included in Section 4 and the FS evaluation as a COC and benthic risk driver based on the SQS exceedance.

[c] All SMS chemicals were identified as risk drivers for benthic invertebrates. Total DDTs were identified as a COC based on the exceedance of DMMP criteria. However, total DDTs were not identified as risk drivers.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
COC – contaminant of concern
COPC – contaminant of potential concern
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredge Material Management Program
ERA – ecological risk assessment
FS – feasibility study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
HQ – hazard quotient
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SMS – Washington State Sediment Management Standards
SQS – sediment quality standards
SVOC – semivolatile organic compound
TBT – tributyltin
TEQ – toxic equivalent

Total PCBs was selected as a risk driver for English sole and brown rockfish because PCBs in tissue residues exceeded the higher LOAEL TRV that was associated with significant effects and uncertainties are low in the exposure data. TBT was not selected as a risk driver for rockfish because the LOAEL was exceeded by tissue concentrations in three individual fish but not by the EPC. The three dietary COCs for fish were not selected as risk drivers because the site sediment concentrations were similar to regional background concentrations and because of uncertainties in exposure or effects data.

6 SUMMARY OF THE BASELINE HUMAN HEALTH RISK ASSESSMENT

This section summarizes the baseline HHRA that has been completed as part of the SRI/FS for the EW. The HHRA presents risk estimates for various scenarios under which people could be exposed to COPCs present in fish and shellfish tissue, sediment, and surface water in the EW. To the extent possible, the EW HHRA is consistent with the approach and methods that were approved by EPA for use in the HHRA for the LDW (Windward 2007d), which is a Superfund site that is located upstream of and contiguous with the EW and has physical and functional characteristics similar to those of the EW.

Because knowledge of current and future site use is imperfect, the scenarios evaluated in this assessment have been selected in an attempt to not underestimate risks (i.e., to be health protective) and, as such, may overestimate risks for many site users. The dataset for the EW HHRA consisted primarily of tissue, sediment, and surface water chemistry data collected from the EW as part of the EW SRI sampling efforts, along with available historical data collected since 1995.

The following subsections summarize the various components of the EW HHRA, including the exposure assessment (which includes the CSM, data evaluation and screening for COPCs, and the selection of exposure parameters), toxicity assessment, risk characterization, uncertainty analysis, and selection of risk drivers for human health. The complete EW HHRA is included as Appendix B of this SRI.

6.1 Exposure Assessment

This section summarizes the CSM and selection of exposure pathways, the data evaluation and COPC screening, and the selection of exposure scenarios and associated exposure parameters used in the EW HHRA. Additional details regarding these topics are presented in Section B.3 of the EW HHRA (Appendix B).

6.1.1 Conceptual Site Model

The CSM describes scenarios under which people could be exposed to COPCs in EW seafood tissue, sediment, or surface water (Figure 6-1). Exposure scenarios were selected for consistency with the LDW HHRA (Windward 2007d) and through input from EPA and various site users, including the Muckleshoot and Suquamish Tribes. Exposure pathways

consisted of exposure through the consumption of seafood from the EW for various seafood consumption scenarios; dermal contact with and incidental ingestion of sediment (collectively referred to as direct sediment contact) during shore recreational, occupational exposure, or seafood harvesting in the EW; and dermal contact with and incidental ingestion of surface water in the EW during water recreation (e.g., while swimming).

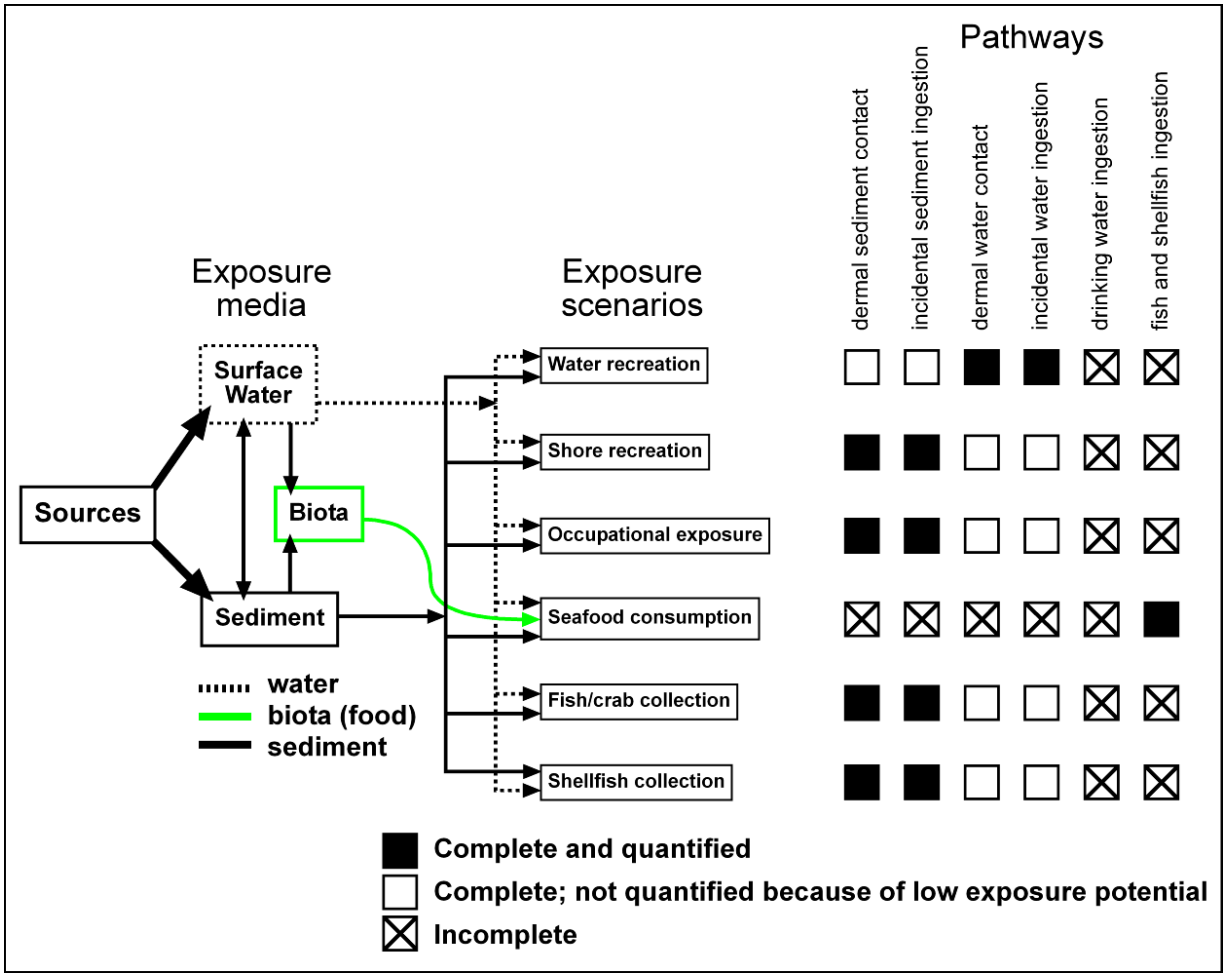


Figure 6-1
Conceptual Site Model for the EW HHRA

6.1.2 Data Evaluation and COPC Screening

This section summarizes the evaluation of the available data for use in the HHRA and the COPC screening process.

6.1.2.1 Data Evaluation

The data evaluation section of the EW HHRA (Appendix B, Section B.2) includes a description of what data were available, a determination of how the data were used in the EW HHRA, and a discussion of the suitability of the data for risk assessment purposes.

Tissue chemistry data for evaluating exposure through seafood consumption were available for English sole, perch (shiner surfperch and striped perch), brown rockfish, crab, clams (including geoducks), and mussels collected from within the EW. The seafood consumption rates used in the EW HHRA were based on recent regional consumption surveys for areas in and around Puget Sound but were not specific to the consumption of seafood from only the EW. Tissue chemistry data from the EW were not available for some of the species reported as being consumed in these regional studies. However, the species collected from the EW were considered representative of all trophic groups of seafood that could be consumed from the EW (e.g., English sole are considered to be representative of other benthic fish such as speckled sanddab) and were thus used as surrogates as necessary. It should be noted that human health risk estimates for the EW did not include the consumption of salmon, despite the fact that of all of the fish species caught in the EW for seafood consumption, salmon is one of the most highly preferred and consumed species (1999a). The exposure of salmon to bioaccumulative chemicals in EW sediment is not anticipated to significantly influence the concentrations of these chemicals in their tissue, primarily because of the very small portion of their lives spent in the EW (i.e., the vast majority of their lives is spent in Puget Sound and the Pacific Ocean). An analysis presented by O'Neill et al. (1998) indicated that less than 1% of the PCB body burden of adult salmon migrating through the LDW was obtained from prey items consumed in the LDW. Similarly, contributions to the adult salmon PCB body burden attributable to the EW would be expected to be minimal. This approach to the use of tissue chemistry data was consistent with that used in the LDW HHRA (Windward 2007d).

Sediment chemistry data consisted of subtidal and intertidal surface sediment samples:

- **Subtidal sediment** – Samples were analyzed as either individual grab samples or as composite samples depending on the analyte, and were collected from a depth of 0 to 10 cm.

- **Intertidal sediment –** Samples were analyzed as MIS composite samples, and were collected from a depth of 0 to 25 cm.

The collection depths were based on the physical characteristics of the EW and on the direct sediment exposure scenarios that these samples were intended to characterize, as discussed in the HHRA (Appendix B). Exposure to chemicals in surface water was evaluated using data collected from 1 m below the water surface.

Tissue, sediment, and surface water data collected from the EW were considered to be representative of chemical concentrations throughout the EW and the expected human exposure at the site. However, it should be noted that any uncertainties associated with these data (e.g., laboratory qualification of data or representativeness of tissue concentrations as compared with what individuals are actually consuming) may impact estimates of exposures and associated risk estimates.

6.1.2.2 COPC Screening

A risk-based screening of the EW data was performed using EPA guidance (EPA 1996) to identify the COPCs to be evaluated in the EW HHRA. The decision process for identifying COPCs is shown in Figure 6-2. This is similar to the process that was used in the LDW HHRA (Windward 2007d) for sediment and tissue. For detected chemicals with regional screening levels (RSLs) developed by EPA for Superfund sites (EPA 2010a), the maximum detected concentration was compared with the applicable RSL. Reporting limits were also compared with RSLs for chemicals with non-detected values that had maximum detected concentrations that did not exceed the RSLs. Additional details regarding this process are presented in Section B.3.2 of the HHRA.

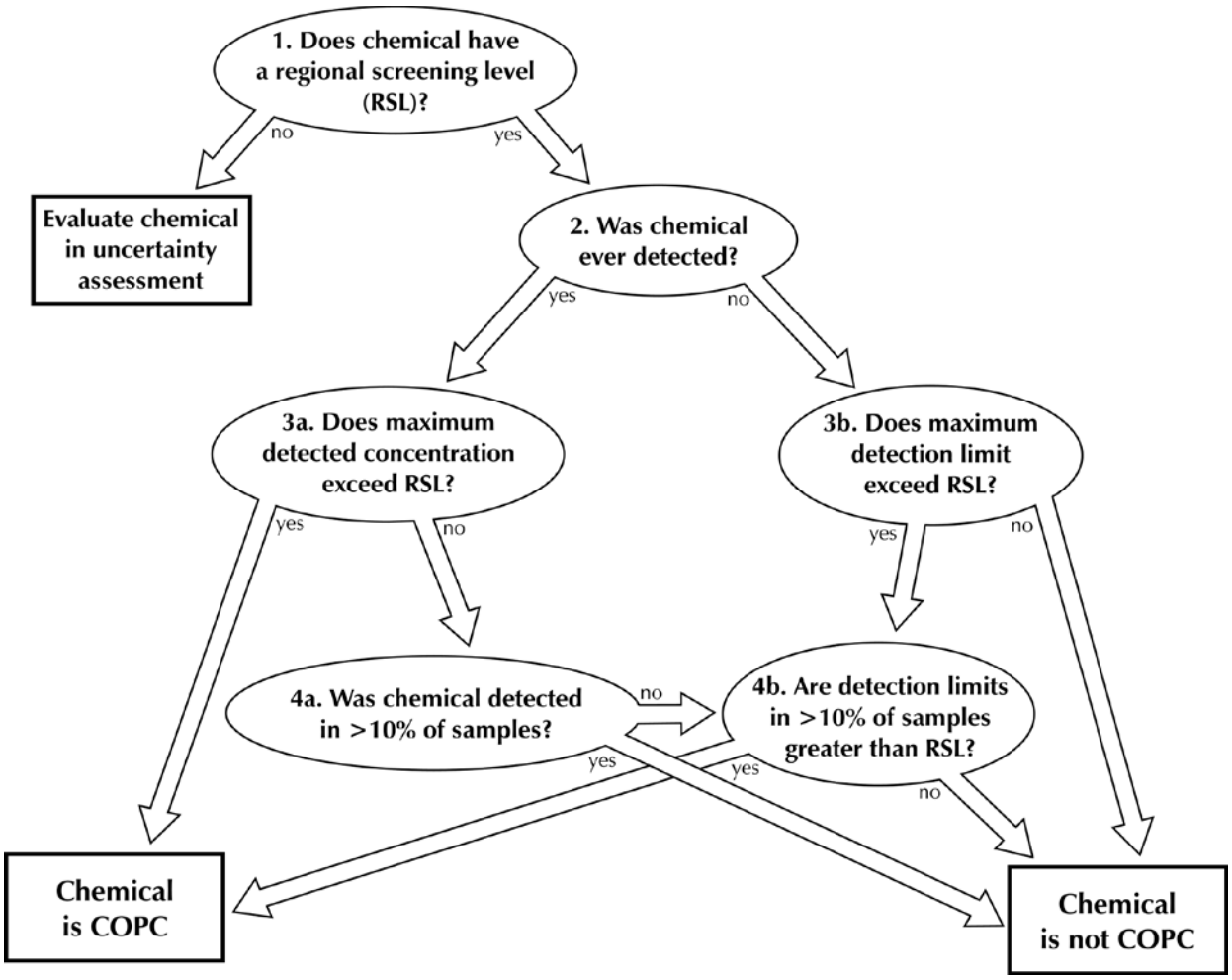


Figure 6-2
COPC Identification Flow Chart

The results of the COPC screen are presented in Table 6-1. For the seafood consumption scenarios, 54 chemicals or chemical groups were identified as COPCs (26 of which were never detected but were selected based on analytical DLs). For the direct sediment exposure scenarios, 12 chemicals or chemical groups were identified as COPCs (2 of which were never detected but were selected based on analytical DLs). Lastly, for the surface water exposure scenarios, 15 chemicals or chemical groups were identified as COPCs (9 of which were never detected but were selected based on analytical DLs). Potential risks for COPCs that were not detected were evaluated as part of the uncertainty analysis (see Section B.6.3.2 of the HHRA for details).

Table 6-1
COPCs Identified for EW HHRA Scenarios

COPC	Detection Frequency % (Ratio)			Selected as a COPC?				
					Direct Sediment Exposure Scenarios			
	Tissue[a]	Sediment[b]	Surface Water[c]	Seafood Consumption Scenarios	Netfishing	Habitat Restoration	Clamming[d]	Surface Water Exposure Scenarios
Detected in All Exposure Media								
Antimony	35 (34/98)	2 (3/185)	39 (11/28)	X	X		X_{ND}	
Arsenic[e]	88 (83/94)	70 (161/231)	100 (28/28)	X	X	X	X	X
Cadmium	58 (57/98)	70 (161/231)	96 (27/28)	X				
Chromium	86 (84/98)	100 (231/231)	68 (19/28)	X				X
Cobalt	47 (45/95)	100 (105/105)	21 (6/28)	X			X	
Copper	100 (98/98)	100 (231/231)	100 (28/28)	X				
Lead[f]	18 (18/98)	99 (228/231)	68 (19/28)	X	X		X[g]	
Mercury	87 (107/123)	97 (233/239)	75 (21/28)	X				
Molybdenum	85 (78/92)	62 (68/110)	nd	X				
Vanadium	61 (56/92)	100 (105/105)	96 (27/28)	X	X	X	X	X
Zinc	100 (98/98)	100 (231/231)	68 (19/28)	X				
cPAH TEQ	71 (68/96)	97 (233/241)	11 (3/28)	X	X	X	X	
Naphthalene	21 (20/96)	49 (118/241)	29 (8/28)					X
1,4-Dichlorobenzene	1 (1/98)	64 (149/232)	4 (1/28)	X	X			
Total PCBs	98 (121/124)	94 (227/241)	100 (28/28)	X	X	X	X	X
PCB TEQ	100 (28/28)	100 (17/17)	100 (28/28)	X	X[h]	X[h]	X	X[h]
Total DDTs	78 (18/23)	9 (13/152)	nd	X				
Total chlordane	70 (16/23)	2 (2/95)	nd	X				
Heptachlor	4 (1/23)	1 (1/100)	nd	X				
Dioxin/furan TEQ	100 (28/28)	100 (17/17)	nd	X	X		X	

COPC	Detection Frequency % (Ratio)			Selected as a COPC?				
					Direct Sediment Exposure Scenarios			
	Tissue[a]	Sediment[b]	Surface Water[c]	Seafood Consumption Scenarios	Netfishing	Habitat Restoration	Clamming[d]	Surface Water Exposure Scenarios
Detected in at Least One of the Three Exposure Media								
Selenium	100 (92/92)	0 (0/117)	100 (28/28)	X				
Dibutyltin as ion	9 (9/98)	44 (26/59)	0 (0/28)	X				
TBT as ion	75 (82/110)	95 (63/66)	0 (0/28)	X				
BEHP	0 (0/57)	88 (203/232)	7 (2/28)	X_{ND}				
BBP	0 (0/98)	46 (106/232)	0 (0/28)	X_{ND}				
Benzo(a)pyrene	50 (48/96)	93 (225/241)	0 (0/28)					X_{ND}
Pentachlorophenol	4 (2/57)	5 (11/232)	0 (0/28)	X				
1,2,4-Trichlorobenzene	0 (0/98)	5 (12/232)	0 (0/28)	X_{ND}				
2,4-Dinitrotoluene	0 (0/98)	1 (1/175)	0 (0/28)	X_{ND}				X_{ND}
Aniline	0 (0/92)	1 (1/143)	0 (0/24)	X_{ND}				
n-Nitroso-di-n-propylamine	0 (0/98)	1 (1/175)	0 (0/28)	X_{ND}				X_{ND}
n-Nitrosodiphenylamine	0 (0/98)	1 (2/232)	0 (0/28)	X_{ND}				
Aldrin	0 (0/23)	2 (2/100)	nd	X_{ND}				
Dieldrin	48 (11/23)	0 (0/100)	nd	X				
alpha-BHC	17 (4/23)	0 (0/95)	nd	X				
beta-BHC	9 (2/23)	0 (0/95)	nd	X				
Heptachlor epoxide	9 (2/23)	0 (0/95)	nd	X				
Mirex	43 (10/23)	0 (0/81)	nd	X				
Not Detected in Any of the Exposure Media								
1,2-Diphenylhydrazine	0 (0/6)	0 (0/5)	nd	X_{ND}				
2,4,6-Trichlorophenol	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				
2,4-Dichlorophenol	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				
2,4-Dinitrophenol	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				
2,6-Dinitrotoluene	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				
2-Nitroaniline	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				

COPC	Detection Frequency % (Ratio)			Selected as a COPC?				
					Direct Sediment Exposure Scenarios			
	Tissue[a]	Sediment[b]	Surface Water[c]	Seafood Consumption Scenarios	Netfishing	Habitat Restoration	Clamming[d]	Surface Water Exposure Scenarios
3,3′-Dichlorobenzidine	0 (0/87)	0 (0/167)	0 (0/28)					X_{ND}
4,6-Dinitro-o-cresol	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				X_{ND}
4-Chloroaniline	0 (0/88)	0 (0/163)	0 (0/28)	X_{ND}				X_{ND}
4-Nitroaniline	0 (0/94)	0 (0/174)	0 (0/28)	X_{ND}				
Bis(2-chloroethoxy)methane	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				
Bis(2-chloroethyl)ether	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				X_{ND}
Hexachlorobenzene	0 (0/98)	0 (0/232)	0 (0/28)	X_{ND}				X_{ND}
Hexachlorobutadiene	0 (0/98)	0 (0/232)	0 (0/28)	X_{ND}				
Hexachlorocyclopentadiene	0 (0/98)	0 (0/164)	0 (0/28)	X_{ND}				
Hexachloroethane	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				
n-Nitrosodimethylamine	0 (0/88)	0 (0/158)	0 (0/24)	X_{ND}			X_{ND}	X_{ND}
Nitrobenzene	0 (0/98)	0 (0/175)	0 (0/28)	X_{ND}				
Toxaphene	0 (0/95)	0 (0/86)	nd	X_{ND}			X_{ND}	

[a] The detection frequency for tissue was based on all tissue types included in the EW HHRA.

[b] The detection frequency for sediment was based on both subtidal and intertidal sediment samples.

[c] The detection frequency for surface water was based on total water concentrations for metals.

[d] Based on both the tribal clamming and 7-day-per-year clamming scenarios.

[e] For the seafood consumption scenarios, the arsenic assessment was based on inorganic arsenic exposure and toxicity data.

[f] No SL was available for lead. An alternative modeling method recommended by EPA was used instead to screen lead data (see Appendix B, Section B.3.3.5, for more information on lead models).

[g] Lead was identified as a COPC for only the tribal clamming scenarios (not the 7-day-per-year clamming scenario).

[h] PCB TEQ did not screen in as a COPC for these scenarios, but because total PCBs did screen in, PCB TEQ risks were evaluated.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
BHC – benzene hexachloride
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
DDT – dichlorodiphenyltrichloroethane
EPA – US Environmental Protection Agency
nd – no data
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SL – screening level
TEQ – toxic equivalent

X – Indicates that the chemical was selected as a COPC and was detected in the scenario exposure media.

X_{ND} – Indicates that the chemical was selected as a COPC, but was not detected in the scenario exposure media.

6.1.3 Exposure Scenarios and Associated Exposure Parameters

Human exposures to COPCs were estimated for a variety of seafood consumption, direct sediment exposure, and surface water exposure scenarios, as summarized below. Exposure estimates were based on the concentration of each COPC and health-protective assumptions regarding the rates and frequency of seafood consumption, as well as the rates, frequency, and duration of direct sediment contact or surface water exposure.

Several levels of exposure were evaluated in the EW HHRA to describe different intensities (e.g., frequency and duration) of site use or seafood consumption. These exposure levels include reasonable maximum exposure (RME) scenarios, high-end exposure scenarios, central tendency (CT) exposure scenarios, unit of exposure scenarios, and previously developed regional exposure scenarios. The following bullets describe how each was used in the risk assessment:

- **RME scenarios –** RME is the highest exposure that is reasonably expected to occur at a site. EPA generally uses RME scenarios to evaluate remedial actions at a site (EPA 1989). RME, by definition, likely overestimates exposure for many individuals. RME scenarios were evaluated for seafood consumption (adult and child tribal and API scenarios) and direct contact with sediment (netfishing and tribal clamming scenarios). With regard to the adult tribal seafood consumption scenarios, application of EPA's tribal seafood consumption framework (EPA 2007b) has resulted in the use of Tulalip seafood consumption survey data to characterize adult tribal RME seafood consumption (although the EW is not part of the Tulalip Tribes' Usual and Accustomed [U&A] fishing area). The selection of the Tulalip consumption rate to represent adult tribal RME seafood consumption is discussed below (Section 6.1.3.1).
- **High-end scenario** – An additional tribal scenario was also evaluated based on Suquamish seafood consumption survey data. This scenario represents a high-end risk for the EW site (EPA 2005a). In addition, a second tribal clamming scenario representing a level of exposure higher than that of the RME scenario was also evaluated.
- **CT scenarios –** In characterizing uncertainty in exposure and risk, it is useful to examine CT exposures (National Research Council 1994). CT risk estimates are intended to reflect average exposures. Average exposure estimates are not favored in

decision-making because they will underestimate exposure for a substantial number of individuals (EPA 1989).

- **Unit of exposure scenarios –** Another method of examining exposure is to identify a unit of exposure that a member of the public can use to assess the risks associated with their individual behavior. This approach was used to characterize seafood consumption exposure (based on the consumption of various seafood types) and direct contact exposures from clamming. The unit of exposure evaluated was one meal per month for seafood consumption and 7 days per year for clamming. Rather than describing a behavior that is specific to the EW, these scenarios are intended to serve as a basis on which individuals can evaluate their own exposure using a method that is readily scaled to various seafood consumption levels or frequency of clamming (i.e., a change in the rate of consumption or clamming frequency to higher or lower amounts results in a proportional change in the amount of chemical exposure and risk). This approach is not intended to represent a measured or established consumption rate or recreational clamming frequency for the EW. For example, older surveys on seafood consumption in Puget Sound suggested that seafood consumption by recreational anglers is greater than one meal per month (PSEP 1988).
- **Regional exposure scenarios** – Another method for evaluating risk is to use levels of exposure developed for nearby areas, as was done for estimating risks based on exposure to surface water while swimming. The three levels of exposure (high, medium, and low) that were previously developed for Elliott Bay and the Duwamish River (King County 1999a) were evaluated for the EW to provide a range of possible risk estimates. However, in this case, this approach likely resulted in a significant overestimation of surface water exposure levels for the EW, given that these levels of exposure were developed for areas that include larger numbers of recreational access points (e.g., Elliott Bay) than does the EW and do not have the EW's high concentration of large ship and tug boat traffic.

The exposure assessment presents the equations and parameters used to quantify exposures to COPCs in each scenario. The quantification of exposure consists of an estimate of the contaminant concentrations to which people might be exposed. This estimate is calculated from the concentration of each COPC and health-protective assumptions regarding intake rates of seafood, sediment, and surface water and the frequency and duration of the intake.

When possible, exposure parameters were consistent with those used in the LDW HHRA (Windward 2007d). The following subsections briefly discuss the parameterization for the scenarios evaluated in the EW HHRA. Additional details regarding the selection of exposure parameters are presented in Section B.3.3 of the EW HHRA.

6.1.3.1 Seafood Consumption Scenarios

Various seafood consumption scenarios were evaluated in the EW HHRA. Although the collection and consumption of seafood from the EW are known to occur (a creel study by King County (1999a) identified the Spokane Street Bridge on the EW as one of the more popular fishing locations along the shores of the Duwamish River and Elliott Bay), no seafood consumption surveys that focused solely on the consumption of seafood from the EW were available for individuals (e.g., recreational anglers, tribal members, or other communities) who either currently consume seafood or may consume seafood from this resource in the future. Therefore, the rates of seafood ingestion assumed for the seafood consumption scenarios were selected by EPA based on data collected from several regional surveys (Toy et al. 1996; EPA 1999a; Suquamish Tribe 2000).[90] Seafood harvest and consumption in the vicinity of CERCLA sites are likely to be suppressed. Because of this, EPA Region 10 believes it is appropriate to use seafood consumption rates derived from surveys that cover areas with levels of contamination that are lower than those at CERCLA sites (EPA 2011a). Such an approach is needed to characterize risks based on reasonable future use following the remediation of chemical contamination. In evaluating risks and exposures from smaller sites (such as the EW) within larger bodies of water (such as Puget Sound), EPA Region 10 believes that using a holistic approach is appropriate and thus using consumption rates associated with larger water bodies is necessary (EPA 2011a). This will support remedial actions that result in the uniform protection of public health throughout the larger water body.

[90] The Tulalip Tribes' survey (Toy et al. 1996), which was used to develop the tribal RME consumption scenario for the EW, did not include seafood obtained from the EW. Although the API survey (EPA 1999a) focused on King County, specific seafood harvest locations were not reported. The EW is a very small portion of the much larger fishing area that was included in the Suquamish Tribe's survey. Thus, the applicability of the overall consumption rate from these surveys to the EW alone is uncertain.

EPA Region 10 developed a framework to promote internal consistency in Puget Sound tribal seafood consumption risk assessments (EPA 2007b). In this framework, EPA selected Puget Sound tribal seafood consumption information to develop RME tribal seafood consumption rates for risk assessment for RCRA and CERCLA sites in the Puget Sound region. The application of EPA's tribal seafood consumption framework (EPA 2007b) has resulted in the use of Tulalip seafood consumption survey data to characterize adult tribal RME seafood consumption in the EW. The rate based on the Tulalip Tribes' study (Toy et al. 1996) was determined by EPA to be the most appropriate for application to the LDW and is therefore defined as the adult tribal RME scenario for the EW.

Inasmuch as the EW is within the U&A fishing area of the Suquamish Tribe, and the Suquamish Tribe has requested that their seafood consumption data be used to characterize risk, the EW HHRA also evaluates risk using Suquamish Tribe consumption rates. The scenario based on the Suquamish data is provided to characterize a range of tribal consumption rates and is not designated as the tribal RME scenario. Although, as stated above, the framework supports consistency in internal EPA policy regarding tribal seafood consumption risk assessment, the recommendations of the framework (EPA 2007b) do not replace or supersede the need for consultation between EPA and the tribes to develop site-specific risk assessments. Discussions between EPA and the Suquamish Tribe did not result in tribal concurrence regarding the use of the Tulalip tribal consumption rates as the RME scenario for the EW HHRA.[91] Rather, the use of the Tulalip rates represents an EPA policy decision. However, the Muckleshoot and Suquamish Tribes recognize that risk-based sediment cleanup levels for bioaccumulative risk driver contaminants based on seafood consumption risks will likely be below background, regardless of whether Tulalip or Suquamish consumption rates are used to develop cleanup levels. For this reason, the Suquamish Tribe has not pursued their disagreement with EPA more vigorously regarding the selection of the Tulalip Tribes' rate to characterize RME seafood consumption risks for the EW. The Suquamish Tribe regards the EW seafood consumption rate decision to be site-specific and does not regard it as being precedent-setting.

[91] The Suquamish Tribe requested that the tribal RME scenario be represented as a range of exposures based on the Tulalip and Suquamish consumption rates.

In the absence of a tribal seafood consumption survey that relates specifically to the consumption of seafood from only the EW, it is not known whether tribal members currently consume seafood from the EW at the rates assumed or might do so under future conditions. There is uncertainty regarding the application of these rates to the EW, and it is likely that the current rates of consumption of seafood from the EW are lower than those documented in the Tulalip tribal study because of the existing seafood consumption advisories. EPA's Superfund risk assessment guidance requires that exposure estimates be protective of future uses (EPA 1989). Tribes with treaty rights to obtain seafood from the EW may increase their consumption rate in the future as conditions in the EW improve with regard to chemical contamination.[92] Consumption rates also reflect cultural practices and traditions, which differ between tribes, and future use scenarios should reflect the tribes' desire to be able to harvest resources throughout their U&A fishing areas. Consequently, the seafood consumption rates evaluated for the RME scenarios in the EW HHRA are intended to be protective of both current and future uses.

As discussed above, the RME tribal scenario evaluated in the EW HHRA was based on Tulalip Tribal data. This scenario (the adult tribal RME seafood consumption scenario based on Tulalip data) includes a consumption rate of 97.5 g[93] of seafood per day (approximately three meals per week, assuming 227-g [8-oz] meals (EPA 2000b)) based on a Tulalip tribal study on the consumption of resident species of fish and shellfish from the Puget Sound region (not including salmon). This consumption rate was assumed to be applicable to the ingestion of seafood caught in the EW and was further divided into seafood categories as presented in Table 6-2. In addition to the adult tribal RME seafood consumption scenario based on Tulalip data, risks associated with the consumption of resident fish and shellfish were also quantified for seven other scenarios, which are listed below along with their total consumption rates:

- Adult tribal CT scenario based on Tulalip data: 15 g/day

[92] Although the amount and type of seafood consumed from a particular area may be affected by the habitat present there, it is not assumed that the overall tribal consumption rates are affected by the EW site.

[93] Rate does not include the consumption of anadromous fish. The total consumption rate, including anadromous fish, is 194 g/day (EPA 2006b).

- Child tribal RME scenario based on Tulalip data: 39 g/day
- Child tribal CT scenario based on Tulalip data: 6.0 g/day
- Adult tribal scenario based on Suquamish data: 583.5 g/day
- Adult Asian and Pacific Islander (API) RME scenario: 51.5 g/day
- Adult API CT scenario: 5.3 g/day
- Adult one-meal-per-month scenario: 7.5 g/day

Exposure scenarios for tribal children based on Tulalip data, adult tribal members based on Suquamish data, and API adults included a combination of the seafood categories listed in Table 6-2 (i.e., a market basket approach). As noted above, the ingestion rates presented in Table 6-2 include the consumption of only resident fish (not salmon). For the adult one-meal-per-month scenario, risks were evaluated based on the consumption of one meal per month of pelagic fish (perch or rockfish), benthic fish fillets, crab edible meat, or clams. Consistent with EPA risk assessment guidance, all assumptions regarding the amounts of seafood ingested in the RME scenarios were selected to be health-protective in order to avoid underestimating risks.

Table 6-2
Parameters for the Seafood Consumption Scenarios

Scenario	Ingestion Rate (g/day)								Meals per Month[d]	Exposure Duration (years)
	Benthic Fish[a]	Crab[b]	Mussel	Clam	Geoduck[b]	Perch[c]	Rockfish[c]	Total		
Adult tribal RME (Tulalip data)	7.5	34.4	0.8	39.3	7.4	7.1	1.0	97.5	13.1	70
Adult tribal CT (Tulalip data)	1.2	5.3	0.1	6.0	1.1	1.1	0.2	15	2.0	30
Child tribal RME (Tulalip data)	3.0	13.7	0.3	15.7	3.0	2.8	0.4	39.0	13.1	6
Child tribal CT (Tulalip data)	0.48	2.1	0.04	2.4	0.44	0.44	0.08	6.0	2.0	6
Adult tribal (Suquamish data)	25.9	49.8	5.0	393.7	49.8	0.6	55.4	583.5	78	70
Adult API RME	2.4	10.6	4.6	29.1	na	0.5	4.4	51.5	6.9	30
Adult API CT	0.24	1.1	0.5	3.0	na	0.05	0.45	5.3	0.7	9
Adult one meal per month	7.5	7.5	na	7.5	na	7.5	7.5	na	1.0	30

[a] Includes both fillet and whole-body consumption.

[b] Includes both edible-meat and whole-body consumption.

[c] Both perch (fillet and whole body) and rockfish (whole body) were classified as pelagic fish in this risk assessment.

[d] It was assumed that one adult meal was equal to 227g (8 oz). Child consumption rates were 40% of adult rates (EPA 2007b). For the purpose of calculating meals per month for children, this 40% conversion was assumed to represent a smaller meal size (40% of the adult meal size, which is equal to 91 g or 3.2 oz).

API – Asian and Pacific Islander
CT – central tendency
EPA – US Environmental Protection Agency
na – not applicable
RME – reasonable maximum exposure

6.1.3.2 Direct Sediment Exposure Scenarios

The direct sediment exposure scenarios evaluated in the EW HHRA included two netfishing scenarios (RME and CT), a habitat restoration worker scenario, and three clamming scenarios (tribal RME, tribal 183 days per year, and 7 days per year).[94] As in the LDW HHRA (Windward 2007d), exposure frequency and duration assumptions for the evaluation of direct sediment exposure under the commercial netfishing scenario were based on site use information collected from the Muckleshoot Indian Tribe, which conducts commercial netfishing for adult salmon in the Duwamish River, including the EW. Exposure parameter values for the clamming scenarios, which were consistent with those in the LDW HHRA (Windward 2007d), were based primarily on direction from EPA (e.g., 2007), default EPA exposure parameters (e.g., 1997c), and best professional judgment when site-specific data on exposure frequency and duration were not available (Table 6-3). The exposure parameter values for the habitat restoration worker scenario were based on default EPA exposure parameters and best professional judgment for frequency and duration assumptions.

Table 6-3
Parameters for the Direct Sediment Exposure Scenarios

Scenario	Incidental Sediment IR (g/day)	Exposure Frequency (days/yr)	Exposure Duration (years)	Skin Surface Area Exposed (cm^2)	Body Weight (kg)
Netfishing RME	0.050	119	44	3,600[a]	81.8
Netfishing CT	0.050	63	29	3,600[a]	81.8
Habitat restoration worker	0.1	15	20	6,040[b]	71.8
Tribal clamming RME	0.1	120	64	6,040[b]	81.8
Tribal clamming, 183-day-per-year	0.1	183	70	6,040[b]	81.8
Clamming, 7-day-per-year	0.1	7	30	6,040[b]	71.8

[94] The EW HHRA does not include an evaluation of the child beach play scenario because of the lack of suitable exposure areas.

[a] Recommended skin surface area value for commercial/industrial worker. Assumes that head, hands, and forearms are uncovered (i.e., exposed).
[b] Assumes that 39% of the total adult body surface area is exposed.
CT – central tendency
IR – ingestion rate
RME – reasonable maximum exposure

6.1.3.3 Surface Water Exposure Scenarios

Exposure to surface water in the EW was assessed for a swimming scenario, for which the exposure parameters were based on the adult swimming scenarios presented in the *King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay* (King County 1999a). As was done in the King County assessment, three levels of exposure (high, medium, and low) were evaluated (Table 6-4). The exposure parameters for each of these exposure levels are presented in Table 6-4.

Table 6-4
Parameters for the Adult Swimming Scenarios

Scenario Exposure Level	Incidental Water IR (ml/hr)	Event Duration (hrs)	Exposure Frequency (days/yr)	Exposure Duration (years)	Skin Surface Area Exposed (cm^2)
Low	25	0.17	2	9	4,900
Medium	50	1	12	30	19,400
High	75	2.6	24	70	21,800

IR – ingestion rate

However, it should be noted that the levels of exposure presented in Table 6-4 are likely significant overestimates of swimming exposure levels for the EW, given that they were developed for areas that include a greater number of recreational access points (e.g., Elliott Bay) than does the EW and do not have the EW's high concentration of large ship and tug boat traffic. Thus, none of these were designated as an RME for the EW because a swimming scenario is unlikely to be realistic for either current or future use in a commercial waterway such as the EW.

6.1.3.4 Exposure Point Concentrations

EPCs are the concentrations of COPCs in EW seafood tissue, sediment, and surface water that were used in the exposure equations to calculate COPC intake. The EPC was either the

95% UCL if there were sufficient detected values in the dataset[95] or the maximum concentration of a COPC, and was intended to represent a long-term exposure concentration. In a few cases, the EPC was set equal to one-half the maximum RL if this value was higher than the maximum detected concentration or there were no detected concentrations.

EPCs for the seafood consumption scenarios were calculated separately for various types of seafood, referred to as consumption categories. Ten consumption categories were developed based on seafood tissue types available in the EW: fillets of benthic fish, whole bodies of benthic fish, perch (both fillets and whole body), whole bodies of rockfish, edible meat of crab, whole bodies of crab, clams, edible meat of geoduck, whole bodies of geoduck, and mussels. A COPC intake was then calculated for each consumption category using the COPC tissue dataset and the consumption rate for each category. The contaminant intakes for each consumption category were then summed for each seafood consumption scenario (except the adult one-meal-per-month scenario) to yield an overall COPC intake for that scenario.

EPCs for the direct sediment exposure scenarios (i.e., netfishing, habitat restoration, and clamming) were calculated for the sediment area over which the exposure could potentially occur. The netfishing scenario assumed that people who engage in commercial netfishing could be exposed to both intertidal and subtidal sediment that might adhere to their nets. For both the habitat restoration and clamming scenarios, it was assumed that individuals would only come into contact with intertidal sediment. The intertidal area was further divided such that all accessible intertidal sediment (i.e., sediment not under piers and accessible by boat or shoreline access) was used to assess risks for the habitat restoration worker and tribal clamming scenarios, while only the intertidal area sediment to which the general public has access was used to assess risks for the 7-day-per-year clamming scenario (which is intended to be more representative of recreational clamming than are the tribal clamming scenarios). For the swimming scenario, EPCs were calculated assuming site-wide exposure to COPCs in EW surface water.

[95] Data management rules for calculating EPCs considered the detection frequency and the number of samples (Appendix B, Section B.3.3.4). When EPCs were based on a UCL, the 95th percentile or higher UCL was selected, as recommended by the ProUCL software.

6.2 Toxicity Assessment

EPA toxicity values (i.e., slope factors [SFs] for the evaluation of carcinogenic risks or reference doses [RfDs] for the evaluation of effects other than cancer) were identified for all COPCs. Toxicity values for each COPC have been established by EPA and other agencies and are based on either laboratory experiments that used animals or epidemiological studies of human populations who were unintentionally exposed in the workplace or in the environment. The SFs provide a health-protective means to evaluate risks because they represent upper-bound estimates of carcinogenic potency. Similarly, non-cancer toxicity values (i.e., RfDs) are health-protective because they are typically based on the most sensitive endpoint and population or test organism for which adequate data are available and include uncertainty factors or extrapolations to account for sensitive sub-populations or other limitations of the toxicity study data on which they are based.

In addition, it should be noted that the toxicity of co-planar PCBs and dioxins/furans was assessed using a toxic equivalency approach (i.e., a TEQ approach), and the toxicity of multiple cPAHs was assessed using a similar relative potency approach. In these approaches, the component chemicals are assigned a TEF (for PCBs or dioxins/furans) or PEF (for cPAHs) that describes their toxicity relative to that of the reference compound (2,3,7,8-TCDD for PCBs and dioxins/furans; benzo[a]pyrene for cPAHs). For example, a compound that is assumed to be equal in toxicity to the reference compound would have a TEF/PEF of 1.0, while a compound that is assumed to be half as toxic as the reference compound would have a TEF/PEF of 0.5.

A detailed discussion of the toxicity values and the TEF/PEF approach used in the EW HHRA is presented in Appendix B, Section B.4.

6.3 Risk Characterization

This section presents the risk estimates calculated using the exposure parameters and toxicity values discussed in Sections 6.1 and 6.2, respectively. Additional details are presented in Section B.5 of the EW HHRA (Appendix B).

6.3.1 Risk Estimate Calculations

Carcinogenic risks and non-carcinogenic health effects were evaluated separately in the EW HHRA because of fundamental differences in assumptions about the mechanisms of these

toxic effects (EPA 1989). Carcinogenic risk estimates were calculated by multiplying the estimated contaminant intake by the SF. Cancer risk estimates were compared with EPA's acceptable risk range of 10^{-6} to 10^{-4} established in the National Contingency Plan for Superfund sites (40 CFR 300). The lifetime risk of developing cancer in the US population is one in two (i.e., 5×10^{-1}) for men and one in three (i.e., 3×10^{-1}) for women (American Cancer Society 2006). A 1×10^{-6} excess cancer risk[96] represents an additional one-in-one-million probability that an individual will develop cancer over a 70-year lifetime as a result of exposure to contaminants in EW sediment and surface water (either through direct exposure or indirect exposure through the consumption of seafood). A COPC was identified as a COC when the excess cancer risk was greater than 1×10^{-6} for one or more of the RME scenarios.

Contaminants with non-carcinogenic health effects are generally not toxic below a certain threshold; a critical contaminant dose must be exceeded before adverse health effects are observed. The potential for non-carcinogenic health effects is represented by the ratio of the estimated contaminant intake to the critical contaminant dose (an RfD) and is expressed as an HQ. Exposures that result in an HQ less than or equal to 1 are unlikely to result in non-cancer adverse health effects. A COPC was identified as a COC when the HQ was greater than 1 for one or more of the RME scenarios. Contaminants that affect the same organ or physiological function (called "toxicity endpoints") may have additive effects. For those COPCs, the HQs for the same endpoint may be summed as a hazard index (HI). Effect-specific HIs were calculated for scenarios when the sum of all HQs was greater than 1, as was done for the LDW HHRA (Windward 2007d).

6.3.2 Seafood Consumption Scenarios

Estimated excess cancer risks and non-cancer HQs were highest for the seafood consumption scenarios (Tables 6-5 and 6-6, respectively), as compared with the direct sediment contact and surface water exposure scenarios. The total excess cancer risk for all carcinogenic COPCs was 1×10^{-3} for the adult tribal RME seafood consumption scenario based on Tulalip data. PCBs were identified as the primary contributor (70% of the total excess cancer risk), with excess cancer risks estimates equal to 1×10^{-3}. Other COPCs with excess cancer risks greater

[96] Excess cancer risk is defined as the additional probability (i.e., the probability above the lifetime cancer risk) of an individual developing cancer based on exposure to contaminants in the EW.

than 1×10^{-6} that contributed more than 5% to the total excess cancer risk were cPAH TEQ[97] (1×10^{-4}, 7% of the total excess cancer risk), inorganic arsenic (2×10^{-4}, 14% of the total excess cancer risk), and dioxin/furan TEQ (1×10^{-4}, 7% of the total excess cancer risk). The relative contribution to the total excess cancer risk was generally similar for other seafood consumption scenarios, with these four COPCs together contributing 95% or more of the total excess cancer risk for all scenarios. Total excess cancer risks for the two other RME scenarios were lower than those for the adult tribal RME scenario based on Tulalip data but still greater than the threshold of 1×10^{-6}: equal to 4×10^{-4} for the child tribal RME scenario based on Tulalip data and equal to 6×10^{-4} for the adult API RME scenario.

[97] TEQs were used for totaling certain groups of chemicals (cPAHs, PCBs, and dioxins/furans) relative to the most toxic component of the group: benzo(a)pyrene for cPAHs and 2,3,7,8-tetrachlorodibenzo-*p*-dioxin for dioxin-like PCBs and dioxins/furans.

Table 6-5

Estimated Excess Cancer Risks for the Seafood Consumption Scenarios

COPC[a]	Estimated Excess Cancer Risk											
								Adult One Meal per Month				
	Adult Tribal RME (Tulalip Data)	Adult Tribal CT (Tulalip Data)	Child Tribal RME (Tulalip Data)	Child Tribal CT (Tulalip Data)	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Benthic Fish	Clam	Crab	Pelagic Fish, Rockfish	Pelagic Fish, Perch
Arsenic[b]	2×10^{-4}	1×10^{-5}	4×10^{-5}	4×10^{-6}	2×10^{-3}	8×10^{-5}	2×10^{-6}	3×10^{-7c}	1×10^{-5}	2×10^{-6}	7×10^{-7}	2×10^{-6}
cPAH TEQ	1×10^{-4}	4×10^{-6}	1×10^{-4}	9×10^{-6}	1×10^{-3}	5×10^{-5}	9×10^{-7}	1×10^{-7}	9×10^{-6}	4×10^{-7}	9×10^{-8}	5×10^{-7c}
1,4-Dichlorobenzene	1×10^{-6d}	7×10^{-8d}	2×10^{-7d}	3×10^{-8d}	7×10^{-6d}	$4 \times 10^{-7\,d}$	8×10^{-9d}	4×10^{-8c}	$4 \times 10^{-8\,c}$	4×10^{-8c}	4×10^{-8c}	2×10^{-7c}
Pentachlorophenol	2×10^{-6d}	4×10^{-8d}	4×10^{-7d}	2×10^{-8d}	2×10^{-5d}	3×10^{-7}	4×10^{-9}	1×10^{-8c}	4×10^{-8}	1×10^{-8c}	1×10^{-8c}	3×10^{-8c}
Total PCBs	1×10^{-3}	5×10^{-5}	2×10^{-4}	2×10^{-5}	9×10^{-3}	4×10^{-4}	7×10^{-6}	2×10^{-4}	6×10^{-6}	1×10^{-5}	4×10^{-4}	1×10^{-4}
PCB TEQ[e]	7×10^{-4}	4×10^{-5}	1×10^{-4}	2×10^{-5}	6×10^{-3}	3×10^{-4}	8×10^{-6}	1×10^{-4}	5×10^{-6}	1×10^{-5}	3×10^{-4}	9×10^{-5}
Total DDTs	1×10^{-6}	9×10^{-8}	2×10^{-7}	4×10^{-8}	1×10^{-5}	6×10^{-7}	1×10^{-8}	2×10^{-7}	2×10^{-8}	2×10^{-8c}	5×10^{-7}	2×10^{-7}
alpha-BHC	4×10^{-6d}	2×10^{-7d}	7×10^{-7d}	1×10^{-7d}	2×10^{-5d}	9×10^{-7d}	3×10^{-8d}	1×10^{-7c}	1×10^{-7c}	1×10^{-7c}	2×10^{-7}	1×10^{-7c}
beta-BHC	1×10^{-6d}	7×10^{-8d}	2×10^{-7d}	3×10^{-8d}	7×10^{-6d}	3×10^{-7d}	8×10^{-9d}	4×10^{-8c}	4×10^{-8c}	3×10^{-8c}	4×10^{-8c}	3×10^{-8c}
Dieldrin	8×10^{-6d}	5×10^{-7d}	1×10^{-6d}	2×10^{-7d}	5×10^{-5d}	2×10^{-6d}	7×10^{-8d}	2×10^{-7}	3×10^{-7c}	3×10^{-7c}	4×10^{-7}	5×10^{-7}
Total chlordane	2×10^{-6}	9×10^{-8}	3×10^{-7}	4×10^{-8}	1×10^{-5}	7×10^{-7}	1×10^{-8}	4×10^{-8}	8×10^{-8}	2×10^{-8c}	1×10^{-7}	5×10^{-8}
Heptachlor	1×10^{-6d}	7×10^{-8d}	2×10^{-7d}	3×10^{-8d}	7×10^{-6d}	3×10^{-7d}	1×10^{-8d}	4×10^{-8c}	4×10^{-8c}	4×10^{-8c}	5×10^{-8c}	4×10^{-8c}
Heptachlor epoxide	2×10^{-6d}	2×10^{-7d}	4×10^{-7d}	7×10^{-8d}	1×10^{-5d}	7×10^{-7d}	2×10^{-8d}	9×10^{-8c}	9×10^{-8c}	9×10^{-8c}	1×10^{-7}	9×10^{-8c}
Mirex	4×10^{-6d}	3×10^{-7d}	8×10^{-7d}	1×10^{-7d}	3×10^{-5d}	1×10^{-6d}	4×10^{-8d}	2×10^{-7c}	2×10^{-7c}	2×10^{-7c}	4×10^{-7}	2×10^{-7c}
Dioxin/furan TEQ[e]	1×10^{-4}	6×10^{-6}	2×10^{-5}	3×10^{-6}	7×10^{-4}	4×10^{-5}	1×10^{-6}	5×10^{-6}	3×10^{-6}	3×10^{-6}	2×10^{-5}	9×10^{-6}
Total TEQ excess cancer risk for dioxins/furans and co-planar PCBs	**8×10^{-4}**	**5×10^{-5}**	**1×10^{-4}**	**2×10^{-5}**	**7×10^{-3}**	**3×10^{-4}**	**9×10^{-6}**	**1×10^{-4}**	**8×10^{-6}**	**1×10^{-5}**	**3×10^{-4}**	**1×10^{-4}**
Total excess cancer risk (excluding PCB TEQ)[f]	**1×10^{-3}**	**7×10^{-5}**	**4×10^{-4}**	**4×10^{-5}**	**1×10^{-2}**	**6×10^{-4}**	**1×10^{-5}**	**2×10^{-4}**	**3×10^{-5}**	**2×10^{-5}**	**4×10^{-4}**	**1×10^{-4}**
Total excess cancer risk (excluding total PCBs)[f]	**1×10^{-3}**	**6×10^{-5}**	**3×10^{-4}**	**4×10^{-5}**	**1×10^{-2}**	**5×10^{-4}**	**1×10^{-5}**	**1×10^{-4}**	**3×10^{-5}**	**2×10^{-5}**	**3×10^{-4}**	**1×10^{-4}**

[a] Only those COPCs with an excess cancer risk greater than 1×10^{-6} for one or more scenarios are included in this table.

[b] Arsenic EPCs and risk estimates are based on inorganic arsenic.

[c] There were no detected values of this COPC for this seafood category. Risk estimate was based on one-half the maximum RL.

[d] Greater than 50% of the risk associated with this COPC was derived from seafood categories with no detected values.

[e] No mussel data were available for this COPC. When the CDI and risk values were calculated, the portion of seafood consumption that had been assigned to mussels was divided proportionally among the remaining consumption categories.

[f] Total risk values include the risks associated with all COPCs.

API – Asian and Pacific Islander
BHC – benzene hexachloride
CDI – chronic daily intake
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
DDT – dichlorodiphenyltrichloroethane
PCB – polychlorinated biphenyl
RL – reporting limit
RME – reasonable maximum exposure
TEQ – toxic equivalent

Shaded cells identify excess cancer risks greater than 1×10^{-6}.

Table 6-6
Estimated Non-Cancer Hazards for the Seafood Consumption Scenarios

COPC[a]	Estimated Non-Cancer Hazard												
	Adult Tribal RME (Tulalip Data)	Adult Tribal CT (Tulalip Data)	Child Tribal RME (Tulalip Data)	Child Tribal CT (Tulalip Data)	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month				
								Benthic Fish	Clam	Crab	Pelagic Fish, Rockfish	Pelagic Fish, Perch
Arsenic[b]	0.4	0.05	0.9	0.1	4	0.4	0.03	0.002	0.08	0.01	0.004	0.009
Cadmium	0.7	0.08	2	0.2	2	0.4	0.03	0.01	0.01	0.09	0.004	0.004
Cobalt	0.6	0.07	1	0.2	4	0.5	0.04	0.01	0.07	0.05	0.02	0.02
Mercury	0.6	0.07	1	0.2	3	0.4	0.04	0.05	0.02	0.09	0.2	0.04
TBT as ion	0.3	0.03	0.7	0.07	4	0.4	0.03	0.007	0.05	0.003	0.2	0.04
Total PCBs[c]	27	3	58	6	214	24	1	13	0.4	0.8	21	8
Total PCBs[d]	8	0.8	17	2	61	7	0.4	4	0.1	0.2	6	2
PCB TEQ[e]	7	0.9	14	2	58	7	0.6	2	0.1	0.3	6	2
Dioxin/furan TEQ[e]	1	0.1	2	0.3	7	0.9	0.07	0.1	0.06	0.07	0.4	0.2
Total TEQ[e]	**8**	**1**	**16**	**2**	**65**	**8**	**0.7**	**2**	**0.2**	**0.4**	**6**	**2**
HIs by Endpoint:												
hematological endpoint[f]	**0.3**	**0.05**	**0.8**	**0.1**	**2**	**0.2**	**0.02**	**0.01**	**0.02**	**0.04**	**0.03**	**0.02**
immunological endpoint[g]	**27**	**3**	**59**	**6**	**218**	**24**	**1**	**13**	**0.5**	**0.8**	**21**	**8**
kidney endpoint[h]	**0.8**	**0.1**	**2**	**0.2**	**3**	**0.5**	**0.04**	**0.02**	**0.02**	**0.1**	**0.01**	**0.01**
liver endpoint[i]	**0.06**	**0.008**	**0.1**	**0.02**	**0.3**	**0.04**	**0.003**	**0.007**	**0.006**	**0.004**	**0.01**	**0.008**
neurological endpoint[j]	**28**	**3**	**59**	**6**	**218**	**25**	**1**	**13**	**0.4**	**0.9**	**21**	**8**
endocrine endpoint[k]	**0.6**	**0.08**	**1**	**0.2**	**4**	**0.5**	**0.04**	**0.01**	**0.08**	**0.05**	**0.02**	**0.02**
integumentary endpoint[l]	**28**	**3**	**59**	**6**	**219**	**25**	**1**	**13**	**0.5**	**0.8**	**21**	**8**
digestive system endpoint[m]	**0.5**	**0.06**	**1**	**0.1**	**2**	**0.3**	**0.03**	**0.005**	**0.04**	**0.04**	**0.02**	**0.02**
developmental endpoint[n]	**10**	**1**	**20**	**3**	**71**	**8**	**0.7**	**4**	**0.2**	**0.5**	**7**	**2**

[a] Only those COPCs with HQs greater than 1 for one or more scenario are included in this table.

[b] Arsenic EPCs and risk estimates are based on inorganic arsenic.

[c] HQ used for the calculation of the immunological, integumentary, and neurological endpoint HIs (Appendix B, Table B.4-1).

[d] HQ used for the calculation of the developmental endpoint HI (Appendix B, Table B.4-1).

[e] HQs for PCB TEQ and dioxin/furan TEQ were not presented in the EW HHRA because no RfD was available to calculate these values. The recently released RfD for 2,3,7,8-TCDD has since been used to calculate the HQs presented in this table. Additional information regarding these new HQs are presented in Attachment 7 to the HHRA (Appendix B of this SRI).

[f] Hematological endpoint includes the following chemicals: antimony, selenium, and zinc.

[g] Immunological endpoint includes the following chemicals: dibutyltin, total PCBs, and TBT.

[h] Kidney endpoint includes the following chemicals: cadmium, molybdenum, and pentachlorophenol.

[i] Liver endpoint includes the following chemicals: 1,4-dichlorobenzene, alpha-BHC, total chlordane, total DDTs, dieldrin, heptachlor, heptachlor epoxide, mirex, and pentachlorophenol.

[j] Neurological endpoint includes the following chemicals: mercury, total PCBs, and selenium. Neurological effects associated with exposure to lead are discussed in Appendix B, Section B.5.4.

[k] Endocrine endpoint includes the following chemicals: antimony and cobalt.

[l] Integumentary endpoint includes the following chemicals: arsenic, total PCBs, selenium, and vanadium.

[m] Digestive system endpoint includes the following chemicals: chromium and copper.

[n] Developmental endpoint includes the following chemicals: mercury, PCBs (the higher of either the total PCB HQ based on the developmental RfD or the PCB TEQ HQ), and dioxin/furan TEQ.

API – Asian and Pacific Islander
BHC – benzene hexachloride
COPC – contaminant of potential concern
CT – central tendency
DDT – dichlorodiphenyltrichloroethane
EPC – exposure point concentration
HI – hazard index
HQ – hazard quotient
PCB – polychlorinated biphenyl
RfD – reference dose
RME – reasonable maximum exposure
TBT – tributyltin

Shaded cells identify non-cancer HQs greater than 1.

Of the non-RME scenarios, risks were highest for the adult tribal scenario based on Suquamish data (total excess cancer risk of 1×10^{-2}), approximately 5 times higher than risks for the adult tribal RME scenario based on Tulalip data. Total excess cancer risk estimates for the CT scenarios were one or more orders of magnitude lower than those for the adult tribal RME scenario based on Tulalip data (Table 6-5) but still greater than the 1×10^{-6} threshold. For the adult one-meal-per-month scenarios, total excess cancer risks estimates were highest for pelagic fish (rockfish) consumption and lowest for crab consumption and ranged from 2×10^{-5} to 3×10^{-4} (all were greater than the 1×10^{-6} threshold). For all of the non-RME scenarios, excess cancer risks were greater than 1×10^{-6} for some or all of the COPCs shown in Table 6-5.

As shown in Table 6-5, excess cancer risks from PCBs were calculated in two ways: as the sum of detected Aroclors (referred to herein as total PCBs) and as a TEQ.[98] In general, the risk from total PCBs calculated as a sum of detected Aroclors was equal to or up to approximately two times higher than the risk calculated from the PCB TEQ. Because of this difference, the total risk (i.e., the sum of individual COPC risk estimates for each exposure scenario) was calculated two ways, first by including total PCBs and excluding PCB TEQ and then by including PCB TEQ and excluding total PCBs. Both of these summation approaches for the total excess cancer risk are presented in Table 6-5. The total TEQ risk (i.e., sum of PCB TEQ and dioxin/furan TEQ) was also calculated for each scenario because of the shared mode of toxicity of the two contaminant groups. For all seafood consumption scenarios, PCB TEQ contributed the majority (over 63%) to the total TEQ risk.

In the evaluation of non-cancer hazards, total PCB HQs were greater than 1 for all three RME scenarios, and the cadmium HQ was greater than 1 for the child tribal RME scenario based on Tulalip data, indicating some potential for adverse effects other than cancer (Table 6-6). For the non-RME scenarios, total PCB HQs were greater than 1 for all scenarios, except the adult API CT scenario and the crab and clam adult one-meal-per-month scenarios. In addition to total PCBs, arsenic, cadmium, cobalt, mercury, and TBT all had HQs greater than 1 for the adult tribal scenario based on Suquamish data. Different contaminants

[98] PCB TEQ is calculated using TEFs, which relate the toxicity of the co-planar PCB congeners (i.e., those with dioxin-like properties) to the toxicity of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin.

can have different toxic effects (e.g., may adversely affect different endpoints such as kidney, liver, or neurological) that are not additive. The maximum HIs for all scenarios were for either the immunological endpoint, neurological endpoint, or integumentary endpoint. Total PCBs accounted for over 80% of these non-cancer HIs.

As discussed previously, those COPCs with excess cancer risks greater than 1×10^{-6} or HQs greater than 1 for one or more RME scenarios were identified as COCs. For the seafood consumption scenarios, COCs include arsenic, cadmium, cPAH TEQ, pentachlorophenol, total PCBs, PCB TEQ, alpha-benzene hexachloride (BHC), dieldrin, total chlordane, heptachlor epoxide, mirex, and dioxin/furan TEQ.

Risk estimates presented in the EW HHRA indicate that elevated risks result from exposure to a small number of contaminants, as demonstrated by the distribution of total excess cancer risks by COPC for all seafood consumption scenarios (Figure 6-3). Although there is some variability with regard to their percent contribution, arsenic, cPAH TEQ, total PCBs, and dioxin/furan TEQ together contribute 95% or more of the total excess cancer risk for the seafood consumption scenarios.

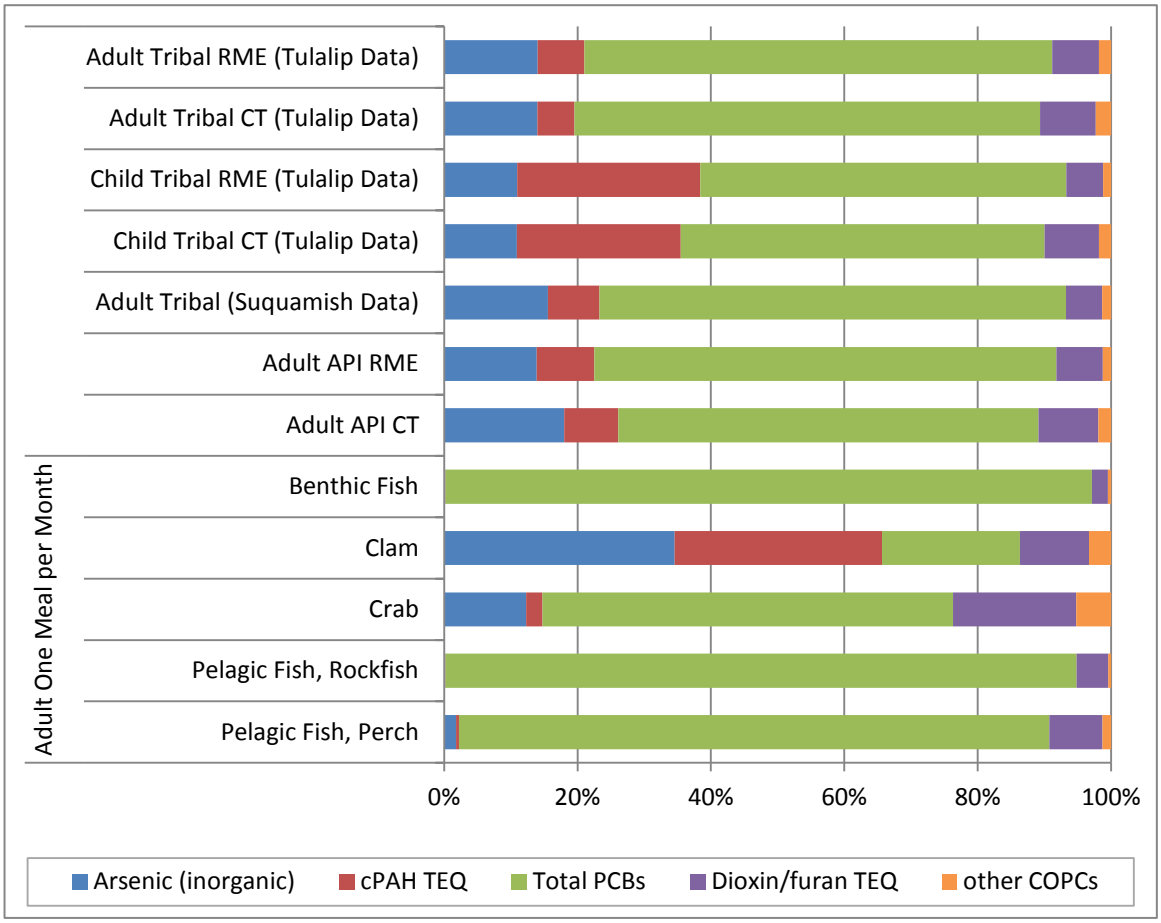
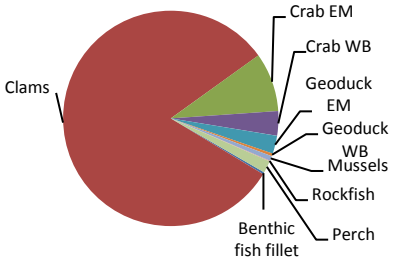
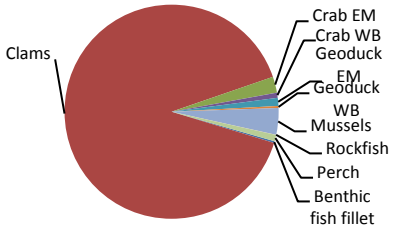
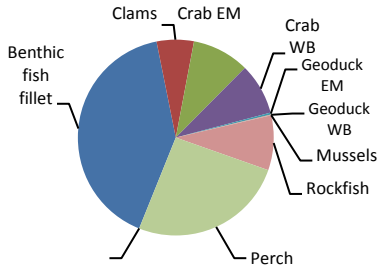
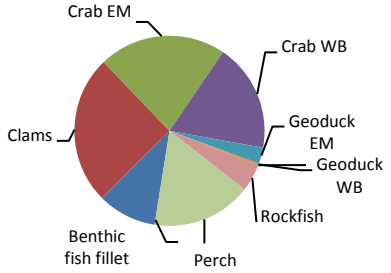


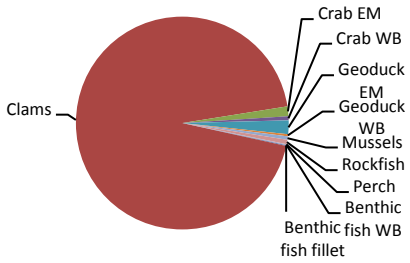
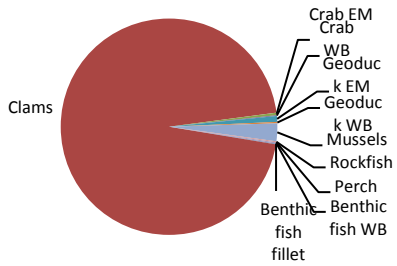
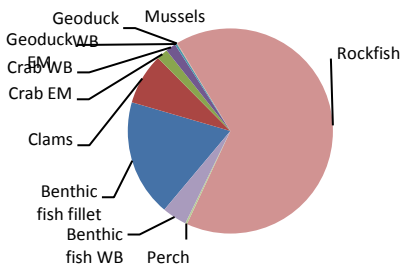
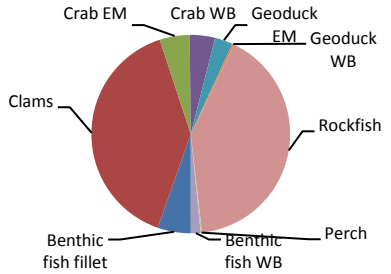
Figure 6-3
Percent Contribution of COPCs to the Total Excess Cancer Risk for the Seafood Consumption Scenarios

A general review of background tissue and sediment data for the four COCs contributing the greatest percentage of the overall risk to people in EW indicated that only arsenic had sufficient data and had concentrations in background and EW samples that were similar enough to conduct an incremental risks evaluation (i.e., to estimate incremental risks from site-related contamination). For the direct sediment exposure scenarios, this evaluation found that incremental cancer risks were greater than 1×10^{-6} (i.e., concentrations in EW sediment samples were higher than those in upstream sediment samples). For the seafood consumption scenarios, incremental cancer risks were less than or equal to 1×10^{-6}, indicating that tissue concentrations of inorganic arsenic in the EW were similar to those in background areas in Puget Sound.

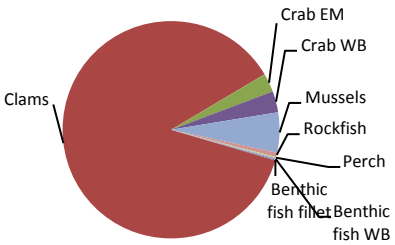
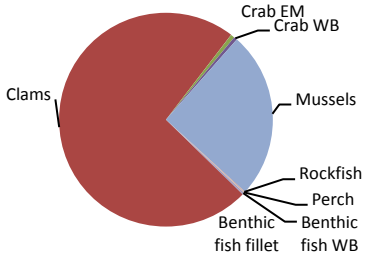
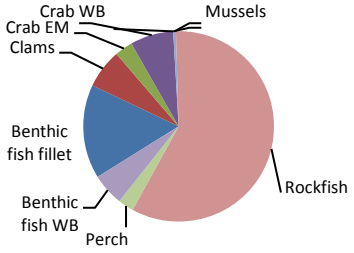
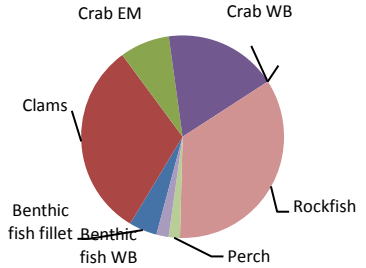
It is also helpful to consider the risk estimates in terms of the proportions of risk related to the consumption of individual seafood types. Elevated risk estimates associated with inorganic arsenic and cPAH TEQ in seafood are largely attributed to clams for all adult seafood consumption scenarios (Figure 6-4). In contrast, the seafood consumption categories that contribute the majority of the risk for PCBs and dioxin/furan TEQ are more variable by scenario. For PCBs, risks are primarily attributable to benthic fish fillet, perch, and/or rockfish. For dioxin/furan TEQ, risks are primarily attributable to clams, crab (both edible meat and whole body), and/or rockfish. It should be noted that although Figure 6-4 shows these proportions for only three adult seafood consumption scenarios evaluated in the EW HHRA, these figures capture the variability across all tribal and API consumption scenarios evaluated in the EW HHRA.

Arsenic excess cancer risks by seafood category	cPAH TEQ excess cancer risks by seafood category	Total PCB excess cancer risks by seafood category	Dioxin/furan TEQ excess cancer risks by seafood category
			
14% of total excess cancer risk	*7% of total excess cancer risk*	*70% of total excess cancer risk*	*7% of total excess cancer risk*

a) Proportion of excess cancer risk by seafood consumption scenario for the adult tribal RME scenario based on Tulalip data

			
16% of total excess cancer risk	*8% of total excess cancer risk*	*70% of total excess cancer risk*	*5% of total excess cancer risk*

b) Proportion of excess cancer risk by seafood consumption scenario for the adult tribal scenario based on Suquamish data

			
14% of total excess cancer risk	*9% of total excess cancer risk*	*69% of total excess cancer risk*	*7% of total excess cancer risk*

c) Proportion of excess cancer risk by seafood consumption scenario for the adult API RME scenario

Figure 6-4

Proportion of Cancer Risks by Seafood Category for the Adult Seafood Consumption Scenarios

6.3.3 Direct Sediment Exposure Scenarios

Excess cancer risks for the direct sediment exposure scenarios were much lower than those for the seafood consumption scenarios (Table 6-7). Excess cancer risks for all scenarios were less than the upper end of EPA's risk range (1×10^{-4}). Total excess cancer risks were 7×10^{-6} for the netfishing RME scenario and 3×10^{-5} for the tribal clamming RME scenario. Excess cancer risks for individual COPCs were also greater than the threshold of 1×10^{-6} for arsenic (3×10^{-6}) and cPAH TEQ (3×10^{-6}) for the netfishing RME scenario, and for arsenic (1×10^{-5}), cPAH TEQ (2×10^{-5}), and total PCBs (3×10^{-6}) for the tribal clamming RME scenario. In addition, for the tribal clamming RME scenario, the excess cancer risk for the total TEQ sum (PCB TEQ and dioxin/furan TEQ) was equal to 2×10^{-6}, although neither the PCB TEQ nor dioxin/furan TEQ risks independently were greater than 1×10^{-6}. Based on RME scenarios the following COCs were identified for direct sediment exposures: arsenic and cPAHs for netfishing and arsenic, cPAHs, total PCBs and total TEQ[99] for tribal clamming.

Table 6-7

Estimated Excess Cancer Risks for Direct Sediment Exposure Scenarios

COPC	Estimated Excess Cancer Risk					
	Netfishing		Habitat Restoration Worker	Clamming		
	RME	CT		Tribal RME	Tribal – 183 Days per Year	7 Days per Year
Arsenic	3×10^{-6}	7×10^{-7}	5×10^{-7}	1×10^{-5}	2×10^{-5}	4×10^{-7}
cPAH TEQ	3×10^{-6}	2×10^{-7}	7×10^{-7}	2×10^{-5}	3×10^{-5}	5×10^{-7}
Total PCBs	6×10^{-7}	6×10^{-8}	2×10^{-7}	3×10^{-6}	6×10^{-6}	1×10^{-7}
PCB TEQ	3×10^{-7}	4×10^{-8}	5×10^{-8}	1×10^{-6}	2×10^{-6}	3×10^{-8}
Dioxin/furan TEQ	6×10^{-7}	1×10^{-7}	na	1×10^{-6}	2×10^{-6}	4×10^{-8}
Total TEQ excess cancer risk for dioxins/furans and co-planar PCBs	**9×10^{-7}**	**1×10^{-7}**	**na**	**2×10^{-6}**	**4×10^{-6}**	**7×10^{-8}**
Total excess cancer risk (excluding PCB TEQ)[a]	**7×10^{-6}**	**1×10^{-6}**	**1×10^{-6}**	**3×10^{-5}**	**6×10^{-5}**	**1×10^{-6}**
Total excess cancer risk (excluding total PCBs)[a]	**7×10^{-6}**	**1×10^{-6}**	**1×10^{-6}**	**3×10^{-5}**	**5×10^{-5}**	**1×10^{-6}**

[a] Total risk values include the risks associated with all COPCs. However, only those COPCs with excess cancer risks greater than 1×10^{-6} for at least one scenario are listed in this table.

[99] Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ. When excess cancer risks for either PCB TEQ or dioxin/furan TEQ were not independently greater than 1×10^{-6}, the sum of these two chemicals (total TEQ) was identified as a COC if it was greater than this threshold.

COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
na – not applicable (not a COPC)
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent

Shaded cells identify excess cancer risks greater than 1×10^{-6}.

No COPCs had excess cancer risks greater than 1×10^{-6} for the netfishing CT scenario, clamming CT scenario, habitat restoration worker scenario, or 7-day-per-year clamming scenario. In addition, the total excess cancer risks for these scenarios were also less than the 1×10^{-6} threshold. The total excess cancer risk for the tribal clamming 183-day-per-year scenario was greater than 1×10^{-6} (equal to 6×10^{-5}), with arsenic, cPAH TEQ, total PCB, PCB TEQ, and dioxin/furan TEQ risks all greater than the 1×10^{-6} excess cancer risk threshold. Non-cancer hazards are not expected for direct sediment exposures; no COPCs had HQs greater than 1, and no endpoint-specific HIs were greater than 1 for any direct contact scenario.

As with the seafood consumption scenarios, an evaluation of risk contribution was performed for the direct sediment exposure scenarios with total excess cancer risks greater than 1×10^{-6}. Arsenic, cPAH TEQ, dioxins/furans, and PCBs were evaluated because these COPCs had excess cancer risks greater than 1×10^{-6} and each contributed greater than 5% of the total excess cancer risk for at least one scenario. Cancer risks were highest for arsenic and cPAH TEQ, which together accounted for over 84% of the total excess cancer risk (Figure 6-5). PCBs and dioxin/furan TEQ were lesser contributors.

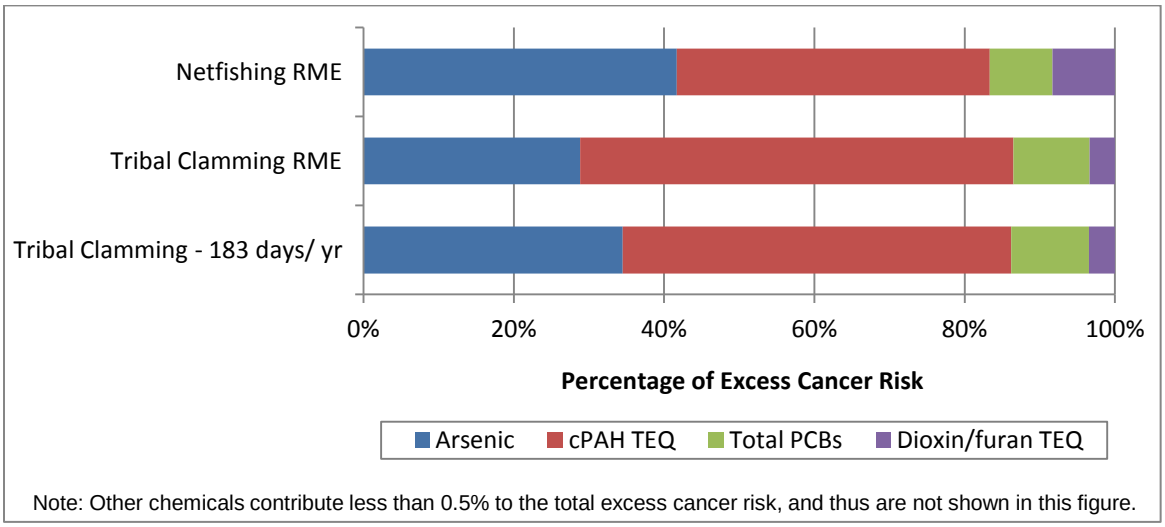


Figure 6-5

Percent Contribution of COPCs to the Total Excess Cancer Risk for Direct Sediment Exposure Scenarios with Total Excess Cancer Risks Greater than 1×10^{-6}

6.3.4 Surface Water Exposure Scenarios

In addition to the seafood consumption and direct sediment exposure scenarios, three levels of swimming exposure were evaluated to assess risks to adults based on exposure to surface water in the EW.[100] The only excess cancer risks that were greater than the 1×10^{-6} threshold were for PCB TEQ for both the high level of exposure (which assumed 2.4 hours of swimming, 24 days per year) and the medium level of exposure (which assumed 1 hour of swimming, 12 days per year) (cancer risks were equal to 9×10^{-6} and 2×10^{-6}, respectively). The total excess cancer risks (which included all COPCs) for the high-level of exposure was 9×10^{-6} and was 2×10^{-6} for the medium-level of exposure (i.e., PCB TEQ accounted for nearly 100% of the total risk). No other COPCs (including total PCBs) had excess cancer risks greater than 1×10^{-6} and no COPCs had non-cancer HQs greater than 1 for any exposure level. As discussed in Section B.5.3.3 and B.6.2.3 of the EW HHRA (Appendix B), the PCB TEQ risk estimate is considered highly uncertain based on both current and anticipated

[100] The three levels of exposure evaluated for swimming were high (which assumed a 2.6-hour swim, 24 days per year for 70 years), medium (which assumed a 1-hour swim, 12 days per year for 30 years), and low (which assumed a 10-minute swim [0.17 hours], 2 days per year for 9 years). No RME level of exposure was defined, and thus no COCs were identified based on exposure to surface water (see Section B.5.3.3 of the EW HHRA for details [Appendix B]).

future site use and on the uncertainty associated with the application of the dioxin-like TEQ approach for dermal exposure, which contributed nearly all (over 99%) of PCB TEQ swimming risk (as compared with the incidental ingestion of water).

6.3.5 Risks Associated with Exposure to Lead

Risks from exposure to lead were not quantified following the methods used for other COPCs. Because the toxicokinetics (i.e., absorption, distribution, metabolism, and excretion) of lead are well understood, health risks from lead exposure were evaluated based on blood lead concentrations, which were modeled. The results of blood lead modeling for children and adults found that risks associated with lead are below levels of concern, and thus lead was not identified as a COC for human health in the EW (see Section B.5.4 of the EW HHRA for additional details).

6.3.6 Cumulative Risk Estimates Across Multiple Scenarios

Risks for multiple scenarios were summed to represent the possible exposure of a single individual to EW COPCs during different activities. Summed risks are presented in Table 6-8 as three scenarios of different combinations of seafood consumption, direct sediment exposure, and surface water exposure scenarios. The summed excess cancer risk estimate for each of these three scenarios is the same as their respective estimates for seafood consumption alone after rounding to one significant figure, as recommended by EPA (1989). This analysis demonstrates that the contributions of netfishing, clamming, and swimming to estimated risks are relatively small in comparison with the contributions of seafood consumption, and it highlights the significance of the seafood consumption exposure pathway for all users of the EW. Excess cancer risks were generally lowest for swimming.

Table 6-8

Excess Cancer Risk Estimates Across Scenarios

Activity	Excess Cancer Risk[a]
Adult Tulalip RME Combination Scenario	
Netfishing RME	7×10^{-6}
Swimming (medium level of exposure)	2×10^{-6}
Adult tribal RME seafood consumption based on Tulalip data	1×10^{-3}
Total	**1×10^{-3}**

Activity	Excess Cancer Risk[a]
Adult Tulalip CT Combination Scenario	
Netfishing CT	1×10^{-6}
Swimming (low level of exposure)	2×10^{-8}
Adult tribal CT seafood consumption based on Tulalip data	7×10^{-5}
Total	**7×10^{-5}**
Adult RME Clamming Combination Scenario	
Tribal clamming RME (120 days per year)	3×10^{-5}
Swimming (medium level of exposure)	2×10^{-6}
Adult tribal RME seafood consumption based on Tulalip data	1×10^{-3}
Total	**1×10^{-3}**

[a] For the seafood consumption and sediment exposure scenarios, total excess cancer risk estimates that excluded PCB TEQ were used because these were equal to or higher than total excess cancer risk estimates that excluded total PCBs. For swimming, the total excess cancer risk estimates that excluded total PCBs were used because they were higher than the total that excluded PCB TEQ.

CT – central tendency
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent

6.4 Uncertainty Analysis

There are uncertainties associated with the risk estimates for each exposure scenario in the EW HHRA. For example, the RME exposure assumptions were developed to result in high-end estimates of the risks associated with the EW. To be health-protective of potentially exposed populations, these risk estimates are intended to not underestimate risk and thus are likely to overestimate risk for most individuals.

Risk estimates were highest for the seafood consumption scenarios, but the uncertainties associated with these risk estimates are also very high. The tribal and API seafood consumption rates that were used in the EW HHRA, although based on well-designed consumption surveys, were not specific to populations who primarily fish in the EW. Although the collection and consumption of seafood from the EW are known to occur (a creel study by King County (1999a) identified the Spokane Street Bridge on the EW as one of the more popular fishing locations along the shores of the Duwamish River and Elliott Bay), it is uncertain how well they represent the behavior of people who eat fish and shellfish primarily from the EW, either now or in the future. Given the lack of EW-specific seafood consumption rate estimates, the risk-per-unit consumption for various seafood categories can be used by individual seafood consumers to better understand their risks.

Another important uncertainty is in the methods used to characterize the cancer risks associated with exposure to PCBs, which are a group of chlorinated organic compounds with similar chemical properties. Two methods were used in the EW HHRA to assess risks associated with this group of contaminants:

- **Arithmetic sum of PCBs –** Exposures to total PCBs based on the arithmetic sum of Aroclors were evaluated using the cancer SF provided by EPA for total PCBs.
- **Toxicity-weighted sum of dioxin-like PCBs –** Data for PCB congeners that are thought to have toxic effects similar to those of dioxins/furans were weighted based on their toxicity relative to dioxins/furans. This weighted sum is referred to as PCB TEQ. PCB TEQ exposures were evaluated using the cancer SF for dioxins/furans.

Because total PCB risk estimation methodology includes, to some degree, the risks posed by dioxin-like PCB congeners, the cancer risk estimates from these two methods were not summed in estimating cumulative risks in order to avoid double-counting cancer risks posed by dioxin-like PCBs. Hence, the risk estimates for the two methods were presented separately in the EW HHRA. Although this approach avoids the double-counting of dioxin-like PCB cancer risks, it is possible that each method for quantifying PCB cancer risks on its own underestimates the overall PCB health risk. For example, differential bioaccumulation of more highly toxic PCB congeners in environmental mixtures relative to industrial Aroclor mixtures may lead to higher risks than those computed using total Aroclors or dioxin TEQ risks individually. The issues associated with assessing risks posed by environmental PCB mixtures, various approaches for addressing double-counting, and quantitative risk estimates derived using these approaches are discussed in detail in the uncertainty analysis (Section B.6) of the EW HHRA (Appendix B).

Additional uncertainties are associated with the chemistry data, exposure assumptions, and toxicities of COPCs. Taking into account the uncertainties, the assessment tended to overestimate risks more than underestimate them, consistent with the health-protective nature of risk assessment. Thus, despite the uncertainties, the baseline characterization of RME risks for the EW is considered to be health-protective and sufficient to support risk management decisions.

6.5 Summary of Risk Drivers

Risk drivers were identified from the COC list based on several considerations, including: 1) risk magnitude relative to acceptable risk thresholds (including a consideration of background concentrations, if applicable), 2) percent contribution to the total risk estimate, 3) detection frequency, and 4) other data quality or uncertainty considerations.

A subset of the COCs identified for the seafood consumption RME and direct sediment exposure RME scenarios were identified as risk drivers:

- **Seafood consumption scenarios –** Of the 12 COPCs that were identified as COCs, 3 were identified as risk drivers (cPAH TEQ, PCBs,[101] and dioxin/furan TEQ).[102]
- **Direct sediment exposure scenarios –** Of the four COPCs that were identified as COCs, two were identified as risk drivers (arsenic and cPAH TEQ).

It should be noted that no RME level of exposure was defined for the swimming scenario, and thus no COCs or risk drivers were identified for that scenario.

A summary of risks for each COC, as well as a more detailed discussion of the selection of risk drivers, is presented in Table 6-9. Additional details regarding the selection of risk drivers are presented in Section B.7 of the EW HHRA (Appendix B).

[101] The consideration of PCBs as a risk driver is intended to account for both total PCBs and PCB TEQ. It should be noted that risks for total PCBs were higher than those for PCB TEQ for all scenarios.

[102] Although arsenic was identified as a COC, arsenic was not identified as a risk driver for seafood consumption because incremental risks were equal to or less than 1×10^{-6} (i.e., concentrations in tissue samples collected from the EW are similar to or lower than those in samples collected from background areas). Details of this evaluation are presented in Section B.5.5.1.2 of the HHRA (Appendix B) and are summarized in Section 6.3.2.

Table 6-9
COCs and Risk Drivers Selected for the EW HHRA

COC	Selection as Risk Driver and Summary of Rationale	
	Seafood Consumption RME Scenarios	**Direct Sediment Exposure RME Scenarios**
Arsenic	**NO** – risks greater than the upper end of EPA's acceptable risk range (1×10^{-4}); however, incremental risks were equal to or less than 1×10^{-6} because concentrations are similar to or lower than those in samples collected from background areas	**YES** – risk greater than the 10^{-6} threshold, percent contribution to the total risk (29 to 43%), and high detection frequency (70%)
Cadmium	**NO** – HQ equal to 2 for the child tribal RME scenario based on Tulalip data; but considerable uncertainty is associated with this scenario, and HQs for total PCBs were over an order of magnitude higher	**na –** not a COPC
cPAH TEQ	**YES** – risks equal to the upper end of EPA's acceptable risk range (1×10^{-4}), percent contribution to the total risk (7 to 27%), and high detection frequency (71%)	**YES** – risks greater than the 10^{-6} threshold, percent contribution to the total risk (42 to 63%), and high detection frequency (97%)
Total PCBs	**YES** – risks greater than the upper end of EPA's acceptable risk range (1×10^{-4}), percent contribution to the total risk (55 to 70%), and high detection frequency (98%)	**NO** – risks were only slightly greater than the 1×10^{-6} threshold and had a relatively low contribution to the total risk (8 to 9%)
Pentachlorophenol	**NO** – risk slightly greater than the 1×10^{-6} threshold for one of the three RME scenarios; contribution to the total excess cancer risk was less than 1%, and COC was detected in less than 4% of EW samples	**na –** not a COPC
Pesticides[a]	**NO** – risks less than 1×10^{-5}, and each COC contributed less than 1% to the total excess cancer risk (combined contribution was less than 1.5% of the total)	**na –** not a COPC
Dioxin/furan TEQ	**YES** – risks equal to the upper end of EPA's acceptable risk range (1×10^{-4}) and high detection frequency (100%)	**NO** – not a COC[b]
Total TEQ (sum of PCB TEQ and dioxin/furan TEQ)	**na**[c]	**NO –** risks were only slightly greater than the 1×10^{-6} threshold and had a relatively low contribution to the total risk (6 to 13%)

[a] Five pesticides were identified as COCs for the seafood consumption scenarios: alpha-BHC, dieldrin, total chlordane, heptachlor epoxide, and mirex.

[b] See Sections 6.3.1 and 6.3.3 for information regarding the selection of COCs for the direct sediment exposure scenarios.

[c] Total TEQ was considered only when neither PCB TEQ nor dioxin/furan TEQ independently qualified as a COC.

BHC –benzene hexachloride
COC – contaminant of concern
COPC – contaminant of potential concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EW – East Waterway
na – not applicable
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
TEQ – toxic equivalent

Risks attributable to the other COCs (i.e., non-risk-drivers) present in the EW are considerably lower than the risks attributable to the risk drivers because the concentrations of other COCs are relatively low and/or because the other COCs are not particularly toxic.

All COCs, including those identified in the EW ERA (Appendix A) are mapped and discussed in this SRI. Risk drivers will be the focus of remedial alternatives analyses in the FS. In addition, in consultation with EPA and consistent with the evaluation of non-risk drivers in the LDW, COCs not selected as risk drivers in the EW HHRA will be evaluated qualitatively in the EW FS. This evaluation will include a follow-up check for the non-risk driver COCs to ensure that sediment with elevated levels of these COCs will be included in the footprint of the remedial alternatives evaluated in the FS. Furthermore, all COCs (risk driver and non-risk driver) will be included in the long-term monitoring plan for the EW.

7 PRELIMINARY BACKGROUND CONCENTRATIONS OF RISK DRIVER CONTAMINANTS

This section presents concentrations of a subset of the selected risk driver contaminants (i.e., PCBs, arsenic, cPAHs, and dioxins and furans)[103] in sediment, tissue, and water collected from background locations outside of EW. The purpose of this section is to summarize the existing background datasets. Understanding background concentrations of these risk driver chemicals is important because it provides a context for both the ecological and human health RBTCs, which are discussed in Section 8. The specific data and summary statistics presented in this section are preliminary; the final background values considered in setting preliminary remediation goals (PRGs) and assessing remedial alternatives will be presented in the FS. EPA will select the remediation goals and the final background concentrations to be considered in the derivation of cleanup levels in the ROD.

Preliminary natural and urban background concentrations of PCBs, arsenic, cPAHs, and dioxins and furans are presented in this section because some of the RBTCs (Section 8) for these contaminants are lower than the preliminary background concentrations. Sediment RBTCs for other risk-driver contaminants based on the SQS and CSL, and for TBT based on benthic invertebrate tissue-sediment relationships, appear to be higher than background concentrations and thus preliminary background concentrations for those risk drivers are not presented in this section.

The Model Toxics Control Act (MTCA) (WAC 173-340-200) and the Sediment Management Standards (SMS) (WAC 173-204-505) defines natural background as concentrations of hazardous substances that are consistently present in an environment that have not been influenced by localized human activities. Thus, as defined in the SMS and MTCA rules, natural background values can be established for human-made compounds (e.g., PCBs) that may not occur naturally or natural compounds that occur as a result of human activity (such as arsenic and mercury). The SMS also defines the new term regional background as the concentration of a contaminant within a department-defined geographic area that is

[103] TBT and the 28 SMS chemicals that were also selected as risk drivers in the ERA based on toxicity to benthic invertebrates are not discussed in this section.

primarily attributable to diffuse sources, such as atmospheric deposition or storm water, not attributable to a specific source or release.

Under CERCLA guidance, anthropogenic or area background refers to natural and human-made substances that are present in the environment as a result of human activities, but that are not specifically related to CERCLA releases at the site (2002a). Natural background refers to substances that are naturally present in the environment in forms and concentrations that have not been influenced by human activity (e.g., naturally occurring metals). Anthropogenic or area background concentrations are generally higher than natural background concentrations.

Section 7.1 presents sediment data for selected risk driver contaminants from samples collected from areas that are not believed to have been influenced by localized human activities. These data are relevant for consideration of natural background concentrations.

Section 7.2 discusses concentrations of chemicals in sediments collected from areas upstream of the EW including the Green River and LDW. Area and anthropogenic background concentrations in sediment have not been formally defined for the EW. Sediment transported into the EW is likely to influence the future quality and characteristics of sediment within the EW (see Section 3). Therefore, multiple sediment datasets to characterize upstream sediment chemistry are presented in Section 7.2. These data provide a range of relevant chemical concentrations that will be considered in the FS in the evaluation of remedial alternatives.

Section 7.3 provides additional context for the data presented in Sections 7.1 and 7.2 by presenting urban sediment data from Seattle and other Puget Sound locations.

Tissue data from Puget Sound are presented in Section 7.4 including tissue data for total PCBs, dioxins and furans and cPAHs. Most of the available tissue data for total PCBs from Puget Sound have been characterized as either near-urban or non-urban (West et al. 2001). The tissue datasets for cPAHs and dioxins and furans are more limited than the total PCB datasets in terms of the number of samples and locations.

7.1 Sediment Datasets Considered for Natural Background

This section provides a summary of sediment data from reference areas in the Puget Sound region that were reviewed for representing natural background. Summary statistics are provided for each reference area or specific study; combined summary statistics or preliminary natural background concentrations were not derived. These data are considered to be representative of non-urban, non-localized concentrations in the Puget Sound region that exist as a result of natural processes and/or the large-scale distribution of chemicals from anthropogenic sources.

7.1.1 Data Sources

Numerous sources were reviewed for background datasets. The natural background datasets presented in the LDW RI are presented for consideration for inclusion in the EW natural background dataset because of the close proximity of the two sites. When identifying the background dataset for the FS, the quality of the data will be an important consideration.

The primary dataset considered for natural background is the *Ocean Survey Vessel (OSV) Bold* Puget Sound 2008 survey dataset (DMMP 2009). This dataset is the largest and most comprehensive dataset available for Puget Sound reference areas. The data can be accessed electronically at http://www.epa.gov/pugetsound/bold.html. All the available data sources are provided in Table 7-1. The *OSV Bold* Puget Sound 2008 survey data includes samples collected and analyzed from 4 State of Washington reference areas plus 10 additional strata, for a total of 14 areas throughout Puget Sound at locations distant from known sources of contamination (Map 7-1) (EPA 2008b). Five samples were collected from each stratum for a total of 70 samples. Samples were analyzed for PCBs (Aroclors and PCB congeners), arsenic, cPAHs, and dioxins and furans, in addition to other analytes.

Table 7-1
Reference Areas Identified for Consideration of Natural Background Concentrations of Total PCBs, Arsenic, and cPAHs

Reference Area	Sources Used to Identify Reference Areas
Puget Sound[a]	DMMP (2009)
Dungeness Bay	Malcolm Pirnie (2007)
Freshwater Bay	Malcolm Pirnie (2007)
Carr Inlet	WSDOH (1995)

Reference Area	Sources Used to Identify Reference Areas
Case Inlet	Battelle (1986)
Dabob Bay	WSDOH; Battelle (1986)
Discovery Bay	WSDOH (1995)
Rich Passage	WSDOH (1995)
Samish Bay	WSDOH (1995); Battelle (1986)
Saratoga Passage	WSDOH (1995)
Sequim Bay	WSDOH (1995); Battelle (1986)
West Beach	WSDOH (1995)
Wollochet Bay	WSDOH (1995)

[a] This dataset is identified as the primary natural background dataset for natural. It consists of 14 strata (reference areas) throughout Puget Sound and is commonly referred to as the *OSV Bold* Puget Sound 2008 survey dataset (DMMP 2009).

Battelle – Battelle Marine Research Laboratory
DMMP – Dredged Material Management Program
cPAH – carcinogenic polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
WSDOH – Washington State Department of Health

As part of the RI at the Rayonier Inc. mill site near Port Angeles, Washington, samples were collected and analyzed for dioxin, furan, and PCB congeners from two areas outside the influence of localized human activities (Dungeness Bay and Freshwater Bay; Map 7-2) (Malcolm Pirnie 2007).

Ten areas in Puget Sound have been identified as "reference areas" by the Battelle Marine Research Laboratory (Battelle) (1986) or WSDOH (1995) (Table 7-1; Maps 7-2, 7-3, and 7-4). Sediment data from these 10 reference areas were obtained from four sources: 1) a study by NOAA and the Washington State Department of Ecology (Ecology) on sediment quality in Puget Sound conducted from 1997 to 1999 (NOAA and Ecology 1999, 2000, 2002), 2) Washington State's SEDQUAL database (Ecology 2004), 3) a Battelle survey of eight bays (1986), and 4) Ecology's Environmental Information Management (EIM) System database (Ecology 2007a). Data were obtained for total PCBs, arsenic, and cPAHs from this search. Data were processed to the extent possible using data management procedures described in Appendix D, although the data from these datasets were generally used as reported in the above sources without further data quality reviews. In addition, sampling and analytical methods used to produce these datasets varied from study to study and potentially from year to year within a given study. Thus, while these data provide a general indication of chemical concentrations in these reference areas, they should not be viewed as a single dataset with consistent methodology.

In the following sections, data from individual studies are summarized separately. The *Ocean Survey Vessel (OSV) Bold* Puget Sound 2008 survey data (DMMP 2009) are summarized as a combined dataset from multiple areas because sampling and analytical methods were consistent in the 14 areas sampled throughout Puget Sound.

7.1.2 Arsenic Surface Sediment Datasets Considered for Natural Background

Arsenic, which was measured as total arsenic, was frequently detected in samples from all 10 reference areas in Puget Sound and was detected in all of the samples from the *OSV Bold* Puget Sound 2008 survey (Figure 7-1) (DMMP 2009). The arsenic concentrations included in the datasets ranged from 0.5 mg/kg dw in Carr Inlet to 27 mg/kg dw in Sequim Bay (Table 7-2). Detection frequencies in individual areas ranged from 48 to 100%. Sampling locations are shown on Maps 7-1 and 7-3. Percent fines ranged from 1 to 98.5% in the Puget Sound 2008 survey, with a mean of 47.4%.

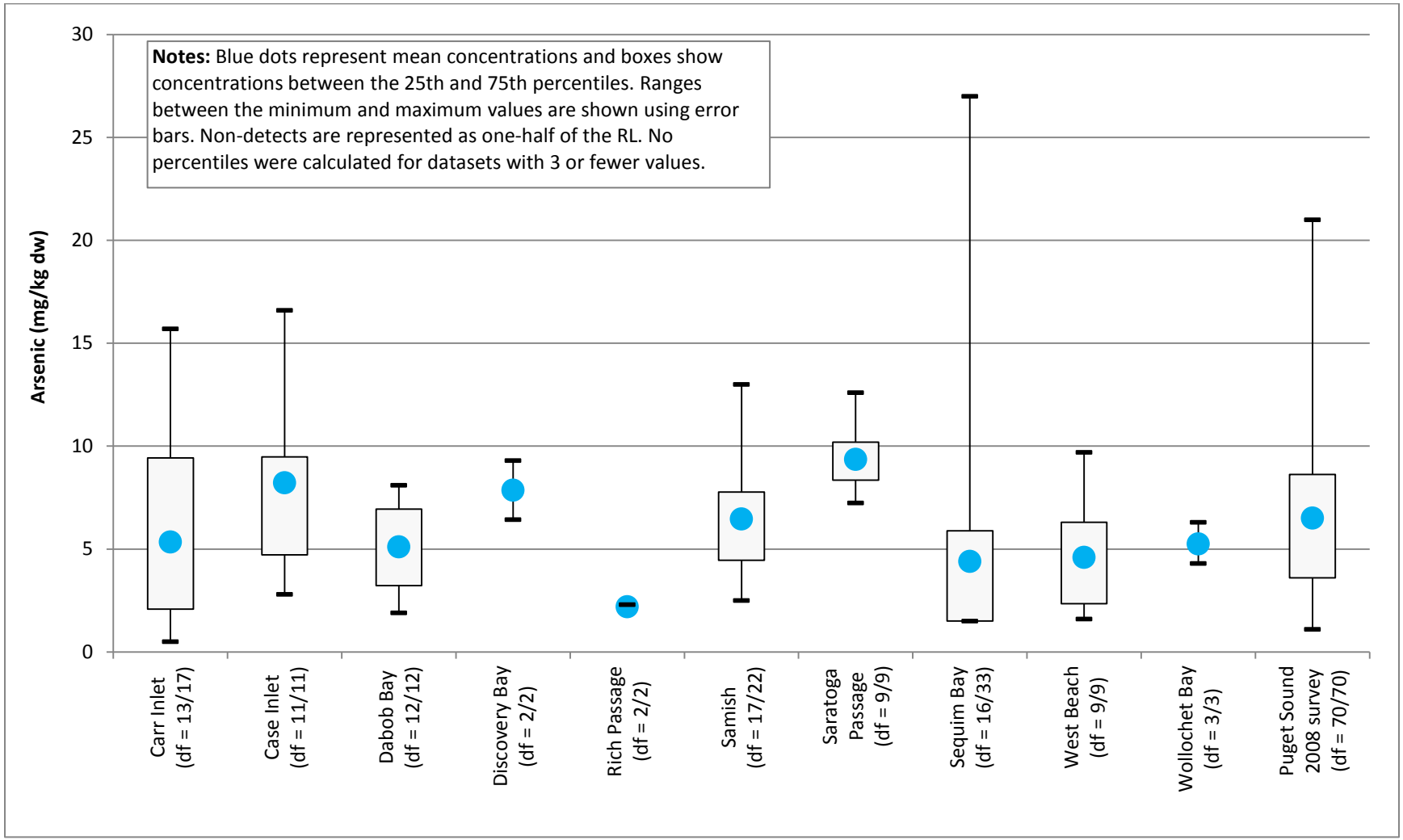


Figure 7-1

Arsenic Concentrations in Surface Sediment from Puget Sound Reference Areas and the *OSV Bold* Puget Sound 2008 Survey (DMMP 2009)

Table 7-2

Summary of Arsenic Datasets Considered for Natural Background

Sampling Location	Sampling Period	Detection Frequency	Concentration (mg/kg dw)								UCL Type
			Minimum Detect	Maximum Detect	Mean Detect[a]	Minimum Non-Detect[b]	Maximum Non-Detect[b]	50th Percentile[c]	90th Percentile[c]	95% UCL on the mean[d]	
Reference Areas											
Carr Inlet	1972 – 2000	13/17	0.500	15.7	6.34	7.0	13.0	3.8	13.6	7.59	95% KM (t) UCL
Case Inlet	1972 – 1999	11/11	2.8	16.6	8.2	na	na	8.1	15.9	10.4	95% Student's-t UCL
Dabob Bay	1995 – 1999	12/12	1.90	8.1	5.11	na	na	5.4	8.0	6.2	95% Student's-t UCL
Discovery Bay	1986 – 1994	2/2	6.43	9.3	7.87	na	na	7.9	9.3	9.3	maximum detect
Rich Passage	1998	2/2	2.10	2.3	2.2	na	na	2.2	2.3	2.3	maximum detect
Samish	1989	17/22	3.20	12.0	6.34	10	52	6.3	12.0[e]	7.16	95% KM (t) UCL
Saratoga Passage	1972 – 1997	9/9	7.2	13	9.36	na	na	9.0	12.6	10.3	95% Student's-t UCL
Sequim Bay	1994 – 1997	16/33	2.65	27.0	7.47	6.0	7.0	3.0	8.9	7.2	95% KM (% bootstrap) UCL
West Beach	1986 – 1990	9/9	1.6	9.7	4.6	na	na	4.6	9.7	6.2	95% Student's-t UCL
Wollochet Bay	1982 – 1996	3/3	4.30	6.3	5.25	na	na	5.2	6.3	6.3	maximum detect
***OSV Bold* Puget Sound 2008 Survey**											
Puget Sound	2008	70/70	1.1	21	6.5	na	na	6.0	11	7.3	95% approximate gamma UCL

Note: Multiple datasets have been collected over time; there were no consistent temporal trends in the data.

[a] The mean detect is equal to the average of all detected concentrations.

[b] Non-detect concentrations are equal to the RL.

[c] Percentiles were calculated using detected values and one-half the RL for samples in which arsenic was not detected. Percentiles are non-parametric percentiles calculated using methods presented in the National Institute of Standards and Technology Handbook of Statistical Methods (NIST and SEMATECH 2006).

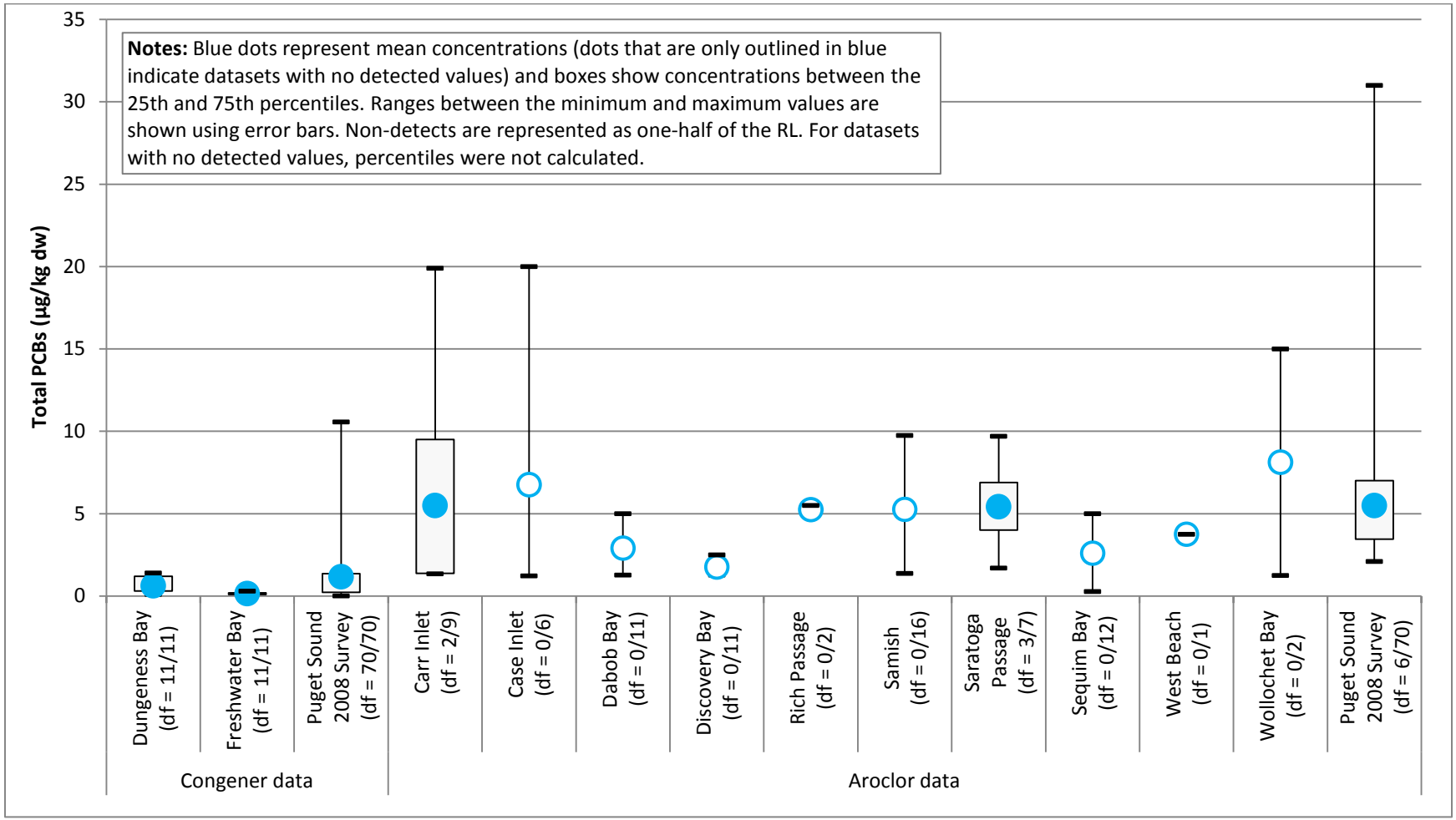
[d] UCLs on the mean were calculated using ProUCL 4 statistical software (EPA 2007c), which accounts for non-detect values in the calculation of UCLs.

[e] Maximum detected value presented; the 90th percentile value was higher than the maximum detect because of elevated RLs.

dw – dry weight
KM – Kaplan-Meier
na – not applicable
OSV – ocean survey vessel
RL – reporting limit
t – Student's t distribution
UCL – upper confidence limit on the mean

7.1.3 PCB Surface Sediment Datasets Considered for Natural Background

Total PCB concentrations were calculated either by summing detected PCB Aroclors or by summing detected PCB congeners. PCB Aroclors were analyzed in all the datasets considered for natural background. The *OSV Bold* Puget Sound 2008 survey dataset (DMMP 2009) is the only dataset which also reported PCB congener concentrations. The analytical method used for PCB Aroclors has a much higher RL than the analytical method used for PCB congeners. Thus, PCBs as Aroclors were detected in only 11 of 140 samples that were analyzed using the Aroclor method, while at least one of the 209 PCB congeners was detected in every sample analyzed using the PCB congener method, resulting in 100% detection (Figure 7-2; Table 7-3). In the 70 samples collected for the *OSV Bold* Puget Sound 2008 survey, the calculated mean concentration of total PCBs as Aroclor sums was 11 µg/kg dw (based on a mean of the total PCB concentration in the six samples with at least one detected Aroclor), compared with 1.2 µg/kg dw for the mean concentration as PCB congener sums (based on a mean of the total PCB concentration in all 70 samples with at least one detected PCB congener). Reference locations with PCB sediment data are presented on Maps 7-1 and 7-2. TOC content in the 70 samples from the *OSV Bold* Puget Sound 2008 survey ranged from 0.2 to 4.0%, with a mean of 1.3%. The organic-carbon normalized PCB concentrations from the *OSV Bold* Puget Sound 2008 survey ranged from 0.0056 to 0.85 mg/kg OC, with a mean of 0.11 mg/kg OC.



Note: A total PCB value was considered a detect if one or more of the component Aroclors or congeners was detected in a given sample. More details regarding the data rules for total PCBs are presented in Table 7-3.

Figure 7-2

Total PCB Concentrations in Surface Sediment from Puget Sound Reference Areas and the *OSV Bold* Puget Sound 2008Survey (DMMP 2009)

Table 7-3

Summary of Total PCB Datasets Considered for Natural Background

Sampling Location	Sampling Period	Analyte	Detection Frequency	Concentration (µg/kg dw)[a]								UCL Type
				Minimum Detect	Maximum Detect	Mean Detect[b]	Minimum Non-Detect[c]	Maximum Non-Detect[c]	50th Percentile[d]	90th Percentile[d]	95% UCL on the mean[e]	
Reference Areas												
Carr Inlet	1984 – 2000	PCB Aroclors	2/9	4.0	19.9	11.5	5.4	60	3.5	19.9[f]	19.9	maximum detect
Case Inlet	1999	PCB Aroclors	0/6	na	na	na	4.9	80	nc	nc	nc	nc
Dabob Bay	1995 – 1999	PCB Aroclors	0/11	na	na	na	5.1	20	nc	nc	nc	nc
Discovery Bay	1994 – 2002	PCB Aroclors	0/4	na	na	na	5.1	10	nc	nc	nc	nc
Dungeness Bay	2006	PCB congeners	11/11	0.2	1.4	0.63	na	na	0.3	1.4	1.4	maximum detect
Freshwater Bay	2006	PCB congeners	11/11	0.1	0.3	0.15	na	na	0.1	0.2	0.19	95% modified-t UCL
Rich Passage	1998	PCB Aroclors	0/2	na	na	na	20	22	nc	nc	nc	nc
Samish	2000 – 2004	PCB Aroclors	0/16	na	na	na	5.5	39	nc	nc	nc	nc
Saratoga Passage	1996 – 1997	PCB Aroclors	3/7	5.7	9.7	7.4	6.8	24	8.0	9.7	9.7	maximum detect
Sequim Bay	1994 – 2002	PCB Aroclors	0/12	na	na	na	1.1	20	nc	nc	nc	nc
West Beach	1994	PCB Aroclors	0/1	na	na	na	15	15	nc	nc	nc	nc
Wollochet Bay	1996 – 1999	PCB Aroclors	0/2	na	na	na	5	60	nc	nc	nc	nc
***OSV Bold* Puget Sound 2008 Survey**												
Puget Sound	2008	PCB Aroclors	6/70	2.1	31	11[g]	5.4	20	4.4	8.0[g]	6.5[g]	95% KM (percentile bootstrap) UCL[h]
Puget Sound	2008	PCB congeners	70/70	0.010	11	1.2[g]	na	na	0.65	2.8[g]	1.5[g]	95% approximate gamma UCL

Note: Multiple datasets have been collected over time; there were no consistent temporal trends in the data.

[a] For PCB Aroclors, the total PCB concentration represents the sum of detected concentrations of nine individual PCB Aroclors for a given sample. For samples in which none of the individual Aroclors were detected, the maximum RL for an individual PCB Aroclor in that sample is used as the concentration. For PCB congeners, the total PCB concentration represents the sum of the detected PCB congener concentrations for a given sample.

[b] The mean detect is equal to the average of all detected concentrations.

[c] Non-detected concentrations for samples in which none of the individual PCB Aroclors were detected were calculated as described in Footnote a.

[d] Percentiles are non-parametric percentiles calculated using methods presented in the *National Institute of Standards and Technology Handbook of Statistical Methods* (NIST and SEMATECH 2006). Percentiles were calculated using both detected and non-detected total PCB concentrations (see Footnote a).

[e] UCLs on the mean were calculated using ProUCL 4 statistical software (EPA 2007c), which accounts for non-detect values in the calculation of UCLs.

[f] Maximum detected value presented; the 90th percentile value was higher than the maximum detected value because of elevated RLs.

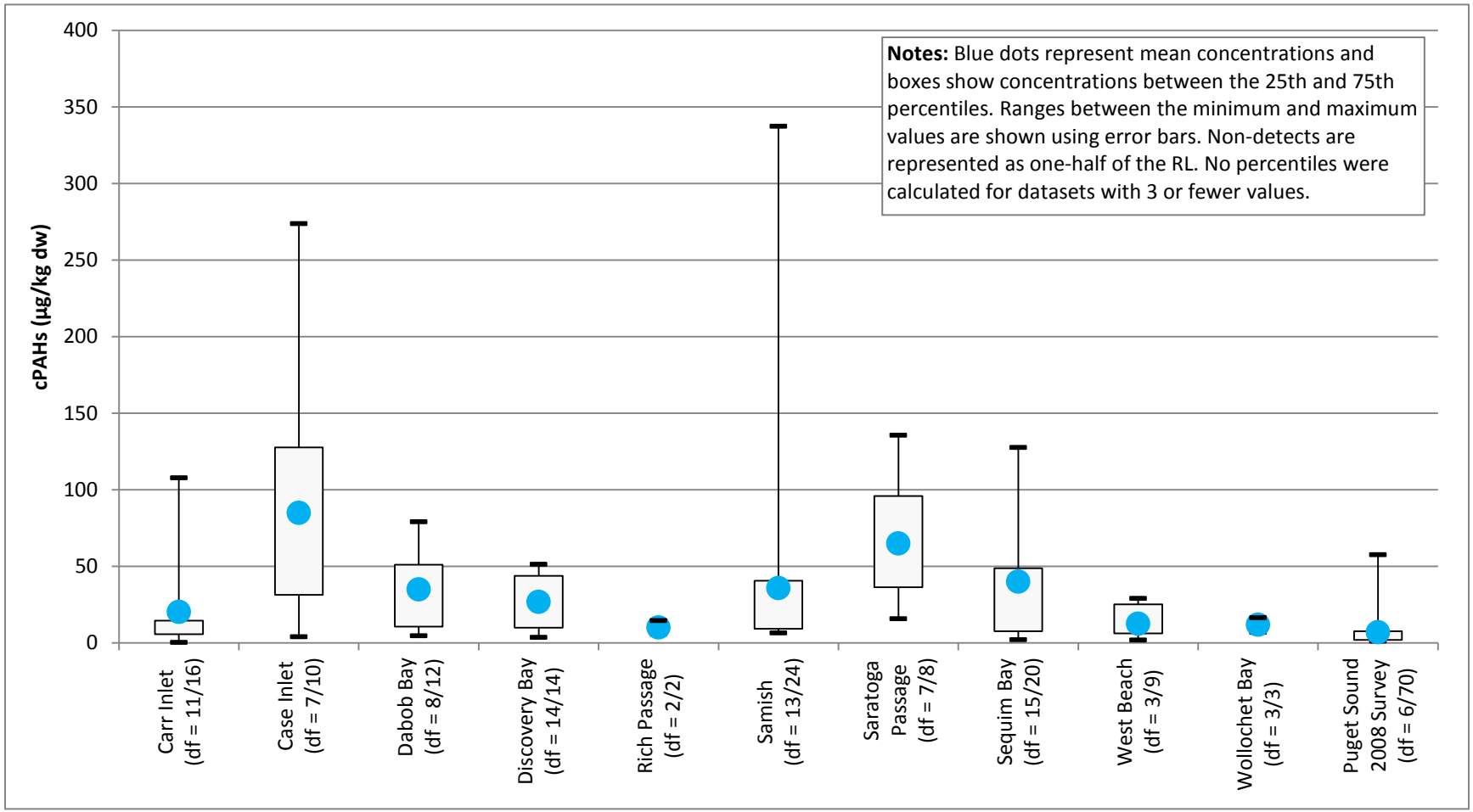
[g] Sediment samples were analyzed for both PCB congeners and PCB Aroclors. The PCB Aroclor analysis is based on the assumption of intact Aroclor patterns, and low-concentration samples typically have highly weathered and degraded PCB congener patterns which are reported as non-detected PCB Aroclors. The detection frequency for PCB Aroclors is much lower than for PCB congeners in this dataset.

[h] Only six detected results were available for PCB Aroclors therefore, there is uncertainty associated with the calculation of the UCL with a limited number of detected results.dw – dry weight

H – Land's H statistic
KM – Kaplan Meier
na – not available
nc – not calculated
OSV – ocean survey vessel
PCB – polychlorinated biphenyl
RL – reporting limit
TOC – total organic carbon
UCL – upper confidence limit on the mean

7.1.4 cPAH Surface Sediment Datasets Considered for Natural Background

At least one cPAH compound was detected in the majority of samples from the 10 reference areas in Puget Sound and the *OSV Bold* Puget Sound 2008 survey (Figure 7-3) (DMMP 2009). The cPAH concentrations ranged from 0.45 µg TEQ/kg dw in Carr Inlet to 274 µg TEQ/kg dw in Case Inlet (Table 7-4). Detection frequencies in individual areas ranged from 33 to 100%, although individual cPAH compounds were sometimes never detected. Sampling locations for the cPAH samples are shown on Maps 7-1 and 7-4.



Note: Total cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as discussed in detail in Appendix D. A cPAH TEQ was considered a detect if one or more of the component cPAHs was detected in a given sample. More details regarding cPAH data rules are presented in Table 7-4.

Figure 7-3

cPAH TEQs in Surface Sediment from Puget Sound Reference Areas and the *OSV Bold* Puget Sound 2008 Survey (DMMP 2009)

Table 7-4

Summary of cPAH Datasets Considered for Natural Background

Sampling Location	Sampling Period	Detection Frequency	Concentration (µg TEQ/kg dw)[a]								UCL Type
			Minimum Detect	Maximum Detect	Mean Detect[b]	Minimum Non-Detect[c]	Maximum Non-Detect[c]	50th Percentile[d]	90th Percentile[d]	95% UCL on the mean[e]	
Reference Areas											
Carr Inlet	1984 – 2000	11/16	0.450	108	24.5	17.2	35.4	9.1	99.2	33.9	95% KM (BCA) UCL
Case Inlet	1992 – 1999	8/11	4.14	274	59.9	256	256	46.0	244.7	154.5	95% KM (Chebyshev) UCL
Dabob Bay	1995 – 1999	8/12	4.78	79.2	27.1	102	102	37.3	75.2	43.1	95% KM (BCA) UCL
Discovery Bay	1994 – 2003	14/14	3.75	51.5	26.9	na	na	29.3	48.5	34.9	95% Student's-t UCL
Rich Passage	1998	2/2	5.84	14.7	10.3	na	na	10.3	14.7	14.7	maximum detect
Samish	1989	13/24	6.63	41.9	19.8	13.4	102	16.7	41.9[f]	21.6	95% KM (t) UCL
Saratoga Passage	1996 – 1997	7/8	15.9	105	55	272	272	58	105[f]	75.3	95% KM (t) UCL
Sequim Bay	1994 – 2002	15/20	2.20	49.4	19.2	8.5	256	18.1	49.4[f]	24.7	95% KM (percentile bootstrap) UCL
West Beach	1986 – 1990	3/9	22.7	29.2	26.6	4.0	13.7	6.4	29.2	29.2	maximum detect
Wollochet Bay	1982 – 1996	3/3	7.00	16.6	12	na	na	12.5	16.6	16.6	maximum detect
***OSV Bold* Puget Sound 2008 Survey**											
Puget Sound	2008	61/70	1.7	58	7.9	1.3	2.5	4.5	15	9.2	95% KM (BCA) UCL

Note: Multiple datasets have been collected over time; there were no consistent temporal trends in the data.

[a] Total cPAHs were calculated by summing the products of individual PAH concentrations and compound-specific PEFs for the seven individual cPAH compounds (benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, benzo(k) fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene), as discussed in Appendix D. Total cPAHs were considered detected if one or more of the individual cPAH compounds were detected. For non-detected compounds, one-half the RL was multiplied by the PEF when calculating cPAH concentrations.

[b] The mean detect is equal to the average of all detected concentrations.

[c] Non-detected values for samples in which none of the individual cPAH compounds were detected were calculated as described in Footnote a.

[d] Percentiles are non-parametric percentiles calculated using methods presented in the *National Institute of Standards and Technology Handbook of Statistical Methods* (NIST and SEMATECH 2006). For samples in which none of the cPAHs were detected, one-half the calculated cPAH concentration was used (see Footnote a).

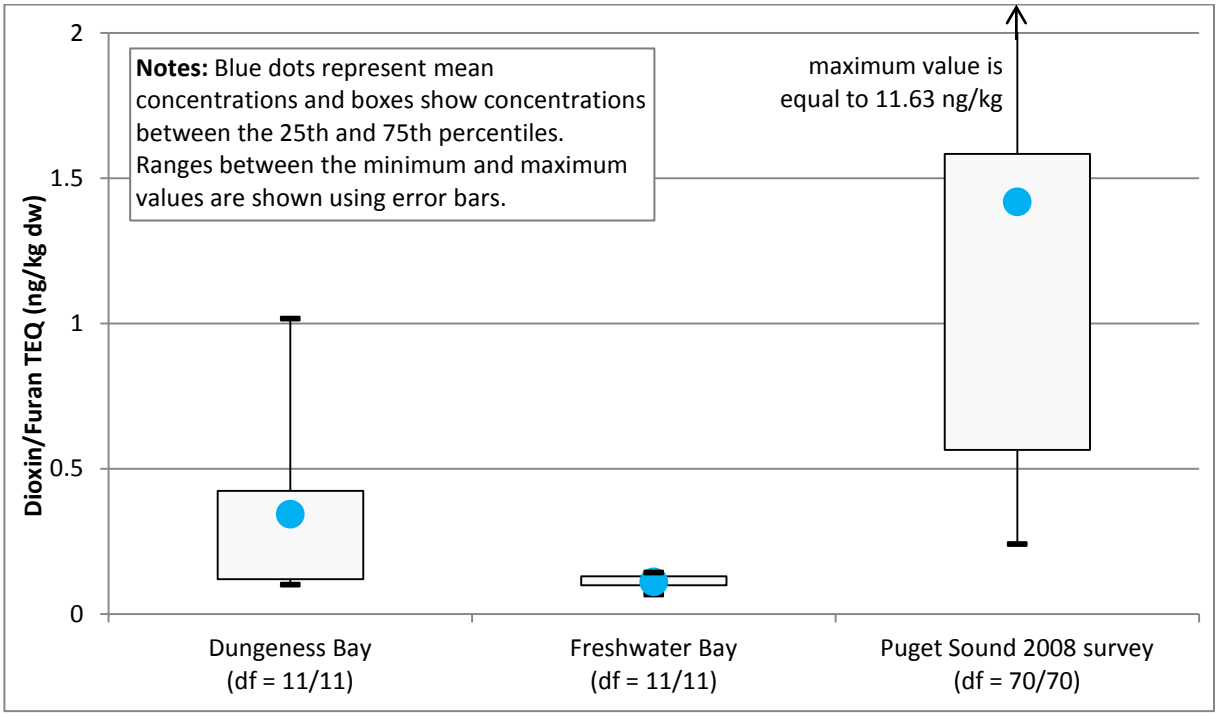
[e] UCLs on the mean were calculated using ProUCL 4 statistical software (EPA 2007c), which accounts for non-detect values in the calculation of UCLs.

[f] The 90th percentile value was higher than the maximum detected value because of elevated RLs.

BCA – bias-corrected accelerated
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EPA – US Environmental Protection Agency
KM – Kaplan Meier
na – not applicable
OSV – ocean survey vessel
PEF – potency equivalency factor
RL – reporting limit
TEQ – toxic equivalent
UCL – upper confidence limit on the mean

7.1.5 Dioxin and Furan Sediment Datasets Considered for Natural Background

The Puget Sound *OSV Bold* Puget Sound 2008 survey (DMMP 2009) provides a robust reference dataset for dioxins and furans; prior to this survey relatively few reference data were available for dioxins and furans. At least one dioxin or furan congener was detected in every sample collected as part of the 2008 survey and in the other two Puget Sound locations sampled (Maps 7-1 and 7-4). The dioxin and furan concentrations ranged from 0.067 ng TEQ/kg dw in a sample collected from Freshwater Bay to 12 ng TEQ/kg dw in a sample collected from the South Sound (Figure 7-4; Table 7-5). For samples from the *OSV Bold* Puget Sound 2008 survey, dioxin and furan concentrations ranged from 0.24 to 12 ng TEQ/kg with a mean concentration of 1.4 ng TEQ/kg (Table 7-5).



Note: A dioxin/furan TEQ was considered a detect if one or more of the component dioxins/furans was detected in a given sample. More details regarding dioxin/furan data rules are presented in Table 7-5.

Figure 7-4

Dioxin and Furan TEQs in Surface Sediment from Two Puget Sound Locations and the *OSV Bold* Puget Sound 2008 Survey (DMMP 2009)

Table 7-5

Summary of Dioxin and Furan TEQ Datasets to Be Considered for Natural Background

Sampling Location	Sampling Period	Detection Frequency	Concentration (ng TEQ/kg dw)[a]								UCL Type
			Minimum Detect	Maximum Detect	Mean Detect[b]	Minimum Non-Detect[c]	Maximum Non-Detect[c]	50th Percentile[d]	90th Percentile[d]	95% UCL on the mean[e]	
Dungeness Bay	2006	11/11	0.101	1.02	0.344[f]	na	na	0.24	0.721	0.542	95% Approximate gamma UCL
Freshwater Bay	2006	11/11	0.067	0.143	0.111[g]	na	na	0.105	0.141	0.123	95% Student's-t UCL
OSV Bold Puget Sound 2008 survey	2008	70/70	0.24	12	1.4[h]	na	na	1.0	2.3	1.6	95% H-UCL

[a] Dioxin and furan TEQs were calculated by summing the products of individual congener concentrations and congener-specific TEFs, as discussed in Appendix D. A dioxin and furan TEQ value was considered detected if one or more of the congeners were detected. For non-detected congeners, the TEF was multiplied by one-half the RL.

[b] The mean detect is equal to the average of all detected concentrations.

[c] Non-detected values for samples in which none of the individual dioxin/furan compounds were detected.

[d] Percentiles are non-parametric percentiles calculated using methods presented in the *National Institute of Standards and Technology Handbook of Statistical Methods* (NIST and SEMATECH 2006).

[e] UCLs on the mean were calculated using ProUCL 4 statistical software (EPA 2007c), which accounts for non-detect values in the calculation of UCLs.

[f] Using the full RLs or 0 for the non-detected dioxin and furan congeners would have resulted in approximately a 70% increase or decrease on average in the mean dioxin/furan TEQ presented in Table 7-5. TheTEQs calculated using the full RLs or 0 for the non-detected congeners were 0.499 and 0.188 ng TEQ/kg dw, respectively (as compared with the value of 0.344 ng TEQ/kg dw calculated using one half the RL).

[g] Using the full RLs or 0 for the non-detected dioxin and furan congeners would have resulted in approximately a 95% increase or decrease on average in the dioxin/furan TEQs presented in Table 7-5. The TEQs calculated using the full RLs or 0 for the non-detected congeners were 0.216 and 0.00568 ng TEQ/kg dw, respectively (as compared with the value of 0.111 ng TEQ/kg dw calculated using onehalf the RL).

[h] Using the full RLs or 0 for the non-detected dioxin and furan congeners would have resulted in approximately a 30% increase or decrease on average in the dioxin/furan TEQs presented in Table 7-5. The mean value calculated using the full RLs or 0 for the non-detected congeners would be 1.7 and 1.2 ng TEQ/kg dw, respectively (as compared with the value of 1.4 ng TEQ/kg dw calculated using one half the RL).

dw – dry weight
H – Land's H statistic
na – not applicable
na – not applicable
OSV – ocean survey vessel
RL – reporting limit
TEF – toxic equivalency factor
TEQ – toxic equivalent
UCL – upper confidence limit on the mean

7.2 Upstream Data

This section presents concentrations of PCBs, arsenic, cPAHs, and dioxins and furans in surface sediment samples and suspended solids that were collected upstream of the LDW and the EW. In addition, sediment core data from the upper reaches of the LDW and surface sediment data and lateral load information from the LDW are provided to represent the upstream conditions closest to the EW.

The following three types of data are summarized in this section:

- Surface sediment data collected upstream of the LDW (upstream of RM 5.0)
- Sediment core data collected in the LDW between RM 4.3 and RM 4.75 (representing material deposited from upstream) by USACE for dredged material characterization
- Estimated chemical concentrations in upstream suspended solids based on Green/Duwamish River water chemistry and TSS data and suspended solids data collected upstream of the LDW
- Surface sediment data collected throughout the LDW

The fact that the LDW is located immediately upstream of the EW complicates the analysis of the upstream data. The suspended solids and sediment that are transported through the LDW may be affected by contaminant concentrations within the LDW. Therefore, there is more uncertainty associated with the use of the LDW upstream dataset for the EW as compared with the use of the LDW upstream dataset for the LDW.

Section 7.2.1 provides a brief overview of sediment transport processes to provide additional context for the different lines of evidence. The data sources and methods for evaluation of each of these datasets are presented in Sections 7.2.2 through 7.2.4.

7.2.1 Review of Sediment Transport Processes and Sediment Physical Properties

A detailed discussion of the physical CSM is provided in Section 3. For the purposes of identifying upstream datasets, the results of the LDW sediment transport model estimated that approximately 99% of the upstream total external sediment load that comes into the EW from upstream sources comes from the Green River, which is located upstream of the LDW.

The remaining 1% of the external sediment load was attributed to lateral sources and eroded bed sediments from within the LDW.

In the sediment transport model constructed for the LDW, an estimated 50% of the sediment load from the Green River was deposited in the LDW and the remaining 50% reached the junction of the EW and WW over a model run that covered a 30-year period (QEA 2008) based on the Green River hydrograph data from 1960 to 1989. Based on this 30-year period, the model-estimated sediment load transported through the LDW to the junction with the EW and WW was 3,239,900 metric tons, with 3,215,300 metric tons from the Green River, 7,700 metric tons from eroded bed sediments within the LDW, and 16,900 metric tons from lateral sources within the LDW(QEA 2008). Therefore, more than 99% of the sediment reaching the junction with the EW and WW originated in the Green River.

7.2.2 Upstream Datasets

A detailed evaluation of the datasets that represent the upstream conditions of the LDW was conducted for the LDW FS (AECOM 2011 [in prep], Appendix C). The datasets were used in the LDW FS to establish upstream input parameters for modeling. These upstream datasets can be used to estimate the input of Green River contaminants associated with suspended solids deposited in the EW. The LDW datasets must also be considered when estimating upstream inputs to the EW. All of these datasets will be reviewed for use in the EW FS when estimating upstream contaminant concentrations for modeling of future waterway conditions.

One source of uncertainty with regard to the use of the LDW dataset for the evaluation of upstream conditions for the EW is that the implementation of remedial actions and source control in the LDW will result in significant reductions in the concentrations of risk driver contaminants in LDW surface sediment and lateral inputs and in reduced concentrations in suspended solids transported into EW from the LDW. As noted above, the majority of the suspended solids that enter the EW are from the Green River. However, the concentrations associated with LDW inputs are higher than the concentrations associated with Green River solids; therefore, reductions in the LDW inputs will result in reductions in the solids concentrations entering the EW. In addition to the datasets used in the LDW FS to characterize LDW upstream background, LDW surface sediment and lateral load information is included here to characterize the upstream data for EW which includes the LDW.

7.2.2.1 Suspended solids and sediments upstream of the LDW

The suspended solids and surface sediments collected upstream of the LDW will be reviewed for use in characterizing the Green River material that represents 99% of the solids entering the EW from upstream.

This section presents concentrations of PCBs, arsenic, cPAHs, and dioxins and furans in surface sediment samples that were collected upstream of the LDW, as well as in subsurface sediment samples that were collected in the Upper Turning Basin of the LDW. Various data were considered as separate lines of evidence. Since each was collected for a different purpose, each line of evidence may have uncertainties and biases in characterizing chemical concentrations in suspended material likely to deposit within the EW. Therefore, all lines of evidence will be further evaluated as part of the upstream inputs assessment in the FS. The following three types of data are presented in this section:

- Surface sediment data collected upstream of the LDW (upstream of RM 5.0[104]) (Map 7-5)
- Sediment core data collected from the Upper Turning Basin between RM 4.3 and RM 4.75 of the LDW (representing material deposited from upstream) by USACE from 1990 to 2010 for dredged material characterization (Map 7-6)
- Estimated chemical concentrations in suspended solids upstream of the LDW based on Green/Duwamish River water chemistry and TSS data and measured suspended solids concentrations from Ecology (2009a).

Data were compiled for total PCBs, arsenic, cPAHs, and dioxins and furans in surface sediments upstream of the LDW (RM 5.0 to RM 7.0). There are two surface sediment datasets summarized in Table 7-6. The first is the LDW RI upstream dataset which was collected as part of the LDW RI. The second dataset is the Ecology upstream dataset that was collected in 2008. The sampling locations are shown on Map 7-5. These data were evaluated to assess the quality of sediment potentially being transported into the LDW and the EW from the Green/Duwamish River system.

[104] RM 5.0 in the LDW is based on RM 0 at the southern end of Harbor Island which is the southern boundary of EW.

Table 7-6
Summary Statistics for Upstream Datasets

Chemical and Data Type	No. of Samples	Detection Frequency (%)	Minimum Detect	Maximum Detect	Mean[a]	50th Percentile[a]	90th Percentile[a]	95% UCL[a]
Total PCBs (µg/kg dw) – Upstream Surface Sediment								
LDW RI upstream surface sediment data (1994 to 2006)[b]	37[c]	49	1.6	140	23	19	40	21
Ecology upstream surface sediment data (2008)	73[d]	52	0.73	12	3	3	6	3
Total PCBs (µg/kg dw) – Upstream Suspended Solids[d]								
King County whole water data (2005 to 2008)	22	100	2.8	162	50	21	107	82
Ecology centrifuged solids data (2008 and 2009)	7	57	7.5	64	14	8	54	36
Total PCBs (µg/kg dw) – Upper Turning Basin and Navigational Channel								
USACE DMMP core data (1990 to 2010)	21	62	10.8	94	36	32	53	40
Arsenic (mg/kg dw) – Upstream Surface Sediment								
LDW RI upstream surface sediment data (1994 to 2006)	24	100	3.3	22	6.8	5	11	8
Ecology upstream surface sediment data (2008)	74	100	3.7	16	7.0	6	10	7
Arsenic (mg/kg dw) – Upstream Suspended Solids								
King County whole water data (2001 to 2008)	100	100	0.50	133	37	29	73	47
Ecology centrifuged solids data (2008, 2009)	7	100	9.2	24	17	14	24	22
Arsenic (mg/kg dw) – Upper Turning Basin and Navigational Channel								
USACE DMMP core data (1990 to 2010)	19	100	3.0	14	7	6	11	8
cPAHs (µg/kg dw) – Upstream Surface Sediment								
LDW RI upstream surface sediment data (1994 to 2006)	16	44	36	260	55	18	135	100
Ecology upstream surface sediment data (2008)	74	81	0.71	230	18	9	57	43

Chemical and Data Type	No. of Samples	Detection Frequency (%)	Minimum Detect	Maximum Detect	Mean[a]	50th Percentile[a]	90th Percentile[a]	95% UCL[a]
cPAHs (µg/kg dw) – Upstream Suspended Solids								
King County whole water data (2008 to 2009)	18	67	29	408	151	74	354	269
Ecology centrifuged solids data (2008 and 2009)	7	100	14.9	621	138	53	400	432
cPAHs (µg/kg dw) – Upper Turning Basin and Navigational Channel								
USACE DMMP core data (1990-2010)	20	95	8	225[e]	73	56	182	130
Dioxin and Furan TEQ (ng/kg dw) – Upstream Surface Sediment								
LDW RI upstream surface sediment data (1994-2006)	4	100	1.1	2.6	2.0	Values ranged from1.1 to 2.6; median was 1.7		
Ecology upstream surface sediment data (2008)	74	73	0.084	8.4	1	0.3	3	2
Dioxin and Furan TEQ (ng/kg dw) – Upstream Suspended Solids								
Ecology centrifuged solids data (2008,2009)	6	100	0.83	16.2	6	3	13	10
Dioxin and Furan TEQ (ng/kg dw) – Upper Turning Basin and Navigational Channel								
USACE DMMP core data (1990-2010)	3	100	0.861	2.8	Not calculated because of limited data			

[a] The mean and percentile concentrations and the UCLs were calculated using the statistical software ProUCL 4.00.04 (EPA 2007c), with non-detects set at full RL.

[b] Outlier of 770 µg/kg for total PCBs was excluded from the dataset statistics because it appeared to be related to an outfall.

[c] Seventeen samples were analyzed for PCB Aroclors, and twenty samples were analyzed using the NOAA method described in Section 4.2.3.

[d] Upstream suspended solids samples from 2001 to 2009 depending on the analyte sampled (King County whole water samples). King County surface water data normalized to solid fractions by dividing by the TSS in the individual sample. All detected arsenic concentrations associated with TSS were calculated as the difference between whole-water (i.e., unfiltered) and filtered sample data.

[e] One sample concentration (1,052 µg/kg dw) was excluded from the cPAH dataset because it was an outlier (as determined by outlier tools in ProUCL software).

cPAH – carcinogenic polycyclic aromatic hydrocarbon
DOC – dissolved organic carbon
dw – dry weight
Ecology – Washington State Department of Ecology
LDW – Lower Duwamish Waterway
na – not applicable
NOAA – National Oceanic and Atmospheric Administration
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
RI – remedial investigation
RL – reporting limit
RM – river mile
TEF – toxic equivalency factor
TEQ – toxic equivalent
TOC – total organic carbon
TSS – total suspended solids
USACE – US Army Corps of Engineers

The Turning Basin subsurface sediment data for total PCBs, arsenic, cPAHs and dioxins and furans are provided to provide a time-integrated sample of Green River material deposited in the upper turning basin of LDW. Finally, the suspended solids data from Ecology and TSS-normalized water data from King County are presented (Table 7-6). The upstream data are limited, and therefore there is uncertainty associated with the characterization of upstream solids concentrations.

7.2.2.2 Surface Sediment from the LDW

LDW surface sediment was estimated to contribute less than 1% of the solids to the EW (AECOM 2012). The spatially weighted average concentrations calculated for surface sediment collected throughout the LDW are provided in Table 7-7. A detailed discussion of the datasets that were used in the calculation of the SWACs is provided in Section 2 of the LDW draft final FS (AECOM 2012). Total PCBs were analyzed in the greatest number of samples, and dioxins and furans were analyzed in the smallest number of samples (Table 7-7).

Table 7-7
Summary Statistics for LDW Surface Sediment Dataset

Contaminant	Unit	Detection Frequency	Percent Detected	Minimum Detect	Maximum Detect	Mean[a]	SWAC[a]
Total PCBs	µg/kg dw	1,314/1,395	94%	1.9	223,000[b]	1,133[b]	364[b]
Arsenic	mg/kg dw	859/918	94%	1.2	1,100	17	15.6
cPAH [c]	µg TEQ/kg dw	853/893	96%	2.2	11,000	460	388
Dioxins and furans[d]	ng TEQ/kg dw	123/123	100%	0.3	2,100	42	25.6

Source: Table 2-3 of the LDW draft final FS AECOM (2011)

[a] The calculated mean and the SWAC use one half the RL for non-detected arsenic data. Mean concentrations were calculated using one-half the highest RL for an individual Aroclor for samples in which no Aroclors were detected.

[b] The mean and SWAC were calculated with two outliers (2,900,000 and 230,000 µg/kg dw) excluded. The SWAC that was calculated with these values included was 1,313 µg/kg dw.

[c] The cPAH TEQ was calculated using compound-specific PEFs (Appendix D).

[d] The dioxin/furan TEQ was calculated using World Health Organization (Van den Berg et al. 2006) mammalian TEQ factors.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
LDW – Lower Duwamish Waterway
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
RL – reporting limit
SWAC – spatially weighted average concentration
TEQ – toxic equivalent

7.2.2.3 LDW Lateral Loads

LDW lateral loads were estimated to contribute less than 1% of the solids to the EW. LDW lateral loads were characterized by a range of values used as input parameters in the LDW bed composition model (BCM), a model used to predict future surface sediment conditions in the LDW following sediment remediation. The LDW source-tracing dataset was used to establish LDW lateral values for PCBs, arsenic, and cPAHs in the FS (AECOM 2012). The dataset consisted of storm drain solids data collected throughout the LDW drainage basin. In order to simulate potential future lateral inputs following the implementation of various degrees of source control, the solids data were screened to remove all values above set concentrations. Available storm drain solids data for dioxins and furans were also evaluated in conjunction with surface sediment samples collected in the vicinity of storm drain outfalls throughout the greater Seattle area. Appendix C of the LDW FS (AECOM 2012) provides a detailed discussion of the methods that were used to estimate lateral values for the LDW modeling.

Table 7-8 provides the LDW lateral loads for each of the four risk drivers. The high values were derived as a conservative representation of current LDW conditions assuming a modest level of source control (e.g., management of high priority sources). The low values were derived to represent the lowest achievable values that could be attained in 30 to 40 years with increased coverage and continued aggressive source control.

Table 7-8
Lateral Input Parameters for the LDW Bed Composition Model

Risk Driver	Unit	LDW BCM Parameters		
		Input	Low	High
Total PCBs	µg/kg dw	300	100	1,000
Arsenic	mg/kg dw	13	9	30
cPAH[a]	µg TEQ/kg dw	1,400	500	3,400
Dioxins and furans[b]	ng TEQ/kg dw	20	10	40

Source: LDW draft final FS AECOM (2012 [in prep]), Table 5-1a, Appendix C.

[a] cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual cPAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound. If none of the cPAH compounds were detected in a given sample, non-detect values represent the sum of one-half the RL multiplied by the PEF for each cPAH compound.

[b] Dioxin and furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQs were calculated for each sample by summing the TEQs for each congener. Dioxin and furan individual congener TEQs were calculated as the product of individual

congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

BCM – bed composition model
LDW – Lower Duwamish Waterway
TEQ – toxic equivalent

7.3 Urban Bays and Lakes Sediment Data

To provide additional context for the sediment concentrations presented in Sections 7.1 and 7.2, this section presents concentrations of total PCBs, arsenic, cPAHs, and dioxins and furans in sediments from urban locations outside the Green/Duwamish watershed. These locations were selected from areas outside of identified CERCLA and MTCA sites and DMMP open-water dredged material disposal sites.

7.3.1 PCBs, Arsenic, and cPAHs

Surface sediment data for total PCBs, arsenic, and cPAHs within the following major urban bays and lakes were extracted from Ecology's EIM System: Elliott Bay, Bellingham Bay, Commencement Bay, Lake Washington, and Lake Sammamish. These data include the results from many individual studies. As noted in the introduction to Section 7, detailed evaluations of dataset representativeness were not performed.

Prior to the calculation of statistics, these data were screened to exclude the following types of samples:

- Samples collected as part of a CERCLA or MTCA cleanup study prior to any sediment remediation (post-remediation monitoring data from any such sites were retained)
- Samples collected as part of routine onsite monitoring of the DMMP open-water dredged material disposal sites

Although data from the open-water dredged material disposal sites may be representative of regional sediment quality, these data were excluded because of the difficulty in attributing the sediment characteristics of the dredged material to the original location from which the sediments were dredged.

Elliott Bay locations were divided into an inner Elliott Bay dataset and an outer Elliott Bay dataset. The inner and outer datasets were defined by drawing a north-south line from the Duwamish head to Pier 91/92. Three locations near the middle and east of the line were included in the outer Elliott Bay dataset because the water depths were greater than 140 m.

The Elliott Bay datasets include data collected from 1991 to 1998 but do not include post-cap monitoring samples from Pier 52/53 and Denny Way. Inner Elliott Bay data are included in Tables 7-9 through 7-11 for informational purposes but are excluded from the summary ranges discussed in this section and in Section 7.5 because inner Elliott Bay receives discharge from the LDW and EW and may be influenced by other known point sources of contamination. Additional screening steps were applied with the objective of generating a single result per chemical for each location, which involved averaging field duplicates, field replicates, and laboratory replicates, as described in Appendix D. In addition, for locations monitored repeatedly over time, only the most recent result was included.

Table 7-9
Total PCB Concentrations in Surface Sediment Samples Collected in Urban Bays and Lakes, Excluding Cleanup and Disposal Sites

Area	Detection Frequency	PCB Concentration (µg/kg dw)							
		Minimum Detect	Maximum Detect	Mean	95% UCL	50th Percentile	90th Percentile	Minimum Non-Detect	Maximum Non-Detect
Inner Elliott Bay	28/37	33	800	190	255	99	576	18	59
Outer Elliott Bay	7/28	8.1	138	38	53	17	82	10	844
Bellingham Bay	6/61	8.0	425	76	164	25	114	15	850
Commencement Bay	49/71	4.0	1,104	61	127	21	64	12	350
Lake Sammamish	25/25	16	88	40	49	34	73	na	na
Lake Washington	1/17	26	26	87	137	47	217	9.5	285

Note: Mean and percentile values were calculated using both detected and non-detected concentrations, where non-detects were set equal to one-half the non-detect concentration. The 95% UCL values were calculated in ProUCL v. 4.0, using both detect and non-detect concentrations.

dw – dry weight

na – not applicable

PCB – polychlorinated biphenyl

UCL – upper confidence limit on the mean

Table 7-10

Arsenic Concentrations in Surface Sediment Samples Collected in Urban Bays and Lakes, Excluding Cleanup and Disposal Sites

Area	Detection Frequency	Arsenic Concentration (mg/kg dw)							
		Minimum Detect	Maximum Detect	Mean	95% UCL	50th Percentile	90th Percentile	Minimum Non-Detect	Maximum Non-Detect
Inner Elliott Bay	25/34	4.7	27	8.6	10.4	7.4	16	6.0	11
Outer Elliott Bay	19/31	2.4	14	5.1	6.4	4.1	9.8	2.9	18
Bellingham Bay	160/162	1.5	19	9.2	9.6	9.2	13	3.3	7.5
Commencement Bay	131/133	1.4	45	9.6	12	8.7	17	13	13
Lake Washington	25/29	2.0	27	7.2	8.9	6.3	13	4.0	20
Lake Sammamish	29/29	1.8	72	15	59	8.7	38	na	na

Note: Mean and percentile values were calculated using both detected and non-detected concentrations, where non-detects were set equal to one-half the RL. The 95% UCL values were calculated in ProUCL v. 4.0, using both detect and non-detect concentrations.

dw – dry weight
na – not applicable
RL – reporting limit
UCL – upper confidence limit on the mean

Table 7-11

cPAH Concentrations in Surface Sediment Samples Collected in Urban Bays and Lakes, Excluding Cleanup and Disposal Sites

Area	Detection Frequency	cPAH Concentration (µg TEQ/kg dw)							
		Minimum Detect	Maximum Detect	Mean	95% UCL	50th Percentile	90th Percentile	Minimum Non-Detect	Maximum Non-Detect
Inner Elliott Bay	64/66	14	4,780	583	1,080	269	1,410	34	36
Outer Elliott Bay	15/21	22	327	116	152	79	292	20	39
Bellingham Bay	53/64	5.8	593	76	108	32	185	15	26
Commencement Bay	45/45	8.8	1,700	223	345	115	527	na	na
Lake Washington	30/33	43	5,290	374	635	216	904	49	855
Lake Sammamish	11/20	57	1,870	234	407	92	574	41	453

Note: Total cPAHs were calculated by summing the products of concentrations and compound-specific PEFs for individual cPAH compounds, as discussed in detail in Appendix D. Mean and percentile values were calculated using both detected and non-detected concentrations, where non-detects were set equal to one-half the non-detect concentration. The 95% UCL values were calculated in ProUCL v. 4.0, using both detect and non-detect concentrations.

cPAH – carcinogenic polycyclic aromatic hydrocarbons
dw – dry weight
na – not applicable
PEF – potency equivalency factor
UCL – upper confidence limit on the mean

The summary statistics for each urban bay or lake were evaluated individually (Tables 7-9, 7-10, and 7-11). Differences in available datasets from one water body to another may also affect the comparability of results across different areas. In addition, aside from the initial

screening discussed above, these data were not thoroughly screened to ensure that all data that might be associated with hazardous waste sites or other point sources of contamination were removed. Therefore, the data summarized in this section are presented only for informational purposes.

Excluding the data from inner Elliott Bay, the mean total PCB concentrations for sediments in urban bays and lakes ranged from 38 to 87 µg/kg dw (Table 7-9). The mean concentrations from these water bodies were within or higher than the range of mean total PCB concentrations from the three datasets evaluated in Section 7.2, which ranged from 3 to 50 µg/kg dw (Table 7-6). The 90th percentiles of the total PCB data in urban bays and lakes ranged from 64 to 217 µg/kg dw, with the exclusion of data from inner Elliott Bay (Table 7-9), compared with 6 to 107 µg/kg dw in the datasets in Section 7.2.

The mean arsenic concentrations in urban bays and lakes ranged from 5.1 to 15 mg/kg dw (Table 7-10). These means are within the range of arsenic means from the datasets evaluated in Section 7.2 (7 to 37 mg/kg dw) (Table 7-6). The 90th percentiles of the arsenic data in urban bays and lakes ranged from 9.8 to 38 mg/kg dw (Table 7-10) compared with 11 to 73 mg/kg dw in the datasets in Section 7.2.

Excluding the data from inner Elliott Bay, the mean cPAH concentrations in urban bays and lakes ranged from 76 to 374 µg TEQ/kg dw (Table 7-11). The mean concentrations from these water bodies were within or higher than the range of cPAH means from the datasets evaluated in Section 7.2, which ranged from 18 to 151 µg TEQ/kg dw (Table 7-6). The 90th percentiles of the cPAH data in urban bays and lakes ranged from 185 to 904 µg TEQ/kg dw, with the exclusion of data from inner Elliott Bay (Table 7-11), compared with 57 to 400 µg TEQ/kg dw in the three datasets in Section 7.2.

7.3.2 Dioxins and Furans

Surface sediment sampling for dioxins and furans in the greater Seattle metropolitan area was conducted as part of the LDW RI sampling event in 2005 (Windward 2005b). This Seattle-area study was designed to collect sediment samples and provide dioxin and furan results near storm drains and other areas receiving runoff associated with typical urban sources. Dioxins and furans from these sources are distributed throughout urban areas via atmospheric deposition followed by stormwater runoff. The total number of samples was

relatively small; conclusions drawn from these results for urban levels should be considered in this context.

The criteria used to select sampling areas representative of LDW background were as follows: 1) the area must receive drainage from basins with land uses similar to the LDW, 2) the area must not be located near known industrial point sources of dioxins and furans, 3) the area must represent a range of receiving water environments, and 4) the area must represent a range of stormwater discharge frequencies, volumes, and types similar to those in the LDW. The sampling locations that met these four criteria are shown on Map 7-7. In order to assess the potential influence of outfall proximity on dioxin and furan concentrations in sediment, two samples, one between 30 and 50 ft from the outfall and a second between 100 and 120 ft from the outfall, were collected at each of four of these locations: Elliott Bay (Terminal 91 [T-91]), Lake Union (I-5 bridge), Lake Washington (Renton), and the Ship Canal (Salmon Bay).

Individual dioxin and furan congener data were converted to a dioxin and furan TEQ. Data were reviewed to determine the appropriate dataset to represent urban conditions expected for areas with stormwater runoff, such as the EW. The dioxin and furan results for all individual samples are provided in Table 7-12. Dioxins/furans ranged from 5.46 ng TEQ/kg dw (Lake Union) to 187 ng TEQ/kg dw (in Salmon Bay). Most of the TEQs were less than 30 ng TEQ/kg dw.

Table 7-12
Dioxin and Furan TEQs in Surface Sediment Samples Collected from Areas Near Storm Drains and from Other Areas Receiving Runoff in the Greater Seattle Metropolitan Area

Location	Location ID	Dioxin and Furan TEQ (ng TEQ/kg dw)	Mean Value (ng TEQ/kg dw)
Elliott Bay (T-91)[a]	EB-SS2a	13.7 J	16.3
	EB-SS2b	18.9 J	
Lake Union (I-5 bridge)[a]	LU-SS9a	5.46 J	15.8
	LU-SS9b	26.1 J	
Lake Washington (Bothell)	LW-SS3	13.2 J[b]	13.2
Lake Washington (Bellevue)	LW-SS4	14.7 J	14.7
Lake Washington (Renton)[a]	LW-SS5a	14.1 J	14.3
	LW-SS5b	14.5 J	

Location	Location ID	Dioxin and Furan TEQ (ng TEQ/kg dw)	Mean Value (ng TEQ/kg dw)
Ship Canal (Salmon Bay)[a]	SC-SS1a	187 J	-
	SC-SS1b	63.1 J	-
Union Bay (Laurelhurst)	UB-SS8	53.4 J	-
Statistics for greater Seattle area locations (excluding samples from the Ship Canal and Union Bay):			
		Mean value	**14.9**
		90th percentile	**16.3**
		95% UCL	**16.0**

[a] Two samples were collected, one approximately 30 to 50 ft from the outfall and the other approximately 100 to 120 ft from the outfall.

[b] Reported concentration is the average of two field samples.

dw – dry weight
ID – identification
J – estimated concentration
na – not applicable
T-91 – Terminal 91
TEQ – toxic equivalent
UCL – upper confidence limit on the mean

The summary statistics presented in Table 7-12 include two adjustments to the set of individual results. The data for the Ship Canal and Union Bay sampling locations are not included because the TEQs were higher than the national range of 0.12 to 16.3 ng TEQ/kg dw (EPA 2000a).[105] Three of the sampled locations had two samples each. The results of the two samples collected at different distances from the outfall at each of these three locations (Elliott Bay, Lake Union, Lake Washington/Renton) were averaged before calculating summary statistics. Averaging was intended to provide a representation of conditions in the general vicinity of the outfalls. The mean dioxin and furan TEQ for this reduced dataset was 14.9 ng/kg dw, higher than the average from EPA's (2000a) national summary (which included both urban and rural locations), but within the range shown above.

7.4 Non-Urban Puget Sound Tissue Data

This section presents the ranges of total PCB, dioxin and furan, and cPAH concentrations in tissue samples from non-urban and near-urban areas in Puget Sound. Non-urban Puget Sound tissue data for arsenic is presented in the HHRA (Appendix B).

[105] The range of dioxin and furan TEQs in sediments of 11 lakes and reservoirs throughout the United States, which were selected to represent background conditions in areas removed from known sources, was 0.12 to 16.3 ng TEQ/kg dw (EPA 2000a), with an arithmetic mean of 5.3 ng/kg dw.

The non-urban Puget Sound tissue data presented in this section come from various studies, with the LDW FS used as a starting point (AECOM 2012). The LDW FS dataset for tissue was compiled using the LDW RI (Windward 2010g), Ecology's EIM database, and other available sources. It should be noted that the sources for the non-urban Puget Sound dataset were generally used as reported without further data quality reviews. In addition, the sampling and analytical methods used to produce these datasets varied from study to study. Thus, although these data provide a general indication of the concentrations of risk drivers in tissues collected throughout Puget Sound, they should not be regarded as a single dataset generated using a consistent methodology.

Criteria for using the data from the non-urban Puget Sound tissue dataset were determined as described below:

- **Species** – Only those species representative of the consumption categories evaluated in the EW HHRA (i.e., benthic fish, perch, rockfish, crabs, clams, geoduck, and mussels) were included in the dataset. Available data for other species, including shrimp, oysters, and other fish species (e.g., salmon and lingcod) were excluded.
- **Proximity to known contaminated sources or urban areas** – Sampling locations near known contaminated sites and near urban areas were excluded from the non-urban Puget Sound tissue dataset. Examples of excluded areas include: Commencement Bay (Tacoma), Elliott Bay (Seattle), Budd Inlet (Olympia), Port Gardner (Everett), Sinclair Inlet (Bremerton), Port Angeles Harbor, Bellingham Bay, and Oakland Bay (Shelton). In addition, samples from some areas (e.g., Fidalgo Bay near Anacortes) were excluded on a case-by-case basis because of their proximity to known sources, proximity to sediment samples with high concentrations (as compared with concentrations in other background areas), and the mobility of the sampled species (mobile species such as fish and crabs collected in Fidalgo Bay were excluded from the dataset, whereas some clam samples were included).

The resulting non-urban Puget Sound tissue dataset contains different numbers of samples for the various risk drivers and tissue types, depending on data availability. These datasets are discussed in more details in the subsections that follow.

7.4.1 PCBs

Non-urban Puget Sound tissue data for PCBs were available for benthic fish fillets (242 samples), rockfish (141 samples), Dungeness crab (17 edible meat, 15 hepatopancreas, and 15 calculated whole body samples), clams (62 samples, including horse clam muscle tissue and soft body tissues for all other species and 10 horse clam gut ball samples), and geoduck (8 edible meat and 5 gut ball samples). A summary of available PCB non-urban Puget Sound tissue data is provided in Table 7-13. Total PCBs were calculated as the sum of detected Aroclors, unless total PCB concentrations were provided in the individual data sources, in which case the reported value for total PCBs was used. If no individual Aroclors were detected in a sample, the total PCB concentration was reported as undetected at the highest RL for an individual Aroclor.

Table 7-13
Total PCB Concentrations in Fish and Shellfish Collected from Non-Urban Areas of Puget Sound Outside of Known Contaminated Sites

Species	Tissue Type	Sampling Location	Sampling Year(s)	Detection Frequency	Individuals per Composite (Average)	Total PCB Concentration (µg/kg ww)			Source
						Mean[a]	Minimum	Maximum	
Benthic Fish									
English sole	fillet	PSAMP – non urban[b]	1989 – 1999	117/189	15.2	11.6	1.3	50.8	West et al. (2001)
English sole	fillet	PSAMP – near urban[b]	1989 – 1999	36/42	13.6	15.9	2.0	75.4	West et al. (2001)
English sole	fillet	Case Inlet/ Dana Passage	2005	3/3	4.7	8.5	5.6 J	13.2 J	Era-Miller (2006)
English sole	fillet	Pickering Passage	2005	0/2	5	nc	5.5 U	5.6 U	Era-Miller (2006)
English sole	fillet	South Puget Sound	2005	2/2	20	nc	6.1 J	6.8 J	Era-Miller (2006)
Rock sole	fillet	Carr Inlet	2005	0/1	5	nc	5.5 U	5.5 U	Era-Miller (2006)
Rock sole	fillet	Case Inlet/Dana Passage	2005	0/1	5	nc	5.5 U	5.5 U	Era-Miller (2006)
Rock sole	fillet	Hale Passage	2005	0/2	5	nc	5.1 U	5.5 U	Era-Miller (2006)
Rockfish									
Copper rockfish	fillet	PSAMP – non-urban[b]	1989 – 1999	1/1	5	nc	4.5	4.5	West et al. (2001)
		PSAMP – near-urban[b]		17/17	3.6	9.6	3.9	22.5	
Quillback rockfish	fillet	PSAMP – non-urban[b]	1989 – 1999	42/79	2.6	12.2	2.0	124	West et al. (2001)
		PSAMP – near-urban[b]		42/42	2.4	40.3	4.1	140	
Yelloweye rockfish	fillet	PSAMP – non-urban[b]	1989 – 1999	2/2	1	nc	16.3	48.2	West et al. (2001)
Crab									
Dungeness crab	edible meat	Padilla/Fidalgo Bay	1999	2/2	5	nc	1.2 J	1.4 J	Ecology (2000)
Dungeness crab	edible meat	Dungeness Bay[c]	2006	7/7	1	1.02	0.46	1.92	Malcolm Pirnie (2007)[d]
	hepatopancreas			7/7	1	25.0	13.1	49.5	
	calc'd whole body[e]			7/7	1	8.44	4.39	16.0	
Dungeness crab	edible meat	Freshwater Bay[c]	2006	8/8	1	0.62	0.43	0.99	Malcolm Pirnie (2007)[d]
	hepatopancreas			8/8	1	17.8	8.80	32.3	
	calc'd whole body[e]			8/8	1	5.96	3.03	10.7	

Species	Tissue Type	Sampling Location	Sampling Year(s)	Detection Frequency	Individuals per Composite (Average)	Total PCB Concentration (µg/kg ww)			Source
						Mean[a]	Minimum	Maximum	
Clams									
Butter clam	soft parts	various locations[f]	1994 – 2005	0/42	na	nc	2.5 U	6.5 U	King County (1995, 2000, 2001, 2005, 2006c, 2009b, 2002)
Butter clam	soft parts	Padilla/Fidalgo Bay	1999	0/1	50	nc	2.5 U	2.5 U	Ecology (2000)
Littleneck clam	soft parts	Padilla/Fidalgo Bay	1999	0/1	50	nc	2.5 U	2.5 U	Ecology (2000)
Littleneck clam	soft parts	Salsbury Point	2003	0/2	10 – 20	nc	2.5 U	2.6 U	Parametrix (2003)
Horse clam	tissue	Dungeness Bay[c]	2002	8/8	1	0.12	0.09	0.14	Malcolm Pirnie (2007)[d]
	gut ball			5/5	1	1.26	0.95	1.49	
Horse clam	tissue	Freshwater Bay[c]	2002	8/8	1	0.14	0.10	0.23	Malcolm Pirnie (2007)[d]
	gut ball			5/5	1	1.66	1.35	2.14	
Geoduck									
Geoduck	tissue	Freshwater Bay[c]	2002	8/8	1	0.64	0.24	1.43	Malcolm Pirnie (2007)[d]
	gut ball			5/5	1	1.35	0.92	2.10	

[a] Mean concentrations were calculated using one-half the highest RL for an individual Aroclor for samples in which no Aroclors were detected. Mean values were not calculated unless there were three or more detected values in a given dataset.

[b] PSAMP data are from various sites around Puget Sound (Map 7-8).

[c] Dungeness Bay and Freshwater Bay were the reference sites used in the Rayonier Mill RI near Port Angeles, Washington (Malcolm Pirnie 2007).

[d] The total PCB concentrations in this study were calculated as the sum of all detected PCB congeners.

[e] Data from composite hepatopancreas samples were mathematically combined with data from composite samples of edible meat to form composite samples of edible meat plus hepatopancreas. Total PCB concentrations in whole-body (i.e., edible meat plus hepatopancreas) crab were calculated assuming 69% (by weight) edible meat and 31% hepatopancreas, based on the relative weights of these tissues in a 16.6-cm Dungeness crab dissected by Windward in 2004 (unpublished data). Detection frequencies were not calculated for these samples because they do not represent individually analyzed samples.

[f] Locations include Edmonds, Carkeek Park, Golden Gardens, Alki Point, Vashon Island, and Normandy Park. Data for clams collected by King County were compiled from seven King County reports (1995, 2000, 2001, 2005, 2006c, 2009b, 2002).

Ecology – Washington State Department of Ecology
J – estimated concentration
na – not available
PCB – polychlorinated biphenyl
PSAMP – Puget Sound Ambient Monitoring Program
U – not detected
ww – wet weight

For fish samples (see Table 7-13, Map 7-8), the primary sources of non-urban Puget Sound PCB data were a PSAMP report (West et al. 2001) and a study conducted by Ecology (2006). The PSAMP study area encompassed the Puget Sound region from Georgia Basin to the South Sound, including over 2,300 km^2 of aquatic habitat and over 2,100 km of shoreline (West et al. 2001) (Map 7-8). Locations throughout the study area were sampled intermittently over a 10-year period from 1989 through 1999 such that all locations were sampled at least once, but not all locations were sampled every year. The species analyzed included English sole, copper rockfish, quillback rockfish, yelloweye rockfish, and adult salmon[106] (both Chinook and coho species). The study conducted by Ecology (Era-Miller 2006) was designed to augment the PSAMP data, and thus some of the locations were co-located with those in the PSAMP monitoring effort. The sampling locations included eight sites in south Puget Sound (Map 7-8). The species sampled during this investigation were English sole and rock sole (see Table 7-13).

Clam and geoduck non-urban Puget Sound PCB data were available from a variety of studies, with the majority of the samples collected as part of the Rayonier mill site near Port Angeles (Malcolm Pirnie 2007) and King County's WQA surveys (1995, 2000, 2001, 2005, 2006c, 2009b, 2002). In the King County survey, PCBs were not detected in any of the 42 butter clam samples collected from various locations around Puget Sound (including Edmonds, Carkeek Park, Golden Gardens, Alki Point, Vashon Island, Normandy Park) (Table 7-13; Map 7-9).

The primary source of non-urban Puget Sound PCB data for crab was the RI for the Rayonier mill site near Port Angeles (Malcolm Pirnie 2007). This investigation included collection of background Dungeness crab tissue samples at Freshwater and Dungeness Bays; the locations were selected to represent background conditions for that RI (Map 7-10). Two Dungeness crab samples collected as part of Ecology's Padilla Bay sampling program (2000) were also considered acceptable for inclusion in the non-urban Puget Sound dataset.

[106] Adult salmon data were not included in Table 7-5 because their exposure to chemicals in EW sediment is not anticipated to significantly influence the concentrations in their tissues, primarily because of the very small portion of their lives spent in the EW.

In general, non-urban Puget Sound total PCB concentrations in fish tissue samples ranged from non-detect to 140 µg/kg ww (Table 7-13; Figure 7-5). Rock sole had the lowest total PCB concentrations, followed by copper rockfish, English sole, yelloweye rockfish, and quillback rockfish. Total PCB concentrations in whole-body Dungeness crabs ranged from 3.03 to 16.0 µg/kg ww. For fish species for which both near-urban and non-urban samples were available from PSAMP (West et al. 2001), the non-urban samples consistently had lower mean total PCB concentrations than near-urban samples.

In clam and geoduck tissue samples, total PCB concentrations ranged from non-detect to 2.14 µg/kg ww, and thus were the species with the lowest concentrations in the non-urban Puget Sound tissue dataset. Total PCB concentrations in non-urban Puget Sound crab tissue samples generally fell between the clam and fish tissue concentrations (Table 7-13).

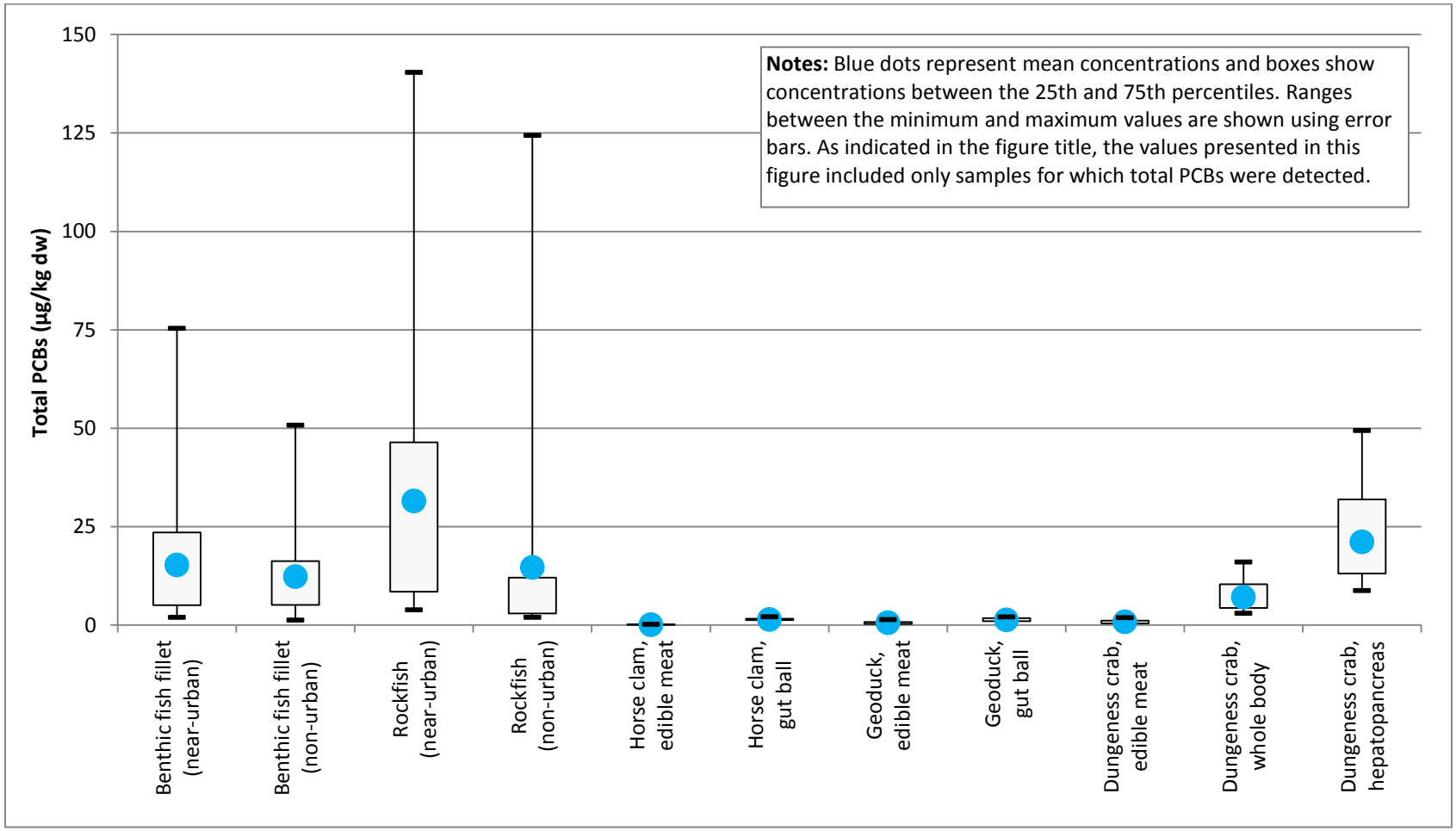
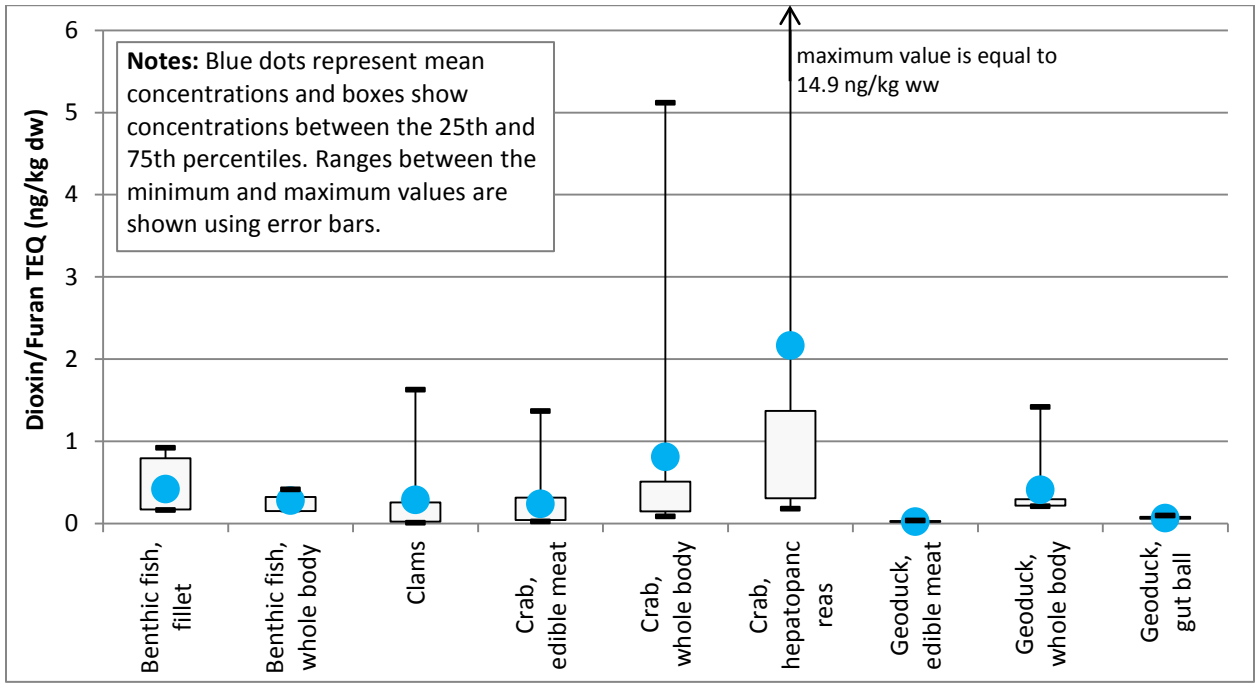


Figure 7-5

Detected Total PCB Concentrations in Tissue Samples Collected from Non-Urban Puget Sound Locations Outside of Known Contaminated Sites

7.4.2 Dioxins and Furans

Non-urban Puget Sound tissue data for dioxins and furans were available for benthic fish fillets (4 samples), whole body benthic fish (7 samples), clams (38 samples), Dungeness crab (27 edible meat, 26 hepatopancreas, and 25 calculated whole body samples), and geoduck (8 edible meat, 5 gut ball samples, and 7 whole body samples). A summary of available dioxin/furan non-urban Puget Sound tissue data is provided in Figure 7-6 and Table 7-14 and. Dioxin/furan TEQs were calculated by summing the products of individual congener concentrations and congener-specific mammalian TEFs (provided in Appendix D). A dioxin/furan TEQ value was considered detected if one or more of the congeners were detected. For non-detect congeners, the TEF was multiplied by one-half the RL.



Note: For clams, species include butter clam, horse clam, littleneck clam, and manila clam.

Figure 7-6
Dioxin and Furan TEQ in Tissue Samples Collected from Non-Urban Puget Sound Locations Outside of Known Contaminated Sites

Table 7-14

Dioxins/Furans in Fish and Shellfish Collected from Non-Urban Puget Sound Locations Outside of Known Contaminated Sites

Species	Tissue Type	Sampling Location	Sampling Year	Detection Frequency	Individuals Per Composite (Average)	Dioxins/Furans (ng TEQ/kg ww)[a]			Source
						Mean[b]	Minimum	Maximum	
Benthic Fish									
Rock sole	whole body	Dungeness Bay[c]	2002	1/1	1	nc	0.152	0.152	Malcolm Pirnie (2007)
Rock sole	whole body	Freshwater Bay[c]	2002	3/3	1	0.320	0.257	0.417	Malcolm Pirnie (2007)
	fillet			2/2	1	nc	0.166	0.191	
Starry flounder	fillet	Dungeness Bay[c]	2002	2/2	1	nc	0.404	0.923	Malcolm Pirnie (2007)
English sole	whole body	Anderson-Ketron disposal site	2007	3/3	5	0.286	0.172	0.345	SAIC (2008)
Clams									
Butter clam	soft parts	Padilla/ Fidalgo Bay	1999	1/1	50	nc	0.907	0.907	Ecology (2000)
Littleneck clam	soft parts	Padilla/ Fidalgo Bay	1999	1/1	50	nc	1.63	1.63	Ecology (2000)
Littleneck clam	soft parts	Salsbury Point	2003	2/2	NS (10 – 20)	nc	0.232	0.266	Parametrix (2003)
Horse clam	edible meat	Dungeness Bay[c]	2006	8/8	1	0.038	0.011	0.161	Malcolm Pirnie (2007)
	gut ball		2006	5/5	1	0.045	0.029	0.061	
	whole body		2002	3/3	1	0.259	0.209	0.318	
Horse clam	edible meat	Freshwater Bay[c]	2006	8/8	1	0.033	0.017	0.062	Malcolm Pirnie (2007)
	gut ball		2006	5/5	1	0.060	0.047	0.075	
	whole body		2002	3/3	1	0.252	0.247	0.259	
Horse clam	whole body	Dungeness Bay	2008	2/2	4.5	nc	1.42	1.57	Ecology (2009c)
Geoduck									
Geoduck	whole body	Dungeness Bay[c]	2002	3/3	1	0.263	0.220	0.297	Malcolm Pirnie (2007)
Geoduck	edible meat	Freshwater Bay[c]	2006	8/8	1	0.025	0.016	0.038	Malcolm Pirnie (2007)
	gut ball		2006	5/5	1	0.068	0.055	0.099	

Species	Tissue Type	Sampling Location	Sampling Year	Detection Frequency	Individuals Per Composite (Average)	Dioxins/Furans (ng TEQ/kg ww)[a]			Source
						Mean[b]	Minimum	Maximum	
	whole body		2002	3/3	1	0.226	0.212	0.238	
Geoduck	whole body	Dungeness Bay	2008	1/1	1	nc	1.42	1.42	Ecology (2009c)
Crab									
Dungeness crab	edible meat	Dungeness Bay/Skagit Bay	1991	1/1	3	nc	0.332	0.332	PSEP (1991)
	hepatopancreas			2/2	3	nc	1.64	2.60	
	calculated whole body[d]			1/1	3	nc	0.844	0.844	
Dungeness crab	edible meat	Padilla/Fidalgo Bay	1999	2/2	5	nc	1.16	1.37	Ecology (2000)
Dungeness crab	edible meat	Dungeness Bay[c]	2002, 2006	10/10	1	0.102	0.044	0.273	Malcolm Pirnie (2007)
	hepatopancreas			10/10	1	0.736	0.266	1.43	
	calculated whole body[d]			10/10	1	0.315	0.132	0.589	
Dungeness crab	edible meat	Freshwater Bay[c]	2002, 2006	11/11	1	0.112	0.027	0.381	Malcolm Pirnie (2007)
	hepatopancreas			11/11	1	0.397	0.182	0.706	
	calculated whole body[d]			11/11	1	0.224	0.089	0.422	
Dungeness crab	edible meat	Anderson-Ketron disposal site	2007	3/3	5	0.467	0.214	0.716	SAIC (2008)
	hepatopancreas			3/3	5	13.5	11.5	14.9	
	calculated whole body[d]			3/3	5	4.51	3.90	5.12	

[a] Dioxin/furan TEQs were calculated by summing the products of individual congener concentrations and congener-specific TEFs. A dioxin/furan TEQ value was considered detected if one or more of the congeners were detected. For non-detect congeners, the TEF was multiplied by one-half the RL.

[b] Mean values were not calculated unless there were three or more detected values in a given dataset.

[c] Dungeness Bay and Freshwater Bay were the reference sites used in the Rayonier Mill RI near Port Angeles, Washington (2007).

[d] Data from composite hepatopancreas samples were mathematically combined with data from composite samples of edible meat to form composite samples of edible meat plus hepatopancreas. Dioxin/furan TEQs in whole-body (i.e., edible meat plus hepatopancreas) crab were calculated assuming 69% (by weight) edible meat and 31% hepatopancreas, based on the relative weights of these tissues in a 16.6-cm Dungeness crab dissected by Windward in 2004 (unpublished data).

Ecology – Washington State Department of Ecology
ns – not specified (range of individuals)
TEF – toxic equivalency factor
TEQ – toxic equivalent
RI – remedial investigation
RL – reporting limit
U – not detected
ww – wet weight

The majority of the samples included in the non-urban Puget Sound tissue dataset for the primary source of dioxins and furans were collected as part of the RI for the Rayonier mill site near Port Angeles (Malcolm Pirnie 2007). This investigation included tissue sampling at Freshwater and Dungeness Bays; the locations were selected to represent background conditions for that RI (Maps 7-11 to 7-13). Species collected in background locations for the Rayonier Mill RI included starry flounder, rock sole, Dungeness crab, horse clam, and geoduck.

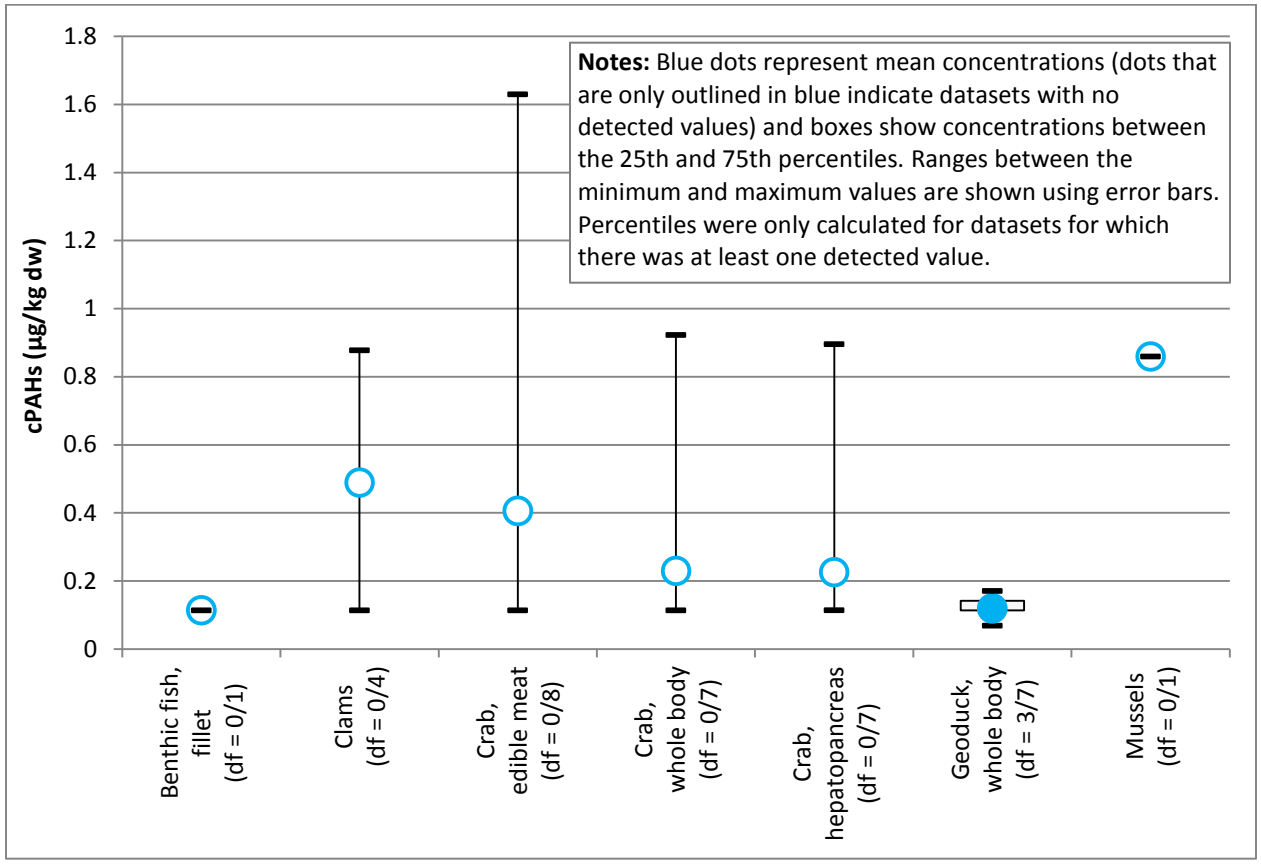
Dioxins and furans were detected in all tissue samples. Clam tissue concentrations ranged from 0.011 ng TEQ/kg ww in horse clam edible meat from Dungeness Bay to 1.63 ng TEQ/kg ww in littleneck clam tissue from Padilla/Fidalgo Bay. Crab tissue concentrations were higher in hepatopancreas samples (0.182 to 14.9 ng TEQ/kg ww) than edible meat samples (0.027 to 1.37 ng TEQ/kg ww) with the highest concentrations reported for Dungeness crab samples from the Anderson-Ketron disposal site. Finally, the benthic fish concentrations ranged from 0.166 to 0.923 ng TEQ/kg ww, with the highest concentration in a starry flounder fillet from Dungeness Bay (Table 7-14).

To better understand the impact of the individual dioxins/furans that were not detected on the dioxin/furan TEQ, the TEQ was also calculated with non-detect values represented as the full RL and 0 (rather than using the half-RL as done in this SRI). For the non-urban Puget Sound tissue dataset, using the full RLs or 0 for the non-detected components would have resulted in approximately a 60 to 70% increase or decrease (on average), respectively, in the dioxin/furan TEQs presented in Table 7-14. These relatively large impacts on the TEQ are an indication that many of the dioxin and furan congeners were not detected in the Puget Sound dataset samples. However, it should be noted that the use of either the full RL or 0 to represent non-detects would also have an impact on the TEQs calculated for the EW (the TEQ would increase or decrease by approximately 30% if the full RL or 0 were used for the non-detected components). The TEQ is less variable in the EW dataset because of the relatively high detection frequency of individual dioxin and furan congeners.

7.4.3 Carcinogenic PAHs

As compared with the non-urban Puget Sound tissue datasets for total PCBs and dioxins and furans, relatively few tissue data were available for cPAHs. Available data on fish, clams (including geoducks), crabs, and mussels were collected from a variety of studies, and with

the exception of clams, the samples generally did not contain detectable concentrations of cPAHs. The cPAH data are summarized in Figure 7-7 and Table 7-15. Additionally, Map 7-14 shows the sampling locations for the non-urban Puget Sound tissue data analyzed for cPAHs.



Note: Mean values were calculated only for species category – tissue type pairs for which there were one or more detected values. All of the tissue samples were analyzed by a high –resolution GC/MS method (EPA Method 8270 SIM) except two of the clam samples, two of the crab edible meat samples, one crab whole body sample, one crab hepatopancreas sample and the mussel sample. These samples were analyzed by EPA Method 8270 with significantly higher reporting limits than the high resolution method.

Figure 7-7

cPAH TEQs in Tissue Samples Collected from Non-Urban Puget Sound Locations Outside of Known Contaminated Sites

Table 7-15

cPAHs in Fish and Shellfish Collected from Non-Urban Puget Sound Locations Outside of Known Contaminated Sites

Species	Tissue Type	Sampling Location	Sampling Year	Detection Frequency	Individuals Per Composite (Average)	cPAHs (µg TEQ/kg ww)[a]			Source
						Mean[b]	Minimum	Maximum	
Benthic fish									
Starry flounder	fillet	Dungeness Bay[c]	2002	0/1	1	nc	0.114 U	0.114 U	Malcolm Pirnie (2007)
Clams									
Butter clam	soft parts	Padilla/Fidalgo Bay	1999	0/1	50	nc	0.851 U	0.851 U	Ecology (2000)
Littleneck clam	soft parts	Padilla/Fidalgo Bay	1999	0/1	50	nc	0.878 U	0.878 U	Ecology (2000)
Littleneck clam	soft parts	Salsbury Point	2003	0/2	10 – 20	nc	0.114 U	0.114 U	Parametrix (2003)
Geoduck									
Geoduck	soft parts	Freshwater Bay[c]	2002	1/3	1	nc	0.114 U	0.142	Malcolm Pirnie (2007)
Geoduck	soft parts	Dungeness Bay[c]	2002	1/3	1	nc	0.114 U	0.171	Malcolm Pirnie (2007)
Geoduck	soft parts	Dungeness Bay	2002	1/1	2	nc	0.069	0.069	Ecology (2009c)
Crab									
Dungeness crab	edible meat	Padilla/Fidalgo Bay	1999	0/2	5	nc	0.935 U	1.63 U	Ecology (2000)
	hepatopancreas			0/1	5	nc	0.896 U	0.896 U	
	calculated whole body[d]			0/1	5	nc	0.923 U	0.923 U	
Dungeness crab	edible meat	Dungeness Bay[c]	2002	0/3	1	nc	0.114 U	0.114 U	Malcolm Pirnie (2007)
	hepatopancreas			0/3	1	nc	0.114 U	0.114 U	
	calculated whole body[d]			0/3	1	nc	0.114 U	0.114 U	
Dungeness crab	edible meat	Freshwater Bay[c]	2002	0/3	1	nc	0.114 U	0.114 U	Malcolm Pirnie (2007)
	hepatopancreas			0/3	1	nc	0.114 U	0.114 U	
	calculated whole body[d]			0/3	1	nc	0.114 U	0.114 U	

Species	Tissue Type	Sampling Location	Sampling Year	Detection Frequency	Individuals Per Composite (Average)	cPAHs (µg TEQ/kg ww)[a]			Source
						Mean[b]	Minimum	Maximum	
Mussels									
Bay mussel	soft parts	Padilla/Fidalgo Bay	1999	0/1	50	nc	0.860 U	0.860 U	Ecology (2000)

[a] cPAH TEQs were calculated by summing the products of individual PAH concentrations and compound-specific PEFs for the seven individual cPAH compounds (benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene). cPAH TEQs were considered detected if one or more of the individual cPAH compounds were detected. For non-detect cPAH compounds, one-half of the RL was multiplied by the PEF when calculating the TEQ.

[b] Mean values were not calculated unless there were three or more detected values in a given dataset.

[c] Dungeness Bay and Freshwater Bay were the reference sites used in the Rayonier Mill RI near Port Angeles, Washington (2007).

[d] Data from composite hepatopancreas samples were mathematically combined with data from composite samples of edible meat to form composite samples of edible meat plus hepatopancreas. cPAH TEQs in whole-body (i.e., edible meat plus hepatopancreas) crab were calculated assuming 69% (by weight) edible meat and 31% hepatopancreas, based on the relative weights of these tissues in a 16.6-cm Dungeness crab dissected by Windward in 2004 (unpublished data).

Ecology – Washington State Department of Ecology
na – not available
nc – not calculated
PAH – polycyclic aromatic hydrocarbon
PEF – potency equivalency factor
RI – remedial investigation
RL – reporting limit
TEQ – toxic equivalent
U – not detected
ww – wet weight

Only one non-urban Puget Sound fish sample was available for cPAHs: a starry flounder fillet sample collected as part of the RI for the Rayonier mill site near Port Angeles (Malcolm Pirnie 2007). cPAHs were not detected in this sample.

Non-urban Puget Sound clam samples were available from two studies and included samples of butter clams (n = 1) and littleneck clams (n = 3). cPAHs were not detected in any of these samples.

Non-urban Puget Sound geoduck samples were available from two studies: the RI for the Rayonier mill site near Port Angeles (Malcolm Pirnie 2007) and Ecology's 2002 Port Angeles Harbor sediment characterization study (Ecology 2009c). Of the seven geoduck samples, three had detected concentrations of cPAHs, with detected cPAH TEQs ranging from 0.069 to 0.171 µg/kg ww. The mean cPAH TEQ for the geoduck samples (detected and non-detected) was 0.120 µg/kg ww.

Non-urban Puget Sound crab samples were also available from two studies: Ecology's 1999 Padilla and Fidalgo Bay sampling program (2000) and the RI for the Rayonier mill site near Port Angeles (Malcolm Pirnie 2007). All of the crabs in the samples were Dungeness crab, and none had detectable cPAH concentrations.

One non-urban Puget Sound mussel sample was available from Ecology's 1999 Padilla and Fidalgo Bay sampling program (2000). cPAHs were not detected in this sample.

7.5 Summary

This section presents an initial summary of data for total PCBs, arsenic, cPAHs, and dioxins and furans from areas outside of the EW.[107] These data provide context for information presented elsewhere in the RI and will be useful in future background or recontamination determinations. However, it should be noted that the specific data and summary statistics presented in this section are preliminary; the background values to be considered in setting PRGs will be presented in the FS. EPA will determine the background levels for the site in the ROD, as well as select the site cleanup goals.

[107] Sediment RBTCs for other risk-driver contaminants based on the SQS and CSL and for TBT based on benthic invertebrate tissue-sediment relationships were higher than background concentrations, and thus preliminary background concentrations for those risk drivers are not presented in this section.

The datasets that are presented in this section include the following:

- Surface sediment data from Puget Sound reference areas and other recent data that are potentially relevant for natural background concentrations
- Data from the Green River (upstream of the LDW), including surface sediment concentrations, suspended solids concentrations, and TSS-normalized concentrations in water
- Data from sediment core samples from the Upper Turning Basin
- Summaries of LDW surface sediment data and LDW lateral input data.
- Tissue data for various species collected from the non-urban Puget Sound areas

Information on urban sediment concentrations from multiple areas is also presented to provide additional context.

Individual datasets address some or all of the four primary contaminants for which background values are of interest: PCBs, arsenic, cPAHs, and dioxins and furans. Detailed evaluations of background datasets and determinations of background-based PRGs will be addressed in continuing assessments to be documented in the FS. Thus, the information presented here is preliminary.

8 RISK-BASED THRESHOLD CONCENTRATIONS

This section presents the derivation of RBTCs, which represent the contaminant concentrations in sediment or tissue that equate to specific risk thresholds. RBTCs for human health were developed for tissue and for sediment and equate to excess cancer risk thresholds of 1×10^{-4}, 1×10^{-5}, and 1×10^{-6} and HQs equal to 1.[108] Human health and tissue and sediment RBTCs were developed for exposure through direct sediment contact and ingestion of seafood. RBTCs for ecological receptors were developed for HQs equal to 1 for fish and invertebrates (i.e., for TBT) or using the SMS values for benthic invertebrates. RBTCs were developed only for COCs that were identified as risk drivers in either the ERA (Appendix A) or the HHRA (Appendix B). RBTCs are used primarily to derive PRGs, which will be developed and used in the FS.

In the HHRA (Appendix B, Section B.7), PCBs, arsenic, cPAHs, and dioxins and furans were identified as risk driver COCs for seafood consumption and/or direct sediment exposure scenarios (Table 8-1). In the ERA (Appendix A, Section A.7), PCBs were identified as a risk driver COC for fish based on risks associated with fish tissue residues.[109] In addition, TBT was identified as a risk driver for the benthic invertebrate community based on benthic invertebrate tissue TBT concentrations. Finally, 28 COCs were identified as risk driver chemicals for the benthic invertebrate community based on detected exceedances of SMS criteria (Table 8-1).

[108] RBTCs were calculated for individual chemicals based on cancer and non-cancer thresholds for the chemical. See Section 8.6.2 for a discussion of RBTCs and total risks.

[109] In the ERA (Appendix A), direct exposure to sediments was explicitly evaluated for fish and wildlife receptors as a component of the overall diet (i.e., incidental sediment ingestion). No risk drivers were identified for fish or wildlife receptors based solely on direct contact with sediments because the majority of the risk is associated with ingestion of dietary items, not direct contact with sediment. Therefore, the PCB RBTC for fish is based only tissue residue concentration.

Table 8-1

Summary of Risk Driver COCs from the HHRA and ERA

Receptor or Exposure Scenario	PCBs	Arsenic	Dioxins and Furans	cPAHs	TBT	Other COCs
HHRA						
Direct sediment exposure	ns	X	ns	X	ns	ns
Seafood consumption	X	ns	X	X	ns	ns
ERA						
Fish	X	ns	ns	na[a]	ns	ns
Benthic invertebrates (sediment exposure)	X	X	ne	na[a]	X	X[b]

[a] cPAHs (as a TEQ) were evaluated only for human health risks. Other approaches (e.g., assessment of individual PAH compounds) were used in the ecological assessment of PAHs.

[b] In addition to arsenic and total PCBs, risk driver COCs identified for the benthic invertebrate community, based on one or more surface sediment samples with exceedances of the SQS, include cadmium, chromium, copper, lead, mercury, silver, zinc, acenaphthene, anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, naphthalene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, BEHP, BBP, dimethyl phthalate, 1,2-dichlorobenzene, 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, 2-methylnaphthalene, 4-methylphenol, 2,4-dimethylphenol, benzoic acid, benzyl alcohol, dibenzofuran, hexachlorobenzene, n-nitrosodiphenylamine, pentachlorophenol, and phenol.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
COC – contaminant of concern
ERA – ecological risk assessment
HHRA – human health risk assessment
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
na – not applicable
ne – not evaluated (in risk assessment)
ns – not selected (as a risk driver)
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
SQS – sediment quality standards
TEQ – toxic equivalent

X indicates that COC has been identified as a risk driver for the exposure scenario.

Various approaches were used to derive the RBTCs for the risk driver COCs in Table 8-1. Mathematical equations based on risk assessment assumptions were used to derive sediment RBTCs for the human health direct sediment contact scenarios (Section 8.1) and tissue RBTCs for the seafood ingestion scenarios (human [Section 8.2] and for exposures of fish [Section 8.4]). Sediment RBTCs for human health seafood ingestion scenarios were developed using a food web model (FWM) and are associated with the tissue RBTCs; their development are presented in Section 8.3.1. Sediment RBTCs for the benthic invertebrate community were based on the tissue RBTC for TBT and on SMS criteria for the other risk drivers (Section 8.5).

To develop RBTCs for sediment for human health seafood consumption scenarios or for the protection of fish, relationships between chemicals concentrations in tissues and those in sediment were needed. Different types of models were used to estimate the relationships, depending on the risk driver COC. For PCBs, a FWM was developed to relate total PCB concentrations in sediment to concentrations in fish, crabs, and clams, which were all relevant for RBTC development (Section 8.3.1). Sediment and tissue dioxin and furan concentrations were related to one another by the development of a biota-sediment accumulation factor (BSAF) which was then used for sediment RBTC development for dioxins and furans (Section 8.3.2). Co-located sediment and clam tissue data were used to evaluate regression models for cPAHs to determine if the derivation of sediment RBTCs was possible (Section 8.3.3). Co-located sediment and benthic invertebrate tissue data were used to derive a sediment RBTC for TBT (Section 8.5.1).

8.1 Sediment RBTCs for HHRA Direct Sediment Exposure Scenarios

Sediment RBTCs were calculated for direct sediment exposure scenarios evaluated in the HHRA (Appendix B). RBTCs based on RME scenarios are important in the development of PRGs, which will be used in evaluating cleanup alternatives.[110] RBTCs for non-RME direct sediment exposure scenarios will also aid in risk management and risk communication.

The RME scenarios for direct sediment exposure evaluated in the HHRA (Appendix B) consisted of tribal netfishing and tribal clamming (120 days per year). Non-RME scenarios consisted of tribal netfishing CT, habitat restoration worker, and other clamming scenarios (i.e., 183 days per year and 7 days per year). Key parameters used to estimate risks associated with direct sediment exposure are summarized in Table 8-2. Detailed descriptions of the direct sediment exposure scenarios and risk results are presented in the HHRA (Appendix B) in Sections B.3 and B.5, respectively. Detailed exposure information for the direct sediment exposure scenarios is presented in Tables B.3-23 through B.3-35, EPCs are summarized in Table B.3-46, chemical toxicity information is presented in Tables B.4-1 and B.4-2, and risk estimates for direct sediment exposure scenarios are presented in Tables B.5-24 through B.5-35.

[110] In accordance with EPA guidance (Section 6.1.2 of EPA 1989), RME scenarios are used to formulate RAOs and evaluate cleanup alternatives at Superfund sites.

Table 8-2

Summary of key assumptions for HHRA direct sediment exposure scenarios

Direct Sediment Exposure Scenario for Which RBTCs Were Derived	Incidental Sediment IR (g/day)	Exposure Frequency (days/year)	Exposure Duration (years)	Skin Surface Area Exposed (cm^2)
RME Scenarios				
Tribal netfishing RME	0.050	119	44	3,600
Tribal clamming RME (120 days per year)	0.1	120	64	6,040
Non-RME Scenarios				
Tribal netfishing CT	0.050	63	29	3,600
Habitat restoration worker	0.1	15	20	6,040
Tribal clamming – 183 days per year	0.1	183	70	6,040
Clamming – 7 days per year	0.1	7	30	6,040

Note: Details regarding exposure assumptions for the direct sediment exposure scenarios are presented in Section 6, Section B.3.3.2 of the HHRA (Appendix B), and Section 6.1.3.2.

CT – central tendency
IR – ingestion rate
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

Sediment RBTCs for direct sediment exposure scenarios were derived for arsenic and cPAHs (i.e., the risk drivers for the direct sediment exposure scenarios) using Equation 8-1 (for carcinogenic effects). The values for key parameters are listed above in Table 8-2. The first term in the denominator addresses dermal exposure; the second term addresses incidental ingestion.

$$RBTC = \frac{TR}{\left[\left[\left(\frac{ABS \times SA \times AF \times FC \times EF \times ED \times CF_1}{BW \times AT_C}\right) + \left(\frac{IR \times FC \times EF \times ED \times CF_2}{BW \times AT_C}\right)\right] \times SF\right]} \quad (8\text{-}1)$$

Where:

RBTC = risk-based threshold concentration in sediment (mg/kg dw)
TR = target risk (i.e., 1×10^{-6}, 1×10^{-5}, 1×10^{-4}) (unitless)
ABS = absorption factor (unitless)
SA = skin surface area (cm^2)
AF = adherence factor (mg/cm^2-day)
FC = fraction from contaminated site (unitless)
EF = exposure frequency (days/year)
ED = exposure duration (years)
CF_1 = conversion factor, kg to mg (0.000001)

BW = body weight (kg)
AT_c = averaging time, cancer (days)
SF = cancer slope factor $(mg/kg\text{-}day)^{-1}$
AT_n = averaging time, non-cancer (days)
IR = incidental sediment ingestion rate (g/day)
CF_2 = conversion factor, kg to g (0.001)

RBTCs were not estimated for non-cancer hazards for direct-contact scenarios because none of the RME scenarios had HQs for an individual chemical greater than 1 or generated endpoint-specific HIs in excess of 1 (Appendix B, Section B.5.6.2). Equation 8-1 is simply a rearrangement of the equation used in the HHRA to estimate excess cancer risk. In this case, rather than inserting a maximum or 95% UCL sediment concentration into the equation and solving for risk, as was done in the HHRA (Appendix B), the target risk is set and the equation is solved for a corresponding sediment concentration.

Sediment RBTCs for the direct sediment exposure RME scenarios are shown in Table 8-3; those for non-RME scenarios are presented in Table 8-4. The non-RME RBTCs are presented for informational purposes only, and are not intended for use in setting clean up levels. The remedial decision-making process will focus on the RME scenarios, although non-RME scenarios may be evaluated as lower- and upper- bound estimates of risk. The RBTCs for the tribal clamming RME scenario were lower than the RBTCs for the netfishing RME scenario at a given target risk level. Considerations relevant to the application of these RBTCs are discussed in Section 8.6.

Table 8-3
Sediment RBTCs for HHRA RME Direct Sediment Exposure Scenarios

Risk Driver	Target Risk	Sediment RBTCs Based on Direct Contact RME Scenarios	
		Netfishing RME	Tribal Clamming RME (120 days/year)
Arsenic (mg/kg dw)	1×10^{-6}	3.7	1.3
	1×10^{-5}	37	13
	1×10^{-4}	370	130
cPAHs (µg TEQ/kg dw)[a]	1×10^{-6}	380	150
	1×10^{-5}	3,800	1,500
	1×10^{-4}	38,000	15,000

[a] cPAH concentrations are expressed in terms of benzo(a)pyrene equivalents.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
HHRA – human health risk assessment
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TEQ – toxic equivalent

Table 8-4
Sediment RBTCs for HHRA Non-RME Direct Sediment Exposure Scenarios

Risk Driver	Target Risk	Sediment RBTCs Based on Non-RME Direct-Contact Scenarios			
		Netfishing CT	Habitat Restoration Worker	Clamming – 183 days/year	Clamming – 7 days/year
Arsenic (mg/kg dw)	1×10^{-6}	11	30	0.80	43
	1×10^{-5}	110	300	8.0	430
	1×10^{-4}	1,100	3,000	80	4,300
cPAHs (µg/kg dw)[a]	1×10^{-6}	1,100	3,300	87	4,700
	1×10^{-5}	11,000	33,000	870	47,000
	1×10^{-4}	110,000	330,000	8,700	470,000

[a] cPAH concentrations are expressed in terms of benzo(a)pyrene equivalents.

cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
dw – dry weight
HHRA – human health risk assessment
RME – reasonable maximum exposure
RBTC – risk-based threshold concentration

8.2 Tissue RBTCs for Human Seafood Consumption

The RME scenarios for seafood consumption evaluated in the HHRA (Appendix B) consisted of the tribal adult and child RME seafood consumption scenarios based on Tulalip consumption data and the adult API seafood consumption scenario. Non-RME scenarios consisted of adult tribal (Suquamish data), adult and child tribal CT (Tulalip data), adult API CT, and adult one-meal-per-month scenarios.

Tissue RBTCs were calculated for seafood consumption exposure scenarios evaluated in the HHRA (Appendix B). Tissue RBTCs were estimated according to the methods described in Section 8.2. The primary use of these RBTCs will be to evaluate post-cleanup monitoring data for risk driver COCs in seafood tissue. In addition to the RBTCs for the RME scenarios, tissue RBTCs were developed for the other non-RME seafood consumption scenarios to aid in risk management and risk communication efforts.

Key assumptions for each of the seafood consumption scenarios are summarized in Table 8-5. The seafood consumption scenarios and risk results are presented in the HHRA

(Appendix B), in Sections B.3 and B.5, respectively. Detailed exposure information for the seafood consumption scenarios is presented in Tables B.3-14 through B.3-22, EPCs are summarized in Table B.3-43, chemical toxicity information is presented in Tables B.4-1 and B.4-2, and risk estimates are presented in Tables B.5-1 through B.5-16.

Table 8-5
Summary of Key Assumptions for HHRA Seafood Consumption Scenarios

Seafood Consumption Scenario for which RBTCs Were Derived	Ingestion Rate (g/day)					Exposure Duration (yrs)
	Pelagic Fish (Perch and Rockfish)	Benthic Fish (fillet and whole body)	Crabs (edible meat and whole body)	Other Shellfish (clams, mussels, and geoduck)	Total	
Adult tribal RME (Tulalip data)	8.1	7.5	34.4	47.5	97.5	70
Child tribal RME (Tulalip data)	3.2	3.0	13.7	19.0	39.0[a]	6
Adult API RME	4.9	2.4	10.6	33.7	51.6	30
Adult tribal (Suquamish data)	56	29.1	48.9	448.5	583.5[a]	70
Adult tribal CT (Tulalip data)	1.3	1.2	5.3	7.2	15.0	30
Child tribal CT (Tulalip data)	0.52	0.48	2.1	2.9	6.0	6
Adult API CT	0.5	0.24	1.1	3.5	5.3	9
Adult one meal per month[b]	7.5	7.5	7.5	7.5	na	30

[a] As a result of rounding, the total IR is equal to 0.1 g greater than the sum of the ingestion rates for the seafood categories.

[b] Adult one-meal-per-month consumption was evaluated by individual seafood categories independently to reflect different fish and consumption practices.

API – Asian and Pacific Islander
CT – central tendency
IR – ingestion rate
na – not applicable
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

Tissue RBTCs for seafood consumption scenarios were calculated for cPAH TEQ, total PCBs, and dioxin/furan TEQ[111] (i.e., the risk drivers for the seafood consumption scenarios) using Equation 8-2 (for carcinogenic effects) or Equation 8-3 (for non-carcinogenic effects; only PCBs). The values for key parameters are listed above in Table 8-5; other parameter values are presented in the HHRA (Appendix B, Section 3).

[111] The methods used to calculate TEQ values for both cPAH and dioxins and furans are described in detail in Appendix D.

$$\text{Tissue RBTC} = \frac{\text{TR}}{\left[\left[\frac{\text{IR} \times \text{FC} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}_C}\right] \times \text{SF}\right]} \quad (8\text{-}2)$$

$$\text{Tissue RBTC} = \frac{\text{THQ}}{\left[\left[\frac{\text{IR} \times \text{FC} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}_n}\right] \times \frac{1}{\text{RfD}}\right]} \quad (8\text{-}3)$$

Where:

RBTC	=	risk-based threshold concentration in seafood items (mg/kg ww)
TR	=	target risk (i.e., 1×10^{-6}, 1×10^{-5}, 1×10^{-4}) (unitless)
IR	=	total seafood ingestion rate (g/day)
FC	=	fraction from contaminated site (unitless)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
CF	=	conversion factor, kg to g (0.001)
BW	=	body weight (kg)
AT_c	=	averaging time, cancer (days)
SF	=	cancer slope factor $(mg/kg\text{-}day)^{-1}$
THQ	=	target hazard quotient (1) (unitless)
AT_n	=	averaging time, non-cancer (days)
RfD	=	reference dose (mg/kg-day)

RBTCs based on carcinogenic risks were estimated for three risk threshold levels, 1×10^{-6}, 1×10^{-5}, and 1×10^{-4}; for non-cancer hazards, the RBTCs corresponding to an HQ of 1 were estimated.

Tissue RBTCs corresponding to the RME seafood consumption scenarios are presented in Table 8-6; tissue RBTCs corresponding to the non-RME seafood consumption scenarios are presented in Table 8-7. RBTCs for non-RME scenarios are presented for informational purposes. The remedial decision-making process will focus on the RME scenarios, although non-RME scenarios may be evaluated to provide lower- and upper- bound estimates of risk. Tissue RBTCs for the seafood consumption scenarios represent the ingestion-weighted average concentration in tissue that results in a certain risk threshold for each scenario. For example, the RBTC for total PCBs for the adult tribal RME seafood consumption scenario based on Tulalip data was 4.2 µg/kg ww at the 1×10^{-5} excess cancer risk level. Thus,

consumption of 97.5 g/day (adult tribal RME daily ingestion rate [IR] based on Tulalip data) of any tissue type with a total PCB concentration of 4.2 µg/kg ww for 70 years would result in a 1×10^{-5} excess cancer risk.

Table 8-6

Tissue RBTCs for HHRA RME Seafood Consumption Scenarios

Chemical	Seafood Consumption Scenario	Unit (ww)	Tissue RBTC[a]			
			Excess Cancer Risk			Non-Cancer Hazard
			1×10^{-6}	1×10^{-5}	1×10^{-4}	HQ = 1
Total PCBs	adult tribal RME (Tulalip data)	µg/kg	0.42	4.2	42	17
	child tribal RME (Tulalip data)	µg/kg	2.3	23	230	7.8
	adult API RME	µg/kg	1.4	14	140	24
cPAHs[b]	adult tribal RME (Tulalip data)	µg TEQ/kg	0.11	1.1	11	na
	child tribal RME (Tulalip data)[c]	µg TEQ/kg	0.12	1.2	12	na
	adult API RME	µg TEQ/kg	0.39	3.9	39	na
Dioxins/ furans[d]	adult tribal RME (Tulalip data)	ng TEQ/kg	0.0056	0.056	0.56	na[e]
	child tribal RME (Tulalip data)	ng TEQ/kg	0.03	0.3	3.0	0.27
	adult API RME	ng TEQ/kg	0.019	0.19	1.9	na[e]

[a] Tissue RBTCs represent ingestion-weighted average concentrations across different seafood categories. Tissue concentrations in individual seafood categories may be higher or lower than the tissue RBTC, but the ingestion-weighted average concentration in all resident seafood consumed must equal the tissue RBTC in order to result in the specified risk threshold.

[b] cPAH concentrations are expressed in terms of benzo(a)pyrene equivalents.

[c] Because of the potential for increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005b), the risk estimate for children for cPAHs is based on dose adjustments across the 0-to-6-year age range of children (see Appendix B, Section B.5.1, for more information).

[d] Dioxins/furans are expressed in terms of 2,3,7,8-TCDD equivalents.

[e] The dioxin/furan HQ for these scenarios did not exceed 1, and thus RBTCs were not calculated.

API – Asian and Pacific Islander
cPAH – carcinogenic polycyclic aromatic hydrocarbon
EPA – US Environmental Protection Agency
HHRA – human health risk assessment
HQ – hazard quotient
na – not applicable
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TCDD – tetrachlorodibenzo-*p*-dioxin
TEQ – toxic equivalent
ww – wet weight

Table 8-7
Tissue RBTCs for HHRA Non-RME Seafood Consumption Scenarios

Chemical	Seafood Consumption Scenario	Unit (ww)	Tissue RBTC[a]			
			Excess Cancer Risk		Non-Cancer Hazard	
			1×10^{-6}	1×10^{-5}	1×10^{-4}	HQ = 1
Total PCBs	adult tribal CT (Tulalip data)	µg/kg	6.4	64	640	110
	child tribal CT (Tulalip data)	µg/kg	15	150	1,500	51
	adult API CT	µg/kg	46	460	4,600	240
	adult tribal (Suquamish)	µg/kg	0.068	0.68	6.8	2.7
	adult one meal per month[b]	µg/kg	11	110	1,100	190
cPAHs[c]	adult tribal CT (Tulalip data)	µg TEQ/kg	1.7	17	170	na
	child tribal CT (Tulalip data)[d]	µg TEQ/kg	0.76	7.6	76	na
	adult API CT	µg TEQ/kg	13	130	1,300	na
	adult tribal (Suquamish)	µg TEQ/kg	0.019	0.19	1.9	na
	adult one meal per month[b]	µg TEQ/kg	3.1	31	310	na
Dioxins/ furans[e]	adult tribal CT (Tulalip data)	ng TEQ/kg	0.085	0.85	8.5	na[f]
	child tribal CT (Tulalip data)	ng TEQ/kg	0.20	2.0	20	na[f]
	adult API CT	ng TEQ/kg	0.62	6.2	62	na[f]
	adult tribal (Suquamish)	ng TEQ/kg	0.00090	0.0090	0.090	0.095
	adult one meal per month[b]	ng TEQ/kg	0.15	1.5	15	na[f]

[a] Tissue RBTCs represent ingestion-weighted average concentrations across different seafood categories. Tissue concentrations for individual seafood categories may be higher or lower than the tissue RBTC, but the ingestion-weighted average concentration in all resident seafood consumed must equal the tissue RBTC in order to result in the specified risk threshold.

[b] The adult one-meal-per-month value represents the tissue RBTC that corresponds to consumption of any type of seafood at a rate of one meal per month (7.5 g/day).

[c] cPAH concentrations are expressed in terms of benzo(a)pyrene equivalents.

[d] Because of the potential for increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005b), the risk estimate for children for cPAHs is based on dose adjustments across the 0-to-6-year age range of children (see Appendix B, Section B.5.1, for more information).

[e] Dioxins/furans are expressed in terms of 2,3,7,8-TCDD equivalents.

[f] The dioxin/furan HQ for these scenarios did not exceed 1, and thus RBTCs were not calculated.

API – Asian and Pacific Islander
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CT – central tendency
EPA – US Environmental Protection Agency
HHRA – human health risk assessment
HQ – hazard quotient
na – not applicable
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
TCDD – tetrachlorodibenzo-*p*-dioxin
TEQ – toxic equivalent
ww – wet weight

Consumption of numerous types of seafood, such as crabs, clams, and fish (as specified in the adult tribal RME exposure parameters based on Tulalip data) would also result in a 1×10^{-5} excess cancer risk as long as the ingestion-weighted average of the various tissue

concentrations consumed was 4.2 µg/kg ww. For the three risk driver COCs evaluated, the tissue RBTCs for the adult tribal RME scenario based on Tulalip data were lower than all other RME scenarios for a given risk threshold for excess cancer risk(Table 8-6). For the non-cancer hazard the tissue RBTC for the child tribal RME scenario based on the Tulalip data resulted in the lowest values.

The tissue RBTCs for PCBs and dioxins/furans presented in Tables 8-6 and 8-7 are compared with empirical EW tissue concentrations and with background tissue data (presented in Section 10). However, it should be noted that the tissue RBTCs represent an ingestion-weighted average concentration in seafood (i.e., are associated with a particular diet and consumption rate), and thus are not directly comparable with single species concentrations.

8.3 Sediment RBTCs for Human Seafood Consumption

The methods selected for deriving sediment RBTCs for human seafood consumption varied by risk driver. For total PCBs, a mechanistic FWM was developed to derive sediment RBTCs (Section 8.3.1). For dioxins and furans, site-specific BSAFs were calculated in order to derive sediment RBTCs from tissue RBTCs (Section 8.3.2). For cPAHs, regression models were evaluated for potential use in deriving sediment RBTCs (Section 8.3.3).

8.3.1 PCB sediment RBTCs for Human Seafood Consumption

8.3.1.1 Methods for Calculating Total PCB Sediment RBTCs for Human Seafood Consumption

For total PCBs, a FWM was used to derive sediment RBTCs for seafood consumption scenarios. Information regarding the FWM design, specific input parameters, calibration, and performance of the FWM is presented in Appendix C (Section C.2). In addition, Appendix C describes how the FWM was used to derive sediment RBTCs. The FWM was first calibrated to select a "best fit" set of parameter values that yielded predicted tissue concentrations closest to empirical data for all tissue types modeled. Next, the calibrated FWM was run with a wide range of sediment concentrations.[112] The sediment concentration that generated tissue concentration predictions closest to the ingestion-weighted average concentration in tissue

[112] Assumptions of total PCB concentration in water were also needed for RBTCs development. These assumptions were associated with ranges of sediment concentration and are provided in Appendix C.

provided in the Section 8.2 was identified as the sediment RBTC (for each exposure scenario and target risk level). In addition, a range of sediment RBTCs for total PCBs was estimated for each seafood exposure scenario, using upper and lower bound parameter sets in the FWM as described in Appendix C. The RBTC range represents the range of estimates generated by the FWM while still meeting the FWM performance criterion, which required that the estimated concentrations in tissues be within a factor of 2 of the empirical data for all of the target species.[113] A full discussion of the sources of uncertainty in the FWM is presented in Appendix C, Section C.4.

8.3.1.2 Results of Total PCB Sediment RBTC Calculations for Human Seafood Consumption

Sediment RBTCs were calculated to represent the total PCB concentrations in sediment that correspond to a range of excess cancer risk thresholds (1×10^{-4}, 1×10^{-5}, and 1×10^{-6}) for each of the HHRA scenarios evaluated (Tables 8-8 and 8-9 for the RME and non-RME scenarios, respectively). Sediment RBTCs for total PCBs are shown in Table 8-8 as < 1 µg/kg dw at the 1×10^{-5} and 1×10^{-6} target risk levels for the adult and child tribal RME scenarios and for the adult API RME scenario because the water concentrations assumed in the model (0.0006 to 0.0012 µg/L; see Appendix C, Section C.26) resulted in estimated tissue concentrations greater than the tissue RBTCs in Table 8-7, even in the absence of any contribution from sediment. The range of assumed water concentrations corresponds to a range of average sediment concentrations from greater than 250 µg/kg dw in which the water concentrations are the same as the current mean concentration to sediment concentrations less than 50 µg/kg dw where total PCB water concentrations are assumed to be reduced to 0.0006 µg/L. Even if lower concentrations of PCBs in surface water were assumed (e.g. equal to average concentration in the Green River), and sediment concentrations were equal to 1 µg/kg dw, the target risk thresholds of 1×10^{-6} are not predicted to be achievable. However there is uncertainty in the assumed water concentrations and how well they may represent conditions associated with future sediment concentrations and the effects of future source control measures.

[113] For all species except clams, for which estimated concentrations in tissues were required to be within a factor of 3 of the empirical data to be considered acceptable. FWM predictions within a factor of 3 to 5 are considered good.

Table 8-8
Total PCB Sediment RBTCs Based on Excess Cancer Risks for HHRA RME Seafood Consumption Scenarios

Scenario	Risk Level	Lower Bound (µg/kg dw)[a, b]	Sediment RBTC (µg/kg dw)[a]	Upper Bound (µg/kg dw)[a, b]
Adult tribal RME (Tulalip data)	1×10^{-4}	< 1	2	8
Child tribal RME (Tulalip data)		210	250	323
Adult API RME		88	100	121
Adult tribal RME (Tulalip data)	1×10^{-5}	< 1	< 1	< 1
Child tribal RME (Tulalip data)		< 1	< 1	< 1
Adult API RME		< 1	< 1	< 1
Adult tribal RME (Tulalip data)	1×10^{-6}	< 1	< 1	< 1
Child tribal RME (Tulalip data)		< 1	< 1	< 1
Adult API RME		< 1	< 1	< 1

[a] For values presented as < 1 µg/kg dw, a sediment RBTC could not be calculated; even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, FWM-estimated total PCB concentrations in tissue would be greater than the tissue RBTC for the applicable risk level because of the contribution of PCBs from water alone.

[b] Upper and lower bounds were calculated using extremes of parameter set values that still met the FWM performance criterion (i.e., empirical data were within a factor of 2 of FWM-estimated concentrations for all species except clams) (see Appendix C, Section C.2.6).

API – Asian and Pacific Islander
dw – dry weight
FWM – food web model
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

Table 8-9
Total PCBs Sediment RBTCs based on Excess Cancer Risks for Non-RME HHRA Seafood Consumption Scenarios

Scenario	Risk Level	Lower-Bound Concentration (µg/kg dw)[a, b, c]	Sediment RBTC (µg/kg dw)[a, c]	Upper-Bound Concentration (µg/kg dw)[a, b, c]
Adult tribal CT (Tulalip data)	1×10^{-4}	> 470	> 470	> 470
Child tribal CT (Tulalip data)		> 470	> 470	> 470
Adult API CT		> 470	> 470	> 470
Adult tribal (Suquamish data)		< 1	< 1	< 1
Adult one meal per month of benthic fish		404	452	> 470
Adult one meal per month of pelagic fish (rockfish)		100	138	323
Adult one meal per month of pelagic fish (shiner surf perch)		266	318	> 470

Scenario	Risk Level	Lower-Bound Concentration (µg/kg dw)[a, b, c]	Sediment RBTC (µg/kg dw)[a, c]	Upper-Bound Concentration (µg/kg dw)[a, b, c]
Adult one meal per month of crabs		> 470	> 470	> 470
Adult one meal per month of clams		> 470	> 470	> 470
Adult tribal CT (Tulalip data)	1×10^{-5}	21	33	50
Child tribal CT (Tulalip data)		100	126	183
Adult API CT		83	100	112
Adult tribal (Suquamish data)		< 1	< 1	< 1
Adult one meal per month of benthic fish		19	20	28
Adult one meal per month of pelagic fish (rockfish)		< 1	< 1	< 1
Adult one meal per month of pelagic fish (shiner surf perch)		< 1	< 1	< 1
Adult one meal per month of crabs		145	346	> 470
Adult one meal per month of clams		> 470	443	> 470
Adult tribal CT (Tulalip data)	1×10^{-6}	< 1	< 1	< 1
Child tribal CT (Tulalip data)		< 1	< 1	< 1
Adult API CT		< 1	< 1	< 1
Adult tribal (Suquamish data)		< 1	< 1	< 1
Adult one meal per month of benthic fish		< 1	< 1	< 1
Adult one meal per month of pelagic fish (rockfish)		< 1	< 1	< 1
Adult one meal per month of pelagic fish (shiner surf perch)		< 1	< 1	< 1
Adult one meal per month of crabs		< 1	< 1	< 1
Adult one meal per month of clams		< 1	< 1	< 1

[a] Values presented as < 1 µg/kg dw, a sediment RBTC could not be calculated; even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, FWM-estimated total PCB concentrations in tissue would be greater than the tissue RBTC for the applicable risk level because of the contribution of PCBs from water alone.

[b] Upper and lower bounds were calculated using extremes of parameter set values that still met the FWM performance criterion (i.e., empirical data were within a factor of 2 of FWM-estimated concentrations for all species except clams) (see Appendix C, Section C.2.6). Note that the sediment lower and upper bounds for multi-species diets were all generated using the same upper and lower bound FWM parameter sets. However, for the adult one meal per month scenarios, the FWM parameter sets yielding the maximum and minimum concentrations for each species within the SPAF bounds (SPAF ≤ 2 for all species except clam; SPAF ≤ 3 for clams) were selected for bounding purposes. Hence, sediment lower and upper bounds for the adult one meal per month scenarios each generated different FWM parameter sets.

[c] Values presented as > 470 µg/kg dw indicate that even under current conditions in the EW, excess cancer risks are estimated to be less than the target risk level. (i.e., the current mean sediment SWAC of 470 µg/kg dw corresponds to a cancer risk less than the specified risk level, so an RBTC for that risk level would be above the current mean SWAC).

API – Asian and Pacific Islander
CT – central tendency
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

dw – dry weight
FWM – food web model
HHRA – human health risk assessment
SPAF – species predictive accuracy factor
SWAC – spatially weighted average concentration

At the 1×10^{-4} target risk level, the sediment RBTCs were 2 and 250 µg/kg dw for the adult and child tribal RME scenarios, respectively.[114] The lower and upper bound values ranged from < 1 to 8 µg/kg dw for the adult tribal RME scenario and from 210 to 323 µg/kg dw for the child tribal RME scenario (Table 8-8). Sediment RBTCs for the non-RME scenarios ranged from < 1 µg/kg dw for the adult tribal scenario based on Suquamish data to > 470 µg/kg dw for a number of scenarios at the 1×10^{-4} target risk level (Table 8-9). A SWAC of 470 µg/kg dw represents current conditions in the EW; a sediment RBTC of > 470 µg/kg dw indicates that even under current conditions in the EW,[115] excess cancer risks are estimated to be less than the target risk level. Sediment RBTCs for total PCBs corresponding to non-cancer hazards for RME scenarios with a target HQ of 1 were also estimated; all RBTCs were < 1 µg/kg dw (Table 8-10). RBTCs for the non-RME scenarios ranged from < 1 to > 470 µg/kg dw (Table 8-11).

Table 8-10
Total PCBs Sediment RBTCs for HHRA RME Seafood Consumption Scenarios Based on Non-Cancer Hazard Quotient of 1

Scenario	Lower-Bound Concentration (µg/kg dw)[a, b]	Sediment RBTC (µg/kg dw)[a]	Upper-Bound Concentration (µg/kg dw)[a, b]
Adult tribal RME (Tulalip data)	< 1	< 1	< 1
Child tribal RME (Tulalip data)	< 1	< 1	< 1
Adult API RME	< 1	< 1	< 1

[114] It should be noted that although the ratio of the adult-to-child excess cancer risks and tissue RBTCs is equal to approximately 5.4, the ratio of adult-to-child sediment RBTCs is quite different (equal to approximately 125). This change in the ratio occurs because of the use of the FWM, in each modeled species changes at a different rate as a result of changes in sediment concentrations. If the conversion from tissue to sediment was done using a simple multiplier, the ratio for the sediment RBTCs would be the same (i.e., equal to 5.4). Instead, the use of the more complex and realistic FWM introduces more variability in this ratio because variability among the various modeled species.

[115] A sediment SWAC of 470 µg/kg dw was used in the FWM because it reflected the most current sediment interpolation at the time of model calibration.

[a] Values were presented as < 1 µg/kg dw because they could not be calculated; even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, FWM-estimated total PCB concentrations in tissue would be greater than the tissue RBTC for the applicable risk level because of the contribution of PCBs from water alone to tissue PCB levels.

[b] Upper and lower bounds were calculated using estimates from parameter sets that met the FWM performance criterion (i.e., empirical data were within a factor of 2 of FWM-estimated concentrations for all species) (see Appendix C).

API – Asian and Pacific Islander
dw – dry weight
FWM – food web model
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure

Table 8-11

Total PCBs Sediment RBTCs for HHRA non-RME Seafood Consumption Scenarios Based on Non-Cancer Hazard Quotient of 1

Scenario	Lower-Bound Concentration (µg/kg dw)[a, b, c]	Sediment RBTC (µg/kg dw)[a, b]	Upper-Bound Concentration (µg/kg dw)[a, b, c]
Adult tribal CT (Tulalip data)	80	100	100
Child tribal CT (Tulalip data)	4	13	23
Adult API CT	157	194	250
Adult tribal (Suquamish data)	< 1	< 1	< 1
Adult one meal per month of benthic fish	52	56	76
Adult one meal per month of pelagic fish (rockfish)	< 1	< 1	< 1
Adult one meal per month of pelagic fish (shiner surf perch)	14	15	36
Adult one meal per month of crabs	284	> 470	> 470
Adult one meal per month of clams	> 470	> 470	> 470

[a] Values presented as < 1 µg/kg dw, a sediment RBTC could not be calculated; even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, FWM-estimated total PCB concentrations in tissue would be greater than the tissue RBTC for the applicable risk level because of the contribution of PCBs from water alone to tissue PCB levels.

[b] Values presented as > 470 µg/kg dw indicate that even under current conditions in the EW, excess cancer risks are estimated to be less than the target risk level.

[c] Upper and lower bounds were calculated using estimates from parameter sets that met the FWM performance criterion (i.e., empirical data were within a factor of 2 of FWM-estimated concentrations for all species except clams) (see Appendix C, Section C.4). Note that the sediment lower and upper bounds for multi-species diets were all generated using the same upper and lower bound FWM parameter sets. However, for the adult one meal per month scenarios, the FWM parameter sets yielding the maximum and minimum concentrations for each species within the SPAF bounds (SPAF ≤ 2 for all species except clam; SPAF ≤ 3 for clams) were selected for bounding purposes. Hence, sediment lower and upper bounds for the adult one meal per month scenarios each generated different FWM parameter sets.

API – Asian and Pacific Islander
CT – central tendency
dw – dry weight
FWM – food web model
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
SPAF – species predictive accuracy factor

For RBTCs presented as < 1 µg/kg dw, a sediment RBTC could not be calculated; even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, FWM-estimated total PCB concentrations in tissue would be greater than the tissue RBTC for the applicable risk level because of the contribution of PCBs from water alone to the tissue PCB levels. This issue arises even at total PCB concentrations in water equal to the mean concentration (0.0003 µg/L) in the Green River, upstream of the both the EW and the LDW. Further explanation of the importance of water contribution to FWM predicted tissue concentrations is provided in Appendix C, Section C.2.6.

8.3.2 Dioxin and Furan Sediment RBTCs for Human Seafood Consumption

For dioxins and furans, site-specific BSAFs were calculated in order to derive sediment RBTCs. The primary reason a FWM was not used to derive sediment RBTCs for dioxin and furans was because there are no dioxin and furan data for water or benthic invertebrate tissues available (a site specific parameter), and some FWM parameters were expected to be difficult to estimate (e.g., uptake and elimination rates for dioxin and furan congeners). Finally, the application of the FWM model to a toxicity equivalent mixture of compounds such as the dioxin and furan TEQ is complicated, and would have required certain input parameters that are not readily available (such as an octanol-water partition coefficient [K_{OW}] value weighted to account for differences in toxicity of the various dioxin and furan congeners).

Another alternative method to estimate relationships between tissue and sediment that was evaluated for dioxins and furans is regression modeling. However, appropriate datasets were not available for this approach. For example, for English sole, perch and crab, tissue data were available for three supercomposites for the entire waterway resulting in an insufficient number of data points for developing regression relationships. Although clams and rockfish tissue dioxin and furan data were location-specific, there were no corresponding sediment data for the clams and dioxins/furans were largely not detected in clams and therefore no regression relationship could be evaluated. For rockfish, exploratory regression analysis indicated no regression relationship with the sediment data for the rockfish.

Dioxin and furan sediment RBTCs were developed using site-specific BSAFs, which were based on empirical data collected from the EW. BSAF values were calculated for a subset of four individual dioxin and furan congeners that were selected because they were the

congeners that had the greatest contributions to the dioxin/furan TEQ values in tissues. A detailed discussion of the BSAF calculations for these congeners and their application to deriving sediment RBTCs is provided in Appendix C.

Because BSAFs are specific to individual receptor species and are a function of their trophic level, sediment RBTCs were calculated for four seafood categories, brown rockfish (whole body), crab (whole body), English sole (whole body) and shiner surfperch (whole body). The area-wide dioxin and furan sediment SWAC was used in the calculation of BSAFs for all of these species. The tissue samples analyzed for dioxins and furans for crab, English sole and shiner surfperch were all composited on an area-wide basis. The brown rockfish were analyzed as individual fish however, there were no corresponding sediment samples analyzed for dioxin and furan The relationship between brown rockfish tissue concentrations and the dioxin and furan concentrations in the proximate subtidal composite sediment sample was investigated, and no significant relationship could be established. In addition, brown rockfish prey are likely to move over an area larger than the area represented by the subtidal composite areas. Therefore, the brown rockfish BSAFs were calculated using the area-wide SWAC dioxin/furan TEQ concentration. Although location-specific tissue data are available for clams, corresponding sediment data are not available and application of available site-wide sediment data would not be appropriate for clams; hence, clam BSAFs were not calculated. In addition, dioxins/furans had a low frequency of detection in clam tissues.

The starting point for calculating dioxin and furan sediment RBTCs for the adult and child tribal and adult API RME scenarios was the tissue RBTCs presented in Section 8.2. These tissue RBTCs represent the ingestion-weighted average concentrations in tissues that correspond to a certain risk level for each scenario. In order to calculate sediment RBTCs using the dioxin/furan BSAFs, it was necessary to calculate species-specific tissue RBTCs. The main assumptions required for these calculations were:

- The relative ingestion rates for the various items in the market basket diet (i.e., the percentages of various seafood types that people eat)
- The relative tissue contaminant concentrations among the food items

Because both of these factors may change in the future, it is important to recognize that there is considerable uncertainty associated with the dioxin/furan sediment RBTCs based on these species-specific tissue RBTCs. Additional details regarding the calculation of these species-specific tissue RBTCs are presented in Appendix C.

Once the species-specific tissue RBTCs were calculated, dioxin/furan TEQ sediment RBTCs were calculated for the four congeners, dioxin/furan TEQ sediment RBTCs were calculated for the species for which BSAFs were available (i.e., brown rockfish, whole body English sole, whole body crab, and whole body shiner surfperch). The sediment RBTC value was calculated using the mean BSAF for each species. It should be noted that the benthic fish fillet tissue RBTCs were converted to a whole body tissue RBTCs using a fillet-to-whole-body conversion factor. Details on the calculation of sediment congener RBTCs from the BSAFs, and conversion to dioxin/furan TEQ sediment RBTCs are provided in Appendix C. The dioxin/furan TEQ sediment RBTCs were similar across the four species for each of the RME scenario-risk level combinations, with the lowest sediment RBTCs calculated for the adult tribal RME scenario based on Tulalip data and the highest sediment RBTCs calculated for the child tribal RME based on Tulalip data (Table 8-12).

Table 8-12
Sediment RBTCs for Dioxins and Furans based on Excess Cancer Risks in HHRA RME Seafood Consumption Scenarios

Scenario	Risk Level	Sediment RBTC (ng TEQ/kg dw)				
		Mean	Brown Rockfish	Crab	English Sole	Shiner Surfperch
Adult tribal RME (Tulalip data)	1×10^{-4}	18	18	18	17[a]	17
Child tribal RME (Tulalip data)		94	96	97	89[a]	94
Adult API RME		48	49	50	46	48
Adult tribal RME (Tulalip data)	1×10^{-5}	1.8	1.8	1.8	1.7[a]	1.7
Child tribal RME (Tulalip data)		9.4	9.6	9.7	8.9[a]	9.4
Adult API RME		4.8	4.9	5.0	4.6	4.8
Adult tribal RME (Tulalip data)	1×10^{-6}	0.18	0.18	0.18	0.17[a]	0.17
Child tribal RME (Tulalip data)		0.94	0.96	0.97	0.89[a]	0.94
Adult API RME		0.48	0.49	0.50	0.46	0.48
Child tribal RME (Tulalip data)[b]	HQ = 1	8.2	8.4	8.0	8.0	8.4

[a] The benthic fish fillet concentration was converted to a whole body concentration using the ratio of the dioxin and furan TEQ concentrations in English sole fillet and whole body samples in order to use a whole body concentration in the BSAF calculations.

[b] Child tribal RME (Tulalip data) was the only RME with an HQ > 1 for dioxin and furan TEQ.

API – Asian and Pacific Islander
dw – dry weight
HHRA – human health risk assessment
HQ – hazard quotient
na – not applicable (HQs did not exceed 1)
RME – reasonable maximum exposure
TEQ – toxic equivalent

At the 1×10^{-6} target risk level, all the sediment RBTCs for the RME scenarios were less than 1 ng TEQ/kg dw. At the 1×10^{-4} target risk level, sediment RBTCs for dioxin/furan TEQ ranged from 17 to 18 ng TEQ/kg dw for the adult tribal RME scenario and ranged from 89 to 97 ng TEQ/kg dw for the child tribal RME scenario (Table 8-12). Sediment RBTCs for the adult API RME ranged from 46 to 50 ng TEQ/kg dw at the 1×10^{-4} target risk level.

8.3.3 cPAH Sediment RBTCs for Human Seafood Consumption

As discussed in the HHRA (Appendix B), the majority of cPAH exposure, and hence, the majority of cPAH risk associated with seafood consumption is from the consumption of clams. The following provides additional detail regarding the breakdown of the cPAH TEQ risk for the RME scenarios evaluated in the HHRA (Appendix B):

- **Adult and child tribal RME scenarios based on Tulalip data** – The cPAH TEQ excess cancer risk was equal to 1×10^{-4} for both of these scenarios, with 90.0% of that risk attributable to the consumption of clams. The clam excess cancer risk was equal to 9×10^{-5} for both the adult and child scenarios.
- **Adult API RME scenario –** The cPAH TEQ excess cancer risk was equal to 5×10^{-5} for this scenario, with 73.1% of that risk attributable to the consumption of clams (clam excess cancer risk of 4×10^{-5}). The remaining portion of the cPAH TEQ risk was mostly attributable to the consumption of mussels (25.3% of the total risk; excess cancer risk of 1×10^{-5}).

Because of the importance of clam consumption in the cPAH TEQ risk estimate, the clam tissue/sediment relationship was evaluated to assess the potential for calculating sediment RBTCs for cPAHs associated with consumption of clams in the EW using site-specific data. Because mussels live in the water column, no paired sediment-tissue data were collected for mussels, and thus a sediment RBTC based on the consumption of mussels could not be developed.

Regression models were investigated in an attempt to relate site-specific concentrations of cPAHs in composite clam tissue samples and co-located sediment samples. Linear regressions were not improved using log-transformed sediment and/or tissue concentrations so the linear regressions are presented. The first regression was conducted with all of the clam species collected in EW which consisted of butter clams, cockles, littleneck clams, and softshell clams results are presented in Table 8-13 and Figure 8-1. The relationship was not significant with an r^2 value of only 0.12 and p-value of 0.26. A second analysis was based on butter clam tissues alone, for which the greatest number of samples from EW were available (n = 7); results are provided in Table 8-13 and Figure 8-2. This relationship was also not significant with an r^2 of 0.01 and p-value of 0.82. The PAH compound that contributed the majority of the cPAH TEQ value in both sediment and clam tissues was benzo(a)pyrene. Benzo(a)pyrene consistently contributed 60 to 70% of the TEQ in both clam tissue and sediment. Therefore, the regression relationships for benzo(a)pyrene were investigated and found to be similar to those observed for the cPAH TEQ. Finally, the relationship between clam tissue cPAH concentrations and the sediment cPAH concentrations measured in the intertidal area composites was investigated, and the relationships were not significant (Table 8-13).

Table 8-13
Results of cPAH Regression Analyses

Tissue Dataset	Sediment Dataset	n	Regression Equation	r^2 Value	Significance of Regression
All species	co-located grab samples	11	tissue = (0.02 x sediment) + 4.48	0.12	p = 0.29
Butter clam	co-located grab samples	7	tissue = (0.001 x sediment) + 13.39	0.01	p = 0.82
All species	co-located grab samples	11	Log(tissue) = 0.63 x log(sediment) -0.68	0.34	p = 0.06
Butter clam	co-located grab samples	7	Log(tissue) = 0.30 x log(sediment) + 0.14	0.05	p = 0.63
All species	intertidal area composites	11	tissue = (0.001 x sediment) + 10.6	0.045	p = 0.53
Butter clam	intertidal area composites	7	tissue = (0.005 x sediment) + 15.4	0.08	p = 0.54

cPAH – carcinogenic polycyclic aromatic hydrocarbon
n – number of data pairs

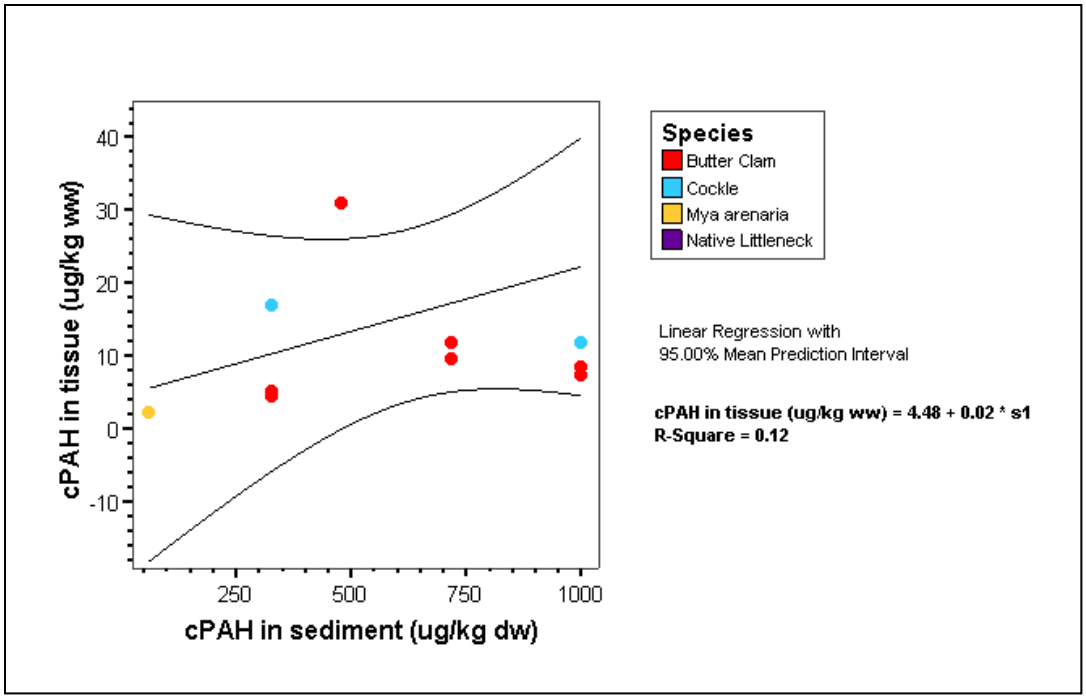


Figure 8-1

Linear Regression of cPAH Concentrations in EW Clam Tissue Relative to Concentrations in Co-Located Sediment

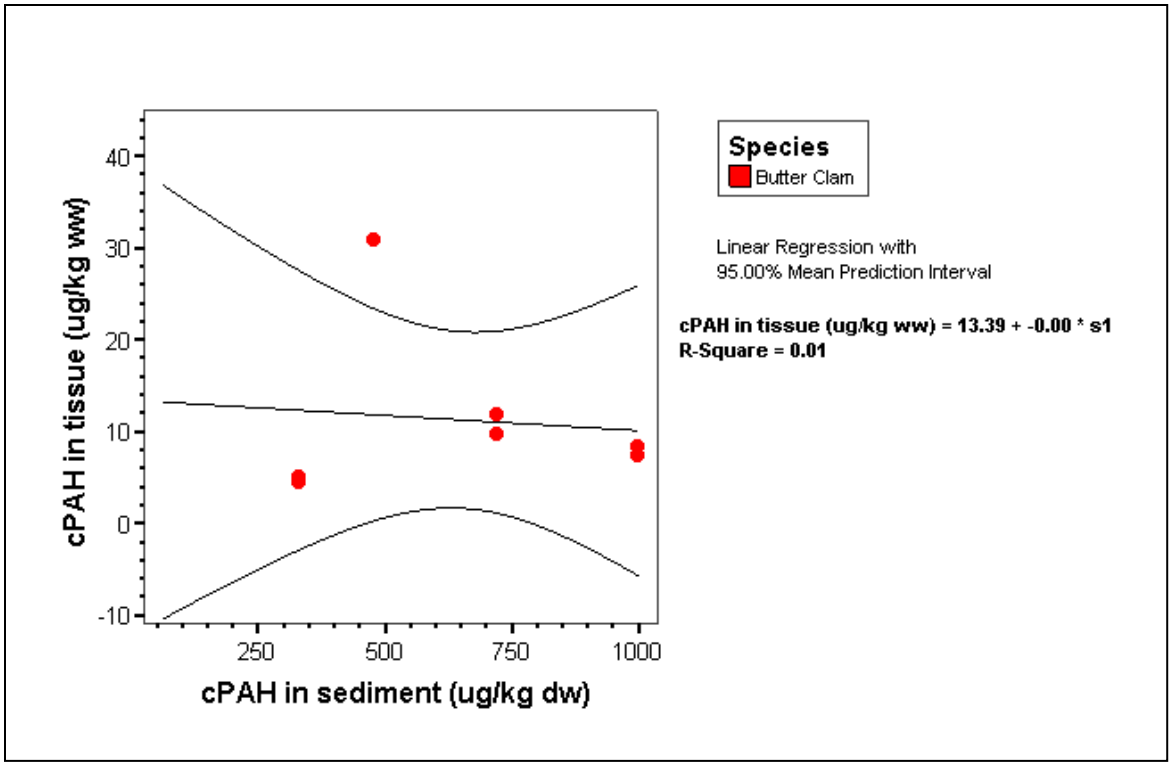


Figure 8-2
Linear Regression of cPAH Concentrations in EW Butter Clam Tissue Relative to Concentrations in Co-Located Sediment

A number of uncertainties make the regression model unsuitable for the purpose of remedial decision-making, including:

- The relationships between tissue and sediment were not statistically significant for cPAHs for all clams or for butter clams alone
- A low percent of the variance explained by the regression
- Confidence intervals are broad

Based on the information discussed above, the clam tissue-to-sediment relationship for cPAHs in the EW is too uncertain to develop a RBTC for sediment based on clam consumption. The predominant clam species collected in the EW was butter clam (*Saxidomus gigantean*), which is a filter-feeding clam. For filter-feeding clams, water and suspended particulates in the water are likely to be important sources of bioaccumulated chemicals (Abraham and Dillon 1986). Foster et al. (1987) did not report the uptake of PAHs

by the filter-feeding clam *M. arenaria* in their study, during which the clams "appeared to remain isolated from exposure to contaminated sediment." Therefore, any potential effect of sediment remediation on concentrations of cPAHs in clam tissue for filter-feeding species such as butter clam, is highly uncertain. Long-term clam tissue monitoring following sediment remediation and source control may be needed to determine whether decreases in cPAH concentrations in sediment in the future affect cPAH concentrations in clam tissue and, if so, to what extent.

8.4 Sediment RBTCs for Fish as Ecological Receptors

PCBs were identified as a risk driver COC for English sole and brown rockfish in the ERA (Appendix A). This section presents the derivation of both tissue and sediment RBTCs for these receptors. Both types of RBTCs were calculated because although remediation goals will be sediment-based, tissue RBTCs are relevant for risk communication and monitoring. Similar to the sediment RBTCs for total PCBs based on human health seafood consumption, sediment RBTCs for fish as ecological receptors were developed using the FWM.

8.4.1 Tissue RBTCs for English Sole and Brown Rockfish

Two tissue TRVs from the same study (Hugla and Thome 1999) for total PCBs were used to evaluate risk to English sole and brown rockfish. The lower and higher exposure levels were associated with whole-body concentrations of 520 and 2,640 µg/kg ww, respectively. During the first reproductive season, no spawning was reported at the high exposure level, and no adverse effects were reported for the lower exposure level. One year following exposure, significant reductions in fecundity (when compared to control fish) were reported at both exposure levels. Egg mortality in the high-level dietary exposure group was close to 100% and was significantly higher than the control (which had a mean egg mortality of 52.4%), and egg and larval mortality significantly increased as PCB concentrations in eggs increased. At the lower dose, egg mortality was not significantly different from controls. Because of the uncertainties in this study (as discussed in Appendix A, Section A.4.2.1.3 and A.6.2.2.2) two tissue RBTCs are considered for fish receptors with the lower RBTC having greater uncertainty. The fish tissue RBTCs for total PCBs are 520 and 2,640 µg/kg ww.

8.4.2 Sediment RBTCs for Fish as Ecological Receptors

Sediment RBTCs for total PCBs for English sole and brown rockfish were derived using the FWM as described in Section 8.3.1. Information regarding the FWM design, specific input parameters, calibration, and performance of the FWM is presented in Appendix C (Section C.2), which describes how the FWM was used to derive sediment RBTCs. The sediment RBTCs for fish were derived using the calibrated FWM based on the "best fit" parameter set. The "best fit" set of parameter values yielded predicted tissue concentrations closest to empirical data for all tissue types modeled; the same parameter set was used for all sediment RBTC calculations (human health and fish). The sediment upper and lower bounds for the total PCBs RBTCs were estimated using upper and lower bound parameter sets (i.e., separate parameter sets for rockfish and for English sole) in the FWM. The RBTC range represents the range of estimates generated by the FWM while still meeting the FWM performance criterion, which required that the estimated concentrations in tissues be within a factor of 2 of the empirical data for all of the target species.[116] A full discussion of the sources of uncertainty in the FWM is presented in Appendix C, Section C.2.

The sediment RBTCs for English sole and brown rockfish are provided in Table 8-14. The sediment RBTC values associated with the tissue RBTC of 520 µg/kg ww for English sole and brown rockfish were 100 and 39 µg/kg dw total PCBs, respectively. The lower and upper bounds ranged from 21-123 µg/kg dw sediment. The sediment RBTCs calculated for the tissue RBTC of 2,640 µg/kg ww were > 470 µg/kg dw for English sole and 458 µg/kg dw for rockfish. Sediment RBTCs of > 470 µg/kg dw indicate that even under current conditions in the EW,[117] average tissue concentrations are estimated to be less than the tissue RBTC. This is consistent with the fact average tissue concentrations in both species are less than the RBTC of 2,640 µg/kg ww. Only 4 out of the 15 individual rockfish samples and 7 out of 13 English sole whole-body composite tissue samples exceeded the tissue RBTC of 2,640 µg/kg ww.

[116] For all species except clams, for which estimated concentrations in tissues were required to be within a factor of 3 of the empirical data to be considered acceptable. FWM predictions within a factor of 3 to 5 are considered good.

[117] A sediment SWAC of 470 µg/kg dw was used in the FWM because it reflected the most current sediment interpolation at the time of model calibration.

Table 8-14

Total PCB Sediment RBTCs for Fish

Fish	Tissue RBTC= 520 µg/kg ww			Tissue RBTC= 2,640 µg/kg ww		
	Lower Bound (µg/kg dw)[a]	Sediment RBTC (µg/kg dw)	Upper Bound (µg/kg dw)[a,]	Lower Bound (µg/kg dw)[a]	Sediment RBTC (µg/kg dw)	Upper Bound (µg/kg dw)[a]
English sole	97	100	123	> 470	> 470	> 470
Rockfish	21	39	100	288	458	> 470

[a] Upper and lower bounds were calculated using estimates from parameter sets that met the FWM performance criterion (i.e., empirical data were within a factor of 2 of FWM-estimated concentrations for all species except clams) (see Appendix C, Section C.4).

dw – dry weight
FWM – food web model
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
ww – wet weight

8.5 RBTCs Based on Benthic Invertebrate Exposure

As described in the sections that follow, RBTCs were derived for benthic invertebrates for TBT based on tissue residue evaluation and for 28 risk driver COCs based on SMS.

8.5.1 TBT Tissue and Sediment RBTCs for Benthic Invertebrates

TBT was identified as a risk driver for benthic invertebrates in the EW ERA. The tissue RBTC for benthic invertebrates was equal to the TBT tissue TRV used in the ERA: 120 µg/kg ww. This tissue TRV was based on the sterilization of female gastropods due to imposex after chronic exposure to TBT in water (Gibbs et al. 1988). In order to develop a sediment TBT RBTC for benthic invertebrates, the relationship between benthic invertebrate tissue TBT concentrations and the TBT concentrations in co-located sediment samples was investigated in order to develop a sediment RBTC. The development of the sediment RBTC for TBT is summarized here and presented in detail in Appendix C.

Two EW datasets were considered in developing a sediment RBTC based on the tissue TRV. The first dataset was based on field-collected tissue samples. TBT concentrations were measured in 12 composite samples of benthic invertebrates collected throughout the EW (Map 4-2) as part of the SRI. The second dataset was based on tissue and sediment samples that were analyzed as part of laboratory bioaccumulation testing conducted using two different EW sediment samples and two test organisms. The two test organisms were the marine polychaetes *Nephtys caecoides* and *Armandia brevis* (Windward 2003*).*

The first step in developing an RBTC for TBT was to evaluate the relationships in the SRI data through regression analysis. The initial regression relationship based on the SRI EW composite benthic invertebrate tissue and co-located sediment data is shown in Figure 8-3. The regression relationship had an r^2 of 0.3 and p value of 0.07. This regression relationship was not useful for determining an RBTC value because of the lack of significance in the regression.

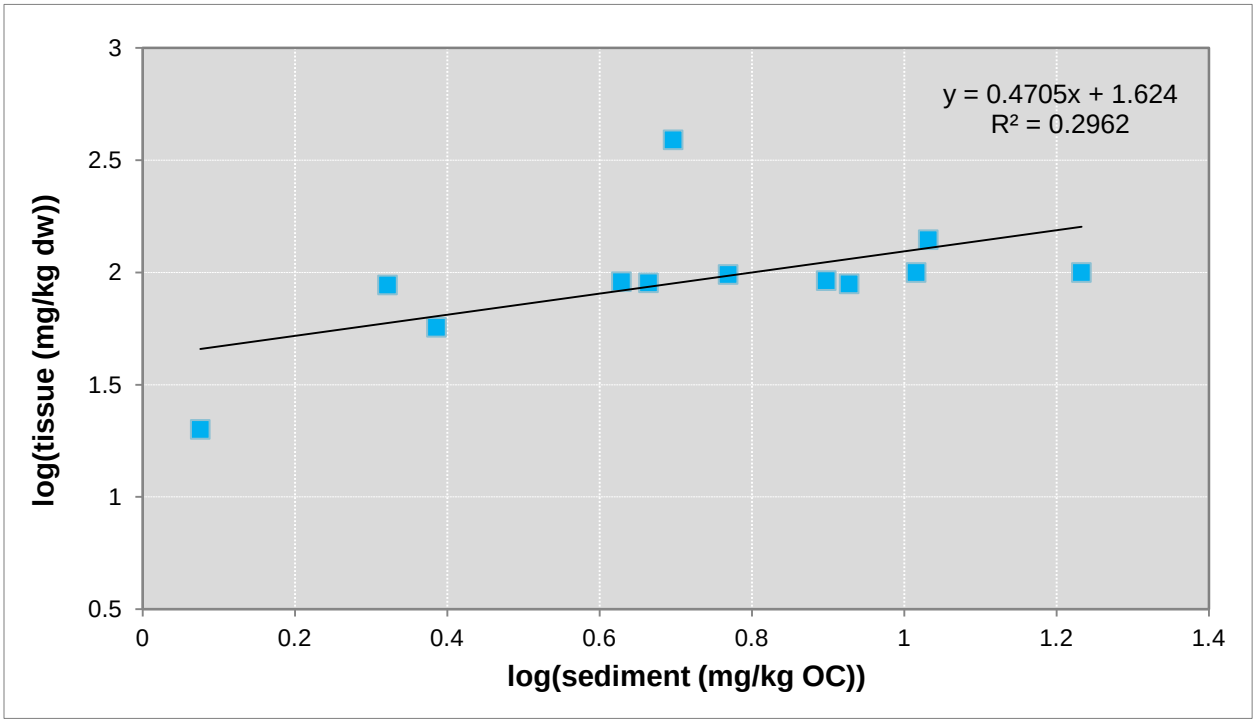


Figure 8-3
Regression Relationship between Concentrations TBT Tissue and Sediment TBT

Rather than using the regression relationship in Figure 8-3, the TBT RBTC was developed based on a bioaccumulation factor (BAF) approach consistent with the approach used by Meador et al. (2002). The BAF approach was used with both datasets (i.e., the SRI data and the bioaccumulation test data). A BAF value was calculated for each tissue and sediment sample based on the dry-weight tissue concentration and the organic carbon-normalized sediment concentration (Equation 8-4). The BAF values calculated for each sample are shown in Figure 8-4. It is important to note that there is considerable uncertainty associated with the calculation of the BAF values due to the lack of correlation between the tissue and sediment concentrations for both the SRI and the bioaccumulation test datasets.

$$BAF = \frac{\text{dry weight tissue TBT concentration}}{\text{OC} - \text{normalized sediment concentration}} \quad (8\text{-}4)$$

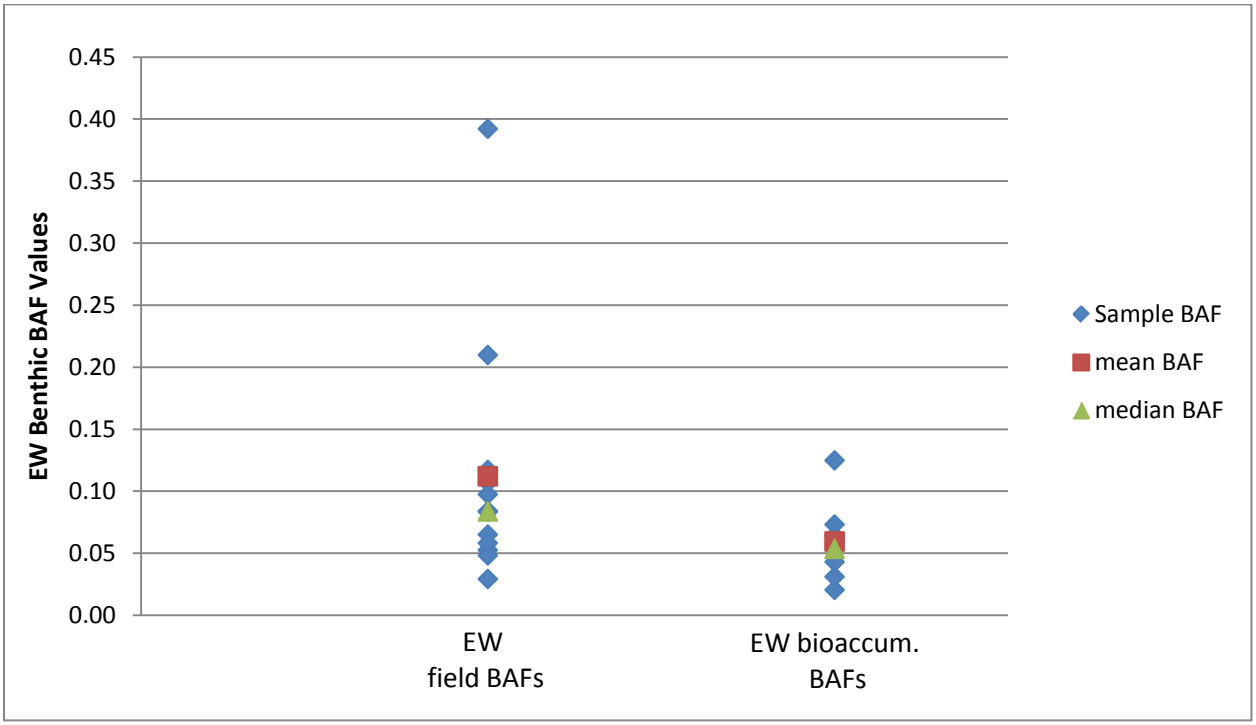


Figure 8-4
Distribution of EW BAF Values for TBT

Using Equation 8-5 to develop sediment TBT RBTC values, the mean and median TBT BAF values were used to estimate sediment concentrations that correspond to the TBT tissue TRV used in the ERA. RBTCs were calculated separately for the SRI dataset and the bioaccumulation test dataset for both test species and the *Armandia* dataset alone.

$$\text{Sediment RBTC}(\text{mg/kgOC}) = \frac{\text{dry weight tissue TBT TRV}}{\text{BAF}} \quad (8\text{-}5)$$

The ranges of estimated sediment RBTC values are presented in Table 8-15.

Table 8-15
Estimated TBT Sediment RBTCs for Benthic Invertebrates

Dataset	Count	BAF Type	BAF	Tissue TRV (mg/kg dw)	Sediment RBTC (mg/kg OC)
EW benthic invertebrate tissue	12	mean TBT BAF	0.11	0.60	5.5
		median TBT BAF	0.08	0.60	7.5
EW bioaccumulation (*Neanthes* and *Armandia*)	6	mean TBT BAF	0.06	0.60	10
		median TBT BAF	0.05	0.60	12
EW bioaccumulation (*Armandia* only)	4	mean TBT BAF	0.08	0.60	7.5
		median TBT BAF	0.07	0.60	8.5

BAF – bioaccumulation factor
dw – dry weight
EW – East Waterway
OC – organic carbon
RBTC – risk-based threshold concentration
TBT – tributyltin
TRV – toxicity reference value

The sediment RBTCs range from of 5.5 to 12 mg/kg OC and represent concentrations in sediment ranging from 88.0 and 192 µg/kg TBT dw at a TOC concentration of 1.6% dw, which is the site-wide mean TOC concentration for EW surface sediment.

The sediment RBTC for TBT based on the median BAF value for the field-collected benthic invertebrate dataset is 7.5 mg/kg OC. This value was selected because the field dataset is the largest dataset and represents the benthic organisms present in the EW and the range of sediment TBT concentrations present throughout the waterway. The median BAF (0.08) represents the best estimate of the central tendency of the dataset. This value is consistent with the results of the bioaccumulation tests for EW sediment that were conducted with an organism that has been demonstrated to effectively accumulate TBT (i.e., *Armandia brevis*).

8.5.2 Other Risk Driver COCs for benthic invertebrates

In the ERA, 29[118] COCs were identified as risk drivers for the benthic invertebrate community because they had at least one detected exceedance of the SQS in surface sediment. Because SMS are applicable promulgated standards at the site, sediment RBTCs for these 29 COCs were set equal to the SQS and the CSL numerical chemical criteria

[118] The ERA identified 28 COCs based on SMS. However, one additional chemical, anthracene should have been identified as a COC.

(Table 8-16). Toxicity test data for locations with SMS exceedances must also be considered in the application of these RBTCs because toxicity test information overrides chemistry data as part of the SMS. Toxicity test data are presented in Section 4.2.1, and the interpretation of SMS exceedances and site-specific toxicity data are discussed in the ERA (Appendix A). According to the SMS (WAC 173-204-310), locations with all chemical concentrations less than or equal to the SQS are defined as having no acute or chronic adverse effects on biological resources. Locations with any chemical concentrations between the SQS and CSL are defined as having a potential for minor adverse effects. Locations with any chemical concentration greater than the CSL are defined as having higher likelihood for adverse effects, pending confirmatory designation via biological testing (WAC 173-204-310-2).

Table 8-16
SMS Chemical Criteria for Risk Driver Chemicals Identified for the Benthic Invertebrate Community

Chemical	Unit	SQS	CSL
Metals			
Arsenic	mg/kg dw	57	93
Cadmium	mg/kg dw	5.1	6.7
Mercury	mg/kg dw	0.41	0.59
Zinc	mg/kg dw	410	960
PAHs			
2-Methylnaphthalene	mg/kg OC	38	64
Acenaphthene	mg/kg OC	16	57
Anthracene	mg/kg OC	220	1,200
Benzo(a)anthracene	mg/kg OC	110	270
Benzo(a)pyrene	mg/kg OC	99	210
Benzo(g,h,i)perylene	mg/kg OC	31	78
Total benzofluoranthenes	mg/kg OC	230	450
Chrysene	mg/kg OC	110	460
Dibenzo(a,h)anthracene	mg/kg OC	12	33
Dibenzofuran	mg/kg OC	15	58
Fluoranthene	mg/kg OC	160	1,200
Fluorene	mg/kg OC	23	79
Indeno(1,2,3-cd)pyrene	mg/kg OC	34	88
Phenanthrene	mg/kg OC	100	480
Pyrene	mg/kg OC	1,000	1,400

Chemical	Unit	SQS	CSL
Total HPAH	mg/kg OC	960	5,300
Total LPAH	mg/kg OC	370	780
Phthalates			
BEHP	mg/kg OC	47	78
BBP	mg/kg OC	4.9	64
Di- n-butyl phthalate	mg/kg OC	220	1700
Other SVOCs			
1,4-Dichlorobenzene	mg/kg OC	3.1	9.0
2,4-Dimethylphenol	µg/kg dw	29	29
n-Nitrosodiphenylamine	mg/kg OC	11	11
Phenol	µg/kg dw	420	1,200
PCBs			
Total PCBs	mg/kg OC	12	65

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
CSL – cleanup screening level
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
OC –organic carbon
PCB – polychlorinated biphenyl
SMS – Washington State Sediment Management Standards
SQS – sediment quality standards
SVOC – semivolatile organic compound

8.6 Application of RBTCs

The RBTCs derived in this section are an important consideration in the derivation of PRGs in the FS. Three issues related to application of RBTCs are discussed here: spatial considerations (Section 8.6.1) and consideration of total and aggregate risk (Section 8.6.2).

8.6.1 Spatial Considerations

Appropriate application of RBTCs requires explicit consideration of spatial scale. Some RBTCs are appropriate for application on a point-by-point basis, while most others should be applied only at a larger scale. For example, RBTCs based on the protection of benthic invertebrates (sediment RBTC for TBT and the SMS criteria) should be applied on a point-by-point basis because of the small home ranges of these animals and the regulatory framework described in the SMS. All other RBTCs (Sections 8.1 through 8.4) are most appropriately applied at larger spatial scales. RBTCs for human health seafood consumption scenarios should be applied on a EW-wide spatial scale. This is because risks were evaluated at this scale and because most seafood species of fish and crab can forage over the entire site.

For fish, as ecological receptors, the RBTCs would be applied on a site-wide basis for protection of the fish population because either the fish (e.g., English sole) or their prey (e.g., shrimp or smaller fish consumed as prey by rockfish) can forage or move throughout the site.

RBTCs derived for direct sediment contact scenarios for human health should be applied to appropriate exposure areas. The exposure area for the netfishing RME scenario included all of the intertidal and subtidal areas of the EW. The exposure area for the RME clamming scenario included all intertidal areas where clams could occur because such areas are potentially accessible either from a boat or from shore.

8.6.2 Consideration of Total and Aggregate Excess Cancer Risk

Following EPA guidance for conducting HHRAs, total excess cancer risk estimates were calculated in the EW HHRA by summing risk estimates for individual COCs. Total excess cancer risk should also be given consideration during the application of RBTCs in the FS. In practice, total carcinogenic risk can be considered in the application of RBTCs by summing the risks for individual contaminants within a given exposure area to ensure that they do not result in an unacceptable total target risk. For example, if the target excess cancer risks for four individual risk drivers COCs were all set to 1×10^{-6} in the calculation of each of the four individual RBTCs, the total risk for these four COCs at their RBTCs would be no greater than 4×10^{-6}. In this example, if the acceptable target total risk was 1×10^{-5}, then meeting each individual RBTC for the four COCs with an individual target risk of 1×10^{-6} would result in an acceptable total risk estimate for that area at 4×10^{-6} (i.e., less than the target total risk level of 1×10^{-5}). Total risk for non-cancer hazards can only be evaluated if the contaminants affect the same target organs or have the same endpoint effects.

8.7 Summary

RBTCs for risk driver COCs in sediment were derived for consideration in the development of PRGs in the FS; sediment RBTCs for the EW are summarized in Table 8-17. Sediment RBTCs were derived for human health RME direct sediment contact scenarios for arsenic and cPAHs and for human health RME seafood consumption scenarios for total PCBs and dioxins/furans (Table 8-18). Tissue RBTCs (Table 8-18) were also derived for these risk drivers for risk communication purposes. Sediment RBTCs based on the seafood consumption scenarios were estimated for total PCBs using the FWM. Regression models for relating concentrations of cPAHs in clams to concentrations in co-located sediment were evaluated

and found to be unsuitable for developing RBTCs. For dioxins and furans, congener-specific BSAFs that relate tissue to sediment concentrations were calculated for four tissue types that were then used to develop a sediment RBTC for dioxins and furan TEQs (Table 8-17). RBTCs were also estimated for total PCBs in both tissue and sediment for fish as ecological receptors (Table 8-19). A BAF approach was used to develop a sediment RBTC for TBT for benthic invertebrates (Table 8-19), while sediment RBTCs for other risk driver COCs for benthic invertebrates were set equal to SMS criteria.

Table 8-17

Summary of Sediment RBTCs for Human Health Risk Driver COCs

Scenario	Risk Driver	Unit	RBTCs at Various Risk Levels			
			1×10^{-6}	1×10^{-5}	1×10^{-4}	HQ of 1
Sediment RBTCs for Direct Contact Scenarios						
Netfishing RME	arsenic	mg/kg dw	3.7	37	370	nc[a]
	cPAHs	µg TEQ/kg dw	380	3,800	38,000	nc[a]
Tribal clamming RME	arsenic	mg/kg dw	1.3	13	130	nc[a]
	cPAHs	µg TEQ/kg dw	150	1,500	15,000	nc[a]
Sediment RBTCs for Human Seafood Consumption Scenarios						
Adult Tribal RME (Tulalip data)	total PCBs[b]	µg/kg dw	< 1[c]	< 1[c]	2	< 1[c]
	dioxins/ furan TEQ	ng TEQ/kg dw	0.18	1.8	18	nc
Child Tribal RME (Tulalip data)	total PCBs[b]	µg/kg dw	< 1[c]	< 1[c]	250	< 1[c]
	dioxins/ furan TEQ	ng TEQ/kg dw	0.94	9.4	94	nc
Adult API RME	total PCBs[b]	µg/kg dw	< 1[c]	< 1[c]	100	< 1[c]
	dioxins/ furan TEQ	ng TEQ/kg dw	0.48	4.8	48	nc

[a] Sediment RBTCs for direct-contact scenarios were estimated only for excess cancer risks. Sediment RBTCs were not estimated for non-cancer hazards for direct-contact scenarios because none of the RME scenarios had HQs for an individual chemical > 1 or generated endpoint-specific HIs in > 1 (Appendix B, Section B.5.6).

[b] Total PCB RBTCs were generated using the FWM, as discussed in Appendix C.

[c] For RBTCs presented as < 1 µg/kg dw, a sediment RBTC could not be calculated; even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, FWM-estimated total PCB concentrations in tissue would be greater than the tissue RBTC for the applicable risk level because of the contribution of PCBs from water alone to the tissue levels.

API – Asian and Pacific Islander
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSL – cleanup screening level
dw – dry weight
FWM – food web model
HI – hazard index
HQ – hazard quotient
nc – not calculated
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TEQ – toxic equivalent

Table 8-18
Summary of Tissue RBTCs for Human Seafood Consumption Scenarios

Risk Driver COC	Unit	Risk Level	Tissue RBTCs for Human Seafood Consumption Scenarios		
			Adult Tribal RME	Child Tribal RME	Adult API RME
Dioxins and furans	ng TEQ/kg ww	1×10^{-6}	0.0056	0.03	0.019
		1×10^{-5}	0.056	0.3	0.19
		1×10^{-4}	0.56	3.0	1.9
cPAHs	µg TEQ/kg ww	1×10^{-6}	0.11	0.12	0.39
		1×10^{-5}	1.1	1.2	3.9
		1×10^{-4}	11	12	39
Total PCBs	µg/kg ww	1×10^{-6}	0.42	2.3	1.4
		1×10^{-5}	4.2	23.0	14
		1×10^{-4}	42	230	140
		HQ = 1	17	8	24

API – Asian and Pacific Islander
cPAH – carcinogenic polycyclic aromatic hydrocarbon
HQ – hazard quotient
na – not applicable
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
ww – wet weight

Table 8-19
Summary of Sediment and Tissue RBTCs for Ecological Risk Driver COCs

Risk Driver COC	Risk Level	Unit	Tissue RBTCs for Ecological Receptors		Unit	Sediment RBTC for Ecological Receptors[a]		
			Benthic Invertebrates	Fish[b]		Benthic Invertebrates	English Sole	Brown Rockfish
Total PCBs[c]	HQ = 1	µg/kg ww	na[a]	520 and 2,640	µg/kg dw	SMS	100 – > 470[b]	39 – 458
TBT[d]	HQ = 1	µg/kg ww	120	ns	mg/kg OC	7.5	ns	ns

[a] Sediment RBTCs for the remaining 29 risk driver COCs identified for the benthic invertebrate community were presented in Table 8-15.
[b] English sole and brown rockfish.
[c] Total PCB sediment RBTCs were generated using the FWM, as discussed in Appendix C.
[d] TBT sediment RBTC was derived from BAF, as discussed in Section 8.5.1.

dw – dry weight
HQ – hazard quotient
ns – not selected (as a COC or risk driver for this receptor)
OC – organic carbon
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
TBT – tributyltin
ww – wet weight

9 SOURCE AND PATHWAY CHARACTERIZATION

The overall source control evaluation (SCE) requirements were defined in the SRI/FS Workplan (Workplan; Anchor and Windward 2007). Specific details on the approach for source control are described in the EPA-approved SCEAM (Anchor and Windward 2008b). Existing information potentially relevant to the SCE was described in the EISR (Anchor and Windward 2008a) and the SEDGM (Anchor QEA and Windward 2009). Information developed as part of the SRI effort and described in this section will continue to be used during the FS.

Information supporting the SCE process was developed jointly through the activities of the EWG. Consistent with the Workplan (Anchor and Windward 2007) and the SEDGM (Anchor QEA and Windward 2009), additional information developed through other non-CERCLA regulatory programs, studies, and source control activities has been compiled to support the SCE process and is described in this section and supporting appendices.

Information relevant to the specific contaminants that have been identified as COCs in EW sediments during the SRI and risk assessment activities is summarized in this section. The baseline ERA (Appendix A) and baseline HHRA (Appendix B) identified COCs in sediment, tissue, and water of the EW based on various exposure pathways. These COCs include PCBs, PAHs, several phthalates, metals, TBT, and dioxins and furans (see Sections 5 and 6). Source and pathway characterization data are available for all of these compounds; the extent of data varies. Source and pathway characterization activities throughout the EW and its watersheds were prioritized for compounds with multiple potential sources and pathways, including PCBs, PAHs, phthalates, metals, and dioxins and furans. Characterization data available for TBT are more limited because TBT is primarily associated with certain marine ship hull paints, and therefore the primary source of TBT would be from this source. The uses of TBT ship hull paint have been restricted by state and federal laws and by international laws and conventions. Although the use of these compounds is restricted, they may still be released to water and sediments from leaching, flaking, and abrasion of paints from ship hulls. The sediment COCs may be derived from a combination of historical and ongoing potential sources, given that the EW and its adjacent upland areas have been used for industrial, commercial, and shipping operations for nearly a century. Other potential sources of

contaminants include bedrock and volcanic (e.g., metals) sources, and regional and global transport mechanisms (e.g., PCBs).

Source control is an ongoing process that is continually updated and the information provided was available and current at the writing of this report. Consistent with EPA's SRI schedule, potential source and pathway characterization data available through August 2010 are summarized in this SRI report. This section is organized into the following subsections:

- Section 9.1 provides a general overview of potential sources and pathways relevant to EW source control evaluations.
- Section 9.2 describes historical land uses that may have contributed to existing sediment contamination within the EW.
- Section 9.3 provides a discussion of existing source control programs and activities.
- Section 9.4 describes the available information characterizing the pathways by which ongoing sources could potentially impact EW sediments.

Consistent with the scope of the SRI, this section focuses on existing source control programs and associated activities and available data characterizing potential ongoing sources and pathways by which contaminants may be released to the EW. The FS will use this information to develop an analysis of recontamination potential of EW sediments. As described in the Workplan (Anchor and Windward 2007), that information will provide a basis for evaluating source control activities that may be needed for the EW cleanup.

9.1 Potential Sources and Pathways

Potential sources of contaminants to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the EW through various pathways. Potential sources can be either historical or ongoing. The completeness of the pathways with respect to the transport of COCs at levels of concern and the evaluation of potential sources will be conducted in the FS. These pathways include the following:

- Direct discharge into the EW (e.g., CSOs, stormwater, or sheetflow from properties immediately adjacent to the waterway)
- Groundwater discharge
- Bank erosion

- Atmospheric deposition
- Spills and/or leaks to the ground, surface water, or directly into the EW (may be a potential source or pathway)
- Abrasion and leaching of treated-wood structures
- Surface water inputs and sediment transport

These pathways are shown on Map 9-1. A summary of potential sources and pathways is presented in Table 9-1.

Table 9-1

Summary of Potential Sources, Transport Pathways, and Source Control Programs in the East Waterway

	Direct Discharges[a]		Groundwater Discharge[b]	Bank Erosion	Atmospheric Deposition	Spills[c]	Treated-Wood Structures[d]	Surface Water Inputs and Sediment Transport[e]
	Stormwater/Sheetflow	CSOs						
Potential source	Land use activities and atmospheric deposition that deposit contaminants on land surfaces and subsequently are entrained during rainfall events and enter SD systems or sheetflow. Examples include manufacturing, maintenance, and repair activities (industrial and residential), and spills or leaks.	Direct discharge or land use activities and atmospheric deposition that deposit contaminants on land surfaces and subsequently are entrained during rainfall events. Examples include municipal and industrial wastewater and stormwater collected within combined sewer service areas.	Land use activities that result in contamination to soils and groundwater at cleanup or industrial sites.	Land use activities that result in contamination of nearshore bank soils, which may erode due to natural or human activity.	Local, regional, and global air emissions.	Spills of contaminants in upland areas, conveyance areas, or from adjacent or overwater operations.	Treated-wood pilings and structures, which may release contaminants within the EW.	Suspended sediments and associated contaminants from upstream areas (e.g., LDW) and from Elliott Bay.
Pathways	Entrained contaminants in stormwater are conveyed by private and public drainage systems or direct discharge of sheetflow to the EW.	Combined sewer collection and conveyance of stormwater, municipal and industrial wastewater, and associated solids.	Groundwater migration from the EW nearshore areas; potential leakage into damaged SD or sewer lines	Erosion of unstable banks.[f]	Movement of air and entrained particulates and contaminants within EW airshed; direct deposition or transport via stormwater runoff.	Discharge to the EW from adjacent properties or overwater operations. Upland spills impacting groundwater or entrained in conveyance systems (stormwater and CSO).	Release of wood treatment material to surface water or sediment via abrasion/damage or by leaching.	Transport of suspended sediments by river flows, ship prop wash, and tidal currents deposited in the EW sediments.
Point of initial entry to EW	Storm drain outfalls and direct discharge of sheetflow from bridges and terminal aprons	Discharge to the EW at CSO outfalls during CSO discharge events.	Discharge of nearshore groundwater to sediments or to the EW in seeps; discharges of groundwater at stormwater or CSO outfalls.	Unstable bank erosion or failure.	Direct deposition of contaminants onto the EW surface and discharge at outfalls that convey stormwater to the EW.	Direct entry to the EW at the spill location or indirect entry via SD or CSO outfalls	Locations of remaining treated-wood pilings and structures within the EW[e]	Movement of suspended sediments into the EW and potential deposition onto the EW sediments
Examples of ongoing source control program(s)	Local stormwater management programs (e.g., controls on new and redevelopment projects, business, illicit detection elimination programs, O&M programs, and street sweeping), and the NPDES	City of Seattle and King County CSO control programs, compliance, inspection programs, county industrial waste permit programs, and O&M programs.	Site cleanup and associated programs.	Site cleanup and associated programs.	Ecology Air Toxics Program, PSCAA, King County air monitoring, and air emissions reduction programs.	Federal, state, and local spill reporting and response programs; site cleanup and associated programs; and site BMPs.	Permitting (does not allow new installation) and DNR creosote-treated material removal program.[g]	Federal, state, and local source control and cleanup programs.

Note: This table provides a concise summary of each potential source and pathway under evaluation, including the transport pathways by which source-associated materials may be transported to and enter the EW. Different lines of evidence are appropriately used to identify the locations, quantity, and quality of solids and pollutant inputs to the EW as necessary to support the evaluation of potential sediment recontamination in the FS. Sanitary/combined sewer systems may also include EOF structures at pump stations.

[a] No permitted industrial wastewater discharges to the EW were identified during an information review conducted as part of the EISR (Anchor and Windward 2008a). Three outfalls have been identified that had no associated drainage basin delineation and are presumed to be historical (i.e., inactive outfalls). No discharge has been observed from the outfalls and no industrial wastewater permits have been identified.

[b] Groundwater from upland cleanup sites may contribute groundwater to some stormwater or combined sewer conveyances.

[c] Spills to upland properties may contribute contaminants to stormwater or combined sewer systems.

[d] Most creosote-treated pilings and structures have been removed from the EW as discussed in Section 9.4.6.

[e] See Section 3 as well as the EW CSM and data gaps analysis report (Anchor et al. 2008b) and STER (Anchor QEA and Coast & Harbor Engineering 2012 [in prep]).

[f] Most EW shorelines are armored. The current construction of EW shorelines is summarized in Section 9.4.5.

[g] See the DNR *Creosote Removal Program* details at: http://www.dnr.wa.gov/ResearchScience/Topics/AquaticClean-UpRestoration/Pages/aqr_creosote_removal_program.aspx

BMP – best management practice
CSM – conceptual site model
CSO – combined sewer overflow
DNR – Washington State Department of Natural Resources
Ecology – Washington State Department of Ecology
EOF – emergency overflow
EW – East Waterway
FS – feasibility study
LDW – Lower Duwamish Waterway
NPDES – National Pollutant Discharge Elimination System
O&M – operations and maintenance
PSCAA – Puget Sound Clean Air Agency
SD – storm drain
STER – sediment transport evaluation report

9.1.1 Spills and Leaks

Chemicals released through spills and leaks to soil, other ground surfaces (such as roadways), surface water, or groundwater have the potential to migrate to the EW. Leaks can occur from pipes and storage tanks, industrial or commercial equipment, and process operations. Spills can occur accidentally during vehicle fueling and maintenance, or purposefully in the case of illegal dumping. Spills can be considered a pathway when they discharge directly to the EW via nearshore or overwater operations, or a source when indirectly discharged into SDs or combined sewer systems with CSOs to the EW or by movement through soil to groundwater or erosion of impacted soil. See Section 9.3.7 for additional discussion on spills.

9.1.2 Direct Discharges and Sheetflow

In general, direct discharge systems include municipal or other publically owned drainage systems, privately owned and managed SDs, and sanitary/combined sewer systems. In addition to direct discharges, some small percentage of stormwater also enters the EW from adjacent properties via sheetflow. Direct discharge systems and the various types of discharge points (i.e., outfalls) are discussed in further detail in Sections 9.3.1 and 9.4.3. These individual outfalls are defined in this report as locations of discharge of public or private SD systems, CSOs, and emergency overflows (EOFs). Table 9-2 presents a description and the nomenclature used throughout this section for the various direct discharge outfalls in the EW.

Table 9-2
EW Outfall and Drain Nomenclature and Descriptions

Nomenclature	Description
CSO	Combined sewer overflow (CSO) event from an outfall structure on a publically owned and maintained combined sewer system. Combined sewers convey both wastewater (municipal and industrial) and stormwater runoff. Overflows generally occur only during large storm events when the capacity of the combined sewer is exceeded, and not all flow can be successfully conveyed to a treatment plant. Under these conditions, excess flow is discharged to a nearby receiving water body to prevent sewage backups in homes and businesses.
EOF	Emergency overflow point on a combined or sanitary sewer, generally located at a pump station. Discharges are not storm-related. Overflows occur as a result of mechanical failure, pipe obstruction, or power failure. Pump stations in EW are equipped with backup generators. While included for completeness, there are no identified EOFs discharging to the EW.
CSO/SD or EOF/SD	Shared outfall that serves as either a CSO or EOF and a storm drain outfall.

Nomenclature	Description
Public SD	Publically owned SDs that are required to have coverage under an NPDES municipal stormwater permit (Ecology 2010e) (i.e., those owned by the City of Seattle and the Port of Seattle), or federally owned SDs that have coverage under a federal multi-sector general NPDES permit (USCG SD).
Private SD	SDs that discharge stormwater from private properties.
Bridge deck drain	Deck drains located on bridges that extend across portions of the EW.
Apron deck drain	Deck drains that convey stormwater from the over-water apron areas directly to the underlying EW. These apron areas are typically present along the shorelines of the Port of Seattle terminals.

CSO – combined sewer overflow
EOF – emergency overflow
EW – East Waterway
NPDES – National Pollutant Discharge Elimination System
SD – storm drain
USCG – U.S. Coast Guard

9.1.2.1 Stormwater

Stormwater is conveyed to the EW by SDs and CSO systems. Storm drains discharging to the EW include both public and private SD systems. (CSO systems are discussed in the following section.) The public SDs are owned and operated by the City of Seattle or the Port of Seattle and are covered under their respective National Pollutant Discharge Elimination System (NPDES) municipal stormwater permits and Port of Seattle tenant industrial permits, where applicable, or federally owned SDs that have coverage under a federal multi-sector general permit (USCG). All other drainage systems are classified as private (i.e., outfalls not owned by the Port of Seattle, City of Seattle, or USCG).

Storm drains collect urban runoff from roadways and other upland areas (e.g., commercial, industrial, and residential properties). Urban areas have the potential to accumulate particulate materials, dust, oil, asphalt, rust, rubber, metals, pesticides, detergents, and other chemicals resulting from urban activities and atmospheric deposition. Contaminants present on the ground (e.g., roadways, parking lots, residential yards, or industrial yard areas) can then be flushed into SDs during wet weather and transported to the EW in dissolved or particulate form. These drainage networks also provide a pathway for spills and leaks to reach the EW.

9.1.2.2 Combined Sewer Overflows

CSO discharges are a complete pathway for contaminants entering the EW. CSO events can occur during heavy rainfall when the CSO system capacity is insufficient to transport the volume of both sanitary wastewater and stormwater flows to the wastewater treatment plant

(WWTP). When this capacity is exceeded, excess flow is discharged to the EW through an overflow structure (Figure 9-1) or relief point. CSOs consist of a combination of untreated municipal and industrial wastewater and stormwater runoff. Infrastructure improvements have greatly improved system storage capacity and reduced the number of discharges from CSO systems.

Source: King County (2006a)

Figure 9-1
Schematic Diagram of CSO System

9.1.2.3 Sheetflow

Sheetflow is a pathway where surface water runoff directly enters the EW from berth aprons, deck drains, bridges, and areas immediately adjacent to the EW during rain events. In areas lacking stormwater collection systems, potential sources such as contaminated soils or contaminants improperly stored either as raw or as waste materials could be carried directly over these surfaces to the EW.

9.1.3 Groundwater

Groundwater discharge is a potentially complete pathway for transport of contaminants. Groundwater flow in the surrounding basin is generally toward the EW, although the direction varies locally depending on the nature of subsurface materials, hydrostratigraphy, and proximity to the EW. Near the EW, tidal action influences groundwater flow directions,

rates, and water quality. The determination of whether a contaminant identified in groundwater will impact sediment or surface water quality in the EW is a complex process. Groundwater in the EW area is discussed further in Section 9.4.4, and an overview of monitoring information for select facilities is presented in that section and in Appendix J.

9.1.4 Bank Erosion

Unprotected bank soils can be susceptible to erosion through surface water runoff, wind waves, and the action of vessel wakes and prop wash. If shoreline soils are contaminated, erosion can represent a pathway of pollutants to the EW. The presence of shoreline armoring and vegetation affect the potential for bank erosion. Bank slope and soil properties are also factors in the susceptibility of bank areas to erosion; steeper banks are more susceptible to erosion for any given grain size. Currently, the majority of the EW shoreline is armored with constructed steel, wood, and concrete bulkheads; sheetpile walls; and riprap revetments, which reduce the potential for bank erosion. The potential for erosion of bank material as a pathway to EW sediments has been evaluated and is discussed in Section 9.4.5.

9.1.5 Treated-Wood Structures

Historically, pilings and wooden structures treated with creosote or other wood preservatives were commonly used as part of navigation/berthing improvements (e.g., pier and wharf structures, fender systems, and dolphins) and marine structures (e.g., wooden bulkheads).These treated-wood structures are a potential source of contaminants, which can be released to sediments by abrasion or leaching pathways. Treated-wood structures are discussed in Section 9.4.6.

9.1.6 Atmospheric Deposition

Chemicals are emitted to the air from both point and non-point sources. Point sources include emissions (e.g., “stack emissions”) from various stationary (i.e., “fixed” or immobile) industrial facilities (EPA 2001). Non-point sources include emissions from mobile sources such as motor vehicles, marine vessels, and trains, as well as emissions from common materials (e.g., off-gassing from plastics) and road dust resulting from urban traffic. Chemicals emitted to the air may be transported over long distances, generally in the direction of the area’s prevailing winds. They can be deposited from the atmosphere to land and water surfaces through wet deposition (precipitation) or dry deposition (as particles).

Air pollutants can enter waterbodies through either direct or indirect deposition. Direct deposition occurs when particulates with adsorbed chemicals are deposited onto the surface of a water body and then settle to the bottom, becoming part of the sediment. Indirect deposition occurs when chemicals are first deposited on land or other waterbodies in the watershed (e.g., streams and lakes) and then transported to the water body via surface water or stormwater runoff. Air pollutants deposited in the drainage basin can be transported either in dissolved form or adsorbed to solids in the runoff and are ultimately transported to bottom sediments and the water column. Many air pollutants deposited through direct or indirect atmospheric deposition in aquatic systems, such as the EW, have the potential to contaminate sediment because they are hydrophobic and tend to adhere to sediment particles (PSCAA 2003). The potential sources of chemicals to the EW through atmospheric deposition are discussed in further detail in Section 9.4.7.

9.1.7 Surface Water Inputs and Sediment Transport

Surface water inputs and suspended sediment may be transported to the EW from upstream (the Green/Duwamish River and LDW) and from Elliott Bay. The input amounts and types vary greatly during the year; the Green/Duwamish system is variable and it can be influenced by ongoing contaminant inputs from a large area of mixed industrial, commercial, residential, and agricultural lands. The LDW upriver of the EW is also a CERCLA site with contaminated sediments. Contaminants released from outside of the EW drainage basins have the potential to enter the EW through transportation of sediments and water from upriver or Elliott Bay. As presented in Section 4, sediment contaminant levels were lowest in the northern portion of the EW, adjacent to Elliott Bay. Sediments in this area are below SQS chemical and/or biological testing criteria, suggesting that transport of Elliott Bay sediments to the EW does not pose a significant potential for sediment recontamination. Surface water inputs and associated sediment transport into the EW are addressed as part of the sediment transport evaluation and preliminary background concentrations of risk driver COCs (Sections 3 and 7, respectively).

9.2 Potential Historical Sources and Practices in the East Waterway

The following section provides a summary of the historical development and industrial practices along the West and East Upland areas of the EW, as well as other potential

historical sources of contamination to the EW. This subsection documents historical sources that may have contributed to existing contamination within the EW.

9.2.1 Industrial Development of the East Waterway

Harbor Island and the land east of the EW was created by 1909. Early industrial and commercial use of these areas consisted of fish processing facilities, shipyards, petroleum tank farms, flour mills, and lumber yards (EPA 1993b). Industrial and commercial use continued after the 1940s on both sides of the EW, including oil terminals, shipyards, rail transfer terminals, cold storage, lumber yards, and sand and gravel transfer stations (EPA 1993b; Port of Seattle 2011c; USACE 1818-1980 [condition surveys]). During the 1970s and 1980s, significant shoreline areas along both the west and east sides of the EW were transitioned into container use (Port of Seattle 2011a). Map 9-2 illustrates the history of industrial development of the EW and surrounding areas.

9.2.1.1 Harbor Island (West Upland Areas)

Early industrial development on Harbor Island along the EW included shipyard and shipping facilities. Shipyard operations were present at the southeastern area on Harbor Island by 1920. The East Waterway Dock and Warehouse Company was present along the eastern portion of Harbor Island, as was a sand and gravel transfer station in the current location of Olympic Tug and Barge.

In 1935, a secondary lead smelter was constructed near the center portion of Harbor Island with operations consisting of lead reclamation from spent batteries. The smelter was closed in 1984 (see Section 9.2.2.1 for details on air emissions).

During the 1930s and 1940s, particularly during World War II, significant industrial development occurred on Harbor Island. The first oil terminal (Shell Oil Co.) was constructed by 1929 along the EW (USACE 1929). The Port of Seattle acquired portions of the eastern shoreline of Harbor Island in 1941 from the East Waterway Dock and Warehouse Company, and this area was then known as Terminal 20 (T-20). Additional oil terminals were constructed in the center areas of Harbor Island during this time. Todd Shipyards' properties expanded to the east side (USACE 1940s, 1955), the northeast, and southeast areas of Harbor Island, including areas along the EW shoreline.

Seattle Iron and Metal Co. operated a metal salvage facility (metal recycling) in the central/east portion of Harbor Island from 1950 to 1997 (Ecology 1985). As part of the T-18 expansion in 1997, Seattle Iron and Metal Co. was relocated off Harbor Island to a location on the Duwamish Waterway. This facility had discharged wastewater and overflowed wire washwater to the local SDs that drained to the EW, and discharged stormwater from the storage of scrap to local SDs discharging to the EW (Ecology 1985).

During the 1960s and 1970s, the Port of Seattle acquired properties to expand existing shipping and container storage facilities. The T-18 construction included acquisition of the northeastern portion of Harbor Island from Todd Shipyard in 1965 (Port of Seattle 2011c). Continued Port of Seattle development included combining T-18 and T-20 into the expansion of T-18 along the entire eastern shoreline of Harbor Island (Port of Seattle 2011c). The Port of Seattle acquired the Shell Oil Co. property along the EW in 1976 as part of the T-18 expansion (Port of Seattle 2011c). Since the 1980s, T-18) has undergone occasional terminal improvements and remedial actions. Development at the southern end of Harbor Island in the 1990s (i.e., south of the Spokane Street Bridge) created the area that is currently T-102 and the location of the Harbor Island marina. Prior to the infill and development, the T-102 area consisted of aquatic land (Port of Seattle 2011b).

9.2.1.2 East Upland Areas

By 1918, a majority of the East Upland areas were developed for industrial use. The northern portion of the East Uplands was primarily used for flour mills and a bulk petroleum storage facility operated by Standard Oil (USACE 1918, 1919). To the south, early industrial development included shipping piers and a lumber mill at the Spokane Street Terminal (USACE 1918, 1919).

The area of the current USCG facility (Pier 35/36) was used for a flour mill during the early 1900s through the mid-1960s (Hart Crowser 2004). During the 1960s, the mill buildings were demolished and the property was developed into a paper recycling facility and transfer station operated by Rabanco. These operations continued until the early 1990s when USCG acquired the property in 1991. An ink distribution facility (Flint Ink) was also present adjacent to the USCG facility during the 1990s as shown in Map 9-2.

During the 1920s, an additional bulk petroleum storage facility operated by Associated Oil was developed in the north portion of the East Uplands just north of the adjacent Standard Oil facility (Remediation Technologies 1997). These two bulk fuel storage facilities changed ownership over the years and both expanded in the 1950s to include additional storage tanks. The Associated Oil facility was operated by GATX Terminals after 1976 and ceased operations in 1995 when the Port of Seattle acquired the property for redevelopment to container use (Remediation Technologies 1997). The Associated Oil (GATX Terminals) Site has been the subject of a previous MTCA cleanup action, including completion of an RI/FS and Cleanup Action Plan, implementation of a cleanup for soil and groundwater, and implementation of post-cleanup monitoring. Principal contaminants of concern at that site included petroleum, PAH compounds, BTEX compounds, arsenic, copper, and lead. The main contaminant source areas were the subject of the soil removal action. The Standard Oil facility was operated by Chevron until the mid-1980s, when the facility was demolished and the Port of Seattle acquired the property for container use. These areas were both developed into T-30 as a container storage and transfer facility. Portions of T-30 were then developed into a cruise ship terminal that was operational from 1999 to 2008 (RETEC 2006b). Further description of this area, including regulatory status, is presented in Section 9.4.4.2.4.

To the south of T-30, early industrial development consisted of Port of Seattle shipping piers, a lumber mill, and cold storage facilities for preserving fish and fruit. The shipping piers were primarily used for shipping grain and products from the cold storage facilities (Pinnacle Geosciences 2003; Port of Seattle 2011d). During the early 1930s, additional development at the Spokane Street Terminal included the Westinghouse Electric Co. and expansion of the cold storage facility. In the 1940s, Isaacson Iron Works was constructed just north of the Hanford Street Terminal. During the late 1960s and early 1970s, this area began to transition to a container storage and transfer facility (Port of Seattle 2011d). The grain shipping piers were relocated, the lumber mill was demolished, and the ship turning basin was filled. These areas were consolidated by the Port of Seattle in 1972 and became T-25, operating as a container storage and transfer facility.

The East Uplands south of Spokane Street were developed during the 1930s. The property in this area was historically used by a paper bag manufacturer, a lumber storage yard, an auto repair shop, a restaurant, and a foundry supply warehouse (Shannon & Wilson 2005). During the 1980s, the Port of Seattle developed this area into the current use as T-104 for container

storage and transfer. The area adjacent to T-104, known as Poncho's Legacy property, also had historical industrial development including an iron works, a manufacturing company, a welded wire mesh industry, and, most recently, a belt and rubber supply company (Shannon & Wilson 2005).

9.2.2 Historical Regional Air Emissions

Historical regional air emissions include regional smelter facilities, petroleum combustion by motor vehicles, home heating systems (e.g., coal, wood stoves, and natural gas) and industrial facilities, cement manufacturing plants, and other industrial and urban practices. Air emissions were not commonly monitored or regulated prior to the establishment of the Clean Air Act (CAA) in the 1970s.

9.2.2.1 Regional Smelter Facilities

The Asarco copper smelter operated from 1890 to 1985 in Ruston, Washington. Smokestack emissions from the Asarco smelter contained arsenic and lead and were likely a historical source of these metals to the EW (Ecology 2002). Prevailing winds are a large factor in determining the spread of smelter emissions (Ecology 2001); for much of the year, prevailing winds in the EW are from the south (PSCAA 2006a) where the Asarco smelter was located. Heavy metals were distributed through atmospheric deposition to more than 1,000 square miles of the Puget Sound basin from the Asarco smelter. Since the closure of the Asarco smelter, Ecology and several local health departments have initiated studies to outline the extent of the plume "footprint" by testing arsenic and lead concentrations in area soils. Soil samples collected to date show that arsenic concentrations in the EW drainage basin ranged from 17 to 30 mg/kg dw, while lead concentrations ranged from 37 to 200 mg/kg dw (Ecology 2001). MTCA Method A soil cleanup levels for unrestricted land uses for arsenic and lead are 20 and 250 mg/kg dw, respectively. Soil characterization within the plume footprint is still ongoing (Ecology 2007a).

The smelter on Harbor Island operated from 1935 to 1984. It is estimated that the Harbor Island lead smelter deposited lead and facility-associated contaminants through atmospheric deposition over at least 640 ac of land (Area-Wide Soil Contamination Task Force 2003). Emissions from the smelter were also likely deposited into the EW through direct and indirect atmospheric deposition. An air monitoring station formerly located on Harbor Island was used to collect samples to analyze for lead concentrations in the air. Prior to the

smelter's closure in 1984 (EPA 1993b), lead was often detected in air samples at concentrations above federal standards. Quarterly average lead concentrations over 10.5 micrograms per cubic meter (μg/m^3) were reported by the Puget Sound Clean Air Agency (PSCAA) for the 1981 monitoring year(PSCAA 2006d). By 1998, all operations at the Harbor Island smelter ceased, and lead concentrations in air dropped below the quarterly federal standard of 1.5 μg/m^3. Air monitoring on Harbor Island was discontinued in 1999. Lead has been frequently detected in surface sediment samples throughout EW. However, no surface sediment concentrations exceed the SQS value for lead.

9.2.2.2 Historical Urban Air Emissions

In addition to smelter facilities, other historical air emission sources have potentially contributed to sediment contamination in the EW, such as marine shipping, home heating systems (e.g., coal, wood stoves, and natural gas), industrial processes, petroleum combustion emissions from motor vehicles, power generating facilities, wood treatment, waste incineration, and cement kilns.

Air pollutants commonly associated with urban activities in the past included particulate matter (PM), metals, PAHs, PCBs, and dioxins and furans. PM and PAHs were emitted from the burning of fossil fuels such as coal and oil, used in various industrial processes, and used for domestic purposes such as transportation and heat. Wood burning and waste incineration were other historical practices that emitted PM, PAHs, dioxins and furans, and metals (PSCAA 2003).

In the past, large quantities of lead were emitted to the atmosphere from the use of leaded gasoline, which was used primarily from the early 1920s through the 1990s, though it was largely phased-out by the mid-1970s because of health concerns (Ecology 2001). Chromium and nickel emissions are also associated with the burning of fossil fuels (PSCAA 2006d).

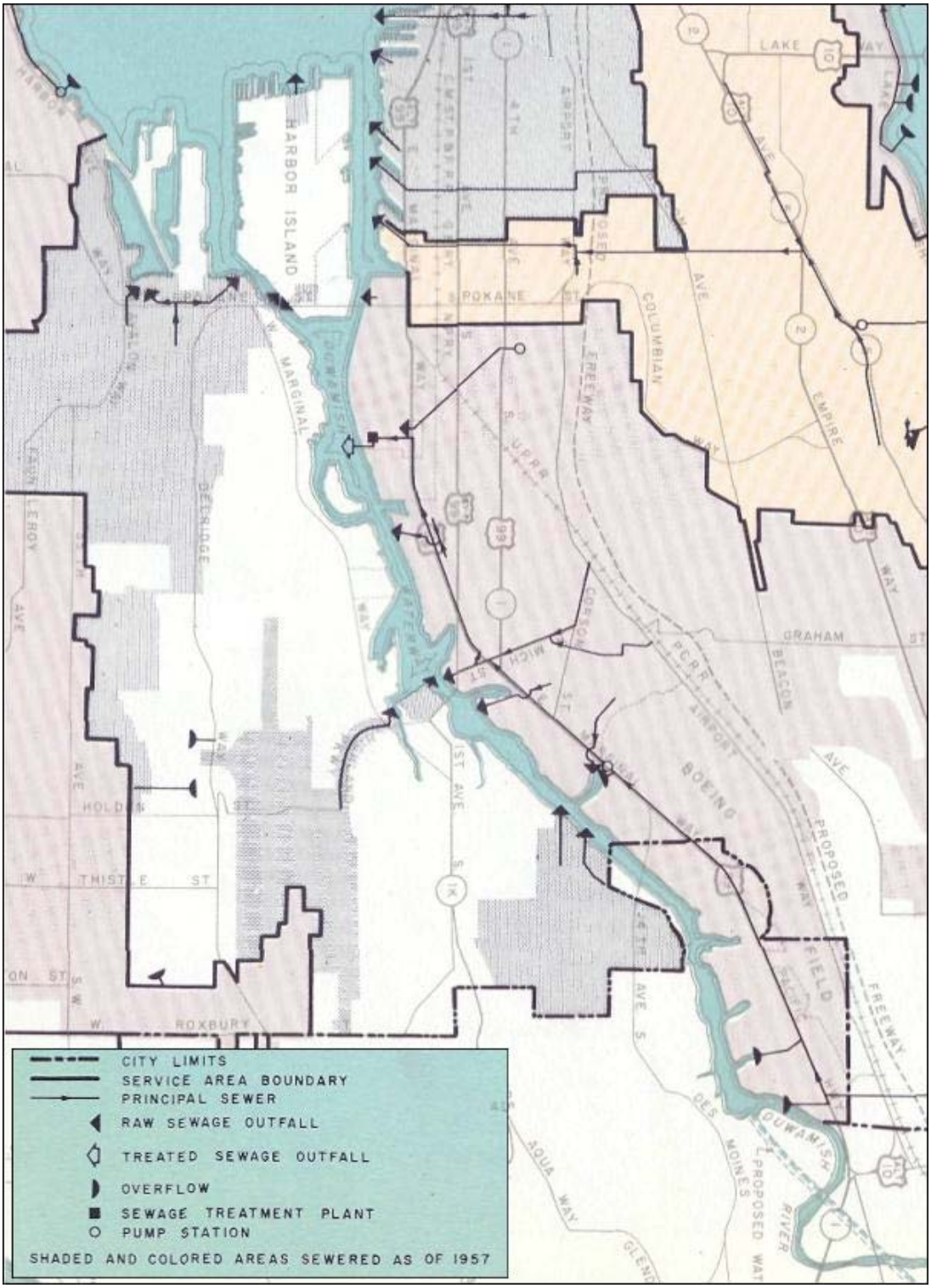
Other historical industrial processes common in the region may have contributed air pollutants. Arsenic is often emitted to the atmosphere through wood treatment processes and distillate oil combustion, and chromium is emitted by chrome electroplaters (PSCAA 2006d). No wood treating facilities using arsenic and no chrome electroplaters are known to have been located on the EW, but multiple such facilities are, or have been, located within the greater Seattle area. Distillate oil combustion sources are common and can include ocean-

going marine vessels, industrial boilers, waste oil heaters, and other sources. Cement kiln emissions can contain chromium, mercury, lead, and zinc, as well as dioxins and dioxin-like compounds, PCBs, and PAHs (EPA 2007a). BEHP is emitted to the atmosphere from plasticized PVC contained in many building products and materials (Floyd|Snider 2007a). Several of the historical atmospheric sources are still present near the EW today, though most emissions are now registered and regulated by PSCAA and EPA.

9.2.3 Historical Direct Discharges

Prior to the creation of Metro (now the King County Wastewater Treatment Division) in 1958, local sewer systems along the waterway discharged raw sewage directly into the EW and LDW. These raw sewage discharges also contained mixed industrial wastes originating from facilities along the waterway. Although the EW is currently served by a combination of separated, partially separated, and combined sewer systems historically, most of the EW area was served by a combined storm/sanitary sewer system.

As shown on Figure 9-2, approximately four combined sewer/sanitary outfalls (raw sewage outfalls) discharged to the EW in 1958. The combined sewer/sanitary outfalls discharged raw sewage, stormwater, and industrial waste streams directly to the EW until they were connected to the conveyance system and sent to the West Point WWTP. The Hanford #2 CSO outfall and the Lander CSO/SD outfall are located in approximately the same locations as historical sewer outfalls. The CSO discharges in these locations currently discharge only when the capacity of the conveyance system is exceeded during periods of heavy rainfall.



Source: Brown and Caldwell (1958)

Figure 9-2

Outfalls that Historically Discharged Raw Sewage to the Duwamish River and East Waterway

The Diagonal Avenue S WWTP was located approximately 0.5 miles upstream of the EW and was operated by the City of Seattle from 1938 until approximately 1969, when the plant was closed and flows were diverted to the West Point WWTP. By the late 1950s, industries that discharged wastewater (industrial or sanitary waste) to the public sewer system or directly to a nearby receiving waterbody were required to obtain a wastewater discharge permit from the Pollution Control Commission. In 1958, the total population served by the Diagonal Avenue S WWTP was about 30,000 (Brown and Caldwell 1958). The Diagonal Avenue S WWTP provided primary treatment for sanitary wastewater, industrial waste streams, and stormwater collected from the Rainier Beach neighborhood near Lake Washington and the industrial district along E Marginal Way S from the Diagonal Avenue S WWTP south to the Upper Turning Basin. Industrial facilities along the east side of the LDW were required to redirect industrial waste discharges to this system in the early 1950s.

Starting in 1969, large portions of the public and private sewer lines were connected into the Elliott Bay Interceptor line. However, because the older collection system was built to collect both sanitary wastewater and stormwater, relief points in the system were created. These are called CSO discharge points and were needed to prevent wastewater from backing up into homes and businesses when the collection system reached capacity from stormwater during rainfall events. System overflows for the EW were eventually limited to the current King County and City of Seattle CSO locations (see Section 9.3.3).

9.2.4 Historical Surface Water Inputs and Sediment Transport

In addition to direct discharge of historical sanitary and industrial wastewater to the EW, historical flows of surface water and suspended sediment contaminated from historical practices have likely been transported to the EW from the Green/Duwamish River and Elliott Bay. As part of the LDW FS, the downriver transport of sediments and the movement of contaminants associated with sediment transport and lateral load inputs were evaluated; however, historical surface water and lateral load contaminant inputs were not evaluated.

9.3 Ongoing Source Control-Related Programs

This section discusses the ongoing source control programs and related work being carried out by various agencies as they implement many different regulatory programs. The various regulatory and public entities currently performing source control work in the EW include the City of Seattle, King County, Port of Seattle, and Ecology. The different source control

methods and tools being used by these entities to identify, characterize, and control sources include the NPDES program and related permits, enforcement, regulations, pollution prevention programs, inspection and maintenance programs, environmental investigations, pathway assessments, and cleanups. In addition, there are regional programs such as PSCAA and interagency work groups (e.g., the recent Sediment Phthalates Work Group [SPWG] and Ecology's Sediment Management Working Group) that have evaluated potential regional sources of contamination from air or ubiquitous urban sources.

Data collected as part of these ongoing programs have been incorporated into this SRI where relevant (e.g., potential source or pathway characterizations in the EW drainage or airshed) to characterize ongoing sources and pathways. As described in the Workplan (Anchor and Windward 2007), the FS will develop an analysis of recontamination potential for EW sediments. That information will provide a basis for evaluating source control activities that may be needed for the EW cleanup. Existing source control programs that are described in this section are ongoing and may evolve over time with changing regulatory requirements and as new information becomes available. That information will provide a basis for evaluating source control activities that may be needed for the EW cleanup.

9.3.1 NPDES

The NPDES program provides a means for limiting discharge of some contaminants to the EW. The program was established in 1972 under Section 402 of the CWA and regulates the discharge of certain wastewater and stormwater to the navigable waters of the US. In Washington, the NPDES program is administered by Ecology, which promulgates NPDES regulations and issues permits to dischargers. NPDES-permitted discharges to the EW include industrial and municipal stormwater, stormwater originating from certain construction projects, and CSOs (Figure 9-3). The USCG facility also discharges stormwater to the EW under a federally administered multi-sector stormwater NPDES permit.

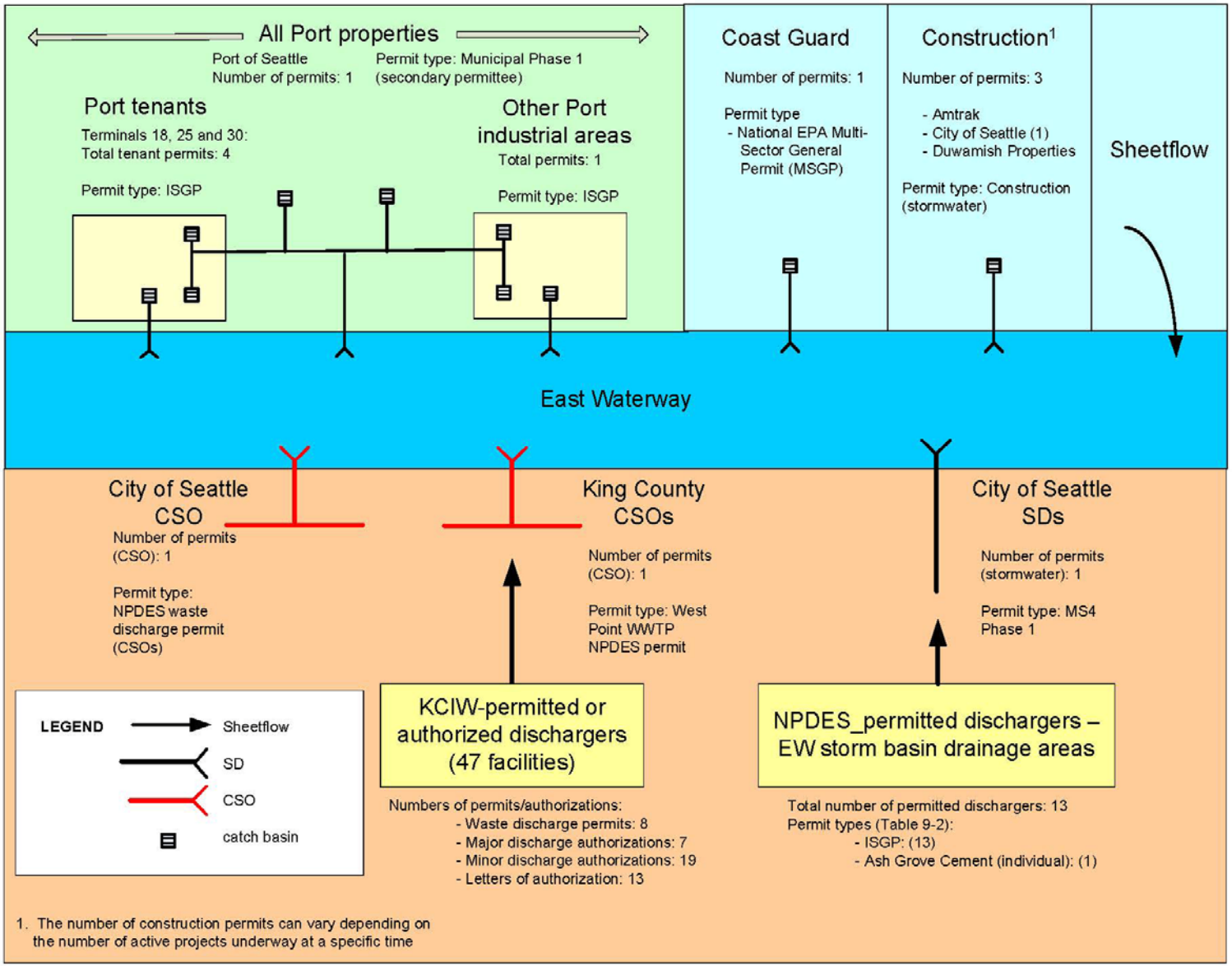


Figure 9-3
NPDES Permit Schematic

Industrial stormwater dischargers located immediately adjacent to the EW basins are regulated under the NPDES program. In addition, a number of industrial stormwater dischargers in the larger EW drainage basins (e.g., those permitted to discharge to municipal conveyances such as separated stormwater or combined sewer systems) qualify to be regulated under the state-administered NPDES. Industrial wastewater discharges to the sanitary and combined sewer systems are permitted by King County (see Sections 9.3.1.2 and 9.3.4). Public stormwater discharges to the EW from a municipal separate storm sewer system (MS4) are covered under Phase I municipal permits. CSOs are covered under CSO permits or are a part of WWTP permits issued to the City of Seattle and King County, respectively. Permits applicable to these various types of discharges are discussed in greater detail below. Municipal stormwater management programs developed as part of NPDES permit implementation are described in Section 9.3.2, and CSO control programs are discussed in Section 9.3.3.

9.3.1.1 Industrial Stormwater Permits

This section provides an overview of industrial stormwater NPDES permits and identifies permitted industrial entities discharging to the EW.

9.3.1.1.1 Industrial Stormwater Permits Overview

Industrial stormwater discharges to the EW from designated types of industries are covered under either a general or individual industrial stormwater permit. Industrial stormwater NPDES permits regulate stormwater discharges only from certain designated categories of industrial facilities (Ecology 2009b). It is important to note that many industrial and commercial operations are not included in these categories, but may still discharge stormwater to adjacent municipal SD systems or directly to surface waters. For example, as described in the following section, 14 businesses in the EW drainage basin are covered by NPDES stormwater permits, and all businesses that require an industrial permit on Port of Seattle-owned land have an active permit. In addition, Seattle Public Utilities (SPU) has inspected more than 400 businesses in the area because they engage in pollution generating activities. SPU refers those businesses that appear to require NPDES permits (either based on their Standard Industrial Classification [SIC] code or because they are a significant discharger), but are not covered by a permit, to Ecology for further evaluation. NPDES industrial stormwater general permits (Ecology 2009b) typically set limits for turbidity, pH,

oil and grease, copper, and zinc. Additional analytes (e.g., total lead, biological oxygen demand, ammonia, nitrate-nitrite nitrogen, and total phosphorus) and their respective limits may be specified based on the type of industry holding the permit as well as site-specific conditions, operating history, and previous monitoring results.

Certain industrial facilities must apply for an individual permit. Individual permits also regulate the discharge of pollutants associated with a particular industrial facility, but also address unique, facility-specific elements or operational or monitoring requirements not included under a general permit. For example, one business with a stormwater discharge to the EW (Ash Grove Cement) is covered under an individual permit that establishes effluent limits based on technology and surface WQC (Ecology 2010d).

Industrial stormwater permit holders are typically required to prepare stormwater pollution prevention plans (SWPPPs) that describe the potential stormwater contaminant sources at a facility and indicate how they are controlled through the use of operational, structural, and treatment best management practices (BMPs). Industrial facilities with stormwater permits are typically required to conduct quarterly monitoring of authorized discharges to surface water (Ecology 2009b), although some individual permits may specify alternate monitoring methods and frequencies.

9.3.1.1.2 Permitted Industrial Stormwater Discharges to the EW

There are approximately 13 industrial stormwater general permits and one individual permit for discharges to the EW, but these are only a subset of the total number of industrial and commercial facilities within the EW drainage area.[119] Table 9-3 lists the active (as of January 2012) individual and general industrial stormwater permits and construction NPDES permits for specific facilities that discharge to the EW. The locations of the facilities with these NPDES permits are shown on Map 9-3. Most nearshore facilities, except Ash Grove Cement, which is covered by an individual industrial NPDES permit, are covered by municipal and/or industrial general NPDES permits or federally administered multi-sector general NPDES permits. Industrial facilities in the larger storm drain basins may be covered under an NPDES permit if they meet the definitions set forth for qualifying facilities under the NPDES

[119] Some industrial stormwater may be discharged to the combined sewer system and, therefore, could have discharge authorization through King County's Industrial Waste Program.

regulations (e.g., their operations correspond to listed SIC codes) or are otherwise required by Ecology to be covered. Facilities not covered under a permit that engage in pollution-generating activities are evaluated through the City of Seattle's business inspection program described in Section 9.3.4.3. Contaminated stormwater generated from industrial processes at facilities that drain to the combined sewer system are evaluated through King County's Industrial Waste Program described in Section 9.3.4.2. There are no facilities discharging to or located in the EW with other industrial NPDES permits (i.e., sand and gravel or boatyard permits).

Ash Grove Cement West, Inc., is the one facility in the EW with an individual industrial stormwater permit (Ecology 2010d). The Ash Grove facility discharges to the City of Seattle's S Hinds Street SD system, which, in turn, discharges to the EW. The permit requires that the stormwater discharge be monitored twice per month for flow, TSS, oil and grease, turbidity, PCB, pH, arsenic (total), copper (total), mercury (total), and zinc (total). In addition, one sample of on-site catchment basin solids is required to be sampled once per year and analyzed for arsenic, mercury, copper, lead, zinc, PCB, SVOCs (including phthalate), diesel- and motor oil-range TPH, PAH, TOC, and grain size.

Table 9-3

Reported Active NPDES Industrial and Construction Stormwater Permits for the East Waterway Storm Basin Drainage Areas

ID Number on Map 9-3	Permitted Facility	Facility Address	Permit Type	Permit No.	Outfall Owner	Outfall ID	Basin	Required Monitoring Parameters
1	Ash Grove Cement West Inc	3801 E Marginal Way S	Individual Industrial Stormwater	WA0032221	City of Seattle	S Hinds Street CSO/SD	S Hinds Street SD	flow, TSS, FOG, turbidity, PCB, pH, total arsenic, total copper, total mercury, total zinc, storm solids[a]
2	Stevedoring Services Terminal 18	1050 11th Avenue SW	Industrial Stormwater General	WAR000467E	Port of Seattle	7 – 19, 22 – 24	B-7, B-10 – B-14, B-16 – B-19, B-22 – B-24	turbidity, pH, total zinc, total copper, oil sheen, fecal coliform
					City of Seattle[b]	5, 21	B-5, B-21	
3	Terminal 25 30 SSA	3225 E Marginal Way S	Industrial Stormwater General	WAR009181	Port of Seattle	26-34	B-26 – B-34	turbidity, pH, total zinc, total copper, oil sheen
4	Port of Seattle Marine Maintenance Shop	25 S Horton Street	Industrial Stormwater General	WAR002517	City of Seattle	S Hinds Street CSO/SD	S Hinds Street SD	turbidity, pH, total zinc, total copper, oil sheen
5	PCC Logistics Seattle	3629 Duwamish Avenue S	Industrial Stormwater General	WAR125003	Port of Seattle	37, 39	B-37, BR-39	turbidity, pH, total zinc, total copper, oil sheen
6	Westway Feed Products Co Inc (aka United Molasses)	1002 SW Spokane Street	Industrial Stormwater General	WAR004526	Port of Seattle	7	B-7	turbidity, pH, total zinc, total copper, oil sheen, BOD, nitrogen, phosphorus
7	Colorado Street Facility Rainier Petroleum	40 S Spokane Street	Industrial Stormwater General	WAR005619	City of Seattle	S Hinds Street CSO/SD	S Hinds Street SD	turbidity, pH, total zinc, total copper, oil sheen, BOD, nitrogen, phosphorus

ID Number on Map 9-3	Permitted Facility	Facility Address	Permit Type	Permit No.	Outfall Owner	Outfall ID	Basin	Required Monitoring Parameters
8	Alaskan Copper Works	3200 6th Avenue S	Industrial Stormwater General	WAR000139E	City of Seattle	Lander CSO/SD	S Lander Street SD	turbidity, pH, total copper, total zinc, oil sheen, lead, TPH
9	Franz Seattle	2901 6th Avenue S	Industrial Stormwater General	WAR002292E	City of Seattle	Lander CSO/SD	S Lander Street SD	turbidity, pH, total zinc, total copper, oil sheen, BOD, nitrogen, phosphorus
10	System Transfer and Storage Co.	2400 6th Avenue S	Industrial Stormwater General	WAR000430	City of Seattle	Lander CSO/SD	S Lander Street SD	turbidity, pH, total zinc, total copper, oil sheen
11	Lee and Eastes Tank Lines	2418 Airport Way S	Industrial Stormwater General	WAR004614C	City of Seattle	Lander CSO/SD	S Lander Street SD	turbidity, pH, total zinc, total copper, oil sheen
12	Amtrak Railroad King Street Maintenance	187 Holgate Street S, Bldg A	Industrial Stormwater General	WAR003235	City of Seattle	Lander CSO/SD	S Lander Street SD	turbidity, pH, total copper, total zinc, oil sheen
13	General Recycling of Washington LLC	4260 W Marginal Way SW Terminal 105	Industrial Stormwater General	WAR002341	City of Seattle	Lander CSO/SD	S Lander Street SD	turbidity, TSS, pH, total copper, total zinc, lead, oil sheen, Harness
14	Amtrak Pacific Northwest Maintenance Facility	187 S Holgate Street	Construction Stormwater General	WAR124656	City of Seattle	Lander CSO/SD	S Lander Street SD	turbidity, pH
15	Spokane Street Viaduct Partial	S Spokane Street	Construction Stormwater General	WAR012115	City of Seattle	S Hinds Street CSO/SD	S Hinds Street SD	turbidity, pH
16	East Marginal Way Grade Separation	E Marginal Way S and S Spokane Street	Construction Stormwater General	WAR124553	City of Seattle	S Hinds Street CSO/SD	S Hinds Street SD	turbidity, pH

ID Number on Map 9-3	Permitted Facility	Facility Address	Permit Type	Permit No.	Outfall Owner	Outfall ID	Basin	Required Monitoring Parameters
17	Duwamish Properties Shoreside Support HQ	910 SW Spokane Street	Construction Stormwater General	WAR124667	Olympic Tug and Barge	6	B-6	turbidity, pH

Source: Ecology PARIS database (Ecology 2011) and EDR (2009). Table was updated February 2012. Outfall ID and Basins associated with each permit holder are based off physical location of facility within delineated basins.

[a] Ash Grove's individual industrial stormwater permit requires one sample of on-site catch basin solids to be sampled once per year and analyzed for arsenic, mercury, copper, lead, zinc, PCB, SVOCs (including phthalate), diesel- and motor oil-range total petroleum hydrocarbons (TPH), PAH, TOC, and grain size.

[b] Portions of Terminal 18 drain to city-owned outfall SW Florida Street SD, B-21.

aka – also known as
BOD – biological oxygen demand
CSO – combined sewer overflow
Ecology – Washington State Department of Ecology
FOG – fats, oils, and grease
NPDES – National Pollutant Discharge Elimination System
PARIS – Permit and Reporting Information System
PCB – polychlorinated biphenyl
PCC – Pacific Coast Container
SD – storm drain
SSA – Stevedoring Services of America
TSS – total suspended solids
USCG – US Coast Guard

9.3.1.2 Municipal Stormwater, CSO, and Multi-Sector General Permits

All public (i.e., City of Seattle-, Port of Seattle-, and USCG-owned) SD outfalls in the EW are covered under Phase I municipal permits or a federal Multi-Sector General Permit (MSGP). The municipal stormwater permit requires the development and implementation of a stormwater management program for separate SD systems owned or operated by the permittee. Implementation of the stormwater management program required under the permit constitutes reduction of pollutants to the maximum extent practicable during the life of the permit, as required in Section 402(p)(3)(B) of the CWA (Ecology 2006a).

The Port of Seattle is covered under the Phase I Municipal Permit as a Secondary Permittee. Secondary permittees are generally required to comply with all relevant conditions of the permit, including the specific requirements listed in Section S6, and with all relevant ordinances, rules, and regulations of the local jurisdiction(s) in which the Port of Seattle is located that govern construction and post-construction stormwater pollution prevention measures, including proper operations and maintenance of the stormwater infrastructure.

King County and City of Seattle CSO discharges are permitted under individual municipal NPDES permits. All King County CSOs located in the EW are covered under the West Point WWTP permit (NPDES No. WA-002918-1) (Ecology 2010b). The City of Seattle CSO located in the EW is regulated under NPDES Permit No. WA-003168-2 (Ecology 2010c). City of Seattle and King County EOF[120] events are reported to Ecology via Ecology's Environmental Report Tracking System. Any dry weather overflows (prohibited in NPDES permits), pump station failures, and blocked lines resulting from fats, oils, and grease; ragging;[121] or other reasons are routinely reported to Ecology's Water Quality Program. The City of Seattle and King County CSO control programs are described in Section 9.3.3.

USCG operates a facility on the northeast end of the EW that is covered under a federal MSGP. Appendix C of the MSGP states that federal facilities in the State of Washington, except those located on Indian Country Lands, are provided NPDES permit coverage by EPA

[120] King County does not have any EOFs in the EW.

[121] Ragging is the build-up of raggy components of raw sewage.

under the MSGP for stormwater discharges associated with industrial activity (EPA 2008a). The permit number provided for these facilities is WAR05000F.

9.3.1.3 Industrial Wastewater

There are no known or reported industrial wastewater discharges to the EW. Any new industrial wastewater discharges would be subject to NPDES regulations.

9.3.1.4 Construction Stormwater

Construction general stormwater NPDES permits are required for clearing, grading, and excavation activities that affect one or more acres and that will discharge into surface water. Permits are also required if Ecology determines that an activity may potentially contaminate surface waters or if a WQS is expected to be violated (Ecology 2010a). All construction projects located in the City of Seattle are also regulated under the City of Seattle Stormwater Code (see Section 9.3.2).

9.3.2 Municipal Stormwater Management

Both the City of Seattle's and the Port of Seattle's municipal stormwater permits require development of a stormwater management plan (SWMP). Some of the stormwater management requirements are different for the City of Seattle and the Port of Seattle in accordance with their respective permit statuses. The SWMPs prepared by the City of Seattle and the Port of Seattle address the following objectives:

- Protect water quality
- Reduce the discharge of pollutants to the "maximum extent practicable"
- Satisfy appropriate requirements of the CWA
- Meet state requirements to use all known, available, and reasonable methods to prevent and control pollution to waters of the state

Highlights of requirements and associated City of Seattle and Port of Seattle activities that are most relevant to the EW source control efforts are described in the following sections.

9.3.2.1 City of Seattle Stormwater Management Program and Related Activities

City-wide stormwater programs are described in the City of Seattle's SWMP (SPU 2010). Under the City of Seattle's Stormwater Code (Seattle Municipal Code [SMC] 22.800-22.808) the City of Seattle has authority to control discharges to the public drainage system, as well as direct discharges to the receiving water bodies in Seattle. SPU and the Seattle Department of Planning and Development (DPD) share responsibility for implementing the code. The code prohibits illicit discharges, spills, and illegal dumping; regulates stormwater discharges from new and redevelopment projects; and authorizes inspections, surveillance, and monitoring to determine compliance. The City of Seattle has also developed four Directors Rules that provide technical guidance on implementing the code (City of Seattle 2009a, b, c, d). Key elements of the City of Seattle Stormwater Code and specific city-wide programs that support source control in the EW are summarized below.

Source control/pollution prevention – The Stormwater Code requires responsible parties to implement source controls to prevent or minimize the amount of pollutants leaving a site or property. Source control requirements include eliminating illicit connections to SDs, performing routine maintenance for SD systems, properly disposing of fluids and wastes, properly storing solid wastes, implementing spill prevention and cleanup programs, and training staff. Specific requirements are described in the City of Seattle's Source Control Manual (City of Seattle 2009b). This portion of the code forms the basis for the business inspection program that SPU has implemented in the EW. SPU has also implemented a city-wide business inspection program. The city-wide program focuses primarily on stormwater issues in areas outside of the EW and LDW Superfund sites, where more extensive inspection programs have been implemented.

Stormwater controls for new and redevelopment projects – New and redevelopment projects, including public projects, are subject to the green stormwater infrastructure, water quality, and construction site stormwater pollution prevention requirements of the code.[122] Code requirements for qualifying projects include:

[122] Because the EW is a large receiving water body, projects are not required to implement flow controls unless they discharge to the combined sewer system.

- **Green stormwater infrastructure –** Projects with 7,000 square feet or more of land disturbing activity or 2,000 square feet or more of new plus replaced impervious surface must implement green stormwater infrastructure to the maximum extent feasible. Green stormwater infrastructure includes small on-site facilities that use infiltration, evapotranspiration, or stormwater reuse to control runoff.
- **Stormwater treatment –** New and redevelopment projects that generate more than 5,000 square feet of new or replaced pollution-generating impervious surfaces are required under the above-cited code to install stormwater treatment facilities such as wet/infiltration ponds, vaults, media filters, and biofiltration swales/strips. City of Seattle Stormwater Code requires these facilities to remove 80% of TSS from runoff as specified by Ecology in the 2012 Stormwater Management Manual and City of Seattle Stormwater Code. Because many of the pollutants found in urban stormwater tend to adhere to particles, these facilities are also effective in reducing the pollutant load.
- **Controls during construction –** All projects are required to implement effective BMPs to control erosion, sediment transport, and other pollutant discharges during construction (City of Seattle 2009b). Projects that will conduct a significant amount of excavation dewatering are also required to submit a dewatering plan for review and obtain a permit from the DPD as documented in SPU DR 02-04 (Side Sewer Permit for Temporary Dewatering).
- **Illicit Discharge Detection and Elimination Program –** The Illicit Discharge Detection and Elimination (IDDE) Program began in 2007 to detect and remove non-permissible discharges to the separated SD system in the City of Seattle. The program is implemented through ongoing business inspections, water quality complaint response, and spill response programs, as well as the EW source-tracing activities (Section 9.3.10). SPU also attempts to prevent illicit discharges through public education and outreach and building code enforcement. In 2009, SPU added a dry-weather field screening element to the IDDE Program to aid in locating illicit connections/discharges to the City of Seattle SD system. The field screening program uses field observations (e.g., color, odor, floatables), field analyses (e.g., turbidity, estimated flow, conductivity, pH, temperature, dissolved oxygen), and laboratory analyses of a select few chemical parameters (e.g., surfactants, ammonia, fluoride, potassium) and microbiological (fecal coliform bacteria) to characterize discharges. When flow is not present, the field screening program relies on field observations,

such as damage or staining, to suggest the presence of intermittent or transitory discharges. Threshold values have been developed to determine when to initiate source tracing at a particular location. Various tools such as dye testing, smoke testing, or closed circuit TV inspections are used to verify the locations of illicit connections. Once the tracing is completed, identified contaminant sources and/or illicit discharges and connections are addressed through removal or disconnection.

The IDDE program conducted work in the S Hinds Street storm drain system to confirm that stormwater from the Ash Grove Cement Company discharges to this City of Seattle-owned outfall. Prior to the IDDE investigation and SPU inspections, the company and Ecology had incorrectly assumed that this site discharged to the combined sewer system.

- **Spill Kit Program –** In 2004, SPU began a city-wide program offering free spill kits to local businesses that manufacture, store, use, or transport liquids as an incentive to improve on-site spill prevention and cleanup practices. Since the program began, SPU has distributed spill kits to nearly 170 businesses in the EW SD basin and combined sewer service area.
- **Street Sweeping –** Another activity that generally supports source control is the City of Seattle's street sweeping program. The City of Seattle has been sweeping streets in Seattle since the turn of the century. In 2011, SPU and the Seattle Department of Transportation (SDOT) modified the street sweeping program to achieve higher water quality benefits. Sweeping is conducted by SDOT staff with funding for the water quality improvements provided by SPU. Modifications include using high-efficiency, regenerative air sweepers on arterial streets in areas served by separated SDs, standardizing sweeping frequency in separated SD basins to every 1 to 2 weeks, and reducing sweeper speed to enhance particle pickup. Streets in the EW study area that are routinely swept are shown on Map 9-4. Approximately 1.6 miles of roadways draining to the EW are swept on a weekly basis, and 24 miles of roadways are swept every other week. Map 9-4 shows all sweeping routes within the separated storm and combined sewer basins in the EW. Many of the streets located in the EW combined sewer basin are in the partially separated portion of the City of Seattle's drainage/wastewater system. In these areas, the streets typically drain to a separated SD system, and these separated systems often discharge to areas outside of the EW

(e.g., Lake Washington and LDW). Roadways that do not drain to the EW are not included in the mileage count provided above.

9.3.2.2 Port of Seattle Stormwater Management Program

The Port of Seattle Seaport and Real Estate properties in the City of the Seattle (the Port) are covered under the Phase I Municipal Stormwater Permit as a secondary permittee. Similar to the City of Seattle, the Port of Seattle also implements and annually updates its SWMP in compliance with the requirements of the Phase I Permit. The Port of Seattle's SWMP addresses stormwater management on permit-covered properties (Phase I properties) and describes specific activities to be implemented to meet each of the applicable permit sections. Some SWMP elements are not EW-specific and include general activities furthering education and public involvement and participation throughout the Seattle community, while others include monitoring and reporting activities. Key elements of the Port of Seattle's SWMP that sustain and enhance source control and are directly relevant to the EW are further summarized below. These activities are conducted in addition to NPDES activities required by tenants' industrial general permit requirements. Additional details regarding the Port of Seattle's stormwater management activities are described in the SWMP (Port of Seattle 2011e). These activities include:

- **Education and outreach –** The Port of Seattle implements an education and outreach program that uses a variety of methods to target the audiences to educate them to help reduce or eliminate behaviors and practices that cause or contribute to adverse stormwater impacts.
- **IDDE Program –** The Port of Seattle implements a program to detect, remove, and prevent illicit connections and illicit discharges, including spills, into SDs owned or operated by the Port of Seattle.
- **Construction site stormwater runoff control –** Section S6.E.4 of the permit requires compliance with City of Seattle Stormwater Code, and where applicable, Ecology NPDES construction stormwater requirements for controlling runoff and pollution from construction sites. The Port of Seattle has adopted many of the construction stormwater pollution prevention measures similar to those described for the City of Seattle above.

- **Post of Seattle construction stormwater management for new and redevelopment –** Under S6.E.5 of the Phase I permit, the Port of Seattle complies with City of Seattle stormwater code requirements and coordinates with the City of Seattle on projects owned and operated by Port of Seattle tenants that discharge into the City of Seattle's MS4.
- **Operations and maintenance –** The permit (Section S6.E.6) requires the Port of Seattle to prepare an operations and maintenance (O&M) manual for all stormwater BMPs that are under its functional control and that discharge the Port of Seattle-owned SDs. As part of O&M, the Port of Seattle conducts parking lot and street sweeping and catch basin cleaning in accordance with the O&M manual. Maintenance of stormwater treatment facilities, inspection of suspected problems at stormwater treatment facilities, and other structural BMPs are also conducted.
- **Source control program for existing development –** Under S6.E.7, the Port of Seattle is required to prepare and implement SWPPPs for all Port of Seattle-owned lands (except environmental mitigation sites that are not covered by an NPDES permit).

As part of its source control program for existing development, the Port of Seattle places a high emphasis on coordinating with and providing assistance to its various tenants in the development and implementation of SWPPPs and effective BMPs. In accordance with their municipal permit, the Port of Seattle completes annual inspections of 15% of its land, covering all Port properties over time. These properties are also assessed through the ECAP program and tenants are also regulated under their own industrial general permits.

9.3.3 CSO Control Programs

An important element of source control is the use of discharge permits issued by Ecology. These permits provide requirements for controlling the frequency, volume, and duration of CSO discharges. As part of the City of Seattle and King County NPDES permits, Ecology requires “the greatest reasonable reduction of combined sewer overflows at the earliest possible date” (RCW 90.48.480). Ecology defined "greatest reasonable reduction" to mean "control of each CSO such that an average of one untreated discharge may occur per year" (WAC-173-245-020 (22). Ecology also requires that CSO planning documents specify the means for complying with these regulations.

Prior to 1969, Metro created the regional system to capture 90% of the raw sewage discharges and direct them to the WWTP. Starting in 1969, large portions of the public and private sewer lines were connected into the Elliott Bay Interceptor line, where wastewater is transported to the treatment plant. However, because the older collection system was built to collect both sanitary wastewater and stormwater, relief points (CSO discharge outfalls) in the system were created. Significant progress has been made in reducing CSO events and discharge volumes over the past decades. As described in Section 9.2, wastewater from nearby areas historically flowed from sewers into surface waters. During the 1950s, largely untreated amounts of wastewater totaling more than 20 billion gallons were discharged into Puget Sound waters, the Duwamish River, Green Lake, Lake Union, and Lake Washington (King County 2012). By the 1980s, initial CSO control activities and projects by Metro (now King County) had reduced the CSO baseline to an average of 2.3 billion gallons per year (system-wide). The construction of CSO control projects since then reduced the overall CSO volume to an average of less than 1 billion gallons per year by 2005, and additional projects have subsequently reduced the number of CSO events and discharge volumes even further. In order to meet CSO permit stipulations, King County has issued annual CSO control reports since the 1980s. Discharge volumes were first reported for the 1989 to 1990 reporting period (Metro 1990), and the frequency if discharge events was subsequently included beginning with the 1990 to 1991 period (Metro 1991). Since this period, a number of CSO control projects have been completed and discharges have been significantly reduced.

Under their permits, both King County and the City of Seattle monitor the frequency, volume, and duration of CSO discharges, and the magnitude of storm events at the time of CSO discharges. Monitoring information is submitted to Ecology in monthly discharge monitoring reports and the annual CSO control reports. In addition to providing information on the annual frequency and volume of CSO discharges, the annual reports discuss accomplishments achieved in reducing CSO discharges and explain additional CSO reduction efforts that will be made in the coming year (WAC 173-245-090(1)). CSO control annual reports for King County can be found on King County's CSO page[123] (King County 2012).

[123] http://www.kingcounty.gov/environment/wastewater/CSO/Library/AnnualReports.aspx

The City of Seattle also issues annual CSO control reports, which can be found on the City's website under environment and conservation[124] (SPU 2013).

In addition to discharge monitoring reports and annual CSO reporting requirements, both the City of Seattle's and King County's NPDES permits require the maintenance of long-term control plans and submittal of amendments to CSO reduction plans at the time of NPDES permit renewal. Management practices and policies, called the "Nine Minimum Controls," detailed in both the City of Seattle and King County permits, must also be implemented to reduce CSO frequency, volume, duration, and pollutant loads. The Nine Minimum Controls require the following:

- Implementation of O&M programs for the combined sewer systems
- Maximized use of the storage capacity of the wastewater collection system to reduce CSO discharges
- Use of CSO controls (City of Seattle) and pre-treatment programs (King County) to minimize nondomestic discharges to CSOs
- Maximization of wastewater flow to WWTPs during wet-weather events
- Prohibition of CSO discharges during dry weather, with reporting requirements in the event of a dry weather CSO discharge
- Control of solid and floatable materials in combined sewer system wastewater
- Implementation of pollution prevention plans
- Public notification of CSO events
- Monitoring of CSO outfalls for discharges

In addition to the NPDES requirements, King County and the City of Seattle have unique CSO control programs, which are described in the following subsections.

9.3.3.1 King County

King County's CSO control plan is periodically updated to incorporate current technologies and BMPs, and to integrate CSO control with other Wastewater Treatment Division capital improvement programs to monitor and reduce CSO discharges. Strategies incorporated into

[124] http://www.seattle.gov/util/EnvironmentConservation/Projects/DrainageSystem/SewageOverflowPrevention/ReportsRegulations/index.htm

the control plans include managing pollution at its source, maximizing the use of existing system capacity, monitoring and modeling flows in the system, and constructing new CSO control facilities. An overview of King County's CSO control program is available online (King County 2012).

King County routes combined sewer flows that would otherwise be discharged during CSO events to the regional plants for secondary treatment or CSO (primary) treatment, when possible, to provide the highest level of treatment. In some areas of the system where flows cannot be conveyed to the regional plants, the flows are either conveyed to satellite CSO treatment facilities[125] for treatment prior to discharge, or they overflow at various CSO outfalls in the collection system. Flow control is achieved with the use of an automated control system that manages flows through the conveyance system so that during storm events, the maximum amount of wastewater is contained in pipelines and storage facilities until it can be conveyed to a treatment plant. CSOs discharge untreated wastewater only when flows exceed the capacity of these systems (King County 2011b).

Construction of King County CSO control facilities in the region began in the late 1970s. Early projects involved sewer separation, flow diversion, and storage tunnels. For example, the Lander/Hanford/Bayview conveyance upgrade and stormwater separation project was completed in the early 1990s to reduce CSO volumes from both the Lander and Hanford CSO basins. So far, about $389 million[126] has been spent by King County to control CSO frequency, volume, duration, and quality, and another $148 million[127] is being spent on current projects. In September 2012, King County adopted an amended Long-Term CSO Control Plan (King County 2012), which commits to another $711 million to be spent to achieve CSO control by 2030. Its proposed project for EW CSOs will consolidate the flows from Hanford and Lander with the flows from two waterfront CSOs, King and the Kingdome, into a single satellite CSO treatment facility. This facility is proposed to use a high-rate sedimentation technology and ultraviolet disinfection. The high-rate sedimentation processes are demonstrated to remove approximately 75 to 80% of all solids

[125] At this time, there are no satellite treatment facilities for potential flows to the EW.

[126] In 2010 dollars.

[127] In 2012 dollars.

and associated contaminants, as well as some soluble metals. The plans for this facility will be subject to refinement during detailed design and permitting phases of the proposed project, and final plans may include conveyance expansion, increased storage capacity, and/or treatment (King County 2011b). Since 1988, when monitoring and measuring of CSO flows began, King County flow control efforts have reduced overall CSO volumes from an estimated 2.4 billion gallons per year to approximately 800 million gallons per year system-wide.

9.3.3.2 City of Seattle

The City of Seattle also has a CSO reduction program and has been reporting CSO events and associated discharge volumes on an annual basis as required by its NPDES permit. Since 1980 (the baseline for City of Seattle CSO modeling), the City of Seattle has reduced the annual volume of CSOs from approximately 400 to less than 100 million gallons per year, based on 2008-2009 data (Tetra Tech 2010). Similarly, overflow frequency among all City of Seattle CSOs has declined from an estimated 2,800 events per year in the 1980s to approximately 200 events per year. In the EW, SPU is working with King County on control options for overflows at the Hinds CSO.

The City of Seattle's plan for reducing CSOs (Tetra Tech 2010) focuses on reducing CSOs at critical sites through a cost-effective blend of traditional and sustainable infrastructure. The path forward involves a four-pronged approach: 1) optimize existing CSO infrastructure through low-cost retrofits; 2) construct large CSO infrastructure projects to reduce overflows to Lake Washington; 3) construct natural "green" solutions to reduce CSOs throughout the City of Seattle; and 4) develop a long-term control plan to control all remaining CSOs. The long-range plan is in progress and scheduled to be adopted in 2014. Information about the City of Seattle's long-range CSO control plan is available at the SPU website (SPU 2011a).

9.3.4 Compliance and Inspection Programs

Compliance and inspection programs are conducted by various agencies and NPDES permit holders to identify and manage potential sources of contaminants that are typically generated from business practices within the EW drainage basin. The Port of Seattle, King County, and City of Seattle conduct various inspections/site assessments, based on their applicable regulatory authority, to enhance or assess compliance of permitted dischargers. These inspection locations are presented on Map 9-5. The results of the King County, City of

Seattle, and Port of Seattle inspections are presented Appendix L, Tables L-1 though L-3, respectively.

9.3.4.1 Ecology NPDES Inspections

Ecology NPDES inspections assess compliance with permit requirements, which typically include an assessment of the adequacy of BMPs. These inspections are in addition to stormwater monitoring and inspection activities required of the permittee under the permits. Ecology's goal is to inspect facilities at least once every 2 years and not less than once every permit cycle (5 years) (Cargill 2012). There are 14 facilities with industrial stormwater permits for discharges to the EW, but these are only a subset of the total number of industrial and commercial facilities within the EW drainage area.

9.3.4.2 King County Industrial Waste Program

Inspections conducted under the King County Industrial Waste Program (IWP) identify industrial pre-treatment issues and the need for IWP staff to work with the respective businesses to assist them in implementing corrective actions necessary to comply with federal and local pre-treatment regulations. In addition to broader, programmatic compliance issues, the IWP staff also coordinate with Ecology, the City of Seattle, the Port of Seattle, and other internal King County programs to bring additional focus to source control concerns.

Under the CWA, local wastewater collection and treatment facilities were granted local pre-treatment authority to regulate the types and amounts of chemicals discharged to their sanitary sewer systems. In April 1981, Ecology authorized Metro as the local pre-treatment authority in Seattle and surrounding areas; this authority later shifted to King County through a series of changes in local government. King County established the IWP in 1969, which could issue permits to facilities that discharged to the sanitary sewer system. This program became an EPA-delegated program consistent with the requirements of the CWA in 1981.

The IWP enforces local discharge limits and regulates the discharge of industrial wastewater to the sewer system through the issuance and enforcement of discharge permits. The activities of the IWP serve to reduce industrial loading to the sewer system and to CSOs in the event of discharges to the EW. Requirements may include pre-treatment before discharge and BMPs. King County enforces both federal standards and local limits, which

ever are more stringent. Local limits were established to protect sewer facilities and treatment processes, public health and safety, biosolids quality, and waters receiving the discharge to enable King County to comply with its own NPDES permits. Regulated materials include heavy metals; flammable materials; sulfides; cyanide; pH; fats, oils, and grease; and organic compounds. Since it began, the program has achieved significant improvements in the quality of wastewater received by King County's WWTPs and, thus, in CSO discharges.

The IWP issues industrial wastewater discharge permits and authorizations to companies that have industrial processes with the potential to adversely affect King County's WWTPs. The type of discharge approval issued by the King County Industrial Waste Program (KCIW) to industrial facilities is determined by the nature of the business, the volume and characteristics of the wastewater, and potential risk to the system. Types of approvals are as follows:

- **Waste Discharge Permit**: issued to companies or facilities (defined as significant industrial users [SIUs]) if they meet one or more of the following criteria:
  - Subject to federal categorical standards
  - Discharge more than 25,000 gallons per day (gpd)
  - Represent an apparent risk to the publically owned treatment works (POTWs)
  - Warrant significant regulatory attention for some reason
- **Major Discharge Authorization (Major DA)**:
  - Wastewater discharge generally less than 25,000 gpd but more than 1,000 gpd
  - Not subject to federal categorical standards
  - Represent minor risk to POTW
  - Warrant pollutant(s) self-monitoring and reporting
- **Minor Discharge Authorization (Minor DA)**:
  - Wastewater discharge generally less than 25,000 gpd but more than 1,000 gpd
  - Not subject to federal categorical standards
  - Represent minor risk to POTW

- Letter of Authorization (LA):
  - Wastewater discharge generally less than 1,000 gpd
  - Temporary/short-term discharge approval

Permits require companies to monitor their own discharges. A list of industrial facilities in the EW study area that currently hold industrial waste discharge permits and authorizations governed under the IWP is provided in Table 9-4 and shown on Map 9-6.

Table 9-4
Summary of Current Industrial Waste Discharge Permits and Authorizations in the East Waterway Study Area

Permit No.	Facility Name	Street	Facility Type	Contaminants Monitored
Waste Discharge Permits				
7238-04	Alaskan Copper Works – 6th Avenue	3200 Sixth Avenue S	metal finishing – CFR 433	metals, volatile organics, semi-volatile organics, cyanide, pH, discharge volume
7201-04	Alaskan Copper Works – Marginal Way	3600 E Marginal Way S	metal finishing – CFR 433	metals, volatile organics, cyanide, pH, discharge volume
7116-05	Darigold, Inc. – Rainier Plant	4058 Rainier Avenue S	food processing – dairy	floatable FOG, pH, biochemical oxygen demand, total suspended solids, discharge volume
7577-04	Pacific Iron and Metal	2230 Fourth Avenue S	metals recycling	non-polar FOG, metals, semi-volatile organics, pH, discharge volume, PCB
7820-01	Pepsi-Cola Company	2300 26th Avenue S	food processing - soft drinks	pH, biochemical oxygen demand, total suspended solids, discharge volume
7595-05	Rabanco Recycling Company	2733 3rd Avenue S	solid waste transfer facility	non-polar FOG, metals, pH, discharge volume
7851-02	City of Seattle, SDOT – Spokane Street Viaduct Widening Project	Spokane Street S from Sixth Avenue to E Marginal Way S	construction dewatering	non-polar FOG, volatile organics, pH, discharge volume, settleable solids
7850-01	WSDOT – Viaduct – S Holgate Street to S King Street Viaduct Replacement – Stage 2	Viaduct – S Holgate Street to S King Street	construction dewatering	non-polar FOG, metals, discharge volume, dissolved sulfides, pH, settleable solids, turbidity
Major Discharge Authorizations				
158-03	Cargill Inc. – Corn Milling Division	2 S Horton Street	container washing	pH, discharge volume
4208-01	Lee and Eastes Tank Lines, Inc.	2418 Airport Way S	vehicle washing	non-polar FOG, discharge volume, pH
4008-03	Northwest Cascade Inc. – Seattle	3414.5 Second Avenue S	chemical toilet	volatile organics, pH,

Permit No.	Facility Name	Street	Facility Type	Contaminants Monitored
4201-01	Rainier Commons, LLC – Old Rainier Brewery Site	3100 Airport Way S	general type	PCB
415-04	City of Seattle – SPU – Halladay Decant Station (DA 415)	20th Avenue W and W Halladay Street	decant station	non-polar FOG, volatile organics, pH, discharge volume, settleable solids
4194-01	City of Seattle – Seattle City Light – South Service Center	3613 Fourth Avenue S	vehicle washing	PCB
4069-02	South Center Oil	3215 Fourth Avenue S	groundwater remediation - petroleum	non-polar FOG, volatile organics, discharge volume
Minor Discharge Authorizations				
662-03	Amtrak National Railroad Passenger Corporation	240 S Holgate Street, Bldg B	chemical toilet	discharge volume
745-02	ECO Waterborne Coatings	420 S Hinds Street	general type	na
448-03	Franz – Gai's (PKA Langendorf)	2901 Sixth Avenue S	food processing – bakery	na
636-04	Franz Bakery – Weller Street (aka Gai's Bakery)	2006 S Weller Street	food processing – bakery	na
809-01	Fuji Food Products Inc.	1914 Occidental Avenue S, No. A	food processing – other	na
712-02	Harborview Medical Center	325 Ninth Avenue	hospital	na
721-02	Hospital Central Services Association, Inc.	1300 E Columbia Street	laundry – linen	na
757-02	J.D. Ott Company, Inc.	2244 Sixth Avenue S	machining	na
704-03	Labcorp/Dynacare	James Tower, 550 17th Avenue, Suite 300	laboratory	na
635-03	Mondo and Sons	4225 Rainier Avenue S	food processing – meats	na
748-02	Photographic Center Northwest	900 12th Avenue	photo processing	na
799-01	Recycling Depot	851 Rainier Avenue S	metals recycling	na
801-01	Sound Transit Operations and Maintenance Facility	3407 Airport Way S	transportation facility	na
707-02	Swedish Medical Center – Cherry Hill	500 17th Avenue	hospital	na
706-02	Swedish Medical Center – First Hill	747 Broadway Avenue	hospital	na

Permit No.	Facility Name	Street	Facility Type	Contaminants Monitored
749-02	Thanh Son Tofu	118 12th Avenue	food processing – tofu	discharge volume
746-02	University of Washington – Consolidated Laundry	2901 27th Avenue S	laundry – linen	na
818-01	VA Puget Sound Healthcare System – Seattle Division	1660 S Columbian Way	hospital	na
807-01	WG Recycling Center	3223 Third Avenue S, Suite 100b	general type	na
Letters of Authorization				
11281-01	412 Broadway Apartments, LLC Construction Site	412 Broadway	construction dewatering	discharge volume, settleable solids, pH
11110-01	Austin Mac Inc.	2739 Sixth Avenue S	metal fabrication	na
11017-01	Beacon Hill Dental Associates	3051 Beacon Avenue S	dental office	na
11272-01	Capitol Hill Housing – 12th and Jefferson Construction Site	500 12th Avenue	construction dewatering	discharge volume, settleable solids, pH, non-polar FOG, BTEX
11074-01	ColorGraphics	1421 S Dean Street	printing	pH
10906-01	Insibnia	2301 Sixth Avenue S	construction dewatering	na
11068-01	Lambert Marble & Tile Works, Inc.	700 S Forest Street	general type	na
10454-01	Lighthouse For the Blind, Inc.	2501 S Plum SE	manufacturing	na
10056-01	Roadway Express	3300 Sixth Avenue S	transportation facility	na
10904-01	Seattle Fire Station No. 13	3601 Beacon Avenue S	vehicle washing	na
11179-01	Seattle University – Onsite Compost Facility	769 13th Avenue	composting – yard waste	na
11012-01	System Transfer and Storage Company	2400 Sixth Avenue S	general type	na
11165-01	Young Corporation	3231 Utah Avenue S	metal fabrication	discharge volume, metals

aka – also known as
BTEX – benzene, toluene, ethylbenzene, and xylene
CFR – Code of Federal Regulations
FOG – fats, oils and grease
na – not applicable
PCB – polychlorinated biphenyl
SDOT – Seattle Department of Transportation
WSDOT – Washington State Department of Transportation

In support of this program, King County staff inspect facilities with discharge permits at least once per year and sample wastewater from all permitted companies at least twice per year. Follow-up inspections and wastewater sampling are conducted to verify that identified conditions causing violations are corrected and eliminated. King County bases the enforcement response to each violation on a number of factors, including the severity and duration of the violation and the discharge and enforcement history of the facility or business (King County 2011b, 2006b). King County inspects companies with discharge authorizations at least once every 5 years, but does not regularly conduct sampling, relying instead on self-monitoring at these companies.

King County's IWP also implements the Key Manhole Program. The goals of the program are: 1) to reduce the level of heavy metals in biosolids; 2) to decrease the chance of NPDES violations; 3) to track potential sources of spills and slug loads; and 4) to develop technical expertise of the entire King County wastewater collection system.

Through 2010, Key Manhole Program staff performed weekly reviews of daily influent metals data. This procedure enabled the program to decrease the response time in detecting slug loads, to reduce the chance of NPDES violations, and to aid in the prediction of biosolids quality. IWP also uses the program to investigate potential sources of unusually high pollutant loads (slug loads) and to perform surveillance monitoring when industrial users are suspected of illicit discharges. During 2010, staff received and responded to 19 different situations within King County's service area involving unusual events, such as solvent or gasoline odors, unusual color, visible sheen, high or low pH, high atmospheric or dissolved sulfides, grease, and or other blockages at King County treatment plants and in the sewer conveyance system.

9.3.4.3 City of Seattle Business Inspection Program

SPU's business inspection program in the EW focuses on providing technical assistance and enforcing the source control requirements of the City of Seattle Stormwater Code. Under the City of Seattle Stormwater Code, for all real property (i.e., all lands including improvements, every estate, interest and right, therein, including terms by way of judgment, mortgage, or otherwise, See SMC Section 3.110.020), the City requires property owners to implement and maintain source controls to prevent or minimize the amount of pollutants leaving their property. Source control requirements are specified in the City of Seattle's source control

technical requirements manual (City of Seattle 2009a). There are six city-wide BMPs that are required for all real property in Seattle, as follows:

1. Eliminate illicit connections to storm drains
2. Perform routine maintenance for drainage system
3. Dispose of fluids and wastes properly
4. Proper storage of solid wastes
5. Spill prevention and cleanup
6. Provide oversight and training for staff

In addition to the six city-wide BMPs, the City of Seattle's source control manual also requires certain commercial and industrial activities that drain to the MS4 to implement additional BMPs for site-specific pollution-generating activities. There are currently an additional 38 BMPs for businesses to implement depending on pollution-generating activities. Businesses and public agencies are required to fill out a worksheet included in the City's source control technical requirements manual. A list of site-specific BMPs is provided in Appendix L.

In addition to stormwater issues, inspectors evaluate on-site pollution prevention practices associated with hazardous and industrial waste management and spill control. Following the inspection, the business is notified in writing of any problems found during the inspection and any appropriate BMPs it is required to implement as a result of those problems. The property is then re-inspected after 30 days to confirm that the owner/operator has implemented the necessary changes. Most businesses implement the required changes, but for those that do not, SPU implements a progressive enforcement process. Under SMC 22.808, SPU has authority to issue penalties and notices of violation to obtain compliance with the City of Seattle Stormwater Code.

Business inspections in the EW study area began in 2003 under a joint program with King County. The joint program was designed to minimize the disruption to businesses by conducting a single inspection that covered stormwater, hazardous waste, and industrial waste, rather than having representatives from each program conduct individual inspections. All inspections were conducted under the existing code authorities of each jurisdiction. Inspectors from King County and SPU participated in a cross-training program to learn about

each other's program requirements. Between 2003 and 2005, City of Seattle and King County staff conducted 628 inspections at 376 businesses. Sites were evenly distributed between the combined sewer system and the separated SD system. The majority of the sites inspected in the separated SD system were located in the S Lander Street SD and S Hinds Street SD basins. SPU currently conducts inspections of NPDES-permitted facilities or tenants on Port of Seattle properties only where those sites discharge to the City of Seattle-owned SD system. The inspection locations are presented in Map 9-5.

In 2006, SPU took the lead in the EW business inspection program, with King County providing technical assistance, as needed, for industrial waste and hazardous waste-related issues. King County also continues to conduct routine inspections as part of its ongoing IWP as described above. In 2008, SPU began ranking businesses based on information obtained during the initial inspections to help prioritize business inspections in the EW. Sites were ranked high, medium, or low based on their pollution-generating potential. The rankings, which focus on businesses that discharge to the separated storm drain system, were assigned based on the numbers of corrective actions identified during the initial inspections, as well as drive-by assessments conducted by City of Seattle inspectors. A total of 230 businesses have been ranked to date. Forty-four of the ranked sites were identified as high priority, 85 sites were ranked as medium priority, and 101 sites were ranked as low priority. SPU re-inspected all of the high- and medium-ranked sites in 2006 through 2010.

As of 2010, a total of 1,288 inspections were conducted at 635 businesses in the EW. Businesses inspected between 2003 and 2010 are shown on Map 9-5. Corrective actions were required at 342 of the 439 sites (80%) where full inspections were conducted. SPU tracks 26 types of corrective actions in four program categories (hazardous waste/material management, spill control/prevention, industrial waste management, and stormwater management) in its business inspection database. Problems occurred most often with businesses' spill prevention/control (45% of total corrective actions) and stormwater management (38% of total corrective actions) practices. The most common problems found during business inspections are listed below:

- Lack of spill prevention/control plan (17%)
- On-site SD system needs cleaning (16%)
- Inadequate spill response materials (14%)

- Inadequate employee training in spill response (13%)

9.3.4.4 Port of Seattle Environmental Compliance Assessment Program

The Port of Seattle has a tenant assessment program aimed at maximizing environmental regulation compliance, including compliance with stormwater permits. In the EW, tenant activities include container storage and handling and shipping operations. The Port of Seattle uses assessment visits to observe activities that can affect stormwater discharges and oversee the implementation and operation of appropriate BMPs. These inspections also allow Port of Seattle staff to observe any hazardous or dangerous waste-generating activities, inspect usage and storage of hazardous materials, and investigate any other environmental concerns including air quality, noise, and impacts on neighbors and surrounding communities.

As part of their leases, the Port of Seattle requires tenants to apply for and obtain their own permits where applicable for stormwater management and air discharges, and to write their own plans where applicable for industrial discharges to King County sewers and any spill prevention, control, and countermeasures. Port of Seattle tenants with their own industrial stormwater general permits include SSA at T-18, T-30, and PCC Logistics at T-104. These tenants operating under general stormwater permits are required by Ecology to implement the requirements of their industrial stormwater general permits.

The Port of Seattle has a multi-phased tenant compliance program that includes an environmental review of all new and renewed tenant leases, a walk-through of all new tenant facilities upon occupancy and exit, and, depending on their activity, periodic inspections. The Port of Seattle conducts Environmental Compliance Assessment Program (ECAP) assessments for all of its Seaport property, including vacant or Port of Seattle-operated lands, with a target of 30 assessments per year. Some Port of Seattle tenants do not have industrial activities, so some assessment categories such as hazardous waste management may not apply. With ECAP, the Port of Seattle has a cooperative compliance program through which it communicates potential concerns with tenants, including responsiveness and technical assistance. The ECAP program also serves as a risk management tool to ensure that Port of Seattle tenants are complying with all relevant local, state, and federal environmental regulations. For each ECAP assessment, the Port of Seattle completes a tenant inspection form. The information on the completed form is entered into the Port of

Seattle's electronic database for the specific property and tenant to provide information for follow-up and future visits.

Upon completion of the assessment, the Port provides the tenant with a summary letter of results and recommendations for corrective actions with links to appropriate guidance. The Port of Seattle works directly with the tenant to complete any corrective action recommendations outlined in the summary letter and guidance documentation provided. The Port of Seattle passes on violation concerns if the tenant refuses to cooperate or correct the deficiency. To date, this has not been determined necessary based on inspections conducted on the EW, as issues have been minor in nature and the tenants have been receptive to the program and its findings. In addition, these compliance reviews are incorporated in lease and tenant management discussions with tenants to maximize compliance.

9.3.5 Operations and Maintenance Programs

9.3.5.1 King County

King County implements proper operation and maintenance programs for the sewer system and all CSO outfalls to reduce the magnitude, frequency, and duration of CSOs. The program employs regular sewer inspections; sewer, catch basin, and regulator cleaning; equipment and sewer collection system repair or replacement, where necessary; and disconnection of illegal connections.

Facility operation is managed by West Point WWTP staff using a supervisory control and data acquisition system, which provides monitoring and control capabilities for the treatment plant collection systems. Asset management programs are implemented by West Point WWTP and South WWTP; and collection system staff maintain CSO outfalls, regulator stations, and pump stations. Collection system staff inspect sewers on a specified schedule and perform corrective actions when deficiencies are found. Maintenance schedules and records of visits are available for inspection on request.

9.3.5.2 City of Seattle

The SPU Field Operations Division is responsible for operating and maintaining the City of Seattle drainage and wastewater systems. Catch basins in the drainage system are inspected each year and cleaned when the depth of sediment accumulation in the sump is within 18 in.

of the lowest pipe entering or exiting the structure, or if the sump is more than 60% full, whichever is less. SPU has also implemented a preventative maintenance program in the wastewater collection system to routinely inspect and clean or repair the system. Inspection schedules are based on an evaluation of critical system components to ensure effective operation of the system.

9.3.5.3 Port of Seattle

Most Port of Seattle-owned areas within the EW are tenant-controlled areas. Therefore, tenants have their own NPDES permits that address maintenance in accordance with their own specialized SWPPPs, as required by the applicable permit. These individual SWPPPs refer back to the Port of Seattle O&M manual or to City of Seattle maintenance requirements.

A few areas on the EW that are not tenant-controlled include former T-25 (now part of T-30) and T-102. These areas are managed under the Port of Seattle's NPDES municipal permit. The Port of Seattle conducts its O&M program in accordance with the NPDES permit. The objective of the program is to ensure that all BMPs continue to function properly on properties under the Port of Seattle's functional control.

Port of Seattle O&M activities are divided into the following six categories:

- General housekeeping (street sweeping)
- Storm system facilities maintenance (catch basin cleaning and routine maintenance)
- Fleet and facility maintenance (cleaning, washing, storage, etc.)
- Landscaping (vegetation management and erosion control)
- Small works projects BMPs
- Pavement management

9.3.6 Site Cleanup and Associated Programs

Several state and local programs exist, in addition to the federal CERCLA program, to address the identification and cleanup of contaminated sites. Some of these programs are described below.

9.3.6.1 Ecology Toxics Cleanup Program

The Toxics Cleanup Program (TCP) is the Ecology program that manages the cleanup of contaminated sites caused by releases of hazardous substances to soil, groundwater, surface waters, and sediments. Legal authority for the TCP is derived from Washington's MTCA regulations. Ecology review of cleanups under the MTCA regulations can be provided under formal Agreed Orders, Consent Decrees, and Enforcement Orders, or under Ecology's Voluntary Cleanup Program. Responsible parties can also implement cleanups under MTCA as Independent Remedial Actions without formal Ecology review.

Ecology's TCP includes management of cleanups at sites contaminated by leaking underground storage tanks (LUST). Ecology has special programs to address cleanup of Aquatic Lands (i.e., contaminated sediments) and Brownfields. Map 9-7 presents sites located within the EW study area that have reported releases of hazardous substances that are subject to management under TCP programs, including both completed and ongoing investigations and cleanup actions as identified in state and federal environmental databases. These sites are further detailed in Appendix G, Table G-1. The TCP is an important source control tool for the EW because it is a means by which cleanup of upland contaminated soil and groundwater can be funded and implemented.

9.3.6.2 King County Local Hazardous Waste Management Program

The King County-wide hazardous waste management program (HWMP) complements King County's IWP by educating local residents and small businesses on methods to reduce hazardous waste and prevent water pollution. The HWMP is a non-enforcement program (i.e., does not issue permits or fines) that provides technical assistance throughout King County and includes the EW study area drainage basins. The program activities can also be a useful tool for identifying potentially contaminated sites and referring them to other appropriate agencies (e.g., Ecology or EPA) for follow-up action. The program is a cooperative effort among King County's Department of Natural Resources and Parks (the Solid Waste and Water and Land Resources Divisions), Public Health, the City of Seattle, and 38 cities throughout King County. The program implements the King County area's moderate risk waste plan adopted in 1990 by King County and all of the regional cities.

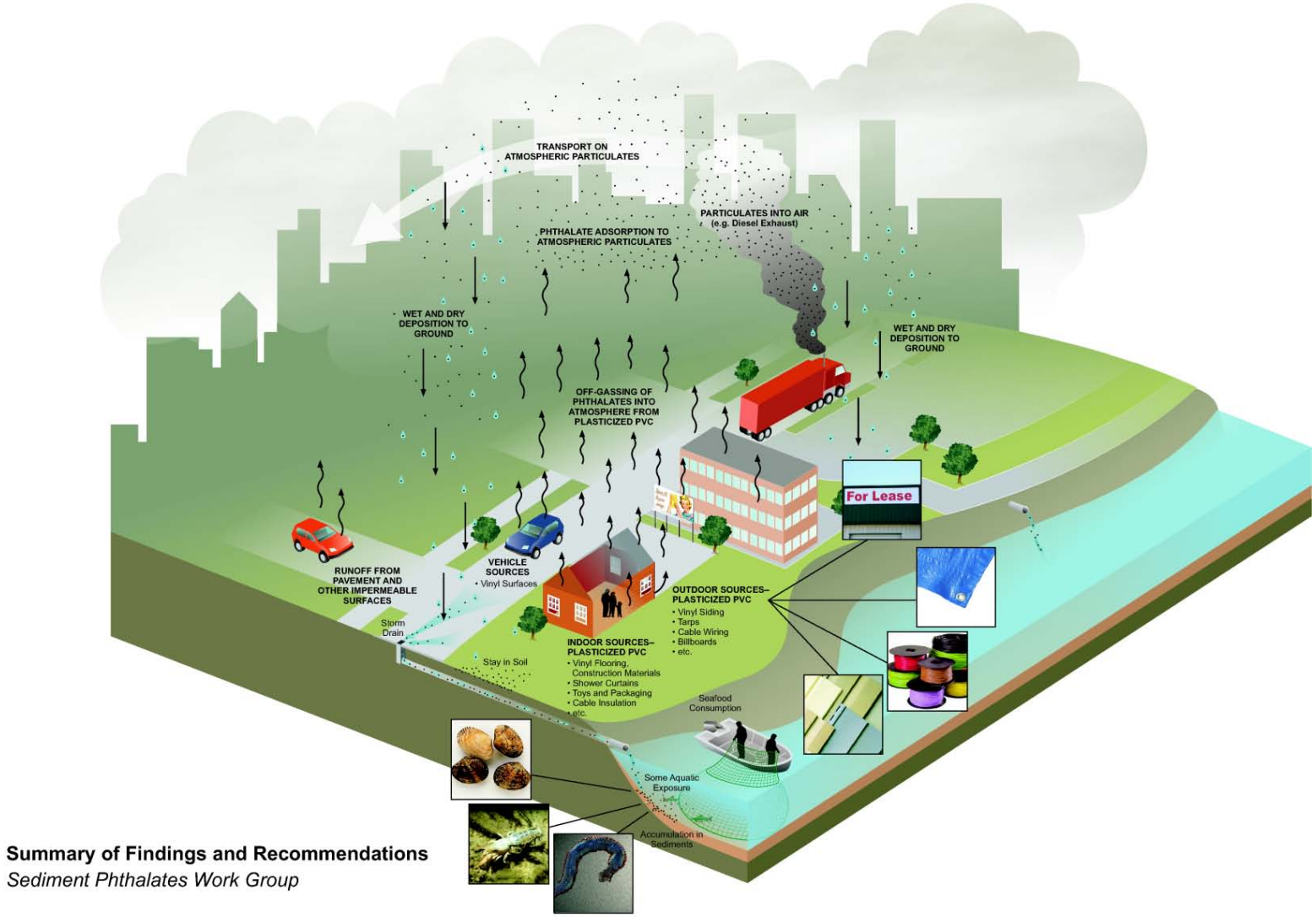
The regional HWMP targets industry groups and geographic areas to provide technical assistance. Program staff make site visits to small businesses throughout King County and all

of its incorporated cities to observe operating practices and make recommendations related to hazardous product storage and waste disposal. Program staff also work closely with many business associations to promote best practices. When problem materials, such as lead, mercury, and solvent-based paints, are found to be disposed of in the sanitary sewer, program staff advise the company on correct practices. When necessary, staff can refer the matter to the IWP for regulatory action. In 2010, approximately 1,000 businesses (system-wide) were visited on site, with many others contacted via outreach to business and community groups. The EW area is included in the general coverage of the program; in addition to its general outreach to businesses, the HWMP has focused on auto body and repair shops, machine shops, laboratories, property managers, nail salons, and dry cleaners, among numerous business types addressed.

9.3.6.3 Sediment Phthalates Work Group

The SPWG was a voluntary work group that included representatives from the City of Seattle, the City of Tacoma, King County, Ecology, and EPA (Ecology 2007b). The categories of information the SPWG studied were phthalate occurrence, phthalate risk and receptors, source identification, source control and treatment, and federal and state regulations relevant to phthalate contamination in sediments (Floyd|Snider 2007a). As stated in the Letter of Agreement for the work group, the goals of the SPWG were to "work together to summarize and evaluate existing information regarding phthalate sediment contamination issues, identify data gaps and provide recommendations on how to address these phthalate sediment contamination dilemmas in the short-term" and to "make recommendations for further study and describe possible frameworks to address sediment phthalate issues for the longer term" (Sediment Phthalates Work Group 2006). An additional goal of the SPWG was to provide recommendations for preventing phthalate recontamination of the LDW after cleanup, which are also applicable to the EW (Floyd|Snider 2007a).

The SPWG concluded that phthalates are widespread in urban and other developed environments and that they are ubiquitous in water, soil, sediment, and air (Floyd|Snider 2007a). Figure 9-4 presents a visual summary of the SPWG's conceptual model of how phthalates move through the environment from various potential sources into sediments. This figure was presented with the SPWG's recommendations and findings (Floyd|Snider 2007a).



Source: Floyd|Snider (2007b)

Figure 9-4
Sediment Phthalates Work Group Conceptual Model

Phthalates from non-point sources can accumulate in sediment through both direct and indirect atmospheric deposition, and atmospheric deposition has been identified as the pathway most likely contributing the majority of phthalates to sediments (Floyd|Snider 2007a). However, when indirect atmospheric deposition occurs, phthalates deposited on surfaces throughout an entire watershed can be carried through surface water runoff (including CSO and SD discharges) to discrete sediment areas where they accumulate (Floyd|Snider 2007a). Based on its studies, the SPWG did not identify any large, easily controllable source of phthalates to sediments, although a few such sources have been identified in the past. Additional summaries of the SPWG can be found in the LDW RI (Windward 2010g).

9.3.7 Spill Response

Spills and leaks may enter the EW through various pathways. This section provides information on data resources for leaks and spills in the EW drainage basin. Ecology, USCG, the Port of Seattle, and SPU maintain spill response programs that support source control efforts in the EW. Spills information is useful to assess the past frequency, volume, and location of spills that have occurred both directly to the EW and those that have occurred within the EW watersheds and that may have contributed pollutants to the combined sewer or separated stormwater direct discharge pathways. Ecology maintains a spill prevention, preparedness, and response program whose goal is to protect public health, safety, and the environment from accidental releases of oil and other hazardous materials (Ecology 2006b). In addition, Ecology provides 24-hour emergency response units state-wide and investigates hazardous material incidents to identify practices that will reduce the number of future spills. Ecology has the authority to issue fines or require changes in operations at facilities that violate spills regulations.

Ecology partnered with EPA, USCG, and other state and local agencies from Oregon and Idaho to produce the Northwest Area Contingency Plan. The plan provides guidelines for response actions to spill incidents, and, in Washington State, it functions as the state-wide master response plan for oil and hazardous substance releases (EPA and USCG 2006). Regulations calling for a regional response plan capable of responding to hazardous materials spills and other releases are contained in 40 CFR 300.

Section 9.4.2 and Appendix E include a summary of reported spill events within the EW or in its associated stormwater basins and combined sewer service areas as documented in publically available spill reporting databases (see Map 9-8).

SPU maintains city-wide spill and water quality complaint response programs. The spill response program maintains a 24-hour response team to control spills that occur throughout the City of Seattle. Spill response records are maintained in a City of Seattle database. Since mid-2007 (when records were available in electronic format), SPU has responded to 75 spills in the separated storm and combined sewer service areas in the EW. In addition to the City of Seattle's spill response program, SPU maintains a Water Quality Hotline for the public to report potential stormwater, illicit discharge, and other water quality-related problems. Inspectors also respond to complaints directly from other City of Seattle departments and agencies. The inspectors attempt to locate the potential source of the water quality problem and the responsible party, and then provide technical assistance, including education on BMPs, for pollution prevention, and provide cleanup assistance when necessary.

The Port of Seattle provides 24-hour on-site spill support for Port properties. In addition, Seaport Maintenance has developed and implements a spill prevention, control, and countermeasures plan in accordance with 40 CFR Part 112 and good engineering practices. The goal of this program is to ensure effective response to environmental incidents through education on reporting and evaluating incident records to assess preparation, response, and recovery measures.

9.3.8 Treated-Wood Structures

Historically, pilings and wooden structures treated with creosote, pentachlorophenol, and chromated arsenicals (e.g., chromated copper arsenate [CCA]) were commonly used as part of navigation/berthing improvements (e.g., pier and wharf structures, fender systems, and dolphins) and marine structures (e.g., wooden bulkheads). These structures can represent potential ongoing sources of contaminants to water and sediment, because some of the treatment chemicals within such structures can be released to water or sediments through abrasion or leaching. The installation of new wooden structures treated with creosote or other wood preservatives is restricted by permitting requirements, and alternative products (e.g., concrete pilings, sheet metal bulkheads, or alternative fendering systems) are used for most new construction. Many of the historical treated-wood structures have been removed

from the waterway during waterfront facility upgrades, as part of mitigation activities, or as part of voluntary activities. Remaining treated structures present in the EW are identified in Section 9.4.6 (see Map 9-9).

The DNR established a program for the removal of creosote-treated materials in the Puget Sound in 2004. Through this program, unused creosote-treated structures are removed from shorelines to enhance nearshore habitat. The program also removes creosoted debris that washes onto beaches, lagoons, and estuaries.

9.3.9 Air Quality Programs

Numerous state, federal, and local programs exist to evaluate air quality and control potential air pollution sources. Air quality and atmospheric deposition information has been collected in the vicinity of the EW by several groups including PSCAA, Ecology, and King County. Efforts are also underway to research the sources, transport, and fate of air pollutants, and to reduce emissions through regulations and voluntary programs. Air emissions monitoring, assessment and emission reduction programs, and additional regulations are discussed below. Additional information related to atmospheric deposition is presented in Section 9.4.7.

9.3.9.1 Air Toxics Studies

Toxic air pollutants, as classified by EPA, are those that have the potential to adversely affect human health (EPA 2007a). They include PAHs, PCBs, phthalates, dioxins and furans, and several metals. Common emission sources of toxic air pollutants include industrial facilities, chemical manufacturing plants, solid waste incinerators, motor vehicles, marine vessels, trains, and wood smoke (PSCAA 2006b, c). Use of solvents, paints, degreasers, and other chemicals can also release toxic air pollutants (EPA 2007a). Air toxics have the potential to affect sediment quality if they migrate to the EW through direct or indirect atmospheric deposition.

Ecology monitors concentrations of these pollutants at Beacon Hill in Seattle. This is done as part of EPA's National Air Toxics Trends Station Network. PSCAA also issues annual air quality data summaries that include monitoring data for some air toxics, as well as other air pollutants (e.g., PM).

Several other air monitoring and atmospheric deposition studies have been conducted in the Puget Sound region. King County conducted an atmospheric deposition study for the LDW (King County 2008b), Ecology conducted an atmospheric deposition study for Puget Sound (Brandenberger et al. 2010), and the City of Tacoma conducted an atmospheric deposition study for the Thea Foss and Wheeler-Osgood Waterways (City of Tacoma 2011). These studies are discussed further in Section 9.4.7. King County is currently conducting an additional atmospheric deposition study in the Green/Duwamish River Basin (King County 2011d).

9.3.9.2 Air Emission Regulations

EPA regulates air pollutants through the CAA (42 United States Code [USC] § 7401 et seq.), and local regulations include the Washington CAA (WAC 173-401) and PSCAA Regulations I, II, and III. PSCAA's regulations provide acceptable source impact levels for approximately 650 chemicals, which are used to evaluate the potential for a single emission source to impact air quality. PSCAA requires dischargers of toxic air pollutants to use best available control technology, described in their regulations, to minimize emissions of these chemicals and protect human health. Currently the Puget Sound region is in compliance with federal air quality standards for all criteria air pollutants for which EPA has set national ambient air quality standards (NAAQS) except for fine PM (FPM) (PSCAA 2011). In 2009, concentrations of FPM exceeded recently updated federal NAAQS at some monitoring stations (although they had been below NAAQS in recent years prior to the update). In 2009, the only monitoring station that did not meet the new daily federal NAAQS for FPM was located in Tacoma. All monitoring stations in the Puget Sound region have been in compliance with the annual federal NAAQS for FPM since it was first established in 1997.

Current regulations governing air quality and related emission control programs are generally based on protecting human health relative to the air exposure pathway and may not be adequate to address atmospheric deposition as an indirect or direct source of contaminants to surface waters. As an indirect source, atmospheric deposition contributes contaminants to stormwater runoff originating in the drainage basins, which is subject to stormwater controls. Direct deposition of contaminants from the atmosphere onto the surface of the EW can only be roughly estimated based on estimates of atmospheric flux. Additional discussion of what is known regarding this potential source is included in Section 9.4.7.

9.3.9.3 Air Emission Reduction Programs (King County and Port of Seattle)

The Port of Seattle, PSCAA, and King County have implemented programs in recent years to improve local air quality by reducing diesel and greenhouse gas emissions. The Port of Seattle has implemented new emission control measures as feasible throughout its operations. For example, cargo cranes have been converted from diesel power to electricity and they have been made larger to make loading and unloading processes more efficient (Port of Seattle 2011a).

With respect to fuel used at the Port of Seattle, the Seaport Division uses ultra-low sulfur diesel fuel that is a 99% biodiesel blend, thus reducing emissions of PM, carbon dioxide, nitrous oxides, sulfur dioxide, carbon monoxide, and hydrocarbons. The Seaport Division also obtained permission from Ecology to install diesel oxidation catalysts on diesel and cargo-handling equipment. The diesel oxidation catalysts oxidize chemicals that pass through, thus reducing pollutant emissions (WSU EEP 2004). Diesel-powered units for refrigerated containers have also been replaced with electrical units (Port of Seattle 2011a).

Another major goal of the Port of Seattle is to reduce the idling time of cargo handling equipment. This has been achieved through the use of a computerized cargo tracking system to reduce wait time. Communication systems are also in place to alert drivers about drawbridge openings, as well as new overpasses and improved intersections to reduce congestion and idling time (Port of Seattle 2011a). The Port of Seattle is also involved in regional efforts to improve air quality. In 2007, the Port of Seattle, Port of Tacoma, and Vancouver Port Authority issued the Northwest Ports Clean Air Strategy, which outlines regulations and efforts to achieve higher air quality (Port of Seattle et al. 2007).

In 2001, PSCAA launched a diesel solutions program that aimed to retrofit vehicles with pollution control devices, use cleaner fuel sources such as ultra-low sulfur diesel and encourage reduced idling time (WSDOH 2008a; PSCAA 2007a). As part of this program, the Port of Seattle and Ecology funded the Seaport Truck Scrappage and Retrofits for Air in Puget Sound (ScRAPS) Program. ScRAPS succeeded in replacing 280 of the container-hauling trucks that had the highest diesel emissions and outfitting 89 of the replacement trucks with retrofitted exhaust systems (PSCAA 2007a). King County has also worked with PSCAA to reduce diesel emissions. Since 2001, all Metro buses have used ultra-low sulfur diesel. In addition, King County has equipped diesel buses with particulate traps, and the

fleet now includes hybrid articulated and zero-emission electric trolley buses (King County 2011e).

9.3.10 East Waterway Source-Tracing Activities

The City of Seattle, King County, and the Port of Seattle are conducting source-tracing and identification sampling activities to support the EW source control efforts. Source-tracing sampling is designed to identify potential sources by strategically collecting samples at key locations within the storm drainage/combined sewer service areas. No single sampling methodology exists to effectively trace potential sources of contaminants to EW sediment. Therefore, a variety of sampling techniques are used. For the most part, sediment (or solids) samples, rather than whole water samples, are generally preferred because sediment is expected to provide a more direct measure of potential contaminant contributions to waterway sediment and is more cost-effective than collecting stormwater samples. In addition, sediment that accumulates in the stormwater/wastewater systems provides a measure of pollutant contributions over a longer time period (generally what has been deposited since the system was last cleaned), whereas water samples provide only a snapshot of a single storm event or CSO event. Also, unlike whole water samples, sediment samples do not usually present detection limit problems for the analytical laboratory. Contaminants present in sediment can usually be quantified, which makes it easier to evaluate and interpret the sample results.

Sampling efforts utilize sediment (or solids) samples collected from various locations within the stormwater/wastewater collection systems. Source sediment sampling enables the source-tracing efforts to maximize coverage of the EW stormwater/wastewater systems and to gather information on the extent and location of contaminants within the systems. Each type of sample represents a different geographic scale and a different component of the sediment in the stormwater/wastewater systems. The following three types of samples have been used to track and identify potential pollutant sources in the EW:

- **Inline Sediment Traps.** Sediment traps consist of a bracket mounted inside the conveyance system that contains a Teflon® bottle to passively collect suspended particulate material that passes by the sampling station. Traps are generally left in place for 6 to 12 months to collect enough material for chemical analysis. Sediment traps typically represent the suspended solids that are transported in the system.

Sampling stations are selected to isolate specific drainage sub-basins or capture contributions from the entire drainage basin (e.g., generally greater than 50 ac for separated storm basin). Sediment traps are typically installed first to identify potential problem areas within a drainage system and are followed up with more intensive sampling to identify potential specific contaminant sources (e.g., inline grabs and on-site catch basin samples).

- **Inline Sediment Grab Samples.** Inline sediment samples are grab samples collected from maintenance holes located on the SD line or combined sewer line. Like sediment traps, inline grab samples also represent contributions on a basin-wide or sub-basin scale. However, inline grabs typically represent the heavier material that accumulates and is transported in the bedload material that moves along the bottom of the pipe. These samples are collected using a long-handled scoop from areas where there is sufficient sediment present for chemical analysis. Inline sediment samples are usually collected prior to installing a sediment trap or prior to cleaning the drain to characterize the chemical quality of sediment in the SD or combined sewer system, and are useful in tracing sources in systems that are not large enough to install a sediment trap.
- **Catch Basin Sediment.** Catch basin samples are grab samples of sediment that has accumulated in the catch basin. Catch basins are part of the stormwater collection system and collect runoff from a fairly small catchment area (less than 1 ac). These structures are equipped with a small sump to capture sediment and other large debris before it can enter the stormwater conveyance system (or before it can enter the combined sewer system). Because many pollutants present in urban stormwater runoff tend to adhere to sediment, catch basins can also trap pollutants. The sediment that accumulates in catch basins provides a qualitative measure of the quality of the stormwater runoff discharged from a specific location. Catch basin samples are collected either from a specific site or property (on-site) or from the public ROW. The samples represent potential inputs from the small catchment area.

When elevated levels of contaminants are found in the drainage system, the owner (i.e., City of Seattle, King County, or Port of Seattle) typically cleans the line and associated structures (catch basins, maintenance holes, and storage vaults) to prevent this material from being flushed into the EW during large storm or CSO events. Line cleaning is an integral part of

the EW source control program. After cleaning, these lines are then re-sampled to aid in evaluating the effectiveness of source control efforts.

9.4 Characterization Data for Pathways

This section provides a potential source and pathway evaluation overview and addresses spills, direct discharges, groundwater pathway, bank erosion, treated-wood structures, atmospheric deposition, and surface water input data for characterizing pathways.

9.4.1 Potential Source and Pathway Evaluation Overview

Identification and characterization of potential source inputs to the EW has been conducted using a variety of characterization approaches. Therefore, multiple lines of evidence, which incorporate a variety of sampling and investigation techniques, are applied as part of the overall source characterization effort. Applicable information from similar or related studies (e.g., source characterization in the LDW) and from the literature (e.g., air emission inventories and airshed studies) may also be employed. Data sources and lines of evidence are presented in Table 9-5.

Table 9-5

Data Sources and Lines of Evidence East Waterway SRI/FS Source Control Evaluation

Information Need and SRI/FS Application	Lines of Evidence Used to Satisfy Information Needs					
	Stormwater Discharges	**CSO Discharges**	**Cleanup Sites**	**Treated-Wood Structures**	**Atmospheric Deposition**	**Spills**
General Source Characterization Data Needs						
Potential source descriptions – Information describing the potential source and useful for evaluating source-specific data needs	Locations and characteristics (e.g., drainage basin boundaries, land use, types of potential sources present, and condition of the drainage system such as extent of sewer separation) of SD basins	Locations and characteristics of combined sewer service areas associated with EW CSO discharges	Information identifying the location and type of cleanup sites, and the status of cleanup activities at nearshore and distal cleanup sites. More detailed information will be developed for nearshore cleanup sites to assess groundwater and bank erosion pathways.	Locations, types, and ongoing uses of treated-wood pilings or structures in or adjacent to the EW	Information about the airshed and local monitoring stations that may provide relevant monitoring data for the EW	Recent reported releases of hazardous materials to the EW
Location data – Definition of pathways by which source materials can reach the EW sediments	Locations of SD outfalls and sheetflow discharge within the EW. For larger drainage systems, information on drainage patterns and sub-basins.	Locations of CSO discharge outfalls within or immediately adjacent to the EW	Locations of cleanup sites relative to drainage infrastructure. Information on groundwater gradients and potential migration pathways between cleanup areas and the EW. Soil and sediment quality data in areas of potentially erodible shorelines.	Locations of treated-wood structures relative to the EW sediments and sediment data	Estimates of the exposed surface of the EW for use in estimating the inputs associated with direct atmospheric deposition)	Spill locations (especially for larger spills)
Quantity information – Data used to estimate the volume of discharge and the quantity of solids associated with the discharge to the EW	Estimates of typical stormwater runoff quantities and associated stormwater solids loads for each of the basins or outfalls	Estimates of the typical quantity and frequency of CSO discharges and estimates of the quantities of associated suspended solids	Hydrogeologic properties useful for estimating net groundwater flow rates or that may affect the mixing or attenuation of groundwater prior to entry into the EW	Condition of treated-wood structures, including factors that may limit potential EW inputs (e.g., piling wraps; planned removals)	Flux values or flux correction factors useful for evaluating the rate of deposition for specific contaminants (flux of total particulates to the EW may not correlate with individual contaminants)	Records describing quantities of spilled materials discharged directly to the EW
Chemical quality data – Information on the chemical quality of source material discharged to the EW	Ranges of chemical concentrations in stormwater solids entering the EW including data collected at the point of discharge as well as data collected within the SD system (e.g., catch basins/maintenance holes located within the ROW and upland properties)	Ranges of chemical concentrations in CSO discharges or CSO solids entering the EW, including analyses of CSO water quality and sediments from within the combined sewer lines	Testing data for nearshore groundwater quality (data may be collected from nearshore sampling locations or from locations along the groundwater transport pathways, depending on the site)	Review of SRI/FS sediment quality data in the vicinity of treated-wood structures	Chemical quality data for atmospheric deposition (data may be collected using air deposition studies or using air quality data)	Data or descriptions of the type of materials spilled directly to the EW
Activities Associated with Ongoing Source Control Programs[a]						
Localized testing – Inspections or sampling focused on identification and analysis of specific localized source inputs may, in some instances, provide information relevant to the SRI/FS source characterization effort	Facility and system inspections provide information on localized source contributions located within a SD system, which is often useful in interpreting source characterization data	Facility and system inspections or associated sampling may, in some instances, provide information on localized source contributions located within a combined sewer system, and some of this information may be useful in interpreting source characterization data	Follow-up evaluations of potential inputs from cleanup sites that may exhibit complete pathways to EW sediments (e.g., more detailed review of cleanup sites in concert with stormwater and CSO source control inspections).	Piling and structure removals as part of ongoing source control and waterfront improvement projects by the Port of Seattle, the Department of Natural Resources, or other parties; Material substitutions as part of new construction.	Air quality monitoring within the EW airshed	Facility inspections associated with spill control programs

Note: This table provides a summary of information developed during the EW SRI SCE (Anchor and Windward 2008b).

[a] These additional activities are associated with ongoing source-tracing and source control activities but may generate data useful for the SRI/FS SCE.

CSO –combined sewer overflow
EW – East Waterway
FS – feasibility study
ROW – right-of-way
SCE – source control evaluation
SD – storm drain
SRI – supplemental remedial investigation

Because the factors that influence the fate and transport of solids and associated contamination within the EW itself can be complex, it is important to consider the characterization data for each potential source along with the sediment transport processes and sediment sampling data (surface and subsurface) for the receiving waterbody. The sediment transport processes within the EW may significantly affect whether and to what extent a potential source influences sediment concentrations. In some cases these processes, including sediment transport, initial settling, resuspension, and redistribution, may significantly affect contaminant concentrations.

Data sources for source control characterization include spill and listed site database queries, programmatic data supplied by the EWG, historical nearshore environmental reports, and field condition evaluations. Reports that contain sufficient data quality are included below.

9.4.2 Spills

Spills are tracked by federal, state, and local spill reporting systems. Information in these systems is stored in searchable databases such as the federal Emergency Response Notification System maintained by USCG, the spills database maintained by Ecology's Spill Prevention, Preparedness, and Response Program, and the database maintained by the City of Seattle's spill response program. These databases typically contain the location, material, and volume of spilled material. These databases were queried by Environmental Data Resources in 2007 in support of the EISR (Anchor and Windward 2008a) and again in December 2009 in support of this SRI report. Spills data from the City of Seattle and Ecology were additionally reviewed in January 2013. Spills information is useful to assess as a direct source and pathway when occurring directly to the EW or as a source to direct discharge pathway, i.e., combined sewer and separated stormwater drainage basins that drain to the EW. The results of the database search are presented in Map 9-8 and in Appendix E, Table E-1.

9.4.2.1 East Waterway Spills Inventory

During the 20-year period 1988 to 2010, a total of 69 spills directly into the EW were reported. The vast majority of the reports related to petroleum releases (59 of 69). Most of these releases (41) consisted of unknown or small quantities (i.e., visible sheen to less than 1 gallon) of petroleum. There were relatively few (12 of 59) spills of medium quantities (i.e., 1 to 10 gallons) of petroleum, and also relatively few (6 of 59) spills of large quantities (i.e.,

10 to 4,000 gallons) of petroleum. Non-petroleum spills included bilge water (1), sewage (2), turpentine (1), paint thinner (1), paint (2), and xylene cresols (1).

9.4.2.2 Spills within East Waterway Drainage Basins

During the 20-year period 1990 to 2012, a total of 276 spills into the EW SD and CSO drainage basins were reported. The majority of the reports related to petroleum releases (146 of 276). Most of these releases (73) consisted of unknown or small quantities (i.e., a sheen to less than 1 gallon) of petroleum. There were relatively few (39 of 146) spills of medium quantities (i.e., 1 to 10 gallons) of petroleum, and also relatively few (34 of 146) spills of large quantities (i.e., 10 to 2,500 gallons) of petroleum. Remaining reported spills (103) to the EW drainage basins included paints, sewage, and other industrial chemicals.

A significant spill occurred in 2008 at Industrial Plating Corporation, located at 2411 6th Avenue S. The spill event occurred due to the rupture of a 50,000-gallon wood-stave storage tank containing sludge from electroplating operations, high pH cleaning chemicals, and rinse water. Heavy metals detected in samples of the spilled solids collected at the facility included cadmium (4,550 mg/kg), chromium (42,800 mg/kg), copper (24,000 mg/kg), and zinc (120,000 mg/kg). The pH in a sample of the liquid material that was spilled was 12.4. Approximately half of the spilled material was estimated to have been contained in a sump inside the building, with another approximately 10 percent of the sludge remaining on the floor of the building (Walton 2008). The remainder of the spill entered the City storm drain and sanitary sewer systems, and a portion of this material reached the EW via the S Lander Street SD. The precise volume of spilled materials discharged to the EW is not known. The SD and sanitary sewer lines affected by this spill were later jetted and cleaned to remove residual contamination (material removed during jetting and cleaning was collected for proper disposal).

Subsequent to the Industrial Plating Corporation spill, sediment sampling was conducted by the Port of Seattle (Keithly 2008) in the area immediately offshore of the Lander CSO/SD outfall. The sampling included nine sampling stations. Concentrations of cadmium (6.76 mg/kg) found in the sample location closest to the outfall exceeded the SQS (5.1 mg/kg). Chromium concentrations in the other eight samples ranged from 1.02 to 2.23 mg/kg. The results of testing provide information on the lateral extent of sediments that may have been impacted by the particular spill event.

9.4.3 Direct Discharges to the East Waterway

This section presents an overview of direct discharges to the EW, which can originate from municipal or other publically owned SD systems, combined sewer systems, and privately owned and managed SD systems. In the area of the EW, these discharge systems primarily transport stormwater collected from industrial, commercial, and residential neighborhoods. Combined sewer systems also have the potential to transport raw sewage including municipal and industrial wastewater during storms of sufficient intensity and duration to trigger CSO events. Table 9-2 presents a description and the nomenclature used throughout this section for the various direct discharge outfalls in the EW.

Available information addressing the following is discussed in this section:

- Locations and characteristics of the SD and CSO basins
- Locations of active SD and CSO outfalls that discharge to the EW
- Land use within the SD and CSO basins
- Average annual stormwater and CSO discharge volumes
- Stormwater and CSO TSS concentrations
- Chemical characteristics of SD and CSO basins (i.e., source-tracing data)

Information on particle size distributions were presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012) for use in Particle Tracking Modeling (see Section 3).

9.4.3.1 Description of Direct Discharge Systems

9.4.3.1.1 Stormwater

The EW SD system consists of two general areas: the S Lander Street SD basin (which extends from the EW to areas as distant as Beacon Hill to the east), and the smaller nearshore SD basins located in areas along the EW, as shown on Maps 9-10a and 9-10b. Nearly all stormwater discharges to the EW via 42 outfalls, but stormwater can also enter the EW directly by means of sheetflow, which typically occurs from terminal aprons, bridge areas, or shoreline slopes. The EW SD drainage basins are shown on Maps 9-10a and 9-10b, and are discussed further below:

- **S Lander Street SD Basin –** This drainage basin, the largest of the EW SD basins, discharges via the Lander CSO/SD outfall. This drainage basin was partially separated

from the Lander CSO basin by King County (formerly Metro) in 1992. The partially separated S Lander Street SD basin collects stormwater from a predominantly industrial area that extends from the EW to Interstate-5 (I-5) and a small residential area on Beacon Hill (Map 9-10a). The Lander CSO/SD outfall consists of a single 96-in.-diameter pipe that discharges stormwater from the separated storm drainage system, as well as CSO discharges from the King County combined sewer system to the EW.

- **Nearshore Drainage Basins –** These are a number of smaller, predominantly industrial drainage areas that are adjacent to the EW and served by 41 outfalls. Approximately half of these basins are located on Harbor Island and the other half are located along the east side of the EW. The nearshore drainage basins include the City of Seattle's B-21 and S Hinds Street SD basins, all Port of Seattle basins, the Olympic Tug and Barge basin, and the USCG basins. Each of the nearshore SD basins and outfalls has been assigned a number for use during the EW SRI/FS. For example, Outfall 7 discharges stormwater from SD basin B-7 (Map 9-10b).
- **Apron Areas –** Apron areas are the portions of terminals that are located over the EW. They extend out from the land and are supported on pilings. Stormwater from these areas discharges directly to the underlying EW via individual apron deck drains rather than through SD networks. The apron areas are located along both the east and the west sides of the EW (Map 9-10b). These apron areas are contiguous with the adjacent nearshore drainage basins and typically have the same types of land uses and industrial activities as the adjoining basins. The apron drainage areas have been assigned numbers for use during the EW SRI/FS; each apron drainage area is assigned the same numbers as the basins to which they are adjacent, but the numbers are preceded by a letter "A" instead of a "B."
- **Bridge Areas –** Several bridges cross the southern portion of the EW, including the West Seattle Bridge, the Spokane Street Bridge, a railroad bridge, and a small access bridge that connects T-102 and T-104. There is also a small bridge at the head of Slip 27 that connects both portions of T-30 (T-30 now includes former T-25). Runoff from the West Seattle Bridge is collected and passed through oil/water separators before discharging to the EW. Runoff from the Spokane Street Bridge is collected in SDs and discharged via a single outfall. Stormwater from the other bridges discharges to the EW via individual bridge deck drains. The bridge drainage areas have been

assigned numbers for use in the EW SRI/FS. The bridge drainage areas are preceded by the letters "BR."

Table 9-6 presents the acreage of the EW SD basins. The delineation of the SD basins that discharge to the EW has been revised from the delineation presented in the SEDGM (Anchor QEA and Windward 2009) based on information presented in the *East Waterway Storm Drain and Combined Sewer Solids Loading Analysis* (SPU 2011b). The drainage basin boundaries result in an overall EW storm drainage basin area of 787.6 ac.[128]

Table 9-6
EW Outfalls and Stormwater Drainage Basins Areas

Basin Category	SD Basin No. or Name	Outfall Name or Number[a]	Drainage System Owner	Basin Area (ac)
S Lander Street Storm Drain Basin (441.9 ac, 56.1% of total SD basin area; 1 outfall)				
Lander	S Lander Street	Lander CSO/SD	SPU	438.3
	S Lander Street	Lander CSO/SD	Port of Seattle	3.6
East Bank Nearshore Basins (150.9 ac; 19.2% of total SD basin area; 23 outfalls)				
Nearshore	B-25, B-36	25 (S Massachusetts Street SD), 36 (S Spokane Street SD)	SPU	9.5
	B-26, B-27, B-28, B-29, B-30, B-31, B-32, B-33, B-34, B-37, B-39	26 – 34, 37, 39	Port of Seattle	87.0
	B-40, B-41, B-42, B-43	40 – 43	USCG	14.9
	S Hinds Street	Hinds CSO/SD	SPU	39.5
West Bank Nearshore Basins (161.3 ac; 20.5% of total SD basin area; 18[b] outfalls)				
Nearshore	B-4, B-5, B-21	4 (SW Spokane Street SD) 5 (SW Spokane EOF/SD) 21 (SW Florida Street SD)	SPU	22.2
	B-11	11 (SW Hanford Street EOF/SD)	Port of Seattle	135.9
	B-1, B-7, B-10, B-12, B-13, B-14, B-16, B-17, B-18, B-19, B-22, B-23, B-24, BR-39	1, 7-10, 12-19, 20, 22-24		
	B-6	6	Olympic Tug and Barge	3.2
	A-7 through A-24	na (multiple bridge deck drains)	Port of Seattle	17.7

[128] The updates to SD basins resulted in a difference of 17 acres, or approximately 2% decrease in acreage.

Basin Category	SD Basin No. or Name	Outfall Name or Number[a]	Drainage System Owner	Basin Area (ac)
Bridges/Aprons (33.2 ac; 4.2% of total SD basin area; multiple discharge points)				
Bridges	BR-4, BR-5, BR-34	na (multiple bridge deck drains)	SPU	5.0
	BR-2 and BR-27	na (multiple bridge deck drains)	Port of Seattle	0.5
Aprons	A-26 through A-33	na (multiple bridge deck drains)	Port of Seattle	10.0
Total SD basin area				787.6

[a] A unique number has been assigned to each outfall; the City of Seattle names its outfalls by the nearest street for ease in identifying its location.

[b] Three small (less than 12-in.-diameter) outfalls (8, 9, and 15) have been observed, but they are not associated with any drainage networks. Since no flow has been observed from these outfalls, they are assumed to be disconnected. All Port of Seattle drainage on T-18 is assigned to other outfalls, so no areas are missing from the stormwater modeling. Therefore, the lack of known drainage network mapping for these outfalls does not affect the overall drainage area or runoff estimates for the EW.

CSO – combined sewer overflow
EOF – emergency overflow
EW – East Waterway
SD – storm drain
SPU – Seattle Public Utilities
USCG – US Coast Guard

Except for a small individual private properties served by private SDs, the EW drainage basins are served by public SDs that discharge to outfalls owned by the Port of Seattle (30 SD outfalls), the City of Seattle (7 SD outfalls) and USCG (four SD outfalls). Two of the City of Seattle SDs, S Hinds Street and S Lander Street, share outfalls with CSOs. The S Lander Street SD has a low-flow diversion structure that directs flow to the EBI. In addition, the City of Seattle sanitary sewer system on Harbor Island has two EOFs: one connected to the Port of Seattle SD system at B-11, and the other to the City of Seattle system at B-5. Therefore, outfalls from B-11 and B-5 are referred to as the SW Hanford Street EOF/SD and SW Spokane Street EOF/SD, respectively. In addition to the public outfalls, there are one private outfalls draining private basins. One private SD outfall serves the Olympic Tug and Barge property adjacent to T-18. Map 9-10b shows the locations of the outfalls, as well as the corresponding ownership.

9.4.3.1.2 Combined Sewer Overflows

The City of Seattle and King County operate combined sewer systems that discharge to the EW during CSO events via three outfalls along the east shoreline of the EW (Map 9-11a). The two King County CSOs discharge from the Lander and Hanford #2 outfalls, which are located on either side of Slip 27. The City of Seattle CSO discharges from the Hinds outfall, which is located near the south end of T-30 (formerly T-25), where the EW widens. The

Lander and Hinds outfalls are CSO/SDs because they serve both CSO basins as well as separated SD basins. The Hanford #2 outfall is only used for CSO discharges from the Hanford #2 CSO basin.

The approximate areas of the CSO basins that discharge to the Lander, Hanford #2, and Hinds outfalls are shown on Map 9-11a and listed in Table 9-7. The CSO basin associated with the Hinds CSO outfall is the smallest. The Hanford #2 and Lander CSO basins are approximately the same size and cover much of the same area, as can be seen on Map 9-11a. There is an interconnecting pipeline on Occidental Street between the Hanford and Lander systems to maximize system storage, resulting in a large overlap in basins between Lander and Hanford #2. In addition, depending on how the flows are managed in the system at Bayview, Hanford at Rainier, and Rainier Pump Station, flows can discharge from either the Lander CSO/SD or the Hanford #2 CSO[129] (see Map 9-11b for the various sub-basins).

Table 9-7
EW CSO Outfalls and CSO Basin Areas

CSO	Discharge No. and Outfall Type	CSO Basin Area (ac)	Operator
Hanford #2	032 (CSO)	4,975[a]	King County
Hinds	107 (CSO/SD)	56	City of Seattle
Lander	030 (CSO/SD)	4,890[a]	King County

[a] The Hanford #2 and Lander CSO basins cover much of the same area. The total CSO basin area is approximately 4,975 ac.

CSO – combined sewer overflow
EW – East Waterway
SD – storm drain

9.4.3.1.3 Land Use in SD and CSO Basins

Land use information for each the SD and CSO basin areas was developed using current King County parcel data (King County 2008a). The areas of each type of land use present within the EW SD basin categories are presented in Table 9-8. Similarly, the areas associated with each type of land use within the CSO basins are presented in Table 9-9. Land use within the SD and CSO basin categories is shown on Map 9-12.

[129] Flows from these subareas can also be discharged through the Duwamish/Diagonal Ave S CSO/SD in the LDW.

Table 9-8
Land Use in EW SD Basins

Land Use	Land Use within Storm Drainage Basin Categories (ac)[a]					% of Total SD Basin Area
	S Lander Street SD	Nearshore Drainage Areas	Apron Areas	Bridge Areas	Total	
Commercial	66.8	5.8	0	0	72.5	9.2
Industrial	226.3	285.9	27.7	1.9	541.7	68.8
Single-family residential	19.4	0	0	0	19.4	2.5
Multi-family residential	15.8	0	0	0	15.8	2.0
ROW	110.9	20.7	0	3.9	135.5	17.2
Parks, open space, and vacant land	2.7	0	0	0	2.7	0.3
Total	**441.9**	**312.2**	**27.7**	**5.8**	**787.6**	**100**

[a] Land use analysis was based on the basin delineations presented in Table 9-2.

EW – East Waterway
ROW – right-of-way
SD – storm drain

Table 9-9
Land Use in EW CSO Basins

Land Use	Hanford #2/ Lander[a]		Hinds		Total CSO Basins	
	Area (ac)	% of Total Area	Area (ac)	% of Total Area	Area (ac)	% of Total Area
Commercial	751	15.1	0	0	751	14.9
Industrial	462	9.3	40.9	73	503	10
Single-family residential	1,360	27.3	0	0	1,360	27
Multi-family residential	389	7.8	0	0	389	7.7
ROW	1,616	32.5	10.6	19	1,627	32.3
Parks/open space/ vacant	376	7.6	2.8	5	379	7.5
Other[b]	21	0.42	1.7	3	23	0.5
Total	**4,975**	**100**	**56**	**100**	**5,031**	**100**

[a] Lander basin is nearly the same area as Hanford #2 basin as they are cross connected.

[b] Other includes undesignated land use and other categories as defined by King County land use parcel files.

EW – East Waterway
CSO – combined sewer overflow
ROW – right-of-way

9.4.3.2 Stormwater and CSO Discharge Volumes and Suspended Solids Concentrations

In addition to basin acreage and land use information, discharge volumes and TSS data for stormwater and CSO discharges are included to further characterize these pathways and potential sources. This information was used to estimate solids loading to the EW (see Section 3) and will be used to evaluate sediment recontamination potential in the FS.

9.4.3.2.1 Stormwater Discharge Volumes

The *East Waterway Storm Drain and Combined Sewer Solids Loading Analysis* (SPU 2011b) presented calculations of annual stormwater discharge volumes based on various annual rainfall scenarios applicable to the EW. Annual runoff volumes were estimated for the years 2000 through 2007, as well as typical dry (1993), wet (2002), and average rainfall (1986) years. Estimates were based on land use, soil types, topography, and rainfall using a simplified Hydrologic Simulation Program – Fortran (HSPF) model. Rainfall data from the City of Seattle's rain gauge No. 15 located at E Marginal Way S and Diagonal Avenue S were used in the model. Annual runoff was calculated for each outfall. Annual stormwater discharge volumes for wet, dry, and average years summarized by SD basin type and ownership are presented in Table 9-10.

Table 9-10
Estimated Annual Stormwater Discharge Volumes

Ownership Category	Area (ac)	Runoff Volume (Mgal/yr)		
		Dry Water Year	Average Water Year	Wet Water Year
SPU basins (low-runoff assumption)[a]	510	138	164	202
SPU bridges	5.0	2	2	3
Total SPU (low-runoff assumption)[a]	**515**	**140**	**166**	**205**
SPU basins (high-runoff assumption)[b]	510	225	268	330
SPU bridges and aprons	5.0	2	2	3
Total SPU (high-runoff assumption)[b]	**515**	**227**	**270**	**333**
Port of Seattle basins	227	127	151	185
Port of Seattle aprons and bridges	28	17	20	24
Total Port of Seattle	**255**	**144**	**171**	**209**
Private basins	18	10	12	15

Source: SPU (2011b)

[a] For partially separated areas in the S Lander Street SD basin. The low-runoff estimate was calculated from SPU GIS maps included only those areas where mapping was available, and shows the on-site drainage connected to the public separated SD system in the ROW.

[b] For partially separated areas in the S Lander Street SD basin. The high-runoff estimate was calculated assuming that half of the remaining parcels that are either not currently mapped or are currently shown as connected to the combined sewer system will be re-plumbed to the SD system in the future as redevelopment occurs.

GIS – geographic information system

ROW – right-of-way

SD – storm drain

SPU – Seattle Public Utilities

9.4.3.2.2 Stormwater Suspended Solids Concentrations

Limited site-specific stormwater TSS data are available for the EW. However, estimates of stormwater TSS concentrations can be derived from available EW site-specific discharge data and estimates developed based on SD basin land use (SPU 2011b). Site-specific stormwater TSS data are available for the S Lander Street SD basin and include data collected as composite samples during storm events and under base-flow conditions. Only the data collected from 1997 to 2002, after the completion of the Lander separation project, are considered applicable to stormwater conditions from the S Lander Street basin. Sampling was discontinued after 2002 and data collected prior to the separation project are not considered to be representative of stormwater TSS concentrations because these samples contained a mixture of sewage and stormwater. The resulting TSS dataset includes 22 stormwater samples collected from the S Lander Street SD system on the main trunk line at Utah Avenue S and at the bus tunnel access road on 5th Avenue S. A summary of the S Lander Street stormwater TSS concentrations is presented in Table 9-11.

Table 9-11

S Lander Street Stormwater TSS Concentrations

Storm Drain Flow Type	TSS Concentration (mg/L)				
	No. of Samples	25th Percentile	Median	Mean	75th Percentile
Storm flow[a]	22	45	65	73	91
Base flow[b]	23	5.2	7.6	10	11

[a] Samples were collected during storm events when no CSO discharges occurred.

[b] Samples were collected during dry weather.

TSS – total suspended solids

The 22 stormwater samples collected by King County were also analyzed for field conductivity and fecal coliform bacteria to detect the possible presence of saline (marine) water from saltwater intrusion in the pipe from the waterway or sewage from illicit sanitary connections during the separation project. Conductivity ranged from 42 to 460 µmhos/cm, which indicates that the samples were largely free of saline water and are thus representative of storm flow conditions. Fecal coliform numbers ranged from 900 to 1,300,000 colony-forming units per milliliter (cfu/mL), which based on the higher concentrations of the range, suggests that samples may have included some sewage. Additional information on the sampling locations and conditions are presented in Section 9.4.3.3.6.

Representative TSS values were estimated based on land use using stormwater data (over 500 samples) compiled from studies conducted in western Washington and Oregon. TSS values from parking lots and other paved areas were used to characterize runoff quality for the largely paved Port of Seattle terminal areas. Land use weighted average TSS concentrations were calculated to account for variations in the quality of stormwater runoff from different types of development in the EW. For all other areas, TSS values were based on available stormwater data for the various land use categories within each drainage basin (e.g., industrial, commercial, single-family residential, multi-family residential, and roadway/ROW). Additional information on the development of TSS values for the EW is available in SPU (2011). Table 9-12 provides 25th percentile, trimmed mean, and 75th percentile TSS values based on land use.

Table 9-12
Estimated Concentrations of TSS in Stormwater
Associated with EW Upland Land Use

Land Use	TSS Concentration (mg/L)		
	25th Percentile	10% Trimmed Mean[a]	75th Percentile
Single-family residential	24	48	70
Multi-family residential	39	68	101
Commercial	32	58	84
General Industrial	34	74	117
Port Industrial[b]	20	43	60
Open space	8	13	18
ROW	34	71	86

Source: SPU (2011b)

[a] The 10% trimmed mean removed 10% of the TSS concentrations at the low and high ends of the dataset to adjust for data extremes.

[b] Based on Port of Seattle tenant NPDES monitoring conducted from 2005-2009 on T-18, former T-25, and T-30. Port of Seattle industrial areas consist primarily of paved surfaces used for container/cargo handling.

EW – East Waterway
NPDES – National Pollutant Discharge Elimination System
ROW – right-of-way
SPU – Seattle Public Utilities
T-18 – Terminal 18
T-25 – Terminal 25
T-30 – Terminal 30
TSS – total suspended solids

The concentrations of TSS measured in stormwater samples collected from the S Lander Street SD are similar to those based on the predominate land use within the basin. The S Lander Street SD basin services predominantly industrial areas and ROWs. The land use-based TSS concentrations reported for these land uses have a mean TSS concentration of 74 and 71 mg/L, respectively, are very similar to the S Lander Street stormwater TSS mean concentration of 73 mg/L (Table 9-11).

9.4.3.2.3 CSO Volumes and Frequencies

Discharge volumes and frequencies for each of the CSOs that discharge to the EW are monitored by the City of Seattle and King County as part of their NPDES CSO permit reporting requirements. Volume and frequency discharge data for each EW CSO were provided by King County and the City of Seattle and presented in the STER (Anchor QEA and Coast & Harbor Engineering 2012). The CSO discharge frequencies and volumes are summarized in Table 9-13.

Table 9-13
East Waterway CSO Discharge Frequencies and Volumes

CSO	Annual Average Discharge	
	Frequency (events/year)	Volume (Mgal/yr)
King County-Owned CSOs[a]		
Hanford #2	13.6	74.3
Lander	6.7	39.8
City of Seattle-Owned CSOs[b]		
Hinds	4.2	1.0

[a] Based on data from 2000 to 2009 (Appendix H).

[b] SPU data also based on 2000 to 2009.

CSO – combined sewer overflow

9.4.3.2.4 CSO TSS Concentrations

TSS concentrations from CSO discharges in the EW can be estimated using data from Hanford #2 and Lander CSO discharges. As described in Section 9.4.3.1.2 and shown on Map 9-11a, there is an interconnecting pipeline on Occidental Street between the Hanford and Lander systems to maximize system storage, and this results in an overlap in basins between Lander and Hanford #2. Because of this and because there was overlap in TSS concentrations for each CSO, the TSS data from Hanford #2 and Lander CSOs have been combined. TSS samples for the Hanford #2 CSO were collected in 1996 to 1997, 2004, and 2007 to 2009; TSS samples for the Lander CSO were collected in 2008 to 2009. There are no data for the Hinds CSO, but because the land use is similar in parts to Hanford #2 and Lander, the same TSS data are assumed to represent the Hinds CSO. Table 9-14 summarizes the TSS concentration data available from the combined Lander/Hanford #2 dataset.

Table 9-14
CSO TSS Concentrations

Source	No. of Samples	TSS Concentrations (mg/L)			
		Min	Max	Mean	Median
Lander/Hanford #2	27	34.6	156	86	94.5

CSO – combined sewer overflow
TSS – total suspended solids

9.4.3.3 Chemical Characteristics

9.4.3.3.1 Storm Drain Solids

Both the Port of Seattle and SPU have sampled solids that accumulate in or are transported by their respective SD systems to provide an estimate of the solids-bound contaminants that could be conveyed to the EW. Types of storm solids sampling methods include collection of material accumulated in inline traps, inline grab samples, and catch basin grab samples. Each of these sampling methods was described in detail in Section 9.3.10. Solid material in the drainage system can be transported in the water column as suspended solids or can move along the bottom of the pipe as bedload material. Because of these different transport mechanisms, no one sampling technique is capable of providing a representative sample of all SD solids that could be discharged. Each type of sampling method may be limited in terms of the range of solids size fractions that are reliably captured in a particular sample. Also, the chemical characteristics of a sample obtained at a particular location are determined, to some

degree, by the geographic extent and nature of the upstream contributing drainage area Therefore, a variety of different sample collection methods and locations are used to characterize SD solids.

Chemical characterization data for SD solids have been collected by SPU (2003 to 2010) and the Port of Seattle (2009 to 2010). Sampling procedures employed by SPU and the Port of Seattle follow recommended protocols set forth in their respective sampling plans (Integral 2008; Windward 2008d). The available SPU and Port of Seattle source-tracing data were reviewed to verify that all sampling data potentially relevant to the EW were included. The dataset includes SD samples that were collected from within the S Lander Street and nearshore SD basins, as well as SD samples from the CSO basins (samples collected from catch basins prior to entering a combined sewer pipe). The SD solids samples collected from the Hinds, Lander, and Hanford #2 CSO basins are included because they are representative of SD inputs in the vicinity of the EW; however, SDs serving these areas typically flow to the combined sewer and only enter the EW during a CSO event. The SD data from the Lander and Hanford #2 CSO basin datasets also include some samples that overlap with the Duwamish/Diagonal CSO basin inasmuch as these systems are connected.

9.4.3.3.2 CSO Solids

King County and SPU have sampled inline solids that accumulate in, or are transported in, the combined sewer systems to provide an estimate of the solids-bound contaminants that could be conveyed to the EW during a CSO discharge event. While the majority of the flows in the combined system are conveyed to the West Point WWTP, some flows and associated solids can be discharged to the EW during CSO events. As with the SD system, solid material in the combined system can be transported in the water column as suspended solids or can move along the bottom of the pipe as bedload material. CSO solids have been sampled using inline grab samples and sediment traps as discussed below.

- Inline sediment traps were mounted to the wall of the Hanford Trunk Line at one location at three levels to collect sediment associated with combined sewer flows. Unlike storm lines, CSO lines always contain flow from municipal and industrial wastewater and, therefore, traps were placed above the sanitary base flow. The three levels include approximately 12 in. (30.5 cm), 36 in. (91.4 cm), and 60 in. (152.4 cm) above baseflows to capture solids more representative of CSO events.

- Inline solids grab samples were collected from the inline sediment accumulated in the Hanford #2 and Lander trunk lines, as well as lateral lines to the Hanford #2 trunk. Inline grab samples typically include solids that have accumulated within the lines in areas where there is sufficient material available for chemical analysis.
- Inline grab samples were collected from the inline sediment accumulated in the Hinds CSO/SD at a station located downstream of the overflow structure. This sample represents contributions from both the separated SD system and the combined sewer system.

Details on sampling and analytical methods are in King County's sampling and analysis plan (King County 2009a), and a data report is being prepared with complete data results and quality assurance (QA) reviews. Samples were collected between 2008 and 2010.

9.4.3.3.3 Summaries of Storm and CSO Solids Source-Tracing Data

A summary of the storm and CSO solids source-tracing data are presented in this section. All sample data collected at a location, regardless of whether the potential source has been identified/controlled or the line has since been cleaned, are included. Table 9-15 presents the detection frequency and ranges of detected concentrations of selected contaminants, including arsenic, mercury, 1-4-dichlorobenzene, BEHP, HPAH, cPAH, total PCBs, and dioxins and furans. These contaminants were selected because they have been identified as COCs in the baseline risk assessments (see Sections 5 and 6). The complete dataset for all COCs is included in Appendix I

Table 9-15
Source-Tracing Results for Direct Discharges – Solids Data Summary

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
On-site Catch Basins[b]									
All EW On-site Catch Basins[b]									
Arsenic	mg/kg dw	72	56%	3	50	9	9.88	6	100
Mercury	mg/kg dw	72	74%	0.01	12.7	0.1	0.43	0.02	0.1
Total HPAHs[c]	µg/kg dw	72	97%	9.5	358,400	6,075	12,506	19	39
Total cPAHs[d]	µg TEQ/kg dw	72	100%	17.2	48,340	605	1,569	na	na
BEHP	µg/kg dw	72	97%	26	1,400,000	17,000	52,458	3,000	23,000
1,4-Dichlorobenzene	µg/kg dw	72	4%	3	520,000	87.5	7,422	6	2,800
Total PCBs (Aroclors)[e]	µg/kg dw	72	89%	9.5	3,200	74	316	19	98
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
All Nearshore Drains[b,g]									
Arsenic	mg/kg dw	27	52%	3.5	16	8	7.9	10	10
Mercury	mg/kg dw	27	78%	0.02	12.7	0.09	0.69	0.03	0.1
Total HPAHs[c]	µg/kg dw	27	100%	440	17,300	6,500	7,555	na	na
Total cPAHs[d]	µg TEQ/kg dw	27	100%	162.9	2,100	710	780	na	na
BEHP	µg/kg dw	27	100%	5,300	75,000	17,000	21,485	na	na
1,4-Dichlorobenzene	µg/kg dw	27	4%	3	550	31	95	6	1,100
Total PCBs (Aroclors)[e]	µg/kg dw	27	89%	10	3,000	58	320	20	31
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
S Hinds Street SD[b]									
Arsenic	mg/kg dw	5	20%	3	40	4	14	6	40
Mercury	mg/kg dw	5	40%	0.02	0.18	0.03	0.07	0.04	0.06

Table 9-15
Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
Total HPAHs[c]	µg/kg dw	5	80%	9.5	7,070	938	2,506	19	19
Total cPAHs[d]	µg TEQ/kg dw	5	100%	17.2	521	102	217	na	na
BEHP	µg/kg dw	5	100%	26	19,000	1,500	6,245	na	na
1,4-Dichlorobenzene	µg/kg dw	5	0%	9.5	170	55	67	19	340
Total PCBs (Aroclors)[e]	µg/kg dw	5	80%	10	760	72	208	20	20
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
S Lander Street SD[b]									
Arsenic	mg/kg dw	16	81%	3	13	10	9.0	6	8
Mercury	mg/kg dw	16	75%	0.03	0.32	0.09	0.12	0.05	0.1
Total HPAHs[c]	µg/kg dw	16	100%	290	358,400	4,930	29,693	na	na
Total cPAHs[d]	µg TEQ/kg dw	16	100%	128	48,340	573	4,009	na	na
BEHP	µg/kg dw	16	88%	1,500	160,000	15,000	29,850	3,000	23,000
1,4-Dichlorobenzene	µg/kg dw	16	0%	36	900	98	183	72	1,800
Total PCBs (Aroclors)[e]	µg/kg dw	16	94%	29	1,120	82	224	98	98
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
All Combined Sewer[b]									
Arsenic	mg/kg dw	24	50%	3.3	50	9	12	7	100
Mercury	mg/kg dw	24	75%	0.01	1.82	0.20	0.43	0.02	0.1
Total HPAHs[c]	µg/kg dw	24	96%	19.5	68,000	5,555	8,702	39	39
Total cPAHs[d]	µg TEQ/kg dw	24	100%	35.3	6,939	725	1,111	na	na
BEHP	µg/kg dw	24	100%	410	1,400,000	20,000	112,003	na	na
1,4-Dichlorobenzene	µg/kg dw	24	8%	20	520,000	198	22,024	40	2,800

Table 9-15

Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
Total PCBs (Aroclors)[e]	µg/kg dw	24	88%	9.5	3,200	151	396	19	48
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
ROW Catch Basins[b]									
All EW ROW Catch Basins[b]									
Arsenic	mg/kg dw	26	38%	3	30	5	10	6	30
Mercury	mg/kg dw	26	50%	0.02	0.32	0.04	0.10	0.03	0.07
Total HPAHs[c]	µg/kg dw	26	96%	240	17,040	2,445	3,181	480	480
Total cPAHs[d]	µg TEQ/kg dw	26	100%	75.47	1,975	319	418	na	na
BEHP	µg/kg dw	26	92%	1,300	18,000	3,950	5,227	7,000	12,000
1,4-Dichlorobenzene	µg/kg dw	26	4%	17.5	470	65	92	35	480
Total PCBs (Aroclors)[e]	µg/kg dw	26	73%	9.5	530	39	78	19	20
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
S Hinds Street SD[b]									
Arsenic	mg/kg dw	1	0%	na	na	na	5	10	10
Mercury	mg/kg dw	1	0%	na	na	na	0.03	0.05	0.05
Total HPAHs[c]	µg/kg dw	1	100%	na	na	na	2,340	na	na
Total cPAHs[d]	µg TEQ/kg dw	1	100%	na	na	na	297	na	na
BEHP	µg/kg dw	1	100%	na	na	na	3,000	na	na
1,4-Dichlorobenzene	µg/kg dw	1	0%	na	na	na	60	120	120
Total PCBs (Aroclors)[e]	µg/kg dw	1	100%	na	na	na	250	na	na
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
S Lander Street SD[b]									

Table 9-15
Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
Arsenic	mg/kg dw	10	40%	3	28	10	10	6	30
Mercury	mg/kg dw	10	50%	0.02	0.25	0.05	0.08	0.03	0.06
Total HPAHs[c]	µg/kg dw	10	100%	847	17,040	3,117	4,938	na	na
Total cPAHs[d]	µg TEQ/kg dw	10	100%	119.6	1,975	345	590	na	na
BEHP	µg/kg dw	10	80%	2,000	12,000	4,700	5,750	7,000	12,000
1,4-Dichlorobenzene	µg/kg dw	10	0%	1.5	140	70	74	35	280
Total PCBs (Aroclors)[e]	µg/kg dw	10	90%	10	210	75	79	20	20
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
All Combined Sewer[b]									
Arsenic	mg/kg dw	15	40%	3	30.0	5.0	9.9	6	10
Mercury	mg/kg dw	15	53%	0.03	0.32	0.04	0.12	0.06	0.07
Total HPAHs[c]	µg/kg dw	15	93%	240	4,750	1,485	2,065	480	480
Total cPAHs[d]	µg TEQ/kg dw	15	100%	75.47	561.9	291	311	na	na
BEHP	µg/kg dw	15	100%	1,300	18,000	3,600	5,027	na	na
1,4-Dichlorobenzene	µg/kg dw	15	7%	30	470	70	107	60	480
Total PCBs (Aroclors)[e]	µg/kg dw	15	60%	9.5	530	30	66	19	20
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
Inline Grabs[h]									
All EW Inline Grabs[h]									
Arsenic	mg/kg dw	76	86%	0.75	88	10	12	6	30
Mercury	mg/kg dw	75	95%	0.01	16.69	0.14	0.88	0.02	0.03
Total HPAHs[c]	µg/kg dw	68	99%	120	51,400	3,112	6,408	1,400	1,400

Table 9-15

Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
Total cPAHs[d]	µg TEQ/kg dw	68	100%	24.1	30,780	804	1,746	na	na
BEHP	µg/kg dw	73	99%	35.5	47,000	2,880	5,508	71	71
1,4-Dichlorobenzene	µg/kg dw	73	47%	2.95	44,500,000	57	666,204	5.9	1,400
Total PCBs (Aroclors)[e]	µg/kg dw	82	80%	2.3	347,030	187	9,169	4.6	33
Total dioxins/furans[f]	ng TEQ/kg dw	17	100%	0.8	784	26	81	na	na
All Nearshore Drains[b, g]									
Arsenic	mg/kg dw	33	79%	3	88	12	16	6	30
Mercury	mg/kg dw	33	88%	0.01	1.27	0.12	0.19	0.02	0.03
Total HPAHs[c]	µg/kg dw	33	97%	120	18,280	3,500	5,226.70	1,400	1,400
Total cPAHs[d]	µg TEQ/kg dw	33	100%	31	4,181	410	733	na	na
BEHP	µg/kg dw	33	97%	35.5	45,000	3,600	7,763	71	71
1,4-Dichlorobenzene	µg/kg dw	33	18%	2.95	700	9.0	67	5.9	1,400
Total PCBs (Aroclors)[e]	µg/kg dw	40	78%	10	86,000	227	2,965	20	33
Total dioxins/furans[f]	ng TEQ/kg dw	13	100%	2.72	784	35	98	na	na
S Hinds Street SD[b]									
Arsenic	mg/kg dw	6	83%	5	20.0	12.2	12.7	10	10
Mercury	mg/kg dw	6	100%	0.04	0.7	0.34	0.37	na	na
Total HPAHs[c]	µg/kg dw	6	100%	148	11,005	7,125	6,228	na	na
Total cPAHs[d]	µg TEQ/kg dw	6	100%	24.1	1,578	613	680	na	na
BEHP	µg/kg dw	6	100%	290	47,000	3,500	10,748	na	na
1,4-Dichlorobenzene	µg/kg dw	6	17%	10	150	53	72	20	300
Total PCBs (Aroclors)[e]	µg/kg dw	6	83%	10	1,140	234	397	20	20

Table 9-15
Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
Total dioxins/furans[f]	ng TEQ/kg dw	1	100%	na	na	na	81.90	na	na
S Lander Street SD[b]									
Arsenic	mg/kg dw	6	83%	3	29.0	10.5	11.7	6	6
Mercury	mg/kg dw	6	100%	0.05	0.29	0.07	0.11	na	na
Total HPAHs[c]	µg/kg dw	6	100%	180	9,250	1,049	2,377	na	na
Total cPAHs[d]	µg TEQ/kg dw	6	100%	53.59	1,247	169	338	na	na
BEHP	µg/kg dw	6	100%	530	7,900	855	2,003	na	na
1,4-Dichlorobenzene	µg/kg dw	6	0%	9.5	38.5	17	20	19	77
Total PCBs (Aroclors)[e]	µg/kg dw	6	33%	9.5	50	10	20	19	20
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
All Combined Sewer[h]									
Arsenic	mg/kg dw	31	94%	0.75	80	4.5	8.3	1.5	7.8
Mercury	mg/kg dw	30	100%	0.02	16.69	0.32	1.89	na	na
Total HPAHs[c]	µg/kg dw	23	100%	377.45	51,400	2,952	9,201	na	na
Total cPAHs[d]	µg TEQ/kg dw	23	100%	221.95	30,780	1,601	3,844	na	na
BEHP	µg/kg dw	28	100%	388	6,890	1,980	2,479	na	na
1,4-Dichlorobenzene	µg/kg dw	28	96%	50	44,500,000	388	1,736,780	100	100
Total PCBs (Aroclors)[e]	µg/kg dw	30	93%	2.3	347,030	261	21,025	4.6	5.2
Total dioxins/furans[f]	ng TEQ/kg dw	3	100%	0.8	12.4	2.8	5.3	na	na
Inline Traps[h]									
All EW Inline Traps[h]									
Arsenic	mg/kg dw	24	50%	3.0	20	7.4	9.2	14.8	6

Table 9-15

Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
Mercury	mg/kg dw	24	100%	0.09	1.96	0.21	0.39	na	na
Total HPAHs[c]	µg/kg dw	22	100%	2,220	42,950	8,725	10,646	na	na
Total cPAHs[d]	µg TEQ/kg dw	22	100%	293.7	12,073	1,226	2,182	na	na
BEHP	µg/kg dw	22	100%	1,200	32,800	13,500	15,255	na	na
1,4-Dichlorobenzene	µg/kg dw	22	14%	29.5	60,900	115	3,069	59	530
Total PCBs (Aroclors)[e]	µg/kg dw	29	62%	10	740	43	106	20	47
Total dioxins/furans[f]	ng TEQ/kg dw	3	100%	37	99.2	47	61	na	na
All Nearshore Drains[b, g]									
Arsenic	mg/kg dw	1	100%	20	20	na	20	na	na
Mercury	mg/kg dw	1	100%	0.18	0.18	na	0.18	na	na
Total HPAHs[c]	µg/kg dw	1	100%	na	na	na	10,900	na	na
Total cPAHs[d]	µg TEQ/kg dw	1	100%	na	na	na	1,160	na	na
BEHP	µg/kg dw	1	100%	na	na	na	24,000	na	na
1,4-Dichlorobenzene	µg/kg dw	1	0%	na	na	na	165	330	330
Total PCBs (Aroclors)[e]	µg/kg dw	4	75%	23.5	740	150	266	47	47
Total dioxins/furans[f]	ng TEQ/kg dw	na	na	na	na	na	na	na	na
S Lander Street SD[b]									
Arsenic	mg/kg dw	19	37%	3	20	5.0	8.8	14.8	6
Mercury	mg/kg dw	19	100%	0.09	0.4	0.20	0.21	na	na
Total HPAHs[c]	µg/kg dw	18	100%	2,220	42,950	8,990	11,715	na	na
Total cPAHs[d]	µg TEQ/kg dw	18	100%	293.7	12,073	1,139	2,070	na	na
BEHP	µg/kg dw	18	100%	1,200	27,000	11,000	12,439	na	na

Table 9-15
Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

Contaminant	Unit	No. of Samples	Detection Frequency	Range of Detects		Median[a]	Mean[a]	Range of Non-Detect RLs	
				Min	Max			Min	Max
1,4-Dichlorobenzene	µg/kg dw	18	0%	29.5	265	100	119	59	530
Total PCBs (Aroclors)[e]	µg/kg dw	21	62%	10	278	41	65	20	24
Total dioxins/furans[f]	ng TEQ/kg dw	2	100%	37	99.2	na	68	na	na
All Combined Sewer[h]									
Arsenic	mg/kg dw	4	100%	7.3	9.8	8.7	8.6	na	na
Mercury	mg/kg dw	4	100%	0.67	1.96	1.2	1.3	na	na
Total HPAHs[c]	µg/kg dw	3	100%	2,290	5,494	4,650	4,145	na	na
Total cPAHs[d]	µg TEQ/kg dw	3	100%	2,835	3,710	3,023	3,189	na	na
BEHP	µg/kg dw	3	100%	26,800	32,800	28,100	29,233	na	na
1,4-Dichlorobenzene	µg/kg dw	3	100%	628	60,900	3,680	21,736	na	na
Total PCBs (Aroclors)[e]	µg/kg dw	4	50%	21	348	142	163	42	46
Total dioxins/furans[f]	ng TEQ/kg dw	1	100%	na	na	na	47.10	na	na

Sources: SPU (2011b); Williston (2011b); Windward (2009b, c, f, g). Individual sample results are included in Appendix I.

[a] Calculated using detected concentrations and one-half the RL for samples not detected.

[b] Samples representative of stormwater inputs.

[c] HPAH results were considered detected if one or more of the components of the sum were detected. If none of the components of the sum were detected, the calculated HPAH concentration was considered not detected.

[d] cPAHs were calculated by summing the products of individual cPAH concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual cPAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

[e] Total PCBs represent the sum of the detected concentrations of the individual Aroclors. If none of the individual Aroclors were detected in a given sample, the non-detect value represents the highest RL.

[f] Dioxin and furan TEQs were calculated using TEFs for mammals presented in Van den Berg et al. (2006) (see Appendix D for a list of these TEFs). Dioxin and furan TEQs were calculated for each sample by summing the TEQs for each dioxin and furan congener. Dioxin and furan individual congener TEQs were calculated as the product of individual congener concentrations and congener-specific TEFs. If an individual congener was not detected, the TEF for that congener was multiplied by one-half the RL for that congener.

[g] All nearshore drains include all SPU nearshore and Port of Seattle nearshore drains as follows:

Table 9-15

Source-Tracing Results for Direct Discharges – Solids Data Summary (cont.)

SPU nearshore includes SW Florida Street SD (B-21), SW Spokane Street SD (B-4), SW Spokane Street EOF/SD (B-5), S Spokane Street SD (B-36), and S Massachusetts Street SD (B-25).

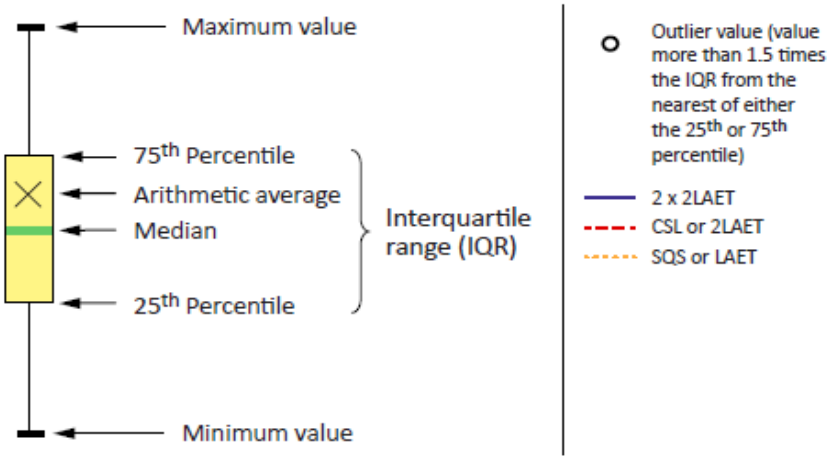
Port of Seattle nearshore includes B-1, B-7, B-10, B-11 (SW Hanford Street EOF/SD), B-12, B-13, B-14, B-16, B-17, B-18, B-19, B-21, B-22, B-23, B-24, B-26, B-27, B-28, B-29, B-30, B-31, B-32, B-33, B-34, B-36, B-37, and B-39.

[h] Samples representative of basin type. All combined sewer samples by inline grabs and inline traps are representative of solids from within the combined sewer system. All other samples are representative of stormwater inputs

BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
EW – East Waterway
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
na – not applicable
PCB – polychlorinated biphenyl
PEF – potency equivalency factor
RL – reporting limit
ROW – right-of-way
SD – storm drain
SPU – Seattle Public Utilities
TEF – toxic equivalency factor
TEQ – toxic equivalent

9.4.3.3.4 Graphical Summaries of Source-Tracing Data

This section presents the source-tracing sample results from SD and CSO conveyances graphically using "box plots." A detailed legend is provided to facilitate the interpretation of the box plots (Figure 9-5). The box plots (Figures 9-6 through 9-13) present the full range of data and summarize the mean, median, and 25th and 75th percentiles for the following contaminants measured in solids: arsenic, mercury, HPAH, cPAH, BEHP, 1,4-dichlorobenzene, total PCBs, and dioxins and furans. Because the concentration ranges can vary by more than an order of magnitude, the vertical axes of the box plots for all chemicals except arsenic are presented in log scale. The box plots represent the full datasets, including outlier data points (concentrations greater than 1.5 times the interquartile range from the nearest of either the 25th or 75th percentile) that may not be representative of typical SD or CSO solids quality within the basins. Many of the elevated contaminant concentrations represented by the outlier data points on the figures were discovered as part of the ongoing source-tracing programs and have been addressed as part of source control activities conducted by the Port of Seattle, City of Seattle, and King County. Therefore, distributions presented in this section have changed through source control actions that have taken place since the data were collected. These activities are discussed in Appendix F.



In this document, values described above (SQS/CSL, LAET/2LAET) that are used for comparison to SD or CSO solids data are referred to as "storm drain screening levels." It should be emphasized that none of these values are applied as cleanup levels to SD or combined sewer solids. It is important to note that any comparison of this kind is most likely conservative given that sediments discharged from SDs or CSOs are highly dispersed in the receiving environment and mixed with the natural sedimentation taking place in the system (Ecology and SAIC 2011).

Figure 9-5

Box Plot Legend

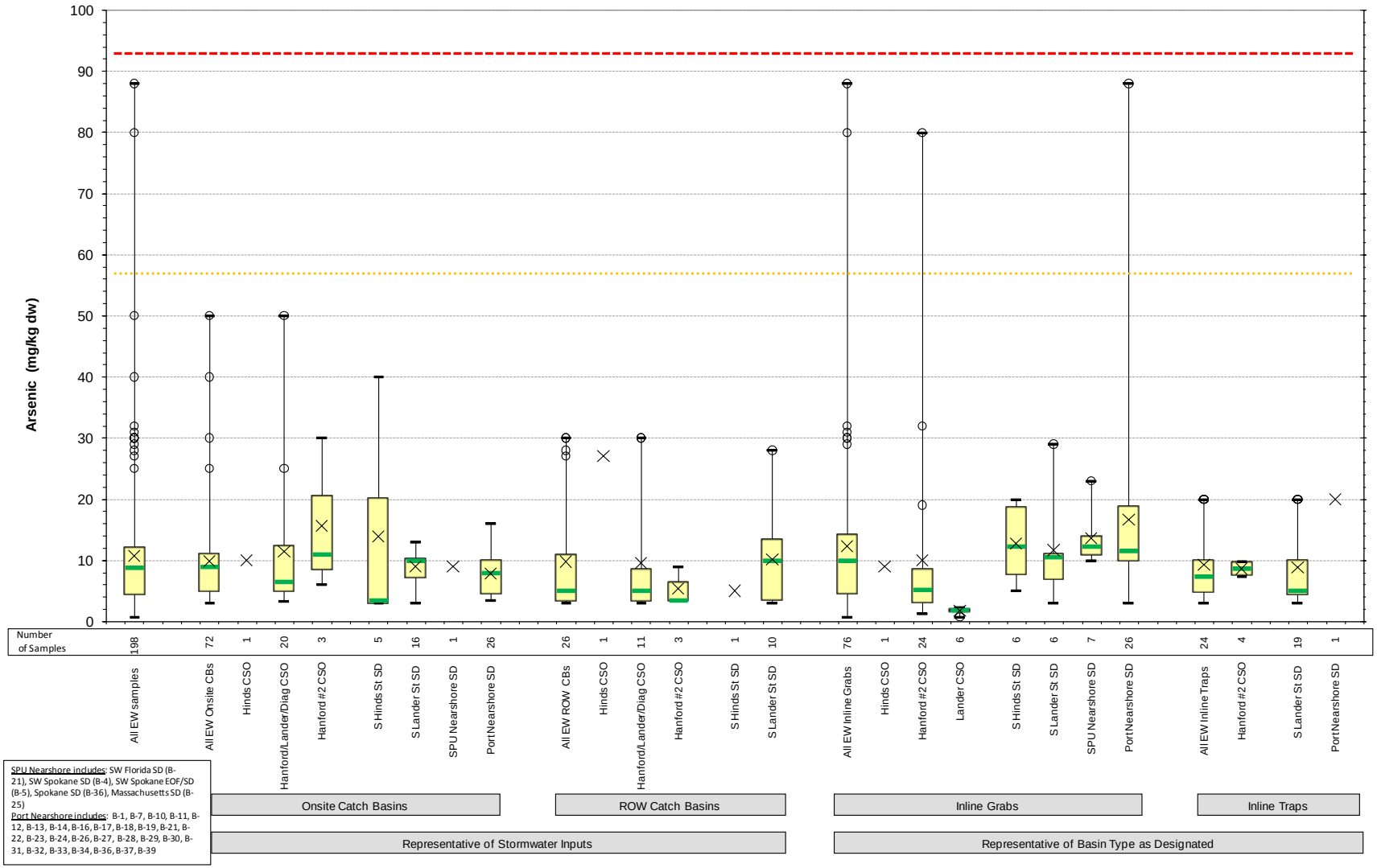


Figure 9-6

Arsenic Source-Tracing Sample Results

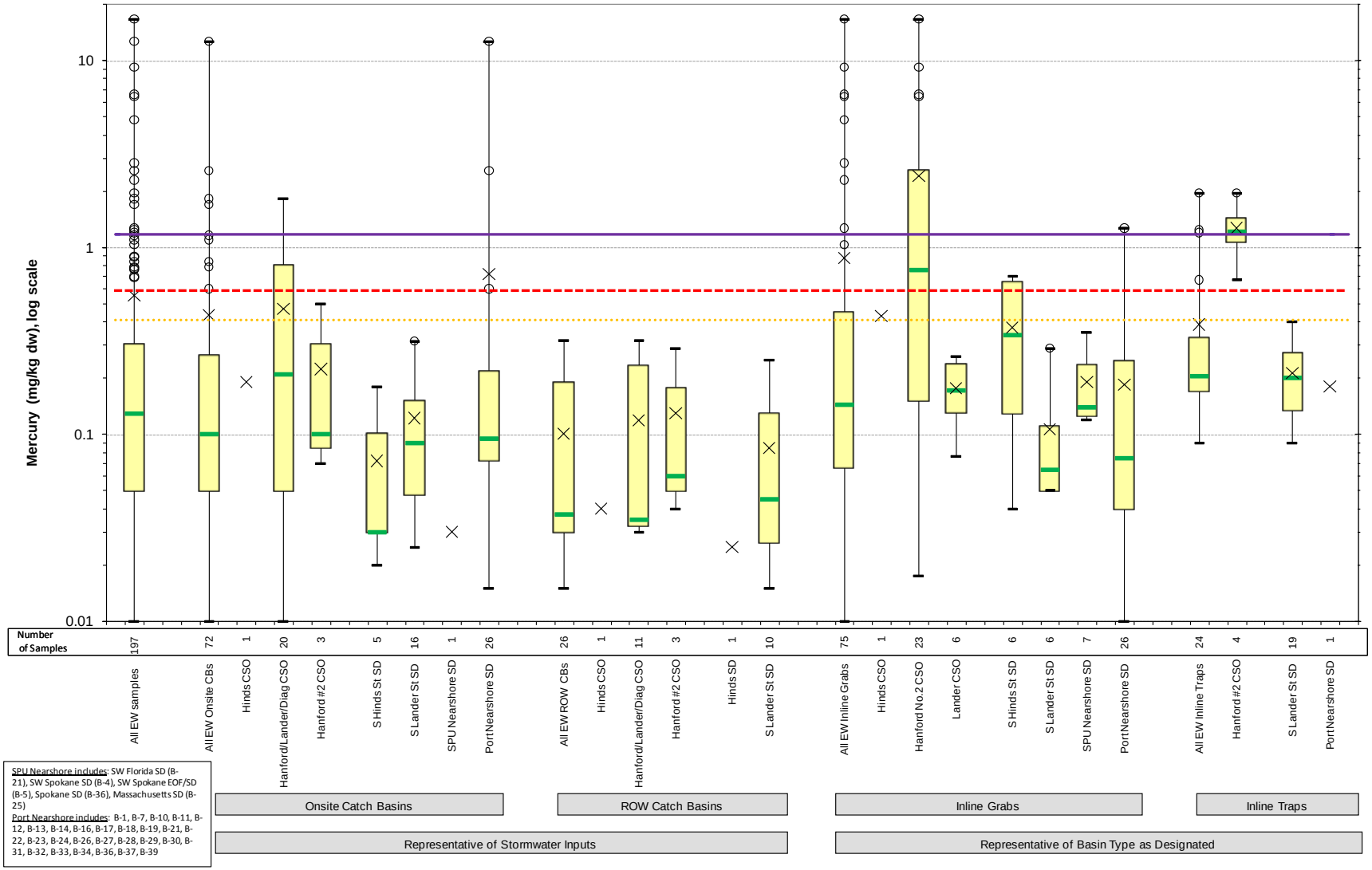


Figure 9-7

Mercury Source-Tracing Sample Results

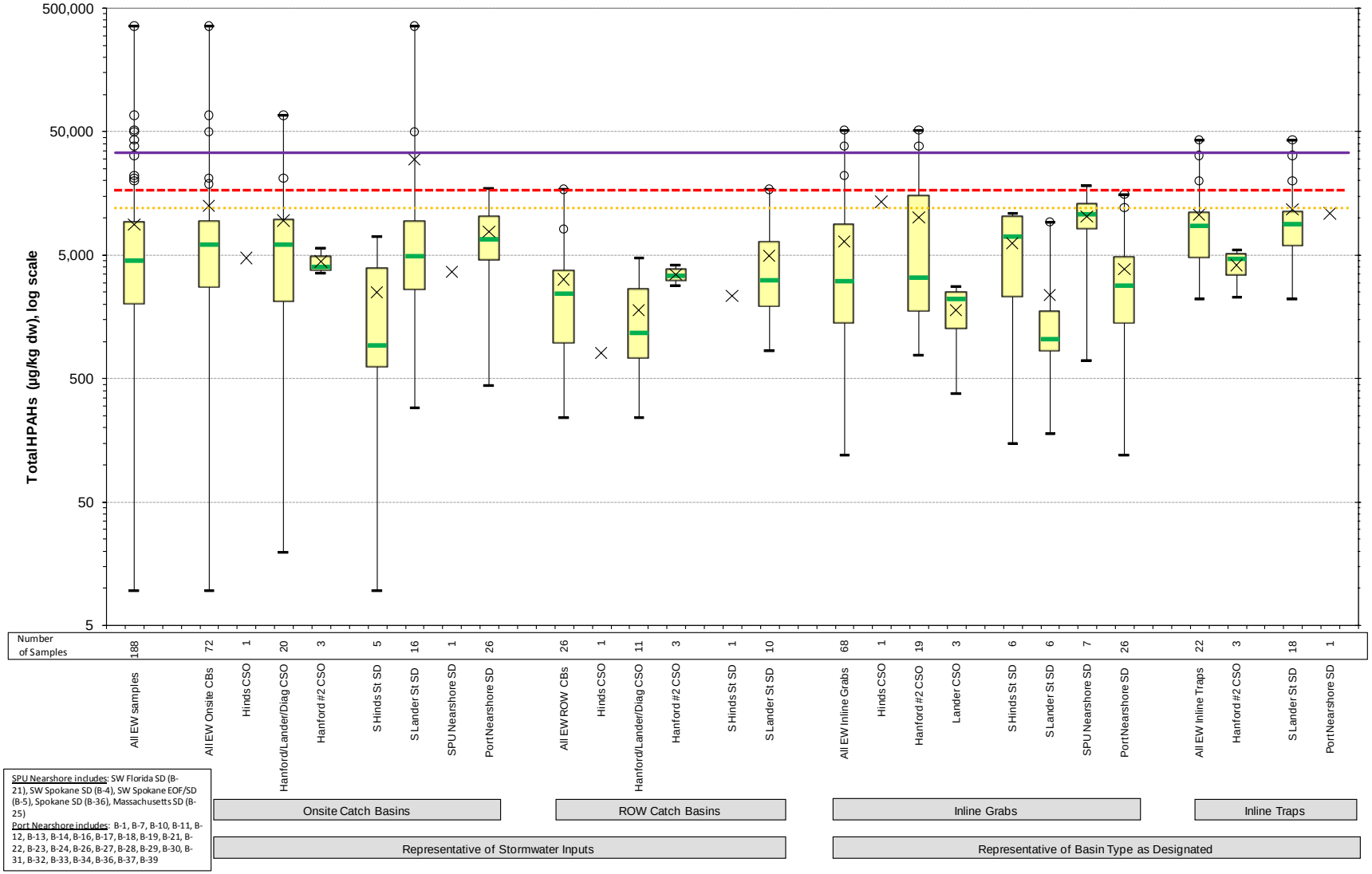


Figure 9-8

HPAH Source-Tracing Sample Results

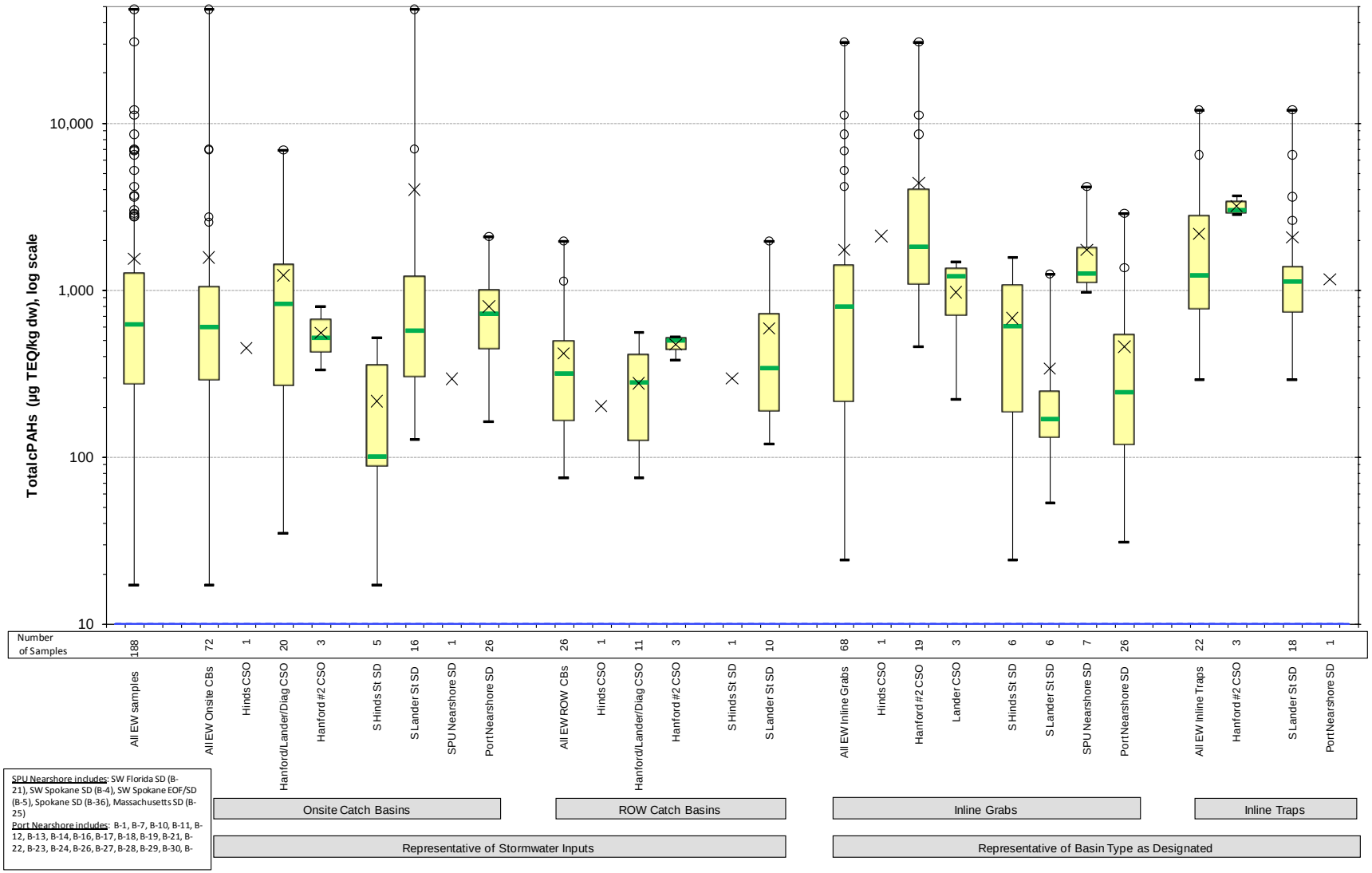


Figure 9-9

cPAH Source-Tracing Sample Results

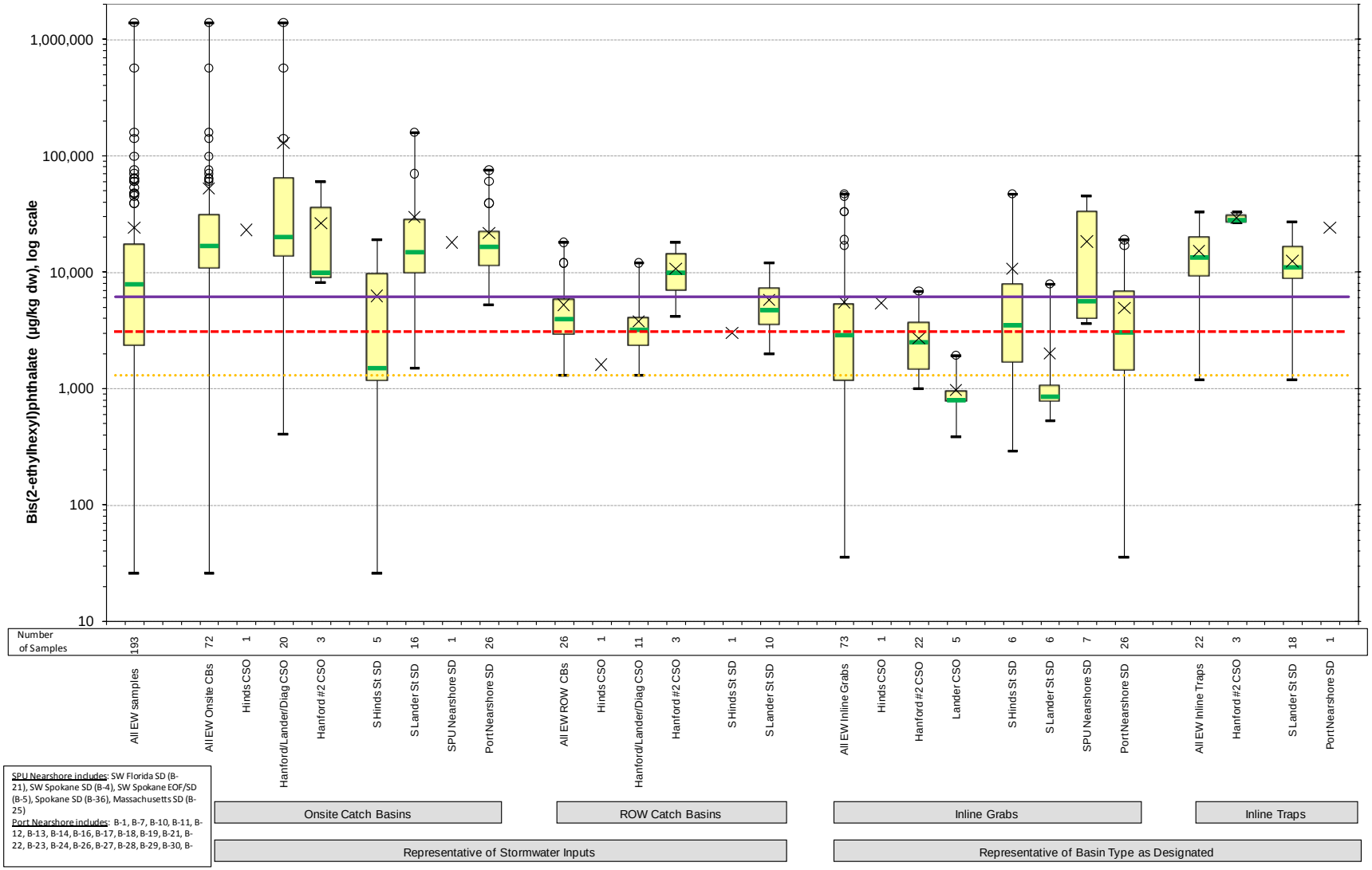


Figure 9-10

BEHP Source-Tracing Sample Results

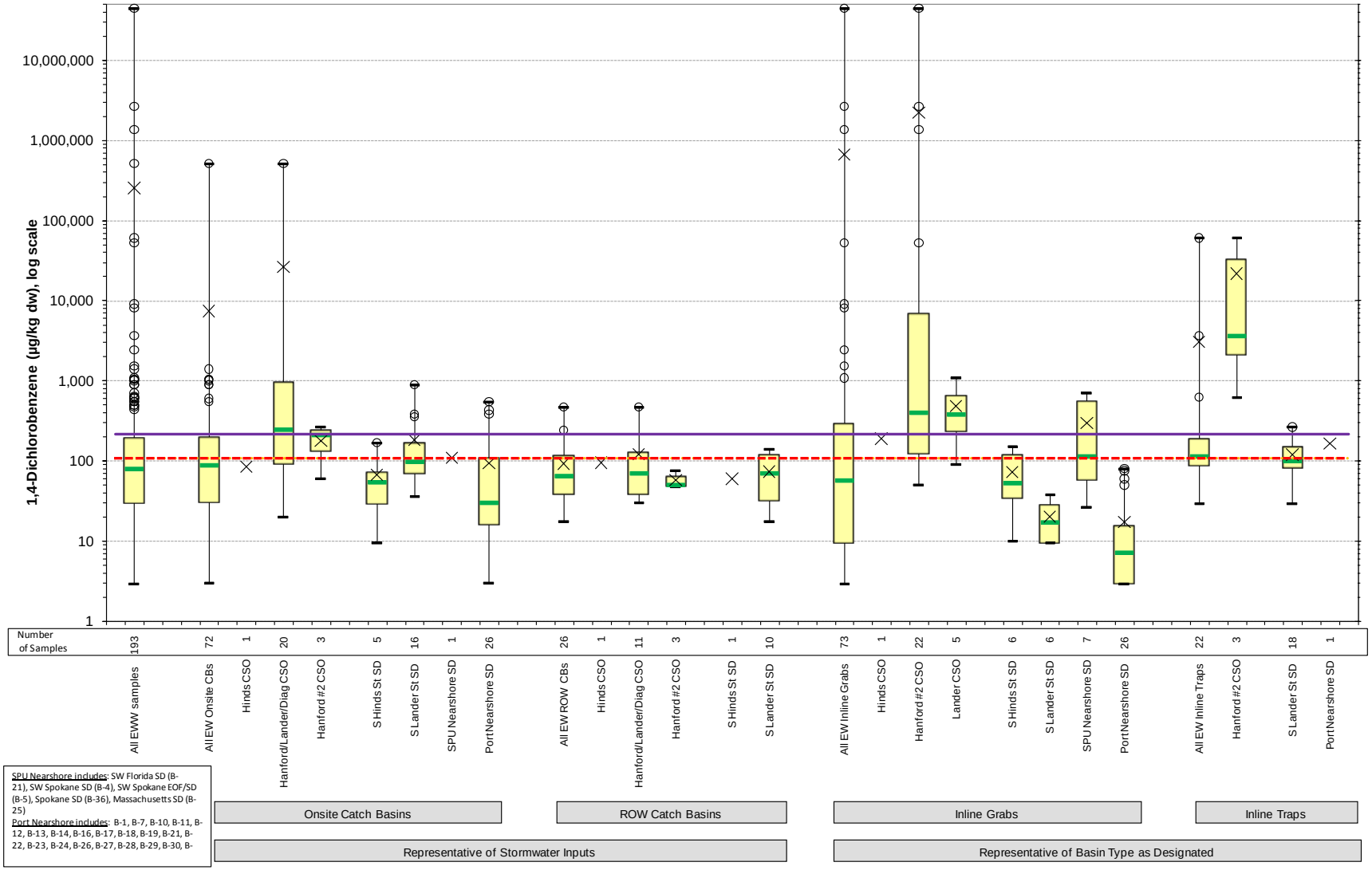


Figure 9-11

1,4-Dichlorobenzene Source-Tracing Sample Results

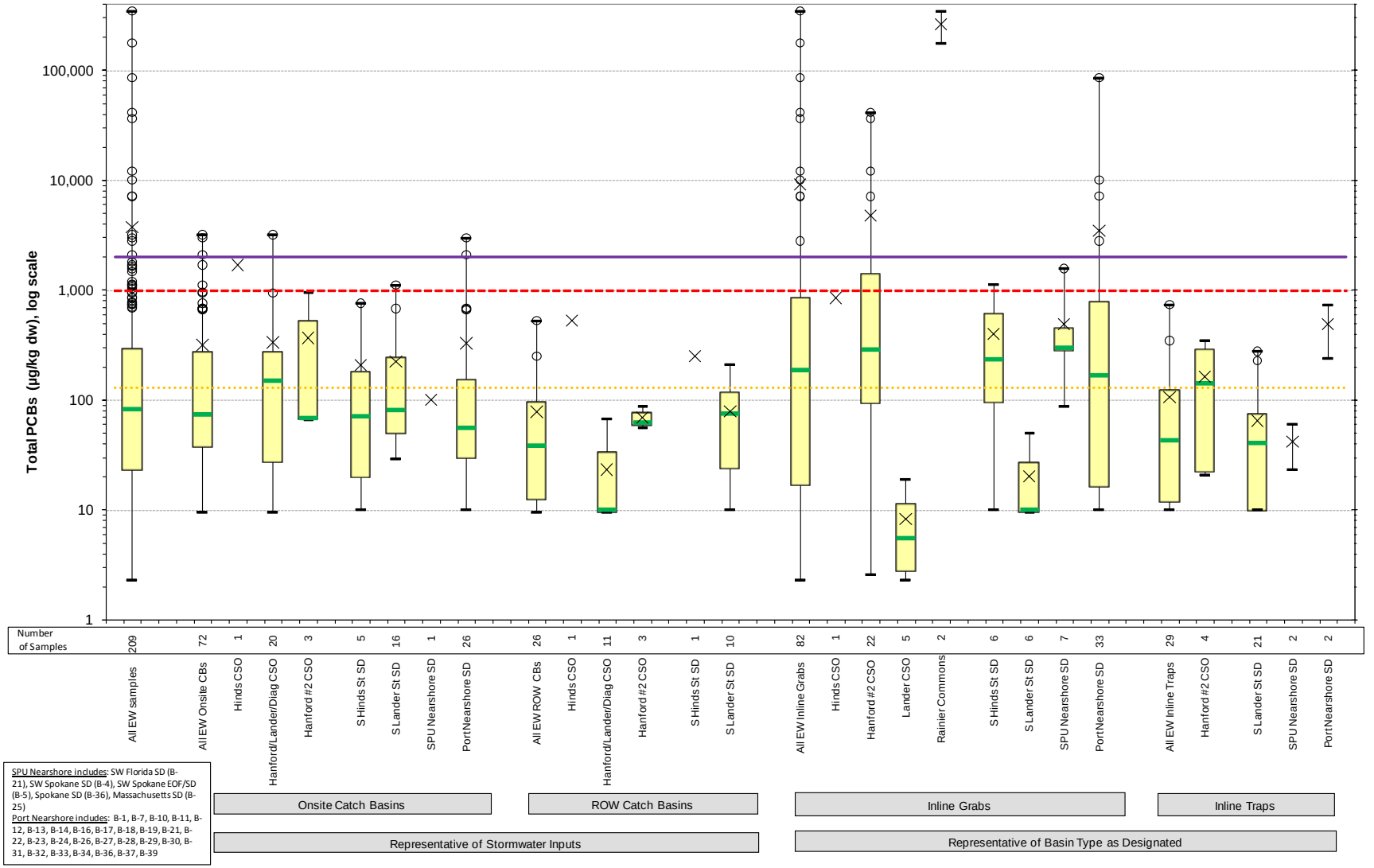


Figure 9-12

Total PCB Source-Tracing Sample Results

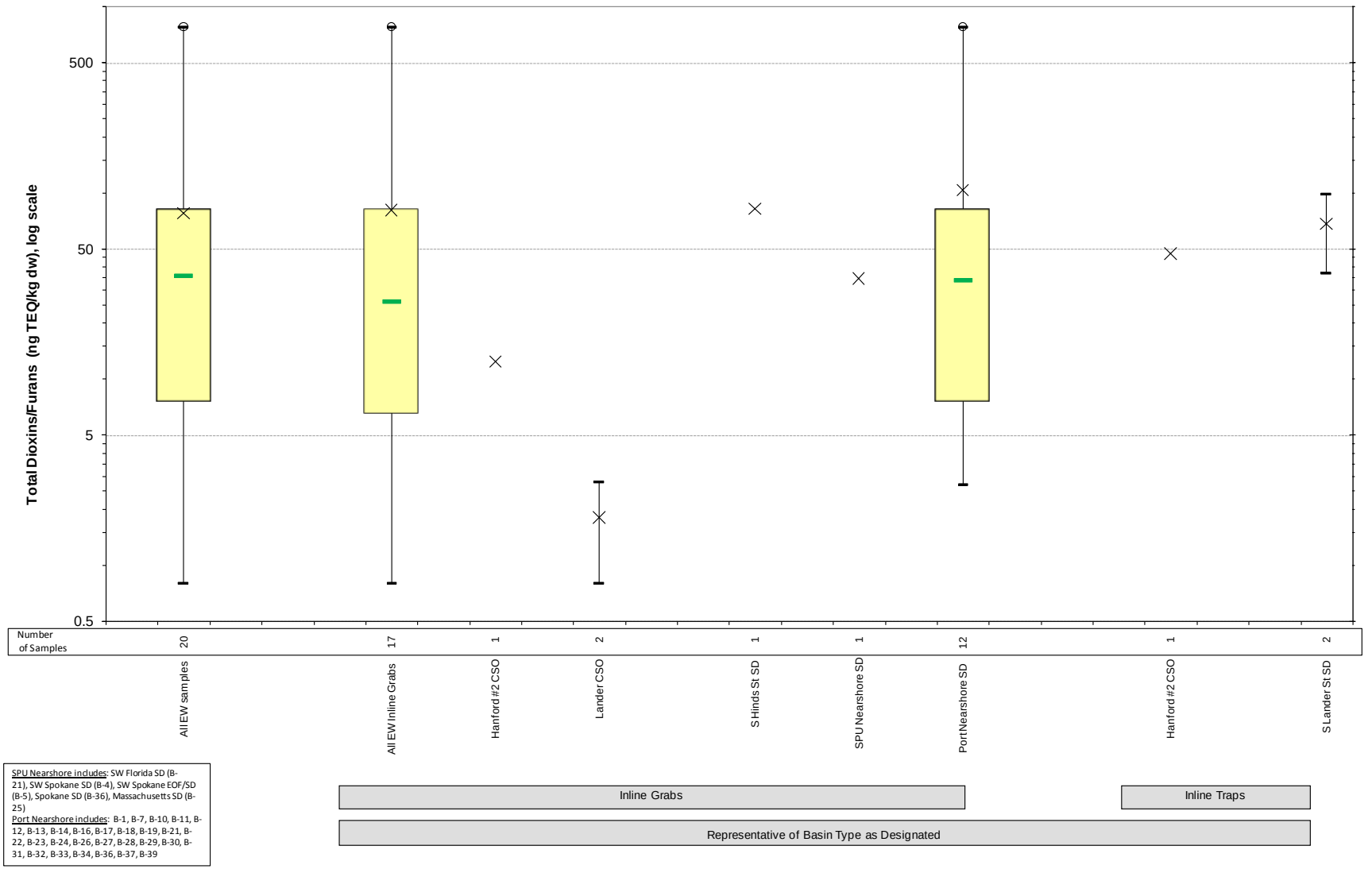


Figure 9-13
Total Dioxin and Furan Source-Tracing Sample Results

Source-tracing data are presented in box plots according to the type of sample (i.e., on-site catch basin, ROW catch basin, and inline grab or inline trap) for the various SD and CSO basins. The data are also presented as pooled datasets—one that includes all of the sample types and basins together and another that pools the data by type, regardless of basin designation. All solids data are presented on a dry-weight basis.

There are no regulatory standards for solids collected from catch basins or in the lines of SD or CSO conveyance systems. State and local source control programs typically compare SD solids data to the SMS to provide a rough indication of overall quality. SMS values shown in the box plots are provided for comparison to SD and CSO solids data and are referred to as "storm drain screening levels." It should be emphasized that none of these values are applied as cleanup levels to SD or combined sewer solids. It is important to note that any comparison of this kind is most likely conservative given that sediments discharged from SDs and CSOs are highly dispersed in the receiving environment and mixed with the natural sedimentation taking place in the system (Ecology and SAIC 2011). In addition, for CSOs, the majority of combined sanitary and stormwater flows are conveyed to the WWTP. SMS-based SD screening levels used include dry-weight sediment values (e.g., SQS and CSL for metals) or the LAETs and 2LAETs (for organics), which are dry-weight equivalents of the SMS values. No similar SMS-based SD screening levels exist for cPAH or dioxins and furans.

Overall results from the source-tracing samples collected for the EW indicate that contaminant concentrations among sample types and basins were variable. Contaminant concentrations were generally higher in samples collected from on-site catch basins than in those from ROW catch basins, likely because most on-site catch basin sampling stations were selected based on source control issues identified during business inspections and other specific source-tracing activities. In addition, samples collected from CSO lines are likely to have higher concentrations of a few contaminants on average than from within SD lines because CSO lines carry both municipal and industrial wastewater, of which the vast majority is conveyed to the WWTP. Finally, all summaries presented below are based on solids data collected from within these systems. Whole-water data, where available, are presented in the water quality sections below.

9.4.3.3.5 Summary of Source-Tracing Data

Arsenic

Arsenic was most frequently detected in inline grabs (86%) compared to other sample types (38 to 56% frequency of detection). Arsenic solids data were found to have a tight concentration range with a few exceptions. Overall, means and medians for the different sample types (e.g., catch basins, inline grabs and sediment traps) were similar (Table 9-15) and almost all samples were below screening values (Figure 9-6). The two highest concentrations were from inline grabs from a Port of Seattle nearshore SD (88 mg/kg dw) and a sewer line (80 mg/kg dw) discharging to the Hanford #2 CSO system (Map 9-13). These concentrations are considered outliers, as shown in Figure 9-6. Source-tracing and control efforts have removed material containing these two highest arsenic concentrations (see Appendix F for details).

Mercury

Mercury was frequently detected in on-site catch basins, inline grabs, and sediment traps (74 to 100%) and detected less frequently in ROW catch basins (50%). The median and mean mercury concentrations were lowest in ROW catch basins (0.04 and 0.1 mg/kg dw), whereas the highest median and mean concentrations were found in sediment traps (0.21 and 0.39 mg/kg dw, respectively) and inline grabs (0.14 and 0.88 mg/kg dw, respectively). Mean concentrations were similar between on-site catch basins (0.43 mg/kg dw) and sediment trap (0.39 mg/kg dw) samples (Table 9-15). Less than 20% of the source samples exceeded the SLs for mercury (18 percent exceeded the SQS and 15% exceeded the CSL). The highest concentrations were generally found in inline grabs from the Hanford #2 CSO system, a few Port of Seattle nearshore SDs, and a few isolated on-site catch basins in the broader Hanford/Lander/Diagonal system (Figure 9-7; Map 9-14). Source-tracing and control efforts for the highest mercury concentrations found are discussed in Appendix F.

HPAH

HPAHs were regularly detected in all source type samples (detection frequencies greater than 96%). Mean and median concentrations were lowest in ROW catch basins (3,181 and 2,445 µg/kg dw) followed by inline grab samples (6,408 and 3,112 µg/kg dw). Mean and medians were higher in on-site catch basins (12,506 and 6,075 µg/kg dw) and sediment traps (10,646 and 8,725 µg/kg dw) (Table 9-15). Less than 15 percent of the samples exceeded the

SLs. The highest concentrations were found in S Lander Street SD in two on-site catch basins (358,400 µg/kg dw in CB151 and 68,000 µg /kg dw in CB26) and one sediment trap (42,950 µg/kg dw), and in one location in Hanford #2 CSO system (51,400 µg/kg dw) (Figure 9-8; Map 9-15). Source-tracing and control efforts for some of the highest HPAH concentrations found are discussed in Appendix F.

cPAH

At least one cPAH compound was detected in all of the source samples, resulting in a detection frequency of 100%.[130] While cPAH concentrations were variable among all sample types and basins (Figure 9-9), mean and median cPAH concentrations were generally higher in sediment traps (2,182 and 1,226 µg TEQ/kg dw) followed by inline grabs (1,746 and 804 µg TEQ/kg dw), and on-site catch basins (1,569 and 605 µg TEQ/kg dw), and lowest in ROW catch basins (418 and 319 µg TEQ/kg dw) (Table 9-15). Similar to the HPAHs, the highest concentrations were found in a few S Lander Street SD and Hanford #2 CSO basin samples.

BEHP

BEHP was regularly detected in all source type samples (detection frequencies greater than 96%) and frequently exceeded the source SLs (Figure 9-10). While BEHP concentrations were variable among all sample types and basins, mean concentrations were highest in on-site catch basin samples (52, 458 µg/kg dw) followed by sediment trap samples (15,255 µg/kg dw), and lowest in ROW catch basin (5,227 µg/kg dw) and inline grab samples (5,508 µg/kg dw) (Table 9-15). Based on inline grabs, concentrations tended to be higher in SD solids than CSO solids (Figure 9-10). However, the highest concentrations were found in on-site catch basins in both SD and CSO systems. As shown on Map 9-16, elevated concentrations of BEHP were present in samples from throughout the EW study area, indicating that BEHP is ubiquitous within a variety of drainage basins. BEHP is commonly detected in Puget Sound sediment and was evaluated by the SPWG, which concluded that phthalates are widespread in urban and other developed environments and ubiquitous in water, soil, sediment, and air (Floyd|Snider 2007a). Based on its studies, the SPWG did not identify any large, easily controllable source of phthalates to sediment.

[130] Not all individual cPAHs were detected in all samples.

1,4-Dichlorobenzene

1,4-dichlorobenzene was infrequently detected in catch basin (both on-site and ROW) and sediment trap samples (4% to 14%); it was most frequently detected in inline grab samples (47%). Mean concentrations were lowest in ROW catch basins (92 µg/kg dw) followed by sediment traps (3,069 µg/kg dw) and on-site catch basins (7,422 µg/kg dw), and the highest in inline grab samples (666,204 µg/kg dw) (Table 9-15). Median concentrations were much lower for all sample types (the highest median for all sample types was 115 µg/kg dw) indicating data are highly skewed. 1,4-Dichlorobenzene exceeded the screening levels in 38% of the samples. The highest concentrations were found in both inline grabs and sediment traps from the Hanford #2 CSO system (Figure 9-11; Map 9-17). A few high concentrations were also found in on-site catch basins within the Hanford/Lander/Diagonal CSO basins. Many of the samples analyzed for 1,4-dichlorobenzene represent samples associated with King County's efforts to investigate the source of elevated 1,4-dichlorobenzene concentrations in the Hanford #2 CSO basin. The source of these elevated concentrations was identified and has since been controlled. Additional details on King County's and the City of Seattle's 1,4-dichlorobenzene source-tracing and control activities are discussed in Appendix F.

Total PCBs

PCBs were frequently detected in catch basins (both on-site and ROW) and inline grabs (73 to 89%) and detected less frequently in sediment traps (62%). The median concentrations of PCBs for all sample types were relatively low (ranged from 39 to 187 µg/kg dw). Mean concentrations were highest for inline grab samples (9,169 µg/kg dw) and lowest for ROW catch basins (78 µg/kg dw) (Table 9-15). Inline and on-site catch basin samples generally contained higher concentrations of PCBs than sediment trap and ROW catch basin samples, but this difference was related to the discovery of specific PCB sources that are being addressed through source control actions. The highest total PCB concentrations were found in inline samples collected from the Rainer Commons property (177,700 and 347,030 µg/kg dw), 4th Avenue S lateral to the Hanford #2 CSO (up to 41,300 µg/kg dw), and a Port of Seattle nearshore SD, basin B-11 (86,000 µg/kg dw) (Figure 9-12; Map 9-18). Overall, 43% of the samples exceeded the LAET and 11% exceeded the 2LAET SLs. Samples above the 2LAET SL were generally found in a few specific areas (Figure 9-12). Other locations with PCB concentrations above the 2LAET-based SL (in addition to those listed above) include

inline grab samples from the S Hinds Street SD (1,140 µg /kg dw) and S Florida Street (1,570 µg/kg dw), a few Port of Seattle nearshore SDs (B11, B16, B24, and B34; 1,040 to 10,100 µg/kg), a few locations in Hanford #2 CSO, and some on-site catch basin samples (CB 22, CB65, and CB153; 1,120 to 3,200 µg /kg) (Map 9-18). Details on source-tracing and control activities for PCBs are discussed in Appendix F.

Dioxins and Furans

A subset of source-tracing samples (20 samples) of inline grabs and sediment traps collected from EW basins were analyzed for dioxins and furans; these data collection efforts focused on samples that would be representative of the overall drainage basin and not specific subareas within a basin (e.g., no catch basins were analyzed). Dioxins and furans were detected in all samples; means were similar between inline grabs and sediment traps (81 and 61 ng TEQ/kg dw, respectively) (Table 9-15). Based on the 14 SD and 3 combined sewer inline grabs, mean concentrations were higher in SDs (98 ng TEQ/kg)[131] when compared to CSOs (5.3 ng TEQ/kg). However, for sediment trap samples, the dioxin/furan ranges overlapped between SDs (37 to 99 ng TEQ/kg) and CSOs (47 ng TEQ/kg)[132] (see Figure 9-13). The highest concentration was identified in Port of Seattle nearshore Basin B34 (784 ng TEQ/kg dw) (Map 9-19); details on source control efforts for this basin are described in Appendix F.

9.4.3.3.6 Storm Drain Water Quality

As discussed in Section 9.4.3.2.2, stormwater quality monitoring data of whole water samples from the S Lander Street SD system are available (Appendix H). This dataset includes data collected between 1997 and 2002 following separation of the combined sewer system in this area; whole water sampling was terminated in 2002.

Sampling was conducted from five locations within the separated system; specifically, four from the SD line along S Lander Street between Utah and Airport Way and one from the wet well of the regulator station where flows from both the separated storm system and

[131] Mean concentration is based on nearshore drains; an in-line grab sample was also collected from the S Hinds Street SD with concentration of 82 ng TEQ/kg dw.

[132] Samples sizes are small, e.g., only two sediment trap samples from S Lander Street SD and one from Hanford #2 CSO are available for this comparison.

combined system are mixed. Samples from the wet well that were collected when no CSO events were occurring have been included because they are representative of water from the separated system. Samples were collected as composite samples at two locations and as grab samples at three locations.

The S Lander Street separated SD line is affected by tidal flows. Rainfall events, rain gauge readings from the nearby Chelan Regulator station on the WW, and field conductivity measurements were used to ensure that storm event sampling occurred during a time when the system was dominated by stormwater, not tidal water. Baseflow samples were collected during low-tide events to decrease the influence of tidal flows. The conductivity indicates that the salinity of the stormwater samples was less than 5 ppt (i.e., brackish conditions) and, therefore, generally indicative of freshwater conditions, suggesting there was limited tidal influence with regard to the storm flow data. Most base flow data have conductivity measurements that suggest brackish to freshwater conditions. Table 9-16 compares the S Lander Street storm and baseflow conductivity and calculated salinity data. The baseflows have higher conductivity and salinity than do the storm flows, indicating that tidal water has a larger influence on the baseflow than on the storm flow.

Table 9-16
Comparison of S Lander Street SD Storm and Base Flow Conductivity and Salinity

	Conductivity (µmhos/cm)						Salinity (ppt)[a]					
Parameter	Min	Max	Mean	Median	25th	75th	Min	Max	Mean	Median	25th	75th
Base flow	218	21,000	3,523	896	559	4,179	< 1	15.9	2.3	< 1	< 1	2.8
Storm flow	42.3	6,450	404	134	88.5	184	< 1	4.5	< 1	< 1	< 1	< 1

Note: Sampling was conducted by King County from 1997 to 2002, and data were presented in the SEDGM (Anchor QEA and Windward 2009).

[a] Salinity was calculated using the average temperature and conductivity of base flow (14.9°C) and storm flow data (14.1°C).

ppt – parts per thousand

SD – storm drain

SEDGM – source evaluation and data gaps memorandum

Table 9-17 summarizes the Lander outfall water sampling data collected under storm flow and base flow conditions, respectively. The table summarizes the frequency and ranges of detected concentrations and the method detection limit (MDL) ranges for all focus contaminants, except cPAHs (because cPAH concentrations were not calculated for whole

water samples due to very low detection frequency) and dioxins and furans (because samples were not analyzed for dioxins and furans). PCBs (as Aroclors) and mercury were not detected in any samples, and BEHP and arsenic were frequently detected in samples.

Table 9-17

S Lander Street Stormwater Water Quality Data

Contaminant	No. of Samples	Detection Frequency	Detected Concentrations (µg/L)				MDL (µg/L)[a]	
			Min	Max	Mean	Median	Min	Max
Storm Flow Conditions								
Arsenic (total)	28	93%	1	5.62	2.7	2.4	0.5	10
Mercury (total)	28	0%	nd[b]	nd[b]	nd[b]	nd[b]	0.2	0.2
HPAHs	28	50%	0.29	3.7	0.84	0.62	0.28	0.8
BEHP	28	100%	1.31	112	10.7	5.55	0.28	0.3
Total PCBs (Aroclors)	28	0%	nd[b]	nd[b]	nd[b]	nd[b]	0.12	0.24
1,4-Dichlorobenzene	28	4%	0.708	0.708	0.708	0.708	0.28	0.3
Base Flow Conditions								
Arsenic (total)	56	84%	1.4	41.8	6.12	2.2	0.5	13
Mercury (total)	56	0%	nd[b]	nd[b]	nd[b]	nd[b]	0.2	0.2
HPAH	56	4%	0.33	1.61	0.97	0.97	0.28	0.75
BEHP	56	100%	0.29	59.4	4.45	2.6	0.28	0.28
Total PCBs (Aroclors)	56	0%	nd[b]	nd[b]	nd[b]	nd[b]	0.24	0.24
1,4-Dichlorobenzene	56	2%	0.34	0.34	0.34	0.34	0.28	0.28

Note: Sampling was conducted by King County from 1997 to 2002, and data were presented in the SEDGM (Anchor QEA and Windward 2009). Data presented in Appendix H, Part H-4.

[a] A non-detected concentration is reported at the MDL.

[b] Range of MDLs is shown on the right.

BEHP – bis(2-ethylhexyl) phthalate
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
MDL – method detection limit
nd – not detected (in any of the samples analyzed)
PCB – polychlorinated biphenyl
SEDGM – source evaluation and data gaps memorandum

9.4.3.3.7 CSO Water Quality

Data are available to characterize water quality of CSOs that discharge to EW. CSO water quality monitoring data have been collected from Hanford #2 CSO in 1996 to 1997, 2004, and 2007 to 2009, and from the Lander CSO from 2008 to 2009. Because of improvements in analytical methods and detection limits, only the most recent data collected from these

systems (2007 to 2009) are summarized in the EW SRI/FS and are included in Appendix H. Older data were presented in the SEDGM (Anchor QEA and Windward 2009).

Sampling and analytical methods used to collect CSO samples in 2007 to 2009 are detailed in King County's sampling and analysis plan (King County 2007), and results and QA reviews are presented in King County's data report (King County 2011c). Sampling was conducted by King County using Isco® auto samplers. Auto samplers were automatically triggered by water depth in the Lander regulator station and by CSO gate openings at Hanford #2 CSO. Composite sampling occurred over a 2-hour period, as long as water depths remained above the intake line at Lander Regulator Station or for Hanford #2 as long as the CSO discharge event continued.

Tables 9-18 and 9-19 present the CSO whole water data summary results for the Hanford #2 and Lander CSOs, respectively, for all focus contaminants.

Table 9-18
Hanford #2 CSO Water Quality Data

Contaminant	Unit	No. of Samples	Detection Frequency (%)	Detected Concentration			
				Min	Max	Mean[a]	Median
Arsenic (total)	µg/L	10	100	1.7 J	2.99	2.31	2.28
Mercury (total)[b]	µg/L	10	70	0.017	0.113	0.054	0.043
HPAHs	µg/L	10	100	0.09	1.04	0.53	0.43
cPAHs[c]	µg TEQ/L	10	70	0.009	0.438	0.106	0.070
BEHP[d]	µg/L	10	40	2.98 J	41.5 J	8.40	2.29
1,4-Dichlorobenzene	µg/L	10	100	78.8	534	183	115.5
Total PCBs (as congeners)	ng/L	10	100	17.7	134	63.1	54.6
Dioxin and furan	pg TEQ/L	2	100	11	11.8	11.4	na

Note: Data were collected from 2007 to 2009 during CSO overflow events (King County 2011c) and are included in Appendix H.

[a] Arithmetic mean was calculated using one-half the MDL when contaminant below the MDL.

[b] The mercury minimum MDL equals 0.005 µg/L; the maximum MDL equals 0.05 µg/L.

[c] Detection frequency of individual cPAH parameters was 35%. cPAHs were calculated by summing the products of individual cPAH concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual cPAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

[d] The BEHP minimum MDL equals 0.024 µg/L; the maximum MDL equals 7.8 µg/L.

BEHP – bis(2-ethylhexyl) phthalate
CSO – combined sewer overflow
J – estimated concentration
na – Not applicable

HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
MDL – method detection limit
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

Table 9-19
Lander CSO Water Quality Data

Contaminant	Unit	No. of Samples	Detection Frequency (%)	Detected Concentrations			
				Min	Max	Mean[a]	Median
Arsenic (total)	µg/L	7	100	1.33	2.67	1.92	2.02
Mercury(total)	µg/L	7	71	0.016	0.287	0.072	0.043
HPAHs	µg/L	7	86	< MDL	0.40	0.22	0.18
cPAHs[b]	µg TEQ/L	7	57	0.0085	0.0778	0.0263	0.0110
BEHP[c]	µg/L	7	29	14 J	38 J	8.32	1.21
1,4-Dichlorobenzene	µg/L	6	100	0.212	0.577	0.435	0.48
Total PCBs (as congeners)	ng/L	7	100	21.8	137	52.3	30
Dioxin and furan	pg TEQ/L	1	100	4.3 J	4.3 J	4.3 J	na

Note: Data were collected from 2008 to 2009 (King County 2011a) and are included in Appendix H.

[a] Arithmetic mean and was calculated using one-half the MDL when contaminant below the MDL.

[b] Detection frequency of individual cPAH parameters was 40%. cPAHs were calculated by summing the products of individual cPAH concentrations and compound-specific PEFs for individual cPAH compounds, as described in detail in Appendix D. If an individual cPAH compound was not detected, the PEF for that congener was multiplied by one-half the RL for that compound.

[c] The BEHP minimum MDL equals 0.024 µg/L; the maximum MDL equals 7.8 µg/L.

BEHP – bis(2-ethylhexyl) phthalate
CSO – combined sewer overflow
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
MDL – method detection limit
J - estimated concentration
na – Not applicable
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

A comparison of the CSO water quality data indicates that contaminant concentrations are generally similar between the datasets, with the exception of 1,4-dichlorobenzene. As discussed in Appendix F, the major source of 1,4-dichlorobenzene for the Hanford #2 CSO was found through source-tracing efforts by King County, and the product that resulted in high levels of 1,4-dichlorobenzene is no longer being used by the identified source. Details of King County's 1,4-dichlorobenzene source-tracing and control activities are discussed in Appendix F.

9.4.4 Groundwater Pathway

This section summarizes groundwater data that are associated with upland cleanup sites (see Table 9-20). This evaluation considers potential contaminant inputs to the EW from both nearshore cleanup sites (those located adjacent to the EW) and those located in areas distant from the EW but within the EW SD basins or combined sewer service areas. The nearshore cleanup sites can potentially contribute pollutants through the groundwater transport. Both nearshore and distant cleanup sites can, in some instances, contribute pollutants to stormwater or to CSO discharges through infiltration of groundwater and soil.

Table 9-20
Summary of Recent Groundwater Monitoring at Nearshore Cleanup Sites

Site and Release Type	Cleanup Status	Site-Specific Groundwater Monitoring Performed	Recent Groundwater Monitoring Reports Used
Harbor Island Soil and Groundwater OU: Multi-parcel cleanup addressed under EPA oversight by Harbor Island Soil and Groundwater OU Group. Site contaminants of concern determined through RI/FS and risk assessment process.	Cleanup activities completed consistent with Soil and Groundwater OU ROD, including soil removals and upland capping. Site is undergoing long-term groundwater monitoring. Remedial actions were largely completed in 2004 and groundwater monitoring began in 2005.	Monitoring is performed consistent with an EPA-approved groundwater monitoring plan. Groundwater monitoring network includes seven nearshore wells along the EW shoreline and additional monitoring wells located in inland areas and in areas adjacent to the West Waterway. A total of 84 well monitoring events from 7 wells have been collected. Well depths were intermediate and shallow based on site-specifics. COCs include metals, cyanide, VOCs, SVOC, and PCBs.	The Third Five-Year Review Report includes data from 2008 to 2010 (EPA 2010b). The Sixth Year Report includes data from 2010 to 2011 (AECOM 2012).
Terminal 102 LUST Site: MTCA soil and groundwater cleanup related to diesel release from former UST.	Tanks and excavated soil were removed from the site, with capping of remaining impacted soils in 1997. Cleanup at this site is complete. Work was performed as an independent action. No request has been made for an Ecology opinion letter following completion of the cleanup.	Groundwater monitoring was performed at time of tank and soil removal, including sampling of six temporary soil borings. Well depths were shallow based on site-specifics. TPH was the COC at this site.	Groundwater monitoring data for six temporary soil borings are described in UST decommissioning report (RETEC 1997).
Coast Guard (Pier 35): MTCA soil and groundwater cleanup related to petroleum USTs formerly used for truck refueling. COCs include petroleum (gasoline and diesel) and arsenic. Contaminated soils and groundwater were also identified in nearshore fill areas.	Former USTs and associated soil contamination have been removed under an independent remedial action in 1990. No additional cleanup actions are planned. No actions have been taken to address identified contaminated soils and groundwater in the nearshore fill areas. No request has been made for an Ecology opinion letter following completion of the cleanup.	Groundwater monitoring was last performed in 2003-2004 as part of a site investigation report. Groundwater monitoring at that time included seven sampling locations (two wells and five temporary borings), all of which were located in upland site areas over 300 ft from the EW. Well depths were shallow based on site-specifics. COCs include metals, TPH, and SVOCs.	Environmental sampling report summarizes results of 2003 to 2004 groundwater monitoring event (Hart Crowser 2004).
Former GATX (Pier 34): MTCA soil and groundwater cleanup related to former bulk fuel handling facility. Site COCs determined through RI/FS process and include petroleum and associated constituents (petroleum, BTEX, and PAHs) and selected heavy metals (arsenic, copper, and lead).	Cleanup action was performed in 1996 as independent remedial action with Ecology oversight after completion of an RI/FS and Compliance Monitoring Plan. Cleanup included plant demolition, removal of contaminated soils, capping, groundwater treatment (by air sparging and vapor extraction), and groundwater monitoring. Cleanup at this site is complete. No request has been made for an Ecology opinion letter following completion of the cleanup.	Groundwater monitoring performed as part of site cleanup included periodic monitoring of five nearshore wells and multiple groundwater seep locations. Compliance wells and seep monitoring locations were located along five transects arranged perpendicular to the shoreline. Groundwater monitoring was also performed at additional upland groundwater well locations used to monitor remediation system performance. Well depths were shallow based on site-specifics. COCs include metals, TPH, VOCs, and PAHs.	Remedial action included 5 years of groundwater monitoring, as summarized in 5-year review report (RETEC 2004). Most recent event from April and August 2003 included monitoring of all nearshore wells and one groundwater seep. Relevant historical data (also summarized in (RETEC 2004)) include most recent seep monitoring data from the monitoring transects.
Former Chevron (Terminal 30): MTCA soil and groundwater cleanup related to petroleum releases (primarily diesel) at the former Chevron bulk fuel handling facility. Site contaminants of concern determined through RI/FS process and include petroleum, BTEX compounds, and PAH compounds.	Initial cleanup action performed during the late 1980s included plant demolition, product recovery, nearshore sediment dredging and capping of the shoreline with clean structural fill and armoring, and upland capping. A draft RI/FS was completed in 1998 under an Agreed Order to determine any other required remedial actions. Groundwater monitoring and other site cleanup actions are ongoing under Ecology oversight. Per Ecology request, a supplemental RI/FS was written in 2012 in accordance with WAC 173-340-350.	Monitoring activities at this site are ongoing. The groundwater compliance monitoring program includes five sets of nearshore wells. Groundwater monitoring is also performed at seven additional upland locations, and product recovery and gauging is performed at 13 additional upland well locations. From 2005 to 2009, 17 rounds of quarterly monitoring occurred. There was one round of monitoring in 2011 and two PAH-focused monitoring events in 2011 and 2012. Well depths were shallow and deep based on site-specifics. COCs include TPH, VOCs, and PAHs.	The site is undergoing ongoing groundwater monitoring. Results of monitoring conducted in 2011 are evaluated (Pacific Groundwater Group 2012).
Terminal 25: MTCA petroleum cleanup associated with former underground diesel storage tanks at former Rainier Cold Storage site.	Former USTs and additional soil contamination have been removed under an independent remedial action in 1989. A separate localized area of PCB-contaminated soil was identified within the SPU ROW in the southern portion of the site in 2011. SPU conducted a partial cleanup of this area and the Port of Seattle completed additional characterization in this area in 2012.	Groundwater monitoring was previously performed in 1989 and 1990 as part of upland site investigations. Monitoring included seven upland sampling locations. The Port of Seattle installed four additional shoreline monitoring wells to provide supplemental groundwater data for the property in 2011. Four rounds of quarterly monitoring occurred between 2011 and 2012. Well depths were shallow based on site-specifics. No compounds were detected above screening criteria so there are no COCs	Results of 1989 and 1990 groundwater sampling summarized in 1990 reports (Landau 1990; Sweet-Edwards/EMCON 1990). Results of the 2011 and 2012 groundwater sampling are summarized in the 2012 Field Investigation Report (Anchor QEA 2012).
Terminal 104 and Vicinity: Cleanup of petroleum contamination was conducted near a LUST in the 1990s. Additional localized groundwater contamination areas were identified during recent environmental assessment activities. Groundwater contamination with TCE and arsenic was identified in a localized area in the southeastern portion of the property and localized areas of petroleum contamination were identified in the northeastern portion of the property.	The LUST was removed and the area was remediated and monitored during the early 1990s. Site investigation of the additional areas was conducted by the Port of Seattle. Some cleanup actions have been conducted as part of site redevelopment.	Extensive groundwater testing was performed as part of recent environmental assessment activities. Sampling included monitoring of groundwater at 13 upland wells and 49 additional temporary borings. Sampling delineated all contaminated groundwater areas. No contamination extending to the EW shoreline was identified. Sampling at 11 of these groundwater locations provides water quality information downgradient of site cleanup areas. Well depths were shallow based on site-specifics. COCs include metals, TPH, VOCs, PAHs, and PCBs.	Groundwater monitoring for the period of 1991 to 1993 from environmental assessment report (EMCON 1992a, b, c, d, 1993). Groundwater monitoring data for the period 2005 to 2007 are summarized in a SRI and Data Summary Report (Environmental Partners 2007).

Note: Site-specific groundwater cleanup levels are those used to evaluate groundwater data in the referenced report(s). Groundwater data referenced in this table are summarized in tabular form in Appendix E.

BTEX – benzene, toluene, ethylbenzene, and xylene
COC – contaminant of concern
Ecology – Washington State Department of Ecology
EPA – US Environmental Protection Agency
EW – East Waterway
FS – feasibility study
LUST – leaking underground storage tank
MTCA – Model Toxics Control Act
OU – Operable Unit
PAHs – polycyclic aromatic hydrocarbons
PCBs – polychlorinated biphenyls
RI – remedial investigation
ROD – Record of Decision
ROW – right-of-way
SPU – Seattle Public Utilities
SRI – supplemental remedial investigation
SVOC – semivolatile organic compound
UST – underground storage tank
TCE – trichloroethene
TPH – total petroleum hydrocarbons
VOCs – volatile organic compounds

9.4.4.1 Groundwater Pathway Overview

The review of nearshore cleanup sites described in this section focuses on the groundwater migration pathway. The data evaluation process included a review of available groundwater monitoring data for each of the nearshore cleanup sites along the EW. This evaluation relies on data reports compiled and attached to the EISR (Anchor and Windward 2008a), the SEDGM (Anchor QEA and Windward 2009), and supplemental sampling data available since the preparation of those reports (Appendix J). Data from wells or sampling locations adjacent to the EW, or in downgradient locations between site cleanup/potential source areas and the EW, were prioritized because these data are most representative of the groundwater-to-sediment pathway.

Groundwater data at cleanup sites may vary over time due to the progress of site cleanup actions. Where data were limited to initial investigations or to less than four sampling events, all data were used. At active cleanup sites where extensive data were available from multiple rounds of sampling, the most recent groundwater data were used. Specific analysis and well construction were determined as appropriate for each cleanup site. Well depths include shallow, intermediate, and deep screen depths, which are presented in Appendix J, Table J-33.

As described in Section 2.6.1, groundwater salinity results in the nearshore environment indicate that: 1) fresh water overrides denser saltwater and thereby confines freshwater discharge to the upper portion of the aquifer near MLLW; 2) upland groundwater mixes with saline groundwater prior to discharging at the shoreline, meaning there is no direct discharge of fresh water to the EW, rather it is all tidally mixed prior to discharge; and 3) tidal influx results in dilution and attenuation of groundwater between nearshore wells and the shoreline. Nearshore well salinity and conductivity information is presented in Appendix J, Table J-34.

Relevant groundwater data were then compared to several screening values as detailed in Section 6 of the SEDGM (Anchor QEA and Windward 2009) to evaluate potential source control issues. The first of these was a direct comparison to the site-specific groundwater cleanup levels. Second, groundwater data were compared to ambient water quality criteria (AWQC) applicable to surface water under state and federal regulations. Third, a conservative groundwater evaluation against reference values was developed using

equilibrium partitioning theory. Additional reference values are used for evaluation of VOCs, cyanide, and petroleum, for which no SMS criteria are available for development of partitioning-based reference values. Each of these methods is described in more detail in Section 6 of the SEDGM (Anchor QEA and Windward 2009). For those contaminants (cPAH and arsenic) that were detected in groundwater at one or more locations, and that had human health RBTCs that were more stringent than the SQS (see Section 8), the SEDGM reference values were updated based on these EW-specific RBTCs (Anchor QEA and Windward 2009). For arsenic, the revised reference value (originally based on the SQS of 57 mg/kg) was based on an average sediment concentration of 7 mg/kg dw throughout intertidal and subtidal areas (based on tribal clamming and tribal netfishing exposures). For cPAH compounds, the revised reference value (originally based on the SQS for each PAH compound) was based on an average sediment concentration of 150 µg TEQ/kg dw in intertidal areas (based on tribal clamming exposures) and an average sediment concentration of 380 µg TEQ/kg dw site-wide (based on tribal netfishing exposures). The equilibrium calculations and resulting groundwater reference values are shown in Appendix J, Table J-35. The use of the updated RBTC-based reference values is conservative for analysis of point-by-point groundwater quality data, because this does not consider the effects of spatial averaging relevant to the risk exposure scenarios on which the RBTCs are based. A tabulation of the contaminant data for the nearshore groundwater datasets, analysis of observed concentration ranges, and development of summary statistics to document any exceedances of site-specific cleanup levels is presented for each nearshore cleanup site. Comparison to screening values was performed without incorporation of attenuation or mixing factors. These data are summarized in Appendix J and in Section 9.4.4.2. If relevant to the site conditions, other factors that may be relevant to groundwater data interpretation (e.g., chemical speciation or groundwater fate and transport properties) are discussed along with the monitoring results (though the data were not adjusted based on those factors).

9.4.4.2 Groundwater Pathway and Nearshore Cleanup Sites

9.4.4.2.1 Harbor Island Soil and Groundwater OU

Table 9-21 summarizes the results monitoring events conducted from 2010 to 2011 for the seven nearshore well locations Harbor Island Soil and Groundwater OU. All wells were screened from 25 to 35 ft bgs, with the exception of HI-12, which was screened from 7 to 17 ft bgs. This includes repeated monitoring events at each of those seven locations. Monitoring

locations and other site features are shown in Map 9-20 through Map 9-22. Site COCs and the requirements of the groundwater monitoring program were identified in the ROD (EPA 1993). The total number of valid testing results for each well varies based on the well monitoring program requirements and data validation issues encountered. The analytical data are tabulated in Appendix J, Tables J-1 through J-8.

As described in the Third Five-Year Review Report (EPA 2010b), low groundwater elevations were noted in an area of the Soil and Groundwater OU near a sanitary sewer lift station. Findings of groundwater gradient monitoring near well HI-17 show that groundwater flows toward a sanitary sewer lift station and not outward toward the waterway. Coarse soil materials associated with utility backfill of this conveyance system likely increase the hydraulic conductivity. The likelihood of this increased conductivity toward the EW is low.

Table 9-21

Summary of Harbor Island Nearshore Groundwater Quality

Chemical	Unit	Chemicals Detected at Nearshore Locations[a]	Reporting Limit of Non-Detects		Detected Chemical Concentration Range	ROD-Specified Cleanup Goals	Nearshore Concentration Exceeds Cleanup Goal	Groundwater Reference Value[b]	Nearshore Concentration Exceeds Reference Value	AWQC/NTR Reference Value – Chronic/Acute /Human Health[c,d]	Nearshore Concentration Exceeds Marine AWQC Chronic Reference Value	Nearshore Concentration Exceeds Marine AWQC Acute Reference Value	Nearshore Concentration Exceeds NTR Human Health Reference Value
			No. of Non-Detects	Range (Min to Max)									
Total Metals													
Arsenic	µg/L	7 of 7	0 of 7	**	0.05 to 1.43	36	0 of 7	27.9	0 of 7	36/69/0.14	0 of 7	0 of 7	**4 of 7**[d]
Cadmium	µg/L	6 of 7	1 of 7	0.008 to 0.034	0.016 to 0.92	8	0 of 7	2.6	0 of 7	9.3/42/na	0 of 7	0 of 7	na
Copper	µg/L	7 of 7	0 of 7	**	0.071 to 4.32	2.9	**1 of 7**	123	0 of 7	3.1/4.8/na	**1 of 7**	0 of 7	na
Lead	µg/L	7 of 7	0 of 7	**	0.018 to 6.49	5.8	**1** of 7	11	0 of 7	8.1/210/na	0 of 7	0 of 7	na
Mercury	µg/L	7 of 7	0 of 7	**	0.00017 to 0.00172	0.025	0 of 7	0.0052	0 **of 7**	0.025/1.8/0.15	0 of 7	0 of 7	0 of 7
Nickel	µg/L	6 of 7	1 of 7	0.07 to 0.6	0.12 to 4.25	7.9	0 of 7	na	na	8.2/74/4,600	0 of 7	0 of 7	0 of 7
Silver	µg/L	6 of 7	1 of 7	0.004 to 0.200	0.004 to 0.046	1.2	0 of 7	1.5	0 of 7	na/1.9/na	na	0 of 7	na
Thallium	µg/L	4 of 7	3 of 7	0.0040 to 0.0800	0.025 to 0.025	6.3	0 of 7	na	na	na/na/6.3	na	na	0 of 7
Zinc	µg/L	7 of 7	0 of 7	**	0.25 to 86.10	76.6	**1 of 7**	33	**1 of 7**	81/90/na	**1 of 7**	0 **of 7**	na
Cyanide[e]													
Available cyanide	µg/L	1 of 7	6 of 7	2 to 2	0.85 to 0.85	1	0 **of 7**	na	na	na	na	na	na
Total cyanide[f, g]	µg/L	4 of 7	3 of 7	4.7 to 10	3.2 to 13.8	1	**4 of 7**[g]	2.8[f]	**4 of 7**	2.8/9.1/220,000	**4 of 7**	**1 of 7**	0 of 7
Volatile Organic Compounds													
1,1,1-Trichloroethane	µg/L	0 of 7	7 of 7	0.50 to 0.50	**	42	0 of 7	na	na	na	na	na	na
1,1,2-Trichloroethane	µg/L	0 of 7	7 of 7	0.50 to 0.50	**	42	0 of 7	na	na	na/na/42	na	na	0 of 7
Benzene	µg/L	1 of 7	6 of 7	0.50 to 0.50	0.070 to 0.070	71	0 of 7	180	0 of 7	na/na/71	na	na	0 of 7
Carbon tetrachloride	µg/L	0 of 7	7 of 7	0.50 to 0.50	**	4.4	0 of 7	na	na	na/na/4.4	na	na	0 of 7
Tetrachloroethene	µg/L	0 of 7	7 of 7	0.50 to 0.50	**	8.8	0 of 7	na	na	na/na/8.9	na	na	0 of 7
Semivolatile Organic Compounds													
Bis(2-ethylhexyl)phthalate	µg/L	1 of 1	1 of 1	0.96 to 0.98	7.3	700	0 of 1	0.28	0 of 1[h]	na/na/5.9	0 of 1[h]	na	0 of 1[h]
Butylbenxylphthalate	µg/L	0 of 1	1 of 1	0.2 to 0.2	**	7,000	0 of 1	0.52	0 of 1	na	na	na	na
Diethylphthalate	µg/L	1 of 1	0 of 1	**	0.029 to 0.033	na	na	484	0 of 1	na	na	na	na
Dimethylphthalate	µg/L	0 of 1	1 of 1	0.2 to 0.2	**	na	na	143	0 of 1	na/na/2,900,000	na	na	0 of 1
Di-n-Butylphthalate	µg/L	1 of 1	0 of 1	**	0.035 to 0.043	na	na	na	na	na	na	na	na
Di-n-Octyl phthalate	µg/L	0 of 1	1 of 1	0.2 to 0.2	**	na	na	0.3	0 of 1	na	na	na	na
Polychlorinated Biphenyls													
Aroclor 1016	µg/L	0 of 7	7 of 7	0.0049 to 0.005	**	0.03	0 of 7	0.44	0 of 7	na	na	na	na
Aroclor 1221	µg/L	0 of 7	7 of 7	0.0099 to 0.023	**	0.03	0 of 7	1.17	0 of 7	na	na	na	na
Aroclor 1232	µg/L	0 of 7	7 of 7	0.0049 to 0.014	**	0.03	0 of 7	1.17	0 of 7	na	na	na	na
Aroclor 1242	µg/L	0 of 7	7 of 7	0.0049 to 0.0082	**	0.03	0 of 7	0.27	0 of 7	na	na	na	na
Aroclor 1248	µg/L	0 of 7	7 of 7	0.0049 to 0.0077	**	0.03	0 of 7	0.27	0 of 7	na	na	na	na
Aroclor 1254	µg/L	0 of 7	7 of 7	0.0049 to 0.005	**	0.03	0 of 7	0.16	0 of 7	na	na	na	na
Aroclor 1260	µg/L	0 of 7	7 of 7	0.0049 to 0.005	**	0.03	0 of 7	0.058	0 of 7	na	na	na	na
Aroclor 1262	µg/L	0 of 7	7 of 7	0.0049 to 0.005	**	0.03	0 of 7	na	na	na	na	na	na
Aroclor 1268	µg/L	0 of 7	7 of 7	0.0049 to 0.005	**	0.03	0 of 7	na	na	na	na	na	na

[a] Harbor Island locations consist of seven wells monitored repeatedly from 2010 to 2011 (i.e., tabulated summaries reflect all data for that period, organized by sampling location). The wells included are HI-1, HI-2, HI-3, HI-4, HI-5, HI-12, and HI-16.
[b] Refer to Section 9.4.4.1 for the derivation of the groundwater reference values for groundwater based on equilibrium partitioning considerations.
[c] AWQC per Washington State (WAC 173-201A-240).
[d] NTR, 40 CFR 131 reference values for Human Health. The reference values for arsenic have not been adjusted to take into account naturally occurring arsenic concentrations that may be present in groundwater or surface water. NTR recommended water quality criterion for arsenic refers to the inorganic form only
[e] The ROD-specified cleanup goal was based on the toxicity of available cyanide, whereas initial sampling was for total cyanide. Additional cyanide speciation work was conducted to evaluate the quantity of available cyanide.
[f] Value based on total cyanide measurements, not on available or free cyanide.
[g] Initial groundwater sampling was performed using total cyanide test methods, though the toxicity criteria on which the cleanup goal was established are based on free (available) cyanide. Testing for available cyanide was introduced beginning in December 2006. The groundwater reference value for available cyanide (2.8 µg/L) is based on the Washington chronic marine criterion (WAC 173-201A) for weak acid dissociable cyanide.
[h] Bis(2-ethylhexyl)phthalate was not detected in subsequent sampling and does not currently exceed reference values.

** – range not applicable
AWQC – ambient water quality criteria
CFR – Code of Federal Regulations
na – not applicable (Chemical does not have an AWQC, SQS, or no partitioning estimate is available from SEDGM Table 6-2 [(Anchor QEA and Windward 2009).)
NTR – National Toxics Rule
SEDGM – source evaluation and data gaps memorandum
ROD – Record of Decision

Groundwater monitoring for PCBs was performed during the 2005, 2006, 2010, and 2011 monitoring events. No PCBs were detected in any of the seven wells. The method reporting limits were less than the cleanup goals and the groundwater reference values.

VOCs have been tested during each of the monitoring events. Most VOCs were undetected. Benzene was detected only in a single well and at concentrations well below the ROD cleanup goals. No groundwater reference values are established because there is no SQS for VOCs.

Both total and available forms of cyanide have been analyzed in the Harbor Island wells. The results of a total cyanide analysis represent the sum of all forms of cyanide regardless of toxicity. These include the free, weak acid dissociable (WAD), and strong acid dissociable forms of cyanide. In contrast, available cyanide analysis includes only free and WAD cyanide and is a better indicator of potential toxicity (AECOM 2012) and is the basis for the state water quality standard for cyanide. Available cyanide has been detected in one well (well HI-5) and was below the ROD cleanup goal for cyanide. No partitioning-based groundwater reference values are established because there is no SQS for cyanide and available cyanide data for groundwater were below applicable water quality water criteria.

Copper, lead, and zinc were detected above ROD cleanup goals. Copper concentrations in well HI-12 ranged from 2.54 to 4.32 µg/L, compared to a cleanup goal of 2.9 µg/L, and were all below the groundwater reference value of 123 µg/L. Lead concentrations in well HI-16 ranged from 0.03 to 6.49 µg/L, compared to a cleanup goal of 5.8 µg/L, and were all below the groundwater reference value of 11 µg/L. Zinc concentrations in well HI-12 varied significantly between monitoring events, ranging from a concentration of 51.1 to 86.1 µg/L. The groundwater reference value for zinc is 33 µg/L. The range in concentrations observed at well HI-12 indicates that further evaluation may be warranted for zinc in this area.

Bis(2-ethylhexyl) phthalate was detected above the groundwater reference in a single analytical sample in 2010. Two subsequent rounds of analysis at well location HI-5 did not detect bis(2-ethylhexyl) phthalate in the 2011 results. Therefore, the single detection of bis(2-ethylhexyl)phthalate at well HI-5 with the subquent non-detect results confirms that the well is not currently exceeding reference values.

Total arsenic was detected above the National Toxics Rule (NTR) criteria, but at levels indicative of natural background concentrations (the NTR criteria have not been adjusted to take into account naturally occurring arsenic in groundwater). Furthermore, the NTR recommended water quality criterion for arsenic refers to the inorganic form only. Two HI-12 detected total arsenic (inorganic and organic species) concentrations were 0.21 and 0.72 µg/L, which is greater than the 0.14 µg/L NTR criteria. Arsenic concentrations were less than all other reference values. Recent studies indicate that the groundwater recharge has been significantly reduced following the 98% surface coverage with asphalt during remediation. There are two general discharge pathways for these groundwater flows: 1) discharge to marine waters; and 2) discharge through deep sanitary sewer piping (AECOM 2012). Further groundwater monitoring is planned for the Harbor Island Soil and Groundwater OU, which will provide verification of the long-term concentration trends observed to date.

9.4.4.2.2 Terminal 102

A summary of the land use history at T-102 was recently completed as part of Ecology's source control activities for the LDW (Ecology and Environment 2008). As described in that report, the majority of Harbor Island was filled for development circa 1905. As of 1936, the area that has become T-102 had not been filled. The T-102 area was filled by 1976, and the Anchor Marina had been constructed along the shoreline by this time. By 1981, Associated Transportation Center used the property for container storage. Redevelopment of T-102 was completed in the mid-1980s, including construction of the Harbor Marina Corporate Center.

Three underground storage tanks (USTs) were associated with the marina. These USTs were removed in October 1996 (Ecology and Environment 2008). Soil and groundwater testing at T-102 has been focused on the areas associated with these UST removals. No reported contamination problems have been noted in other areas of the site. An evaluation of the property is included in the LDW RM 0.0 to RM 0.1 East Source Control Action Plan (Ecology and Ecology and Environment 2009), which identified no further groundwater action for this site related to source control.

Following UST removal, groundwater data were collected from temporary well points. Locations are presented on Map 9-20. Groundwater screen depths were 11 to 14 ft bgs (Appendix Table J-33). The groundwater monitoring data are summarized in Table 9-22. None of the measured concentrations for T-102 groundwater exceeded the site-specific

cleanup level, which was based on the MTCA cleanup levels applicable at the time of the cleanup action (1,000 µg/L).

Table 9-22

Summary of Terminal 102 Groundwater Quality

Chemical	Units	Chemical Detected at Location	Reporting Limit of Non-Detects		Detected Chemical Concentration Range	Site-Specific Cleanup Levels[a]	Downgradient Chemical Concentration Exceeds Cleanup Level	Groundwater Reference Value[b]	Nearshore Concentration Exceeds Reference Value	AWQC/NTR Reference Values – Chronic/Acute/ Human Health [c,d]
			No. of Non-Detects	Reporting Limit						
Diesel WTPH-D	µg/L	0 of 6	6	100	**	1,000	0 of 6	500[b]	0 of 6	500 [b]

[a] Current MTCA Method A cleanup level of 500 µg/L is used as a surrogate value for evaluating total petroleum hydrocarbon data. None of the measured values exceeded the current cleanup level. These values are intended only for preliminary use in this initial evaluation, as the reference values do not take into account site-specific fate and transport processes that likely limit the potential for sediment recontamination to occur.

[b] Marine AWQC per Washington State (WAC 173-201A-240).

[c] NTR, 40 CFR 131 reference values for Human Health for the consumption of organisms only.

[d] The groundwater cleanup level for diesel at the time the independent cleanup action was initiated was 1,000 µg/L.

**– range not applicable
AWQC – ambient water quality criteria
CFR – Code of Federal Regulations
MTCA – Model Toxics Control Act
NTR – National Toxics Rule
WAC – Washington Administrative Code
WTPH-D – Washington total petroleum hydrocarbons – diesel

Because the groundwater monitoring data at T-102 are limited to TPH (diesel-range hydrocarbons), the current MTCA Method A groundwater cleanup level (500 µg/L) was used to evaluate the data rather than the groundwater reference values from Table 6-2 of the SEDGM (Anchor QEA and Windward 2009). Groundwater TPH was not detected in any of the samples collected from T-102. The method reporting limits were well below the current MTCA Method A groundwater cleanup level for diesel (500 µg/L).

No additional cleanup or monitoring activities are ongoing for the T-102 site.

9.4.4.2.3 Pier 35 and Vicinity (Coast Guard)

The USCG property at Pier 35 has undergone multiple rounds of investigation and cleanup under the LUST and voluntary cleanup programs. Most recent groundwater monitoring data from 2003 and 2004 are summarized in Table 9-23. Locations are presented on Map 9-23. Groundwater screen collection depths are not known for this property (Appendix Table J-33)

Table 9-23
Summary of USCG (Pier 35) Groundwater Quality

Chemical	Unit	Chemical Detected at Location	Reporting Limit of Non-Detects		Detected Chemical Concentration Range	Site-Specific Cleanup Goal (µg/L)[a]	Downgradient Chemical Concentration Exceeds Cleanup Level	Groundwater Reference Value[b]	Downgradient Chemical Concentration Exceeds Reference Value	AWQC/NTR Reference Values – Chronic/Acute/ Human Health[c,d]	Nearshore Concentration Exceeds Marine AWQC Chronic Reference Value	Nearshore Concentration Exceeds Marine AWQC Acute Reference Value	Nearshore Concentration Exceeds NTR Human Health Reference Value
			No. of Non-Detects	Reporting Limit									
Metals (dissolved)													
Arsenic	µg/L	5 of 7	2	5	7 to 180	5	**5 of 7**	27.9	1 of 7	36/69/14	**1 of 7**	**1 of 7**	**5 of 7** [d]
Cadmium	µg/L	0 of 7	7	5	**	5	0 of 7	2.6	0 of 7	9.3/42/na	0 of 7	0 of 7	na
Copper	µg/L	0 of 7	7	10	**	592[e]	0 of 7	123	0 of 7	3.1/4.8/na	0 of 7	0 of 7	na
Chromium	µg/L	0 of 7	7	10	**	50	0 of 7	306[f]	0 of 7	50/1,100/na	0 of 7	0 of 7	na
Lead	µg/L	4 of 7	3	2	2 to 5	15	0 of 7	11	0 of 7	8.1/210/na	0 of 7	0 of 7	na
Mercury	µg/L	0 of 7	7	0.5	**	2	0 of 7	0.0052	0 of 7	0.025/1.8/0.15	0 of 7	0 of 7	0 of 7
Nickel	µg/L	2 of 7	5	10	20 to 30	na	na	na	na	8.2/74/4,600	**2 of 7**	0 of 7	0 of 7
Zinc	µg/L	4 of 7	3	1	1 to 2	4,800[e]	0 of 7	33	0 of 7	81/90/na	0 of 7	0 of 7	na
Petroleum Hydrocarbons													
Mineral spirits/stoddard solvent	µg/L	0 of 9	9	100	**	500	0 of 9	na	na	na	na	na	na
Gasoline range hydrocarbons	µg/L	3 of 9	6	100	210 to 350	1,000	0 of 9	1,000[g]	0 of 9	na	na	na	na
Kerosene/jet fuel	µg/L	0 of 9	9	20,000	**	na	na	na	na	na	na	na	na
Diesel-range hydrocarbons	µg/L	0 of 9	9	20,000	**	500	0 of 9	500[g]	0 of 9	na	na	na	na
Heavy oil	µg/L	0 of 9	9	50,000	**	500	0 of 9	500[g]	0 of 9	na	na	na	na
Volatile Organic Compounds													
1,1,2-Trichloroethane	µg/L	1 of 9	8	1	6.6	0.768[e]	**1 of 9**[h]	na	na	na/na/42	na	na	0 of 9
Xylenes	µg/L	3 of 9	6	1	1.1 to 5.3	1,000	0 of 9	na[i]	na	na	na	na	na
Isopropylbenzene	µg/L	2 of 9	7	1	1.5 to 2.1	800[e]	0 of 9	na[i]	na	na	na	na	na
n-Propylbenzene	µg/L	2 of 9	7	1	7.2 to 8.9	320[e]	0 of 9	nai[i]	na	na	na	na	na
4-Chlorotoluene	µg/L	1 of 9	8	1	2	160[e]	0 of 9	na[i]	na	na	na	na	na
1,3,5-Trimethylbenzene	µg/L	3 of 9	6	1	1.5 to 18	400[e]	0 of 9	na[i]	na	na	na	na	na
tert-Butylbenzene	µg/L	1 of 9	8	1	11	320[e]	0 of 9	na[i]	na	na	na	na	na
1,2,4-Trimethylbenzene	µg/L	3 of 9	6	1	2 to 11	400[e]	0 of 9	na[i]	na	na	na	na	na
sec-Butylbenzene	µg/L	2 of 9	7	1	3.7 to 4.6	320[e]	0 of 9	na[i]	na	na	na	na	na
Isopropyltoluene	µg/L	1 of 9	8	1	3.1	400[e]	0 of 9	na[i]	na	na	na	na	na
n-Butylbenzene	µg/L	3 of 9	6	1	1.3 to 12	320[e]	0 of 9	na[i]	na	na	na	na	na
Naphthalene	µg/L	2 of 9	7	1	2.3 to 3.9	160	0 of 9	54	0 of 9	na	na	na	na
Other EPA 8260 VOCs[j]	µg/L	0 of 9	9	**	**	na	na	na	na	na	na	na	na
Semivolatile Organic Compounds[k]	µg/L	0 of 2	2	**	**	na	na	SEDGM Table 6-2	na	na	na	na	na

[a] MTCA method a cleanup level, unless otherwise specified.
[b] Refer to Section 9.4.4.1 for the derivation of the groundwater reference values based on equilibrium partitioning considerations.
[c] Marine AWQC per Washington State (WAC 173-201A-240).
[d] NTR, 40 CFR 131 reference values for Human Health. The reference values for arsenic have not been adjusted to take into account naturally occurring arsenic concentrations that may be present in groundwater or surface water. NTR recommended water quality criterion for arsenic refers to the inorganic form only
[e] MTCA Method B criteria.
[f] Represents total chromium.
[g] Current MTCA Method A cleanup level used as a surrogate value for evaluating total petroleum hydrocarbon data.
[h] This compound was not detected in subsequent resampling of this well and the result is considered suspect.
[i] Selected gasoline-associated volatile organic compounds (alkylbenzenes) were detected in well MW-1C-03 during two sampling events. These compounds were not detected during re-sampling at MW-2C-03, nor were they detected in five geoprobe groundwater sampling locations placed in upgradient and downgradient locations (relative to the MW-1C-03 location). Based on these findings, no complete pathway exists to the EW for these compounds. No additional reference values were defined for these compounds.
[j] None of the EPA 8260 VOC compounds or EPA 8270 SVOC compounds, other than those indicated in Table J-10, were detected in any of the groundwater samples analyzed.
[k] All semivolatile organic compounds were reported as non-detect.

** – range not applicable
AWQC – ambient water quality criteria
MTCA – Model Toxics Control Act
na – not applicable (Chemical does not have an AWQC, NTR, SQS, or a partitioning coefficient is not available from SEDGM Table 6-2 (Anchor QEA and Windward 2009).)
NTR – National Toxics Rule
SEDGM – source evaluation and data gaps memorandum
SL – screening level
SVOC – semivolatile organic compounds
VOC – volatile organic compounds
WAC – Washington Administrative Code

Metals were monitored in site groundwater using both permanent monitoring wells and geoprobe borings. Other than arsenic, none of the measured parameters exceeded their respective site-specific cleanup levels.

Arsenic concentrations were elevated in site groundwater, ranging from 7 µg/L to a high of 180 µg/L. These values exceeded the site-specific cleanup level based on MTCA Method A cleanup levels (5 µg/L) and NTR screening value (0.14 µg/L inorganic arsenic). One of the measured arsenic concentrations exceeded the revised groundwater reference value of 27.9 µg/L for arsenic in groundwater, as well as the marine chronic AWQC criteria as presented in Appendix J, Table J-10. Results indicate that the measured arsenic concentration at one location is a potential concern for sediment recontamination based on the human health RBTC value, but would not be expected to cause an exceedance of the SQS.

Testing for organic compounds included analysis of SVOCs at two of the monitoring well locations. None of the SVOCs were detected.

VOCs were tested at all of the sampling locations, including multiple rounds of testing at the permanent monitoring wells. None of the VOCs exceeded the site-specific cleanup levels, with the exception of 1,1,2-trichloroethane. That compound was detected in one sample from a single monitoring well (MW-1C-03), but was not detected in subsequent re-sampling of that well.

Testing for petroleum hydrocarbons was performed at each of the Pier 35 groundwater sampling locations, including multiple rounds of sampling at the permanent monitoring wells. No exceedances of the site-specific cleanup levels were noted (Table 9-23).

Additional historical data were collected that were not included in the data review presented in this section due to the lack of data quality information (Map 9-23; Dames and Moore 1989). The evaluation included eight boring locations in the nearshore areas of the property. Nearshore soil results showed elevated concentrations of PAHs, lead, and PCBs. As shown in Map 9-23, sediment sampling results adjacent to this fill area identified elevated levels of PAH compounds. Elevated naphthalene concentrations were also detected in the fill material of the shoreline. No ongoing investigation or cleanup activities are occurring at the USCG site. While the data quality is not sufficient for inclusion in this SRI, the results indicate a potential concern for sediment recontamination through potential bank erosion.

9.4.4.2.4 Pier 34 and Vicinity (Former GATX)

As described in the EISR (Anchor and Windward 2008a), the Pier 34 property (Former GATX bulk fuel terminal) has undergone extensive investigation and remediation activities overseen by Ecology. This work included completion of an RI/FS and Cleanup Action Plan, demolition of the former fueling facility, excavation and treatment of contaminated soils, operation of a groundwater treatment system, and implementation of a groundwater monitoring program.

The groundwater monitoring program at the Pier 34 property included multiple components. Some of the components were specifically associated with the operational control of the groundwater remediation system. These included location-specific action levels and trigger levels for different points within the site. In addition, the groundwater monitoring program included the examination of monitoring results from a combination of nearshore groundwater wells and nearshore groundwater seep monitoring nearshore locations to assess the quality of groundwater discharging to the EW (Map 9-23).

Recent groundwater and nearshore seep monitoring data are summarized in Table 9-24 for the five nearshore transects (wells and or seeps). Consistent with the Cleanup Action Plan, seep results are used as the point of compliance in transects 1 through 4. The specific data on which Table 9-24 is based are tabulated in Appendix J, Tables J-11 through J-16.

Table 9-24
Summary of GATX (Pier 34) Nearshore Groundwater and Seep Quality

Chemical	Unit	Chemical Detected at Nearshore Sampling Location[a]	Reporting Limit of Non-Detects		Detected Chemical Concentration Range at Nearshore Location	Site-Specific Cleanup Levels Applicable to Nearshore Groundwater Location[b]	Chemical Exceeds Cleanup Level at Nearshore Sampling Location	Groundwater Reference Values (µg/L)[c,d]	Chemical Exceeds Reference Value at Nearshore Sampling Location	AWQC/NTR Reference Values – Chronic/Acute/ Human Health[e, f]	Nearshore Concentration Exceeds Marine AWQC Chronic Reference Value	Nearshore Concentration Exceeds Marine AWQC Acute Reference Value	Nearshore Concentration Exceeds NTR Human Health Reference Value
			No. of Non-Detects	Range (Min to Max)									
Total Metals													
Arsenic	µg/L	2 of 5	3	1 to 11	7 to 180	2.1[g]	0 of 5	27.9	0 of 5	36/69/0.14	0 of 5	0 of 5	**2 of 5** [f]
Copper	µg/L	2 of 5	3	2 to 10	4 to 7	2.9[g]	0 of 5[g]	123	0 of 5	3.1/4.8/na	0 of 5[g]	0 of 5	na
Lead	µg/L	1 of 5	4	1 to 10	3	5.6	0 of 5	11	0 of 5	8.1/210/na	0 of 5	0 of 5	na
Petroleum Hydrocarbons													
Gasoline-range hydrocarbons	µg/L	0 of 5	5	250 to 2500	**	1,000	0 of 5	na[h]	na	na	na	na	na
Diesel-range hydrocarbons	µg/L	2 of 5	3	250 to 2500	320 to 420	1,000	0 of 5	500[h]	0 of 5	na	na	na	na
BTEX Compounds													
Benzene	µg/L	0 of 5	5	1	**	700	0 of 5	na	na	na/na/71	na	na	0 of 5
Ethylbenzene	µg/L	0 of 5	5	1 to 10	**	430	0 of 5	na	na	na/na/29,000	na	na	0 of 5
m,p-Xylenes	µg/L	0 of 5	5	1 to 10	**	na	na	na	na	na	na	na	na
o-Xylenes	µg/L	0 of 5	5	1 to 10	**	na	na	na	na	na	na	na	na
Toluene	µg/L	0 of 5	5	1 to 10	**	5,000	0 of 5	na	na	na/na/200,000	na	na	0 of 5
PAH Compounds													
Acenaphthene	µg/L	0 of 5	5	1.8	**	710	0 of 5	2.6	0 of 5	na	na	na	na
Acenaphthylene	µg/L	0 of 5	5	5.3 to 5.5	**	na	na	11	0 of 5	na	na	na	na
Anthracene	µg/L	0 of 5	5	0.66 to 0.68	**	na	na	11	0 of 5	na/na/110,000	na	na	0 of 5
Benzo(a)anthracene	µg/L	0 of 5	5	0.05	**	0.93	0 of 5	0.48	0 of 5	na/na/0.031	na	na	0 of 5
Benzo(a)pyrene	µg/L	0 of 5	5	0.07	**	0.93	0 of 5	0.13	0 of 5	na/na/0.031	na	na	0 of 5
Benzo(b)fluoranthene	µg/L	0 of 5	5	0.04 to 0.1	**	0.93	0 of 5	0.29	0 of 5	na/na/0.031	na	na	0 of 5
Benzo(g,h,i)perylene	µg/L	0 of 5	5	0.11	**	na	na	0.012	0 of 5	na	na	na	na
Benzo(k)fluoranthene	µg/L	0 of 5	5	0.06	**	0.93	0 of 5	0.29	0 of 5	na/na/0.031	na	na	0 of 5
Chrysene	µg/L	0 of 5	5	0.15	**	0.93	0 of 5	0.47	0 of 5	na/na/0.031	na	na	0 of 5
Dibenzo(a,h)anthracene	µg/L	0 of 5	5	0.1	**	0.93	0 of 5	0.0046	0 of 5	na/na/0.031	na	na	0 of 5
Fluoranthene	µg/L	0 of 5	5	0.49 to 0.56	**	16	0 of 5	2.3	0 of 5	na/na/370	na	na	0 of 5
Fluorene	µg/L	0 of 5	5	0.46 to 0.47	**	1,400	0 of 5	2.0	0 of 5	na/na/14,000	na	na	0 of 5
Indeno(1,2,3-cd)pyrene	µg/L	0 of 5	5	0.07	**	0.93	0 of 5	0.013	0 of 5	na/na/0.031	na	na	0 of 5
Naphthalene	µg/L	0 of 5	5	2.5 to 2.6	**	2,470	0 of 5	54	0 of 5	na	na	na	na
Phenanthrene	µg/L	0 of 5	5	0.64 to 0.66	**	na	na	4.8	0 of 5	na	na	na	na
Pyrene	µg/L	1 of 5	4	0.27	0.21	6,480	0 of 5	14	0 of 5	na/na/11,000	na	na	0 of 5

a GATX sampling locations in groundwater or shoreline seeps are located along five transects with the data summarized by transect using the well or seep located closest to the EW.
b Groundwater cleanup goals are applicable to groundwater discharges to the sediment bioactive zone and to surface water. Cleanup trigger levels were used as part of the compliance monitoring program to determine whether to continue operating the groundwater treatment system. Refer to Tables J-12 to J-16 for a summary of those values and for the recent monitoring data available for each transect.
c Refer to Section 9.4.4.1 for the derivation of the groundwater reference values for groundwater based on equilibrium partitioning considerations. These are applicable to seeps or, if no seep data are available, to the nearest groundwater well.
d The current MTCA Method A groundwater cleanup levels for petroleum are used as a surrogate for evaluating total petroleum hydrocarbon data.
e Marine AWQC per Washington State (WAC 173-201A-240).
f NTR, 40 CFR 131 reference values for Human Health. The reference values for arsenic have not been adjusted to take into account naturally occurring arsenic concentrations that may be present in groundwater or surface water. NTR recommended water quality criterion for arsenic refers to the inorganic form only
g Cleanup goals for metals in seeps and wells included comparison to background surface water metals concentrations (RETEC 2004).
h No exceedances of groundwater reference values were noted for specific petroleum-associated constituents (e.g., BTEX and PAH compounds). Additionally, nearshore petroleum concentrations in groundwater were less than the MTCA Method A cleanup levels (1,000 µg/L gasoline and 500 µg/L diesel/oil) which represent conservative reference values for total petroleum hydrocarbon data.

** – range not applicable
AWQC – ambient water quality criteria
CFR – Code of Federal Regulations
na – not applicable (Chemical does not have an AWQC, SQS, or no partitioning estimate is available from SEDGM Table 6-2 (Anchor QEA and Windward 2009). Detected values in nearshore seeps and nearshore wells did not exceed measured values in surface water.)
NTR – National Toxics Rule
BTEX – benzene, toluene, ethylbenzene, and xylene
SEDGM – source evaluation and data gaps memorandum
WAC – Washington Administrative Code

The groundwater monitoring program included testing for PAH compounds; benzene, toluene, ethylbenzene, and xylene (BTEX) compounds; petroleum hydrocarbons; arsenic; copper; and lead. Pyrene was detected in one location, but at concentrations well below the site-specific cleanup level. None of the PAH compounds were detected above the groundwater reference values listed in Table 6-2 of the SEDGM or updated cPAH values presented in Appendix J, Table J-35.

Concentrations of BTEX and petroleum were below site-specific cleanup levels along each of the five transect locations. The concentrations of petroleum were also below the current MTCA Method A concentrations.

Arsenic and lead concentrations were below the site-specific cleanup levels and the groundwater reference values. Copper concentrations in two locations were detected at concentrations slightly above the site-specific groundwater cleanup level. However, these concentrations were less than corresponding background samples of surface water collected from the EW. Consistent with the groundwater monitoring plan, the concentrations were not considered to represent an exceedance of the cleanup level. Neither of the measured concentrations exceeded the groundwater reference value for copper.

No ongoing groundwater monitoring is being conducted at the Pier 34 (Former GATX) site.

9.4.4.2.5 Terminal 30 (Former Chevron)

As described in the EISR (Anchor and Windward 2008a), the T-30 property (Former Chevron bulk fuel terminal) has undergone extensive investigation and remediation activities. This work was initiated in the 1980s by Chevron with the demolition of the former fueling facility and extraction of floating diesel-fuel hydrocarbons from the groundwater table, and then furthered by the Port of Seattle with excavation and capping of the shoreline area, capping of the upland area with asphalt paving, and operation of a product recovery and groundwater monitoring program. Subsequent studies were conducted under a MTCA Agreed Order to evaluate the protectiveness of the original remedy and to establish a long-term groundwater compliance monitoring plan for implementation at the site.

The groundwater monitoring program at the T-30 property includes multiple components. In some upland areas, ongoing product recovery is continuing. The monitoring program

includes data collection to inform these ongoing remediation efforts. Additional monitoring is performed to evaluate upland groundwater quality in former source areas. Studies have documented the extent of tidally influenced groundwater mixing that occurs between nearshore wells and the shoreline. There are two well depths at T-30. Monitoring wells MW-84B, MW-85A, MW-86B, and MW-87A are screened from 5 to 20 ft bgs, and wells MW-84A, MW-85B, MW-86C, and MW-87A are screened from 30 to 40 ft bgs (Appendix Table J-33).

Current groundwater well locations are shown in Map 9-24. Nearshore wells include wells screened in both shallow and intermediate groundwater. Only data from nearshore wells were used in screening.

Groundwater concentrations in these wells have been monitored quarterly for BTEX, petroleum, and PAH compounds. Results from 2009 through 2012 are compared in Table 9-25 to site-specific cleanup levels established for protection of adjacent water quality, which are based on the MTCA Method A cleanup levels, MTCA Method B cleanup levels for surface water, and Washington State and federal WQC for surface waters. The specific data on which Table 9-25 is based are tabulated in Appendix J, Tables J-24 through J-32.

Table 9-25
Summary of Terminal 30 Nearshore Groundwater Quality

Chemical	Unit	Chemical Detected at Nearshore Sampling Location[a]	Reporting Limit of Non-Detects		Detected Chemical Concentration Range	Site-Specific Cleanup Level Protective of Surface Water Quality	Chemical Concentration Exceeds Site-Specific Criteria	Groundwater Reference Value[b]	Chemical Concentration Exceeds Reference Value[c]	AWQC/NTR Reference Values – Chronic/Acute/Human Health[d,e]	Exceedances of NTR Human Health Reference Value
			No. of Non-Detects	Range (Min to Max)							
Petroleum Hydrocarbons											
Gasoline-range hydrocarbons	µg/L	1 of 8	7 of 8	0.05 to 250	210 to 210	800	0 of 8	na[c,f]	na	na	na
Diesel-range hydrocarbons	µg/L	3 of 8	5 of 8	0.05 to 50	69 to 160	500	0 of 8	na[c,f]	na	na	na
Motor oil-range hydrocarbons	µg/L	0 of 8	8 of 8	0.25 to 250	**	500	0 of 8	na[c,f]	na	na	na
BTEX Compounds											
Benzene	µg/L	1 of 8	7 of 8	0.5 to 0.5	0.5 to 0.5	23	0 of 8	180[g]	0 of 8	na/na/71	0 of 8
Ethylbenzene	µg/L	1 of 8	7 of 8	0.5 to 0.8	0.88 to 0.88	6,910	0 of 8	na	na	na/na/29,000	0 of 8
o-Xylene	µg/L	0 of 2	2 of 2	0.5 to 0.5	**	na	na	na	na	na	na
m,p-Xylene	µg/L	0 of 2	2 of 2	1 to 1	**	na	na	na	na	na	na
Total xylene	µg/L	2 of 8	6 of 8	1 to 1	1.6 to 1.8	1,000	0 of 8	na	na	na	na
Toluene	µg/L	2 of 8	6 of 8	0.5 to 0.65	1.2 to 1.5	48,500	0 of 8	737[g]	0 of 8	na/na/200,000	0 of 8
PAH Compounds											
2-Methylnaphthalene	µg/L	1 of 8	7 of 8	0.1 to 2.5	0.1 to 0.1	na	na	13	0 of 8	na	na
Acenaphthene	µg/L	7 of 8	1 of 8	0.05 to 0.1	0.18 to 100	643	0 of 8	2.6	**5 of 8**	na	na
Acenaphthylene	µg/L	5 of 8	3 of 8	0.05 to 2.5	0.063 to 0.54	na	na	11	0 of 8	na	na
Anthracene	µg/L	5 of 8	3 of 8	0.05 to 2.5	0.092 to 0.39	25,900	0 of 8	11	0 of 8	na/na/110,000	0 of 8
Benzo(a)anthracene	µg/L	2 of 8	6 of 8	0.01 to 0.5	0.019 to 0.27	0.018	**2 of 8**	0.82	0 of 8	na/na/0.031	**1 of 8**
Benzo(a)pyrene	µg/L	0 of 8	8 of 8	0.01 to 0.5	**	0.018	0 **of 8**	0.02	0 of 8	na/na/0.031	0 of 8
Benzo(b)fluoranthene	µg/L	0 of 8	8 of 8	0.01 to 0.5	**	0.018	0 **of 8**	0.24	0 of 8	na/na/0.031	0 **of 8**
Benzo(g,h,i)perylene	µg/L	0 of 8	8 of 8	0.05 to 2.5	**	na	na	0.012	0 of 8	na	Na
Benzo(k)fluoranthene	µg/L	0 of 8	8 of 8	0.01 to 0.5	**	0.018	0 **of 8**	0.24	0 of 8	na/na/0.031	0 of 8
Chrysene	µg/L	1 of 8	7 of 8	0.01 to 0.5	0.019 to 0.019	0.018	**1 of 8**	8.05	0 of 8	na/na/0.031	0 **of 8**
Dibenzo(a,h)anthracene	µg/L	0 of 8	8 of 8	0.01 to 0.5	**	0.018	0 **of 8**	0.073	0 **of 8**	na/na/0.031	0 of 8
Dibenzofuran	µg/L	0 of 0	0 of 0	**	**	na	na	1.3	0 of 0	na	Na
Fluoranthene	µg/L	5 of 8	3 of 8	0.05 to 2.5	0.12 to 1.6	90	0 of 8	2.3	0 of 8	na/na/14,000	0 of 8
Fluorene	µg/L	6 of 8	2 of 8	0.015 to 2.5	0.069 to 7.6	3,460	0 of 8	2.0	**2 of 8**	na/na/370	0 of 8
Indeno(1,2,3-cd)pyrene	µg/L	0 of 8	8 of 8	0.01 to 0.5	**	0.018	0 **of 8**	0.07	0 **of 8**	na/na/0.031	0 **of 8**
Naphthalene	µg/L	4 of 8	4 of 8	0.05 to 2.5	0.05 to 1.3	4,940	0 of 8	54	0 of 8	na	Na
Phenanthrene	µg/L	5 of 8	3 of 8	0.05 to 2.5	0.16 to 8.4	na	na	4.8	**2 of 8**	na	Na
Pyrene	µg/L	5 of 8	3 of 8	0.05 to 2.5	0.077 to 0.87	2,590	0 of 8	14	0 of 8	na/na/11,000	0 of 8

[a] Terminal 30 locations summarized in this table include eight monitoring wells or paired wells, each of which has been sampled on multiple occasions in 2009. Data are summarized in this table by location. The wells included are MW 85A, MW, 85B, MW 86B, MW 86C, MW 87A, and MW 87B. Refer to Appendix J for a detailed summary of the recent data available for each location.

[b] Refer to Section 9.4.4.1 for the derivation of the groundwater reference values based on equilibrium partitioning considerations.

[c] Current MTCA Method A cleanup level used as a surrogate value for evaluating total petroleum hydrocarbon data.

[d] Marine AWQC per Washington State (WAC 173-201A-240).

[e] NTR, 40 CFR 131 reference values for Human Health for the consumption of organisms only.

[f] Groundwater monitoring has included testing for specific petroleum-associated hazardous substances (e.g., PAH compounds and volatile organics). No exceedances of applicable references have been noted for these compounds. Additionally, nearshore groundwater complies with the MTCA Method A cleanup levels, which provide a conservative groundwater reference value for petroleum hydrocarbons.

[g] Refer to SEDGM Table 6-3 (Anchor QEA and Windward 2009) for the derivation of groundwater reference values for volatile organic compounds.

** – range not applicable
AWQC – ambient water quality criteria
CFR – Code of Federal Regulations
MTCA – Model Toxics Control Act
na – not applicable (Chemical does not have an AWQC, SQS, or does not have a partitioning coefficient in SEDGM Table 6-2 (Anchor QEA and Windward 2009).)NTR – National Toxics Rule
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SEDGM – source evaluation and data gaps memorandum
WAC – Washington Administrative Code

As presented in Table 9-25, groundwater monitoring has not shown any exceedances of any of the reference values in nearshore wells for petroleum hydrocarbons or BTEX compounds. Selected PAH compounds were detected at concentrations greater than the site-specific, reference, and AWQC values. The only exceedances of reference values have been in selected nearshore wells located upland of a buried sheetpile structures installed as part of site geotechnical improvements.

In total groundwater samples, benzo(a)anthracene was detected at concentrations greater than the site-specific screening value at well MW-87B and MW-86B, which also exceeded the NTR WQC value. Chysene was also detected at concentration exceeding the site-specific screening value at well MW-86B. Per direction from Ecology, samples were centrifuged in the 2012 event to determine nature of the PAH detections. These compounds were not detected in centrifuged samples, indicating that these exceedances were associated with suspended particulates in the test samples rather than dissolved contaminants and are not considered mobile.

Three PAH compounds exceeded the groundwater reference values derived in SEDGM Table 6-2 (Anchor QEA and Windward 2009). Acenapthene was detected a concentrations greater than the reference value at five well locations. Fluorene and phenanthrene detections exceeded the reference values in two well locations. The locations are presented in Map 9-24. These compounds were not present above the SQS in sediments located immediately offshore of T-30, suggesting that the groundwater pathway is not complete for these compounds and that they do not represent an ongoing source of sediment contamination.

Groundwater monitoring is continuing at this site as part of ongoing site investigation and cleanup activities conducted by the Port of Seattle under Ecology oversight.

9.4.4.2.6 Terminal 25

Site use at T-25 has varied since early development. As of 1918, T-25 was bordered on the north side by Slip 374, and the southern nearshore portion of the terminal consisted of a turning basin. Uses of buildings and wharves at the property between the 1920s and the 1970s included grain elevators, construction firms, and an iron works, a lumber company, a cold storage facility, and the Westinghouse Electrical Manufacturing Company. By the

1970s, the T-25 site had been redeveloped for its current land usage as a terminal facility, including the filling of the turning basin and slip. Currently, the northern part of the T-25 site is operated by SSA, and the southern portion is vacant and used for parking and construction staging; no above-ground structures are present. Groundwater screen depths ranged from 6 to 19.5 ft bgs (Appendix Table J-33).

The T-25 site is the location of a former LUST removal associated with the former cold storage facility. The LUST removal is described in site investigation reports developed on behalf of the Port of Seattle and summarized in the EISR (Anchor and Windward 2008a). Additional areas of petroleum-contaminated soils were also removed.

In 1989, Blymer Engineers, Inc. drilled 12 soil borings (B-1 through B-12) throughout T-25 to an approximate depth of 10 ft bgs. The boring locations were selected based on historical research of past site uses. Groundwater was not tested as part of this investigation effort. Results of sampling and analysis for various organic and inorganic contaminants were reported in a Phase 1 Environmental Site Assessment (BEI 1989).

Herrera Environmental Consultants completed environmental investigation and soil removal activities for the City of Seattle in October 2010, within the ROW area located along the southern boundary of the site (Map 9-20). The purpose of the investigation was to evaluate environmental soil and groundwater conditions near construction activities for disposal characterization. Soil sample results identified the presence of PCBs at elevated concentrations in soils at the Bent 97 location. PCBs were not detected in the collocated groundwater sample. This location was adjacent to the site of the former Westinghouse laboratory building, which was present between the 1940s and 1960s.

The City of Seattle removed approximately 70 cy of PCB-impacted soil from the Bent 97 area in 2010; however, results of post-removal confirmation testing identified elevated PCB concentrations remaining in soil at the excavation location.

In 2012, the Port of Seattle completed a supplemental soil investigation in the PCB-impacted soil area by advancing 12 subsurface soil borings to 12 ft bgs. At each boring location, four sample intervals (0 to 3-ft, 3 to 6-ft, 6 to 9-ft, and 9 to 12-ft bgs) were submitted for PCB and mercury analysis. Groundwater levels were observed at 10 to 11 ft bgs. No mercury was detected above cleanup levels. Detected Total PCB concentrations ranged from 0.065 to

27.35 mg/kg. All sample analysis in the saturated 9-to-12-ft-bgs sample interval were either non-detect or less than 1 mg/kg dw. The localized area of impacted soils is currently covered by asphalt and roadway structures, and contaminated soils are not present within the groundwater. As described below, no PCBs were detected in groundwater testing performed by the Port of Seattle. No further actions are planned by the Port of Seattle at this time regarding the remaining PCB-containing soils.

Four new groundwater monitoring wells were installed along the shoreline of the EW to provide supplemental groundwater data in 2011 as shown in Map 9-20. Each well was sampled for four consecutive quarters, and samples were submitted for metals, SVOCs, PAHs, and PCBs analysis. All groundwater compliance wells and monitoring data for the site are presented on Map 9-20 and summarized in Table 9-26. A detailed tabulation of the underlying data is provided in Appendix J, Table J-17 through J-22. These tables also summarize the groundwater quality data from previous investigations performed by the Port of Seattle to document site groundwater quality following completion of the LUST removal.

No results for TPHs, BTEX, or PCBs exceeded any screening criteria. All SVOC results were below the screening levels except a single field duplicate sample with detected BEHP and exceeded the groundwater reference value. BEHP was not detected in the parent of the field duplicate (i.e., sample collected from well AQ-MW-3 on February 6, 2012, using the same collection methods) and was not detected at this well or any other during the investigation. Metals results were all below the screening criteria with the exception of arsenic, which exceeded the NTR WQC value at four well locations. All detected PAH concentrations were below all screening values with the exception of acenapthene. Acenapthene exceeded the groundwater reference value at well AQ-MW-1. Elevated concentrations of acenapthene have been noted in adjacent nearshore sediments, within an existing field of creosote-treated timber pilings.

Table 9-26
Summary of Terminal 25 Groundwater Quality Data

Constituent	Unit	Chemical Detected at Location	Reporting Limit of Non-Detects		Detected Chemical Concentration Range	Groundwater Reference Value[a]	Downgradient Chemical Concentration Exceeds Reference Value[b]	AWQC/NTR Reference Values – Chronic/Acute/Human Health[c,d]	Exceedances of NTR Human Health Reference Values
			No. of Non-Detects	Range (Min to Max)					
Conventional Parameters									
Total suspended solids	mg/L	4 of 4	0 of 4	**	1.3 to 25.6	na	na	na	na
Metals, Dissolved									
Arsenic	µg/L	4 of 4	0 of 4	**	0.5 to 10	28	0 of 4	36/69/14	4 of 4 [d]
Cadmium	µg/L	0 of 4	4 of 4	2 to 4	**	2.6	0 of 4	9.3/42/na	na
Chromium	µg/L	0 of 4	4 of 4	5 to 10	**	306	0 of 4	50/1100/na	na
Copper	µg/L	0 of 4	4 of 4	2 to 4	**	123	0 of 4	3.1/4.8/na	na
Lead	µg/L	0 of 4	4 of 4	0.1 to 40	**	11	0 of 4	8.1/210/0.15	0 of 4
Mercury	µg/L	0 of 4	4 of 4	0.1 to 0.1	**	0.0052	0 of 4	0.025/1.8/4600	0 of 4
Nickel	µg/L	0 of 4	4 of 4	10 to 20	**	na	na	8.2/74/na	na
Silver	µg/L	0 of 4	4 of 4	3 to 6	**	1.5	0 of 4	na/1.9/6.3	0 of 4
Zinc	µg/L	0 of 4	4 of 4	10 to 20	**	33	0 of 4	81/90/na	na
Petroleum Hydrocarbons									
Total petroleum hydrocarbons	µg/L	0 of 1	1 of 1	1,000 to 10,000	**	na[b,e]	na	na	na
BTEX Compounds									
Benzene	µg/L	0 of 1	1 of 1	1 to 1	**	180[a]	0 of 4	na/na/71	0 of 4
Ethylbenzene	µg/L	0 of 1	1 of 1	1 to 1	**	na	na	na/na/29,000	0 of 4
Toluene	µg/L	0 of 1	1 of 1	1 to 1	**	737[a]	0 of 4	na/na/200,000	0 of 4
Total xylenes	µg/L	1 of 1	0 of 1	**	1.1 to 1.3	na	na	na	na
Semivolatile Organics									
1,2,4-Trichlorobenzene	µg/L	0 of 4	4 of 4	1 to 1	**	1.1	0 of 4	na	na
1,2-Dichlorobenzene	µg/L	0 of 4	4 of 4	1 to 1	**	5.2	0 of 4	na/na/17,000	0 of 4
1,4-Dichlorobenzene	µg/L	0 of 4	4 of 4	1 to 1	**	7.1	0 of 4	na	na
2,4-Dimethylphenol	µg/L	0 of 4	4 of 4	1 to 1	**	2	0 of 4	na	na
2-Methylphenol (o-Cresol)	µg/L	0 of 4	4 of 4	1 to 1	**	7.1	0 of 4	na	na
4-Methylphenol (p-Cresol)	µg/L	0 of 4	4 of 4	1 to 1	**	77	0 of 4	na	na
Benzoic acid	µg/L	0 of 4	4 of 4	10	**	2243	0 of 4	na	na
Benzyl alcohol	µg/L	0 of 4	4 of 4	5	**	182	0 of 4	na	na
Bis(2-ethylhexyl)phthalate	µg/L	1 of 4	3 of 4	1 to 1.1	2	0.28	1 of 4	na	na
Butylbenzyl phthalate	µg/L	0 of 4	4 of 4	1 to 1	**	0.52	0 of 4	na	na
Diethyl phthalate	µg/L	0 of 4	4 of 4	1 to 1	**	484	0 of 4	na	na
Dimethyl phthalate	µg/L	0 of 4	4 of 4	1 to 1	**	143	0 of 4	na	na
Di-n-butyl phthalate	µg/L	0 of 4	4 of 4	1 to 1	**	na	na	na	na
Di-n-octyl phthalate	µg/L	0 of 4	4 of 4	1 to 1	**	0.3	0 of 4	na	na
Hexachlorobenzene	µg/L	0 of 4	4 of 4	1 to 1	**	0.11	0 of 4	na	na
Hexachlorobutadiene (Hexachloro-1,3-butadiene)	µg/L	0 of 4	4 of 4	1 to 1	**	3.9	0 of 4	na	na
Hexachloroethane	µg/L	0 of 4	4 of 4	1 to 1	**	na	na	na	na
N-Nitrosodiphenylamine	µg/L	0 of 4	4 of 4	1 to 1	**	1.8	0 of 4	na	na
Pentachlorophenol	µg/L	0 of 4	4 of 4	5 to 5	**	5.3	0 of 4	na	na
Phenol	µg/L	0 of 4	4 of 4	1 to 1	**	78	0 of 4	na	na

Constituent	Unit	Chemical Detected at Location	Reporting Limit of Non-Detects		Detected Chemical Concentration Range	Groundwater Reference Value[a]	Downgradient Chemical Concentration Exceeds Reference Value[b]	AWQC/NTR Reference Values – Chronic/Acute/Human Health[c,d]	Exceedances of NTR Human Health Reference Values
			No. of Non-Detects	Range (Min to Max)					
Polycyclic Aromatic Hydrocarbons (µg/L)									
1-Methylnaphthalene	µg/L	4 of 4	0 of 4	**	0.0039 to 1.9	na	na	na	na
2-Methylnaphthalene	µg/L	4 of 4	0 of 4	**	0.0054 to 0.11	13	0 of 4	na/na/70	0 of 4
Acenaphthene	µg/L	4 of 4	0 of 4	**	0.0062 to 7.6	2.6	1 of 4	na/na/2,100	0 of 4
Acenaphthylene	µg/L	2 of 4	2 of 4	0.01 to 0.01	0.0068 to 0.022	11	0 of 4	na	na
Anthracene	µg/L	4 of 4	0 of 4	**	0.0055 to 0.11	11	0 of 4	na/na/110,000	0 of 4
Benzo(a)anthracene	µg/L	1 of 4	3 of 4	0.01 to 0.01	0.0073 to 0.0073	0.32	0 of 4	na/na/0.031	0 of 4
Benzo(a)pyrene	µg/L	0 of 4	4 of 4	0.01 to 0.01	**	0.01	0 of 4	na/na/0.031	0 of 4
Benzo(b)fluoranthene	µg/L	0 of 4	4 of 4	0.01 to 0.01	**	0.09	0 of 4	na/na/0.031	0 of 4
Benzo(k)fluoranthene	µg/L	0 of 4	4 of 4	0.01 to 0.01	**	0.1	0 of 4	na/na/0.031	0 of 4
Total Benzofluoranthene[a]	µg/L	1 of 4	3 of 4	0.01 to 0.02	0.023 to 0/023	0.19	0 of 4	na/na/0.062	0 of 4
Benzo(g,h,i)perylene	µg/L	1 of 4	3 of 4	0.01 to 0.01	0.0069 to 0/0069	0.012	0 of 4	na	na
Chrysene	µg/L	1 of 4	3 of 4	0.01 to 0.01	0.0066 to 0.0066	3.18	0 of 4	na/na/0.031	0 of 4
Dibenzo(a,h)anthracene	µg/L	1 of 4	3 of 4	0.01 to 0.01	0.0099 to 0.0099	0.029	0 of 4	na/na/0.031	0 of 4
Dibenzofuran	µg/L	1 of 4	3 of 4	0.01 to 0.01	0.16 to 1	1.3	0 of 4	na	na
Fluoranthene	µg/L	3 of 4	1 of 4	0.01 to 0.01	0.007 to 0.29	2.3	0 of 4	na/na/14,000	0 of 4
Fluorene	µg/L	2 of 4	2 of 4	0.01 to 0.01	0.17 to 0.96	2	0 of 4	na/na/370	0 of 4
Indeno(1,2,3-c,d)pyrene	µg/L	1 of 4	3 of 4	0.01 to 0.01	0.0095 to 0.0095	0.028	0 of 4	na/na/0.031	0 of 4
Naphthalene	µg/L	4 of 4	0 of 4	**	0.0059 to 2.8	54	0 of 4	na	na
Phenanthrene	µg/L	3 of 4	1 of 4	0.01 to 0.01	0.0061 to 0.45	4.8	0 of 4	na	na
Pyrene	µg/L	2 of 4	2 of 4	0.01 to 0.01	0.0061 to 0.16	14	0 of 4	na/na/11,000	0 of 4
Total cPAH TEQ (7 minimum CAEPA 2005) (U = 1/2)	µg/L	1 of 4	3 of 4	0.01 to 0.01	0.01 to 0.01	na	na	na/na/0.217	0 of 4
Total naphthalenes (U = 1/2)	µg/L	4 of 4	0 of 4	0.01 to 0.013	0.0159 to 4.81	67	0 of 4	na	na
Polychlorinated Biphenyls[f]									
Aroclor 1016	µg/L	0 of 5	5 of 5	0.01 to 1.1	**	0.44	0 of 5	na	na
Aroclor 1221	µg/L	0 of 5	5 of 5	0.01 to 1.1	**	1.17	0 of 5	na	na
Aroclor 1232	µg/L	0 of 5	5 of 5	0.01 to 1.1	**	1.17	0 of 5	na	na
Aroclor 1242	µg/L	0 of 5	5 of 5	0.01 to 1.1	**	0.27	0 of 5	na	na
Aroclor 1248	µg/L	0 of 5	5 of 5	0.01 to 1.1	**	0.27	0 of 5	na	na
Aroclor 1254	µg/L	0 of 5	5 of 5	0.01 to 1.1	**	0.16	0 of 5	na	na
Aroclor 1260	µg/L	0 of 5	5 of 5	0.01 to 1.1	**	0.058	0 of 5	na	na

[a] Refer to Section 9.4.4.1 (Anchor QEA and Windward 2009) for derivation of groundwater reference values for selected volatile organic compounds.

[b] Current MTCA Method A cleanup level used as a surrogate value for evaluating total petroleum hydrocarbon data.

[c] Marine AWQC per Washington State (WAC 173-201A-240).

[d] NTR, 40 CFR 131 reference values for Human Health. The reference values for arsenic have not been adjusted to take into account naturally occurring arsenic concentrations that may be present in groundwater or surface water. NTR recommended water quality criterion for arsenic refers to the inorganic form only.

[e] The groundwater cleanup level for petroleum at the time the independent cleanup action was initiated was 1,000 µg/L.

[f] One temporary soil boring was analyzed for groundwater quality on behalf of SDOT in the vicinity of PCB-contaminated soil identified during a construction project. Groundwater PCB data available from this PCB boring are included though the location is more than 850 ft from the EW.

** – range not applicable
AWQC – ambient water quality criteria
CFR – Code of Federal Regulations
EW – East Waterway
MTCA – Model Toxics Control Act
na – not applicable (Chemical does not have an AWQC, NTR, SQS, or a partitioning coefficient is not available from SEDGM Table 6-2 (Anchor QEA and Windward 2009).)
NTR – National Toxics Rule
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
RL – reporting limit
SDOT – Seattle Department of Transportation
SEDGM – source evaluation and data gaps memorandum
WAC – Washington Administrative Code

9.4.4.2.7 Terminal 104 and Vicinity

Phase 1 and Phase 2 investigations have been performed by the Port of Seattle to provide information regarding environmental conditions at the site. As documented in those reports, the T-104 property was undeveloped until the middle-1940s. Since that time, it has been used as a paper mill, lumber storage yard, auto repair shop, foundry supply warehouse, and cargo transfer and storage yard (Anchor and Windward 2008a).

As described in the EISR (Anchor and Windward 2008a), portions of the T-104 properties have been investigated and remediated by the Port of Seattle prior to their use as part of a transportation improvement project. These historical investigations delineated concentrations of trichloroethene (TCE) and arsenic in the eastern portion of the site where historical industrial site uses were conducted, such as the Poncho's Legacy Site. These former operations and identified concentrations are shown on Map 9-20. Additional groundwater data from 1992 and 1993 has been included in this SRI report regarding the removal of a UST in the western portion of the property. An evaluation of the property is included in the LDW RM 0.0 to RM 0.1 East Source Control Action Plan (Ecology and Ecology and Environment 2009) and no groundwater data gaps were identified. Extensive groundwater sampling has been performed throughout the properties, including the use of both geoprobe borings and permanent monitoring wells. Groundwater screen depths are not available for all locations. Where they are available, the screen depths were from 7 to 12 ft bgs (Appendix Table J-33).

Map 9-20 illustrates the locations of the T-104 properties and the various groundwater sampling locations. Table 9-27 summarizes the results of recent groundwater monitoring at representative downgradient sampling locations, located in between localized impacted areas and the EW. Data from upgradient source locations are not included, as they are not relevant to the analysis of sediment recontamination potential. Appendix J, Table J-23 presents all rounds of each well's results.

Table 9-27
Summary of Terminal 104 Downgradient Groundwater Quality

Constituent	Unit	Chemical Detected at Location	Reporting Limit of Non-Detects		Detected Chemical Concentration Range	Site-specific Cleanup Goal (µg/L)[a]	Chemicals Detected Above Site-specific Cleanup Goal	Groundwater Reference Value[b]	Chemicals Detected Above Groundwater Reference Value	AWQC/NTR Reference Values – Chronic/Acute/Human Health[c,d]	Nearshore Concentration Exceeds Marine AWQC Chronic Reference Value	Nearshore Concentration Exceeds Marine AWQC Acute Reference Value	Nearshore Concentration Exceeds NTR Human Health Reference Value
			No. of Non-Detects	Range (Min to Max)									
Metals (Total)													
Arsenic	µg/L	4 of 17	13	3 to 4.4	4.6 to 5.5	5	**2 of 17**	27.9	0 of 17	36/69/14	0 of 17	0 of 17	**4 of 17**[d]
Barium	µg/L	2 of 17	15	25 to 28	32 to 52	na	na	na	na	na	na	na	na
Cadmium	µg/L	0 of 17	17	4 to 4.4	**	5	0 of 17	2.6	0 of 17	9.3/42/na	0 of 17	0 of 17	na
Chromium	µg/L	1 of 17	16	10 to 11	13	50	0 of 17	306 T	0 of 17	50/1,100/na	0 of 17	0 of 17	na
Lead	µg/L	4 of 20	16	1 to 1.1	1.8 to 4.1	15	0 of 20	11	0 of 20	8.1/210/na	0 of 20	0 of 20	na
Mercury	µg/L	0 of 17	17	0.5 to 0.5	**	2	0 of 17	0.0052	0 of 17	0.025/1.8/0.15	0 of 17	0 of 17	0 of 17
Selenium	µg/L	0 of 17	17	5 to 11	**	180[e]	0 of 17	na	na	na	na	na	na
Silver	µg/L	0 of 17	17	10 to 11	**	180[e]	0 of 17	1.5	0 of 17	na/1.9/na	na	0 of 17	na
Petroleum Hydrocarbons													
Total petroleum hydrocarbons	µg/L	3 of 12	9	250 to 250	150 to 4,300	na	na	na	na	na	na	na	na
Gasoline-range hydrocarbons	µg/L	0 of 10	10	50 to 100	**	1,000	0 of 10	na[f]	na	na	na	na	na
Diesel-range hydrocarbons	µg/L	0 of 10	10	250 o 270	**	500	0 of 10	na[f]	na	na	na	na	na
Lube oil-range hydrocarbons	µg/L	0 of 10	10	400 to 430	**	500	0 of 10	na[f]	na	na	na	na	na
Volatile Organic Compounds													
Benzene	µg/L	0 of 15	15	0.2 to 10	**	5	0 of 15	na	na	na	na	na	na
1,2-Dichlorobenzene	µg/L	0 of 14	14	0.2 to 0.2	**	1,600[e]	0 of 14	5.2	0 of 14	na/na/17,000	na	na	0 of 14
1,1-Dichloroethane	µg/L	0 of 14	14	0.2 to 0.2	**	1,800[e]	0 of 14	na	na	na	na	na	na
cis-1,2-Dichloroethene	µg/L	1 of 14	13	0.2 to 0.2	0.4	180[e]	0 of 14	136	0 of 14	na	na	na	na
trans-1,2-Dichloroethene	µg/L	0 of 14	14	0.2 to 0.2	**	350[e]	0 of 14	na	na	na	na	na	na
Ethylbenzene	µg/L	0 of 26	26	0.2 to 10	**	700	0 of 26	na	na	na/na/29.000	na	na	0 of 26
Toluene	µg/L	5 of 26	21	0.2 to 10	0.27 to 74	1,000	0 of 26	737	0 of 26	na/na/200,000	na	na	0 of 26
Trichlorothene	µg/L	3 of 14	11	0.2 to 0.2	0.89 to 4	5	0 of 14	2,200	0 of 14	na/na/81	na	na	0 of 14
m,p-Xylenes	µg/L	2 of 23	21	0.2 to 10	0.52 to 71	35,000[e]	0 of 23	na	na	na	na	na	na
o-Xylenes	µg/L	1 of 23	22	0.2 to 10	15	35,000[e]	0 of 23	na	na	na	na	na	na
Total xylenes	µg/L	0 of 3	3	1 to 1	**	1,000	0 of 3	na	na	na	na	na	na
Other EPA 8260 VOCs[g]	µg/L	na	na	**	**	na	na	na	na	na	na	na	na
PAH Compounds[h]	µg/L	0 of 6	6	0.0096 to 0.0098	**	0.1	0 of 6	[b]	0 of 6	na	na	na	na
PCBs[i]	µg/L	0 of 2	2	0.048 to 0.049	**	0.1	0 of 2	[b]	0 of 2	0.03/10/0.00017	0 of 2	0 of 2	0 of 2

[a] MTCA Method A cleanup level, unless otherwise specified.

[b] Refer to Section 9.4.4.1 for the derivation of the groundwater reference values based on equilibrium partitioning considerations.

[c] Marine AWQC per Washington State (WAC 173-201A-240).

[d] NTR, 40 CFR 131 reference values for Human Health. The reference values for arsenic have not been adjusted to take into account naturally occurring arsenic concentrations that may be present in groundwater or surface water. NTR recommended water quality criterion for arsenic refers to the inorganic form only

[e] MTCA Method C criteria.

[f] Current MTCA Method A cleanup level used as a surrogate value for evaluating total petroleum hydrocarbon data.

[g] Other EPA 8260 VOC compounds and all PAH and PCB compounds were non-detect.

[h] Results for carcinogenic PAHs in groundwater.

[i] In addition to the two locations listed in this table (MW-13 and MW-15), nine other monitoring wells in upgradient locations were tested for PCBs. No PCBs were detected in any of the sampled locations.

** – range not applicable
AWQC – ambient water quality criteria
CFR – Code of Federal Regulations
D – dissolved metals
MTCA – Model Toxics Control Act
na – not applicable (Chemical does not have an AWQC, NTR, SQS, or a partitioning coefficient is not available from SEDGM Table 6-2 (Anchor QEA and Windward 2009).)
NTR – National Toxics Rule
PAH – polycyclic aromatic hydrocarbon
RL – reporting limit
SEDGM – source evaluation and data gaps memorandum
T – total metals
WAC – Washington Administrative Code

Groundwater monitoring has been performed for metals, petroleum, VOCs, PAH compounds, and PCBs. The specific parameters tested in each location vary based on site conditions. Summary statistics are presented in Table 9-27. These data include findings from each of the environmental studies listed below.

Three downgradient groundwater wells were installed in support of an *Environmental Site Assessment* (Emcon 1992a, 1992b, 1992c, 1992d, 1993) and tested for total lead, BTEX, and petroleum hydrocarbons as shown in Map 9-20 and in Appendix J, Table J-23. These locations were sampled for five rounds from 1991 to 1993. TPHs were detected in the initial round of sampling, but were not detected in subsequent rounds. No exceedances of site-specific cleanup levels, AWQC, or groundwater reference values from Table 6-2 of the SEDGM (Anchor QEA and Windward 2009) have been noted.

The *East Marginal Way Grade Separation Supplemental Investigation and Data Summary Report* (Environmental Partners 2007) detailed 11 of the downgradient groundwater locations that have been tested for heavy metals. Some of these locations have been tested on multiple dates. No exceedances of groundwater reference values from Table 6-2 of the SEDGM (Anchor QEA and Windward 2009) have been noted. Elevated arsenic concentrations were detected at multiple locations in excess of the site-specific cleanup goal and in excess of AWQC values, but these concentrations are below the groundwater reference value. These locations were also located in upgradient areas away from the EW shoreline; arsenic concentrations were not elevated at monitoring points located closer to the shoreline.

Petroleum hydrocarbons have been tested in multiple sampling locations, including seven of the downgradient locations for gasoline and 10 of the downgradient locations for diesel and lube oil. Some of these locations have been tested on multiple dates. Concentrations of petroleum in these locations have been below MDLs. The detection limits were below the current Method A groundwater cleanup levels.

Full-list VOCs (EPA Method 8260) were tested in eight downgradient locations, and BTEX compounds were tested in one additional downgradient location. Very low levels of VOCs were detected in one of these locations, and toluene was detected in four locations. None of the measured concentrations exceeded the site-specific cleanup levels or the groundwater reference values developed in Table 6-3 of the SEDGM (Anchor QEA and Windward 2009).

PAH compounds were tested in six of the downgradient well locations. None of these compounds were detected. PCB compounds were tested in groundwater at 11 locations throughout the site. These locations included two of the downgradient sampling locations, as well as nine upgradient locations in other site areas. PCBs were not detected in any of the sampled locations throughout the site.

There are no ongoing monitoring activities at the T-104 property.

9.4.4.3 Groundwater Pathway and Inland Cleanup Sites

Inland cleanup sites can potentially contribute pollutants to SDs and combined sewers through infiltration of groundwater and soils into conveyance systems. The solids and contaminant inputs associated with stormwater and CSOs are being directly evaluated as described in Section 9.4.3. These evaluations incorporate potential contaminant inputs from multiple sources including indirect atmospheric deposition, stormwater runoff, permitted or non-permitted discharges to the SD or combined sewer systems, and spills occurring within the SD systems or combined sewer service areas.

In support of the SRI report, an expanded database search was conducted to document the listed sites located along the EW and those located in the EW-associated SD and combined sewer service areas. Listed sites are shown in Map 9-7, with detail presented in Appendix G, Table G-1. The updated database search includes the locations of the listed sites relative to stormwater and combined sewer conveyances. As described in the SEDGM (Anchor QEA and Windward 2009), the database query was performed to provide supplemental information potentially useful during source-tracing activities within the EW watersheds. However, the database information is not necessary to characterize current stormwater or CSO discharges to the EW, because these discharges have been characterized directly, thus including any potential contributions from cleanup sites located within the SD or CSO basins.

The database summaries of listed sites were reviewed to identify listings noting EW COCs such as PCBs, PAHs, phthalates, metals, and dioxins and furans. The majority of the listed sites were related to releases of petroleum hydrocarbons. There were no confirmed listings for phthalates or dioxin furans. Of the 238 site listings, 21 noted the presence of heavy

metals, 14 noted PCBs, 10 noted PAHs, and 5 noted arsenic. Refer to Table G-1 for specific information on each site.

9.4.5 Bank Erosion

Shoreline and non-armored banks are identified as a potential source where active erosion of contaminated soils is ongoing. These soils may enter the water body directly, potentially resulting in localized areas of sediment contamination. At most locations within the EW, the existing sea walls and armoring of shorelines minimize the potential for bank soil erosion. A visual inspection was conducted throughout the EW in 2009 to classify the bank construction types, as shown in Maps 9-25a through 25c. The bank construction types were categorized into four types as follows:

- Type A: Engineered bank with armor stone and/or metal bulkhead
- Type B: Engineered bank with rubble or gravel armor and or wooden or concrete bulkhead
- Type C: Non-engineered rubble armored slope or non-engineered mud or gravel bank
- Type D: Non-engineered steep bank with no armor, resulting in higher potential for bank erosion

Of the 30 shoreline segments visually inspected, 16 were Type A (80% of total length), 11 were Type B (17%), 3 were Type C (3%), and none were Type D. The construction of Type A and B banks minimizes the potential for soil erosion. Type C shorelines have a greater potential for soil erosion and are detailed below. As noted above, no Type D shorelines are located in the EW. The Type C banks identified were:

- Bank 8B: This area consists of a sand/gravel sloping shoreline/intertidal area located beneath the Spokane Street Bridge. Intertidal sediments are being evaluated as part of the EW SRI/FS.
- Banks 1 and 2B: These two adjacent areas consist of a steep rubble-armored sloping shoreline at the USCG property (Pier 35/36). Nearshore soils in this area represent recent fill material. Preliminary environmental investigations conducted by EPA and summarized by Dames & Moore (1989) for the USCG identified soil and groundwater contamination in this fill material. In 1988, a preliminary environmental investigation showed elevated levels of heavy metals, PAH compounds, and other contaminants (see Section 9.4.4.2.3). Surface sediments adjacent to this area included

elevated levels of PAH compounds (see Section 4), and porewater sampling conducted along Bank 2B detected elevated levels of naphthalene (see Section 4). The information review for this area of the shoreline is continuing in support of the EW SRI/FS.

9.4.6 Treated-Wood Structures

Historically, treated-wood pilings and wooden structures were commonly used as part of navigation (e.g., pier and wharf structures, fender systems, and dolphins) and structural improvements (e.g., wooden bulkheads). Treated-wood pilings and structures are a potential source of contaminants and can be released to sediments through abrasion or leaching pathways. Treated-wood structures are largely historical because the installation of new treated-wood structures is restricted by permitting requirements, and most treated-wood structures have been removed from the waterway during waterfront facility upgrades. Most of the marine structures present along the EW are constructed of concrete or metal.

Areas of remaining wood structures treated with creosote or CCA preservatives were assessed during a visual inspection conducted in May and June 2010 and updated by the Port of Seattle in 2012. Results of this inspection are shown in Map 9-9. The remaining wooden structures include some older docks, older fender-piling systems, stub pilings remaining in areas where structures or pilings were previously removed, or short sections of wooden bulkheads. Areas with greater numbers of remaining creosote-treated pilings include the following (refer to Map 9-9 for locations):

- Area 1: Replacement is scheduled.
- Area 4: The foundation for the rail bridge along the east side of Harbor Island has approximately 270 creosote-treated pilings. This bridge is in use and the pilings remain integral to the structure.
- Area 6: Approximately 300 creosote-treated foundation pilings support the wooden pedestrian bridge and public access area adjacent to Spokane Street. These pilings are integral to the structure.
- Area 8: Approximately 1,700 creosote-treated pilings remain in the area adjacent to T-25. The Port of Seattle previously removed the dock structure in this area, but the foundation pilings remain in place at this time. Pilings in Area 8 remain in place at this time because the removal project anticipated in 2008 to 2009 was not completed

due to DNR and EPA concerns that piling removal could potentially disturb contaminated sediments present in the vicinity of the pilings.

- Area 14: The existing dock structure adjacent to Pier 34 includes approximately 750 creosote-treated foundation pilings. These pilings are integral to that structure.
- Area 17: The southeastern pier at the USCG facility includes approximately 1,400 creosote-treated foundation pilings. These pilings are integral to the structure. Other piers at the USCG site have been previously upgraded using concrete pilings.

Treated-wood structures may cause sediment contamination through leaching and abrasion. Sediment exceedances with PAH compounds have been observed in the vicinity of creosote-treated pilings adjacent to T-25. In areas with CCA-treated fender pilings, no surface sediment exceedances of SMS criteria were noted for arsenic and copper. The introduction of new creosote-treated structures is restricted through state and federal permitting activities.

9.4.7 Atmospheric Deposition

Airborne pollutants can reach sediment directly, through the deposition of airborne chemicals, primarily in the form of PM onto the water surface, and indirectly, through the deposition of PM on terrestrial surfaces from which they are conveyed via SD systems to water bodies. The characterization of the indirect atmospheric deposition contribution is mainly reflected as a component of stormwater and is addressed through stormwater source characterization (or CSO characterization, which includes stormwater inputs). Direct atmospheric deposition is assessed separately. Information collected as part of various air quality monitoring programs can be used to assess the potential impact of atmospheric deposition to the EW.

Air pollutants can be measured as wet deposition (i.e., particulates and chemicals contained within precipitation), dry deposition (i.e., particles that settle as dust), and gas-phase transfer (i.e., gas exchange across the water surface) (King County 2008b). Wet- and dry-deposition rates can be combined to calculate a total atmospheric deposition rate. Pollutant deposition rates are expressed as average flux rates during a measured time interval (e.g., micrograms per square meter per day [$\mu g/m^2/day$]). Gas-phase transfer rates can influence net transfer rates (either increasing or decreasing net deposition rates) for contaminants with relatively

low molecular weights, such as LPAHs, lighter phthalates, and low-to-mid-range PCBs (EPA 2001; King County 2008b).[133]

Air quality and atmospheric deposition data have been collected along the LDW and at other locations throughout the City of Seattle by several entities, including PSCAA, Ecology, and King County. Information collected as part of these monitoring programs can be used to assess the potential impact of atmospheric deposition in the EW given the proximity of these monitoring stations to the EW and the widespread nature of air pollutants.

9.4.7.1 Particulate Matter

PM includes both solid and liquid particles suspended in the air (PSCAA 2011) and is divided primarily into two size classes: fine particles, which are smaller than 2.5 μm in diameter (PM2.5); and coarse particles, which are between 2.5 and 10 μm in diameter (PM10) (PSCAA 2011). If atmospheric total suspended particulate is considered, very coarse particles up to approximately 40 μm in diameter can be present (EPA 1997). Because PM2.5 has the greatest effect on human health, it is the size class that is monitored by PSCAA. PM2.5 is relevant to source control because it can serves as a transport pathway for chemicals. At least 90% of PM from combustion sources (e.g., wood smoke, diesel exhaust) consists of particulate smaller than 2.5 μm in diameter (EPA 1997).

Wood-burning emissions and dust from roadways and construction sites are the most significant sources of PM2.5 in the region; motor vehicles and marine vessels are also significant sources of PM2.5 (King County and SPU 2005; PSCAA 2006d, 2008). PM2.5 can also be formed through the chemical reaction of gases in the atmosphere (PSCAA 2011).

9.4.7.2 Air Toxics

PSCAA considers more than 400 chemicals to be toxic air pollutants, including PAHs, PCBs, diesel PM (DPM) (a subset of PM2.5), and suspended particulates of some metals such as lead. Dioxin compounds are also considered to be toxic air pollutants. Sources of air toxics

[133] Gas-phase transfer rates were not calculated for the contaminants for which atmospheric deposition data are presented in this section as the sampling methods used to collect particulates and precipitation are generally not very effective at sampling very small particles and gases (King County 2008b).

include motor vehicles, diesel-powered marine vessels, rail cars, wood-burning stoves, solid-waste incinerators, and industrial facilities (PSCAA 2006b, c).

Concentrations of select air toxics (i.e., those of greatest concern with regard to human health) are routinely monitored by PSCAA. Although air quality data are collected and analyzed in the context of potential human health risks from the inhalation pathway, they can also be used to provide information relevant to source control and the atmospheric deposition pathway. In general, concentrations of air toxics in the Puget Sound region have declined since the early 2000s (PSCAA and University of Washington 2010).

In the 2009 Air Quality Data Summary (PSCAA 2011), PSCAA provided information on the chemical composition of PM2.5 samples collected at the Duwamish monitoring station. Of the chemicals included in PSCAA's analysis, arsenic is relevant to source control in the EW; however, because more than half of the samples had arsenic concentrations below the MDL, average annual concentrations were not provided in the report. Data for one other air toxic relevant to source control in the EW were provided by Ecology (Williamson 2008). Air concentration data for 1,4-dichlorobenzene were collected at the Beacon Hill monitoring station.[134] The average 1,4-dichlorobenzene concentration was 0.05 µg/m^3, and the range of concentrations was 0.01 to 0.09 µg/m^3. According to the Agency for Toxic Substances and Disease Registry (ATSDR 2006) 1,4-dichlorobenzene is a widely used chemical that enters the environment primarily as releases to air during its use as a space deodorant, toilet deodorizer, and moth repellant. Detected airborne concentrations within the range detected at Beacon Hill indicate some potential for periodic "washout" of the contaminant by rainfall, similar to the process postulated for phthalates.

9.4.7.2.1 Local Atmospheric Deposition and Air Quality Monitoring

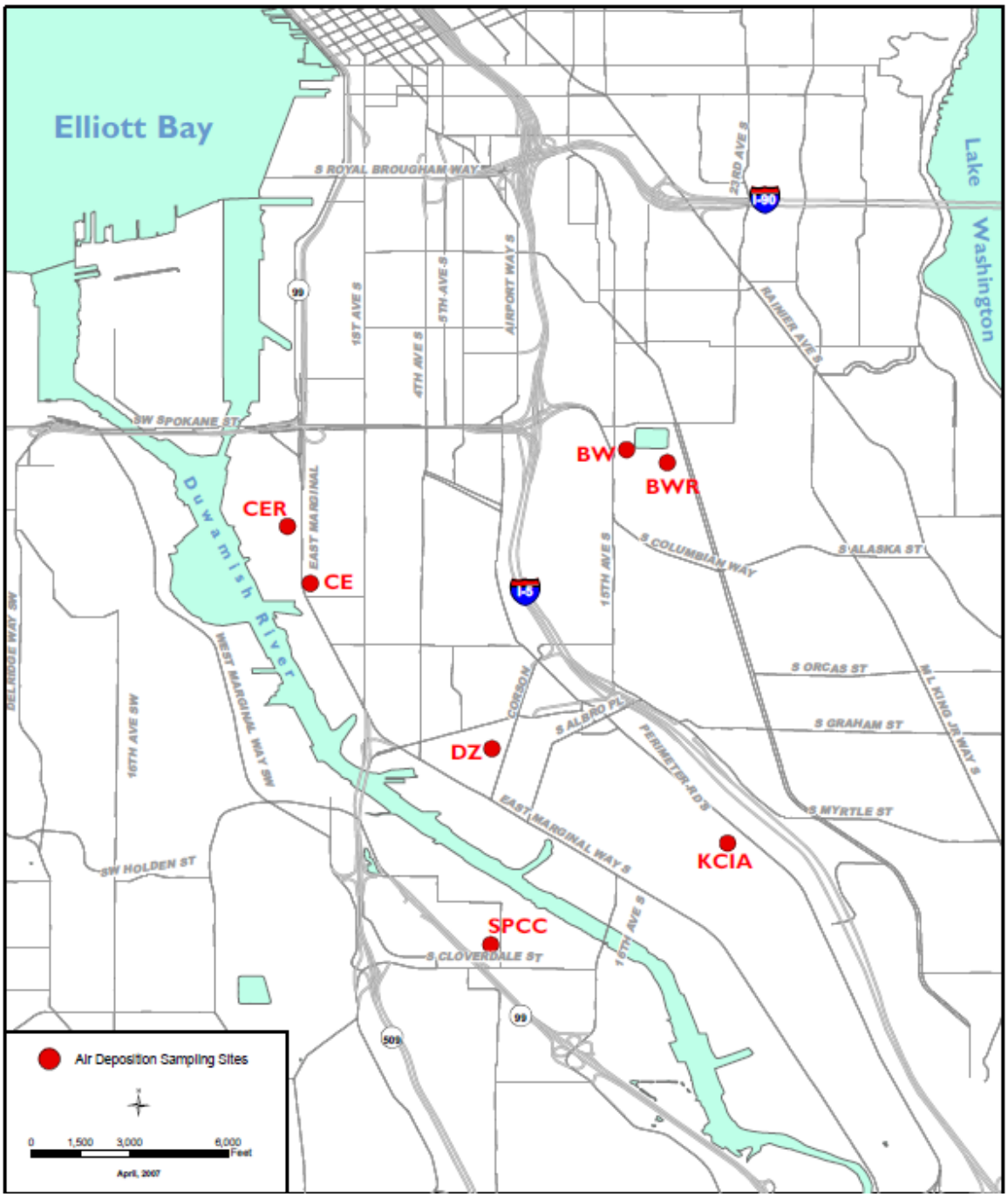
King County LDW Study

Atmospheric deposition data were collected in the LDW by King County between October 2005 and April 2007 (King County 2008b). The study was conducted to evaluate the atmospheric deposition pathway to LDW sediment for PAHs, PCBs, and selected phthalates. As noted in Section 9.4.7, the study included both dry deposition and wet deposition

[134] Although the Beacon Hill monitoring station is considered to represent urban residential rather than urban industrial conditions, this is the only air monitoring station for which 1,4-dichlorobenzene data were available.

sampling methods. Five sampling stations were used during the King County study: Duwamish (station ID CE), Georgetown (ID DZ), South Park (ID SPCC), Beacon Hill (ID BW), and King County International Airport (KCIA) (Figure 9-14). Two of the sampling stations (CE and BW) were relocated during the study (after relocation, station CE was referred to as CER, and station BW as BWR) (Figure 9-14). Data from the Duwamish (CE/CER), Georgetown (DZ), and South Park (SPCC) stations were pooled for summary in this report to represent the commercial/industrial neighborhood conditions near the EW.[135] Duplicate samples collected at the South Park monitoring station were not included in the data analysis.

[135] The relocated Duwamish station (CER) is closest to the EW, approximately 0.7 mile to the southeast of the southern portion of the EW. The distances of the South Park, Georgetown, and Beacon Hill monitoring stations to the southern portion of the EW range from approximately 1 to 3.5 miles.



Source: King County (2008b)
Note: CE = Duwamish, CER = relocated Duwamish, DZ = Georgetown, SPCC = South Park, BW = Beacon Hill, BWR = relocated Beacon Hill, and KCIA = King County International Airport

Figure 9-14

Locations of Monitoring Stations from the King County LDW Study

Table 9-28 summarizes the measured deposition flux values for detected contaminants. Detection frequencies for the combined dataset for the Duwamish, Georgetown, and South Park monitoring stations were above 60% for almost all contaminants. Based on the sample design, lower-molecular-weight contaminants (such as LPAHs) were difficult to sample; therefore, results for these contaminants are not included in Table 9-28. In addition, only two PCB Aroclors (1254 and 1260) were detected, and their detection frequencies were low (13% and 17%, respectively). King County is conducting an additional atmospheric deposition study, the results of which will be available for use in the FS.

Table 9-28

Deposition Flux Values for Air Toxics Measured by King County along the LDW

Contaminant	Contaminant Detected	Detection Frequency (%)	Detected Deposition Flux Values (µg/m^2/day)						Mean Deposition Flux Values Including Non-Detected Data (µg/m^2/day)[a]	
			Min	Max	Mean	Median	25th Percentile	75th Percentile	One-Half MDL	MDL = 0
PCBs[b]										
Aroclor 1254	4 of 30	13	nc[c]	0.044	nc[c]	nc[c]	nc[c]	nc[c]	0.019	0.004
Aroclor 1260	5 of 30	17	nc[c]	0.034	nc[c]	nc[c]	nc[c]	nc[c]	0.019	0.004
PAHs										
Benzo(a)anthracene	38 of 47	81	0.003	0.243	0.063	0.051	0.024	0.077	na	na
Benzo(a)pyrene	29 of 47	62	0.008	0.265	0.095	0.072	0.052	0.135	na	na
Benzo(b)fluoranthene	40 of 47	85	0.010	0.317	0.119	0.103	0.082	0.154	na	na
Benzo(g,h,i)perylene	40 of 47	85	0.010	0.323	0.121	0.104	0.062	0.155	na	na
Benzo(k)fluoranthene	36 of 47	77	0.009	0.317	0.101	0.084	0.057	0.131	na	na
Chrysene	46 of 47	98	0.037	0.464	0.146	0.123	0.093	0.178	na	na
Dibenzo(a,h)anthracene	17 of 47	36	0.020	0.170	0.042	0.030	0.022	0.043	na	na
Indeno(1,2,3-cd)pyrene	34 of 47	72	0.005	0.232	0.078	0.060	0.046	0.100	na	na
Pyrene	46 of 47	98	0.088	0.831	0.241	0.192	0.136	0.271	na	na
Phthalates										
BBP	47 of 47	100	0.163	7.007	0.950	0.599	0.299	1.063	na	na
BEHP	47 of 47	100	0.261	12.240	2.940	2.255	1.396	3.609	na	na
Diethyl phthalate	42 of 47	89	0.007	0.447	0.165	0.142	0.076	0.217	na	na
Dimethyl phthalate	34 of 47	72	0.029	0.153	0.068	0.061	0.049	0.080	na	na
Di-n-butyl phthalate	39 of 47	83	0.002	0.678	0.177	0.093	0.034	0.249	na	na
Di-n-octyl phthalate	27 of 47	57	0.037	2.874	0.658	0.329	0.159	0.748	na	na

Source: King County (2008b)

Note: The data in this table were collected at the Duwamish, Georgetown, and South Park monitoring stations. Duplicate samples collected at the South Park station were not included in the data analysis.

[a] Mean deposition flux values for PCB Aroclors included an MDL substitution for non-detected data. The one-half MDL substitution was set to half the MDL reported by the laboratory; in the other substitution, the MDL was set to zero. The majority of PCB Aroclor data were non-detected data.

[b] Samples were also analyzed for Aroclors 1016, 1221, 1232, 1242, and 1248. All sampling results for these Aroclors were non-detect; therefore, summary statistics were not calculated for these contaminants.

[c] Calculation was not performed because of a lack of detected data.

BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
LDW – Lower Duwamish Waterway
na – not applicable
nc – not calculated
MDL – method detection limit
PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl

A comparison of median PAH atmospheric deposition flux values from the relocated Duwamish monitoring station, the Georgetown monitoring station, and the South Park monitoring station indicates that data collected at all three of these stations likely do represent neighborhood-scale conditions. All median PAH atmospheric deposition flux values from these three monitoring stations were within 0.05 µg/m²/day of each other for each individual PAH measured. This indicates that the influence of mobile and/or localized sources causes little variation in station-to-station air quality conditions in the Duwamish Valley. One reason for this observation may be that all three of these monitoring stations were located within one tenth of a mile of a highway or main transportation arterial such as E Marginal Way S. Therefore, although the atmospheric deposition data collected at these stations were intended to evaluate potential sources to the LDW, they can also be applied to the EW.

Table 9-29 summarizes the measured deposition flux values for detected contaminants for the Beacon Hill station (which is considered to represent urban residential neighborhood conditions). Atmospheric deposition data from the Beacon Hill station are representative of conditions within the EW drainage basin and are therefore useful in evaluating indirect atmospheric deposition. Detection frequencies were 50% or greater for all but one phthalate (di-n-octyl phthalate) and three PAHs (benzo(a)pyrene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene). PCB Aroclors were not detected in any of the samples from the Beacon Hill station.

Table 9-29

Deposition Flux Values for Air Toxics Measured by King County at the Beacon Hill Station

Contaminant	Contaminant Detected	Detection Frequency (%)	Detected Deposition Flux Values (µg/m²/day)					
			Min	Max	Mean	Median	25th Percentile	75th Percentile
PAHs								
Benzo(a)anthracene	6 of 12	50	0.019	0.030	0.023	0.022	0.021	0.023
Benzo(a)pyrene	5 of 12	42	0.021	0.026	0.023	0.021	0.021	0.025
Benzo(b)fluoranthene	10 of 12	83	0.033	0.072	0.047	0.046	0.038	0.049
Benzo(g,h,i)perylene	8 of 12	67	0.033	0.070	0.047	0.043	0.038	0.057
Benzo(k)fluoranthene	7 of 12	58	0.025	0.054	0.037	0.035	0.031	0.040
Chrysene	12 of 12	100	0.023	0.090	0.055	0.051	0.038	0.074
Dibenzo(a,h)anthracene	1 of 12	8	0.012	0.012	0.012	0.012	0.012	0.012
Indeno(1,2,3-cd)pyrene	5 of 12	42	0.025	0.059	0.034	0.027	0.025	0.033

Contaminant	Contaminant Detected	Detection Frequency (%)	Detected Deposition Flux Values (µg/m^2/day)					
			Min	Max	Mean	Median	25th Percentile	75th Percentile
Pyrene	12 of 12	100	0.035	0.157	0.090	0.086	0.073	0.110
Phthalates								
BBP	12 of 12	100	0.193	0.980	0.498	0.495	0.271	0.686
BEHP	12 of 12	100	0.955	3.479	1.640	1.457	1.151	1.993
Diethyl phthalate	11 of 12	92	0.092	0.658	0.209	0.135	0.094	0.276
Dimethyl phthalate	11 of 12	92	0.022	0.104	0.039	0.034	0.028	0.035
Di-n-butyl phthalate	7 of 12	58	0.015	0.143	0.081	0.070	0.037	0.130
Di-n-octyl phthalate	5 of 12	42	0.096	0.165	0.128	0.137	0.099	0.144

Source: King County (2008b)
BBP – butyl benzyl phthalate
BEHP – bis(2-ethylhexyl) phthalate
PAH – polycyclic aromatic hydrocarbon

King County calculated correlation coefficients for the atmospheric deposition data and other associated data provided by PSCAA, which included wind rose data for wind speed and direction and wind rose data for PM, to assess potential relationships between the deposition of air pollutants, the presence of PM, and wind patterns (King County 2008b). Few strong correlations were identified through this comparison. At some monitoring stations, a correlation between deposition of PAHs and the presence of PM was identified; however, a consistent relationship across monitoring stations was not identified.

Winds in the Puget Sound region, including the Duwamish Valley, are predominantly from the south during fall, winter, and early spring (Battelle et al. 2001; PSCAA 2007b). In the late spring and summer, the wind is primarily from the north. When winds are from the south, air monitoring stations in the LDW provide an indication of air pollutants moving from the LDW basins toward the EW. When winds are from the north, the air monitoring stations in the LDW (particularly the Duwamish station, which is located closest to the EW) provide an indication of air pollutants moving toward the LDW from the EW. Because the King County study identified few strong correlations between atmospheric deposition data and wind patterns, it is expected that deposition is similar regardless of whether air is moving from the EW toward the LDW, or vice versa.

King County is currently conducting an additional atmospheric deposition study within the Green/Duwamish Basin including the same Duwamish station previously sampled (King

County 2011d). The new study includes analysis of PCB congeners, dioxins/furans, and select metals and organics. Data are expected to be available by the end of 2013.

PSCAA Air Quality Study

Each year, PSCAA issues an air quality data summary for the Puget Sound region that reports air concentration data for parameters identified as criteria air pollutants by EPA.[136] The most recent report available summarizes air concentration data collected between 2001 and 2009 (PSCAA 2011).

Between 2001 and 2009, the 3-year average of the 98th percentile daily air concentration of PM2.5 in the Duwamish Valley ranged from approximately 28 to 34 μg/m^3, with concentrations generally decreasing over time (PSCAA 2011). All of these average daily concentrations were below the federal daily standard of 35 μg/m^3. Between 2001 and 2009, the 3-year average of the annual mean concentration of PM2.5 in the Duwamish Valley ranged from approximately 10 to 12 μg/m^3, with concentrations generally decreasing over time (PSCAA 2011). All of these annual mean concentrations were below the federal annual standard of 15 μg/m^3.

9.4.7.2.2 Regional Atmospheric Deposition and Air Quality Monitoring

Tacoma and Seattle Air Toxics Study

In 2009, PSCAA and the University of Washington conducted an air toxics evaluation in Seattle and Tacoma (PSCAA and University of Washington 2010). Although the primary purpose of the study was to better understand air toxics in the Tacoma area, data were also collected in Seattle at the Duwamish and Beacon Hill monitoring stations for comparison (Figure 9-15). At the Duwamish monitoring station, the median PM2.5 air concentration in the non-heating season (i.e., April through September) was approximately 7 μg/m^3, and the median PM2.5 air concentration in the heating season (i.e., October through March) was approximately 8.5 μg/m^3. The report also included data for selected air toxics, primarily VOCs and SVOCs. The air toxics data most relevant to EW source control were the data for PAHs monitored at the Duwamish station. Limited data (i.e., mean or maximum

[136] The 2009 Air Quality Data Summary (PSCAA 2011) included results for PM2.5 but not PM10. PSCAA discontinued their monitoring of PM10 in 2006 after EPA revoked the annual standard because there was a lack of evidence that PM10 causes health problems.

concentrations only) were provided for the following individual PAHs: acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzofluoranthenes, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluorene, indeno(1,2,3-cd)pyrene, fluoranthene, naphthalene, phenanthrene, and pyrene.

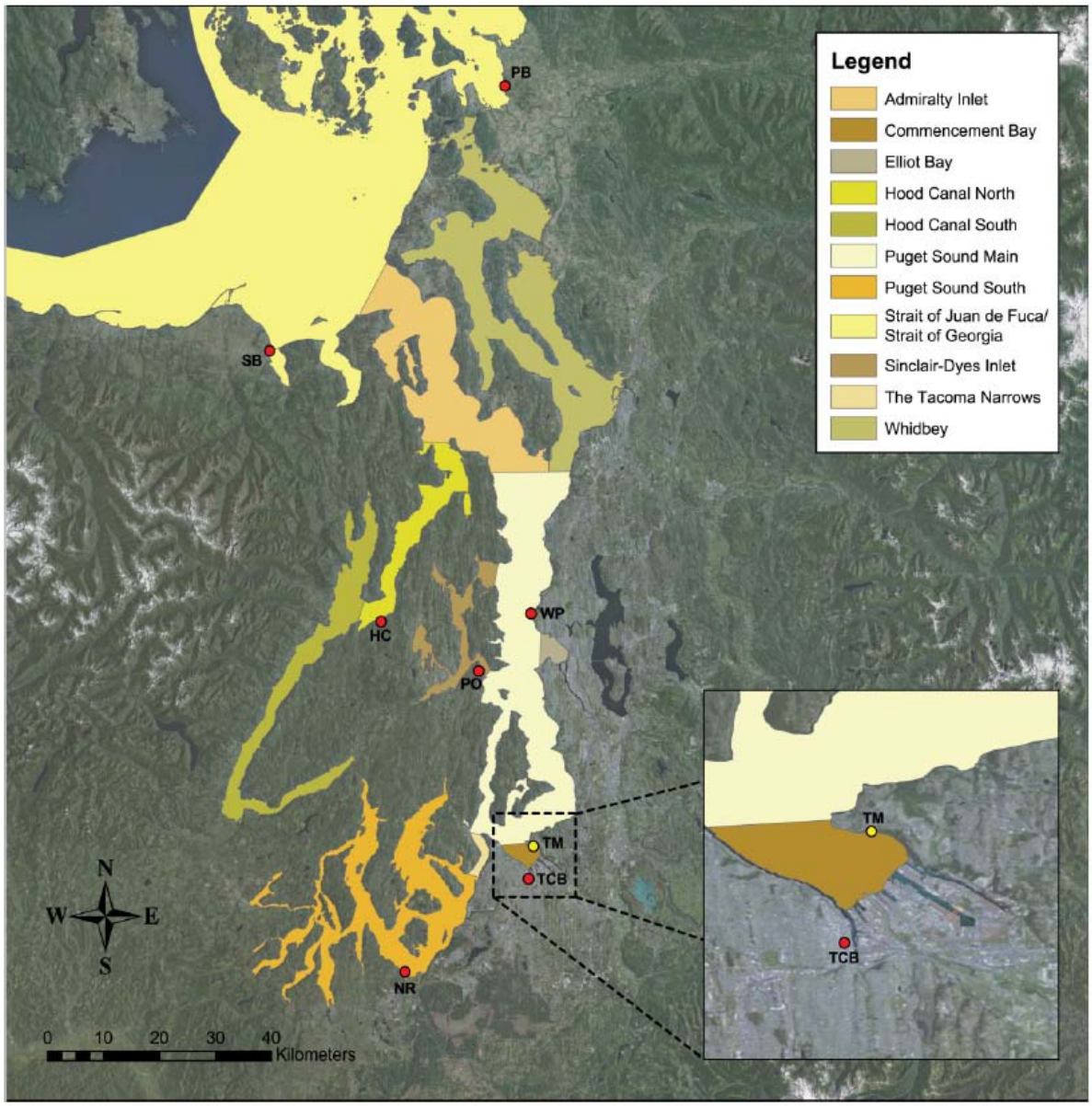
Source: PSCAA and University of Washington (2010)

Figure 9-15

Locations of Monitoring Stations from the Tacoma and Seattle Air Toxics Study

Puget Sound Air Toxics Study

Between 2008 and 2009, Ecology conducted a study to assess atmospheric deposition in Puget Sound (Brandenberger et al. 2010). Atmospheric deposition flux data were collected at eight stations throughout the Puget Sound region. Air toxics monitored in this study included metals, PAHs, and PCBs. One station was located at West Point in Seattle (WP), and one was located near Commencement Bay in Tacoma (TCB) (Figure 9-16). Potential sources of air pollutants at the West Point monitoring station were emissions from trains, ships, and other urban sources (Brandenberger et al. 2010). Potential sources of air pollutants at the Tacoma Commencement Bay monitoring station were metal refineries, pulp and paper mills, and other industrial facilities that burn hydrocarbons or wood fuels. Data from this study provide information on atmospheric deposition trends in the greater Puget Sound region. Data from the West Point and Tacoma Commencement Bay stations can be used for comparison to air quality data collected in other developed/urban areas in the Puget Sound, such as the EW.



Source: Ecology (2010)

Note: Red dots identify the primary monitoring stations. The yellow dot identifies the Tyee Marina (TM) monitoring station, which was added to the study in order to better understand the Tacoma Commencement Bay (TCB) monitoring station area of influence (Brandenberger et al. 2010). Colored shading identifies geographic compartments from a box model used in the study. HC = Hood Canal, NR = Nisqually River, PB = Padilla Bay, PO = Port Orchard, SB = Sequim Bay, TCB = Tacoma Commencement Bay, TM = Tyee Marina, WP = West Point.

Figure 9-16

Locations of Monitoring Stations in Puget Sound Air Toxics Study

The Ecology study (Brandenberger et al. 2010) used the atmospheric deposition monitoring results to estimate contaminant loading to Puget Sound. Based on these estimates, it was concluded that direct atmospheric deposition of trace element metals and PAHs contributes only a small proportion (1 to 5%) of the total input of these contaminants to the sediment of Puget Sound. Surface runoff was identified as the primary source of contaminants to Puget Sound. For total PCBs, the median mass loading to Puget Sound was estimated to be between 0.96 and 1.36 kg/yr. As with trace metals and PAHs, mass loading of PCBs from surface runoff was estimated to be greater than the mass loading from atmospheric deposition (Brandenberger et al. 2010).

9.4.7.2.3 Dioxin/Furan Air Studies

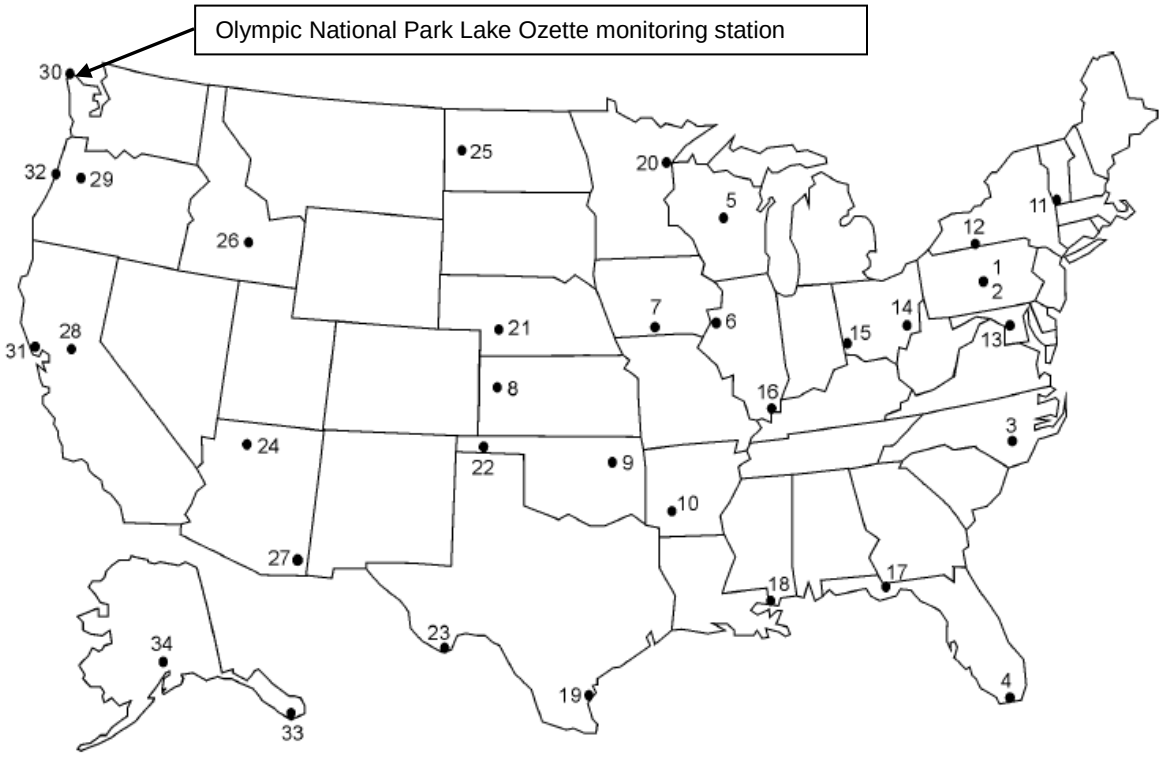
No atmospheric deposition data are currently available for dioxin/furan compounds for the EW or the Puget Sound region; however, King County is currently conducting an atmospheric deposition study in the Green/Duwamish basin that includes dioxins/furans, as well as other compounds. That study will be available and will be used as part of the atmospheric deposition pathway evaluation to be conducted in the FS. Most dioxin-like compounds are released into the environment via air emissions from the combustion of various materials (EPA 2006c). Several industrial activities or facilities have been identified as sources of dioxins to air in Washington State. These include municipal and medical waste incineration, cement kilns, wood waste-powered boilers, a former activated carbon regeneration plant,[137] and wastewater treatment from bleached pulp and paper mills (Ecology 1998). Dioxin emissions are also generated by non-industrial sources such as residential wood burning, residential refuse burning, and the use of fossil-fuel-burning vehicles (Wenning et al. 1992; Cohen et al. 2002). In 2000, residential refuse burning was identified as the greatest nationwide source of dioxin emissions (EPA 2006c).

EPA National Dioxin Air Monitoring Network

EPA has established the National Dioxin Air Monitoring Network (NDAMN) to monitor background air concentrations of dioxin-like compounds in several regions of the United States (Riggs et al. 2003). Monitoring stations within NDAMN are located in rural areas that

[137] The only carbon regeneration facility in the State of Washington (the Cameron-Yakima Inc. facility in Yakima County) ceased operations in 1997.

are expected to be free from the impacts of nearby sources of dioxin-like compounds (Figure 9-17). In 2000, data were collected at 18 rural locations, 8 national parks, and 2 suburban areas located throughout the United States (Cleverly 2002). One NDAMN station is located at Lake Ozette in the Olympic National Park in Washington State (Figure 9-17).



Source: Riggs et al. (2003)

Figure 9-17
Locations of Monitoring Stations in the EPA National Dioxin Air Monitoring Network

Air concentration data for seven dioxin congeners, ten dibenzofuran congeners, and seven coplanar PCBs were collected by NDAMN in 2000 (Cleverly 2002). The average concentration of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) ranged from less than 0.0005 to approximately 0.002 pg/m^3. At rural sites, the average annual air concentrations of dibenzofuran TEQ[138] ranged from 0.0025 to 0.060 pg/m^3, and average air concentrations of

[138] Based on the World Health Organization 1998 TEFs (WHO 1998).

PCB TEQ ranged from 0.0002 to 0.0099 pg/m^3. In the suburban areas, the mean dibenzofuran TEQ value was 0.0155 pg/m^3, and the mean PCB TEQ value was 0.0020 pg/m^3. At Lake Ozette in the Olympic National Park, the annual average of the total CDF/CDD TEQ was less than 0.005 pg/m^3.

Other Studies

Ambient air concentrations of the sum of dioxin and furan compounds were estimated in a study that used data collected in the 1980s and 1990s from Australia, Antarctica, Europe, Japan, and the United States (Lohmann and Jones 1998). For remote areas, ambient concentrations of dioxins and furans were generally below 0.5 pg/m^3. In rural areas, total dioxin and furan concentrations typically ranged from 0.5 to 4 pg/m^3; and in urban/industrial areas, they ranged from approximately 10 to 100 pg/m^3.

The atmospheric deposition of dioxins and furans has been studied in the Great Lakes region (Cohen et al. 2002). Both measured and modeled data indicated that in the 1990s, atmospheric deposition flux values for dioxin and furan compounds in Lake Superior ranged from 0.01 to 10 pg/cm^2/year. It is likely that deposition flux values for Lake Superior would be lower today as the result of dioxin emission reductions efforts.

It is uncertain how relevant the available dioxin and furan air concentration and deposition data are to conditions within the EW airshed, but they have been presented to provide a reference range of possible concentrations and deposition flux values inasmuch as no local data are currently available.

9.4.7.3 Mobile Air Emission Sources

Air pollution is generally widespread, and airshed studies typically assess air quality at the neighborhood, urban, or regional scale, with the acknowledgement that localized micro-scale effects can elevate concentrations of certain parameters. Localized air emissions, such as those from non-point, mobile sources, are difficult to monitor because the presence and location of these sources continually change. Two recent studies provide information on mobile sources of air emissions in the Duwamish Valley and greater Puget Sound region: the *Puget Sound Maritime Air Emissions Inventory* (Starcrest Consulting 2007), which was published by the Puget Sound Maritime Air Forum (PSMAF); and *Health Consultation:*

Summary of Results of the Duwamish Valley Regional Modeling and Health Risk Assessment, which was published by the WSDOH (2008b).

9.4.7.3.1 Puget Sound Maritime Air Emissions Inventory

The *Puget Sound Maritime Air Emissions Inventory* (Starcrest Consulting 2007), hereafter referred to as the Air Emissions Inventory, identified maritime-related activities that involve the use of diesel equipment and estimated emissions of EPA criteria pollutants (and their precursors) generated by the use of that equipment. The purpose of the Air Emissions Inventory was to provide additional information on emissions related to maritime operations and to aid in emissions reduction planning. PSMAF is a voluntary association of ports, air agencies, environmental and public health advocacy groups, and other entities with responsibilities related to air regulations. Members of PSMAF include the Ports of Seattle, Everett, and Tacoma; Washington State Ferries; Burlington Northern Santa Fe Railway; the Northwest Cruise Ship Association; PSCAA; Ecology; and EPA.

The pollutants included in the Air Emissions Inventory (Starcrest Consulting 2007) were carbon monoxide, nitrogen oxides, sulfur dioxides, VOCs, FPM (both PM2.5 and PM10), DPM (a subset of FPM), and the greenhouse gases carbon dioxide, methane, and nitrous oxide. Of these, VOCs and DPM are discussed further as they are most relevant to EW source control (DPM is relevant because it includes PAHs).

The maritime activities and equipment addressed in the Air Emissions Inventory (Starcrest Consulting 2007) included hoteling (the time spent by vessels at berth or anchor), maneuvering (slow-speed, in-port operations), transiting (traveling) of ocean-going vessels, and the use of harbor vessels, rail locomotive, cargo-handling equipment, heavy-duty vehicles, and fleet vehicles. Similar maritime equipment is used in both the EW and the LDW; however, the frequency and distribution of the use of this equipment likely varies between the two waterways—in part because the entire EW shoreline is dominated by container terminals, whereas the LDW shoreline includes container terminals as well as other types of industrial facilities.

The Air Emission Inventory (Starcrest Consulting 2007) presented data based on PSCAA jurisdictional areas, which includes King County (and thus the EW study area); however, the inventory did not address activities in the LDW beyond those conducted at Port of Seattle

facilities. The inventory determined that only 2% of VOC emissions in the PSCAA jurisdictional area are emitted from maritime sources. This 2% equates to approximately 2,100 tons per year (TPY) from all inventoried maritime sources combined. Of the maritime emission sources of VOCs, harbor vessels (including tug boats, ferries, and recreational vessels) contributed the greatest amount.

The Air Emission Inventory (Starcrest Consulting 2007) reported that maritime-related activities generate approximately 30% of the DPM emitted in the PSCAA jurisdictional area. DPM emissions from all inventoried maritime sources were estimated to total approximately 780 TPY. Of the maritime emission sources of DPM, harbor vessels contributed the greatest amount, followed by ocean-going vessels during transiting and hoteling.

The findings of the Air Emissions Inventory (Starcrest Consulting 2007) indicate that harbor vessels and ocean-going vessels are potentially important sources of PAHs (because of their presence in DPM) in the greater PSCAA jurisdictional area, which includes the EW. The potential contribution of PAHs from these vessels to EW sediments has not been studied and would be difficult to quantify because of the frequent temporal and spatial changes in air emissions from transient sources such as maritime vessels.

In 2011, the Air Emissions Inventory was updated (www.pugetsoundmaritimeairforum.org). The updated inventory quantifies maritime-related emissions for the calendar year 2011, and compares the data against the baseline inventory. The inventory estimated greenhouse gases, DPM, and a number of other pollutants, such as sulfur dioxides and VOCs. It also illustrates the effects of emission reduction efforts undertaken by the Port of Seattle and others between 2005 and 2011. Reductions were noted both for absolute overall emissions, and also in cargo-normalized emissions. The cargo-normalized emissions express emissions as emission reduction per 10,000 tonnes of cargo. The data show that maritime-related air pollution has decreased as much as 40% within the Puget Sound region, depending on the sector and contaminant. Port of Seattle total emissions dropped for every pollutant measured.

At the Port of Seattle, DPM emissions were reduced by 27% overall and 34% per 10,000 tonnes of cargo. Greenhouse gas emissions also declined by 5% at the Port of Seattle.

The cargo-normalized emissions reductions are associated with significant, voluntary investments of the maritime industry and government agencies in cleaner technology,

cleaner fuels, and more efficient systems of operation. Voluntary initiatives to reduce emissions include switching to low-sulfur or biodiesel fuels, using shore power, replacing or retrofitting older engines, and improving systems to use equipment more efficiently.

Some of the Port of Seattle programs that have played a part in emission reductions between 2005 and 2011 include shore power at T-91, the At-Berth Clean Fuels program that incentivized carriers to burn fuel with less than 0.5% sulfur content, the Clean Truck Program that included purchase and scrappage of older trucks, the Drayage Truck Registry program that banned older trucks from Port terminals, and installation of retrofits on cargo handling equipment. Additionally, there have been important regulatory changes, such as requirements for cleaner fuel in both on-road and off-road engines, that have contributed to emission reductions.

9.4.7.3.2 The Duwamish Valley Regional Modeling and Health Risk Assessment

As part of the Duwamish Valley regional modeling and health risk assessment (WSDOH 2008b), air emissions from several sources in the Georgetown and South Park residential neighborhoods of south Seattle were modeled to identify air pollutants and their sources. Although this study was conducted to identify geographic areas where health risks from both point source and mobile air pollution sources may be increased, some of the information is also relevant to EW source control. The study found that microscale effects from proximity to mobile sources (e.g., high vehicle traffic along E Marginal Way S) caused higher FPM air concentrations. This study indicated that mobile sources are important contributors of PM air pollutants.

The WSDOH study (2008b) and the Air Emissions Inventory (Starcrest Consulting 2007) indicated that mobile sources such as cargo vessels, tugboats, and motor vehicles can create variability in FPM air emissions throughout a neighborhood or region. The WSDOH study used air modeling to characterize these sources instead of empirical monitoring data because modeling can estimate conditions for a wide geographic area and because “it is not practical or possible to sample continuously for numerous pollutants at an infinite amount of points in an area” (WSDOH 2008b). For source control purposes, it is also most practical to use data that are representative of neighborhood-scale conditions to evaluate direct atmospheric deposition.

9.5 Summary

Key pathways and potential sources of contamination have been identified with potential sources of contamination being the result of both historical and ongoing inputs. Potential source inputs to the EW are subject to a number of ongoing regulatory, permitting, and other source control programs, which will continue to collect data following the completion of this SRI. As described in Section 9.3, these programs are being carried out by various agencies including, but not limited to, the City of Seattle, King County, the Port of Seattle, and Ecology. Data gathered as part of these existing programs and data gathered specifically as part of the SRI are available to document potential contaminant inputs to the EW. These data are available and sufficient for use during the FS to evaluate the potential for sediment recontamination for the FS alternatives analysis. Additional relevant data developed following the completion of this SRI may also be used to augment the dataset in the FS.

Appendix K includes additional figures summarizing selected source tracing data contained in this section and compiled for the EW drainage basins. These figures summarize data from source control inspections, storm drain and combined sewer solids sampling data, and the locations of listed sites and reported spills. These maps supplement the presentation of data contained and described in this section.

Table 9-30 presents the estimated solids inputs to the EW (as developed in Section 3 of this SRI) from the Green River, the LDW (both LDW bedload and lateral inputs), and EW lateral sources, i.e., CSOs and stormwater discharges. The FS will include further evaluation of how these solids inputs may affect recontamination predictions for the EW sediments.

Table 9-30

Summary of Low and High Ranges of Annual EW Solids Inputs

Parameter	Green River	Lower Duwamish Waterway[a]	EW Combined Sewer Overflows[b]	EW Stormwater Drainages[c]
Solids input range (metric TPY)	32,159 to 53,598	256 to 427	62 to 89	65 to 127

[a] Lower Duwamish Waterway includes eroded bed sediments and lateral sources.

[b] CSO ranges are based on the 75th and 25th percentile of TSS and were developed as described in Section 3 of the SRI.

[c] Stormwater ranges are based on the runoff from an average year and ranges based on the 75th and 25th percentile of TSS as presented in the STER Appendix F Table 7 (Anchor QEA and Coast and Harbor Engineering 2012). The low range is based on the SPU basin total (low), and the high range is based on the total (high).

9.5.1 Summary of Spills Pathway

The review of documented spills indicates that the EW has been subject mainly to periodic small-quantity spill events, including both direct spills to the EW, as well as spills to stormwater and combined sewer systems that discharge to the EW. The examination of the past spill record provides information on spill patterns, but cannot be used to predict the quantity, timing, or location of future spill events. The documented spill events have typically been small in volume, but may have the potential to contribute to localized contamination if the spills reach the waterway as occurred during the Industrial Plating spill described in Section 9.4.2. The spills presented on Map 9-8 and Appendix E show documented spill events. Future spills will be managed under existing spill prevention and response programs as described in Section 9.3.4.

9.5.2 Summary of Direct Discharges

Direct discharges to EW occur from municipal or other publicly owned drainage systems, privately owned and managed SDs, sanitary/combined sewer systems, and sheet runoff from properties adjacent to the waterway. Monitoring data are available to document the frequency and quantity of CSO discharges, and stormwater modeling has been conducted to estimate the quantity of stormwater runoff discharged to the EW. Information is also available to estimate the typical suspended solids loadings of these discharges. These data have been used as inputs to model the initial deposition of stormwater and CSO solids entering the EW (see Section 3).

The Port of Seattle, City of Seattle, and King County have conducted extensive characterization and source-tracing work within the stormwater and combined sewer basins discharging to EW. This work provides data characterizing the quality of stormwater and CSO inputs to the EW. The data have been collected using a range of methods, including water quality sampling, sampling of SD and CSO solids (using inline grab and sediment traps), and sampling of catch basins, which characterize stormwater inputs to separated SD or CSO systems. All data, regardless of whether the potential source has been identified or controlled, were summarized. Appendix F summarizes completed source-tracing and source control activities.

- Overall results from the source-tracing solids samples collected for the EW indicate that contaminant concentrations between sample types and basins were variable, but

the differences appear to be related primarily to different source contributions rather than to sampling methodology. Average contaminant concentrations for some COCs were generally higher in samples collected from on-site catch basins than in those from ROW catch basins, likely because many on-site catch basin sampling stations were selected based on source control issues identified during business inspections and other specific source-tracing activities. In addition, samples collected from CSO lines are likely to have higher concentrations of some contaminants on average than from within SD lines, because CSO lines carry both municipal and industrial wastewater, of which the vast majority is conveyed to the WWTP. Findings for specific COCs include the following:

- Arsenic solids data were found to have a tight concentration range and were generally below the screening levels with a few exceptions. The two highest concentrations were from inline grabs from a Port of Seattle nearshore SD and a sewer line discharging to the Hanford #2 CSO system, and source-tracing and control efforts have removed material containing these two highest arsenic concentrations.
- Mercury exceeded the screening levels in less than 20% of the samples. The highest concentrations were generally found in inline grabs from the Hanford #2 CSO system, a few Port of Seattle nearshore SDs, and a few isolated on-site catch basins in the broader Hanford/Lander/Diagonal system.
- Less than 15% of the HPAH samples exceeded the screening levels. The highest concentrations of both HPAHs and cPAHs were found in a few samples from the S Lander Street SD and one location in the Hanford #2 CSO basin.
- BEHP frequently exceeded the source SLs. Elevated concentrations of BEHP were present in samples from throughout the EW study area, indicating that BEHP is ubiquitous within a variety of drainage basins.
- 1,4-dichlorobenzene exceeded the screening levels in 38% of the samples. The highest concentrations were found in both inline grabs and sediment traps from the Hanford #2 CSO system. A few high concentrations were also found in on-site catch basins within the Hanford/Lander/Diagonal CSO basins. Many of the samples analyzed for 1,4-dichlorobenzene represent samples associated with King County's efforts to investigate the source of elevated 1,4-dichlorobenzene concentrations in the Hanford #2 CSO basin. The source of these elevated concentrations was identified and has since been controlled.

- Overall, 3% of the samples exceeded the LAET SLs for total PCBs. Only 11% of the samples were above the 2LAET SL and were generally found in a few specific areas. The highest total PCB concentrations were found in inline grab samples collected from the Rainer Commons property, one area of the Hanford #2 CSO basin, and a Port of Seattle nearshore SD.
- A subset of source-tracing samples (20 samples) collected from EW basins were analyzed for dioxins and furans; these data collection efforts focused on samples that would be representative of the overall drainage basin and not specific subareas within a basin. Based on the 14 SD and 3 combined sewer inline grabs, mean concentrations were higher in SDs when compared to CSOs, but for sediment trap samples, the dioxin/furan ranges overlapped between SDs and CSOs. The highest concentration was identified in Port of Seattle nearshore Basin B34.Water quality data were also available for Hanford #2 and Lander CSOs. A comparison of the CSO water quality data indicates that contaminant concentrations are generally similar between the datasets, with the exception of 1,4-dichlorobenzene. As discussed in Appendix F, the major source of the of 1,4-dichlorobenzene for the Hanford #2 CSO was found through source-tracing efforts by King County, and the product that resulted in high levels of 1,4-dichlorobenzene is no longer being used by the identified source.
- Water quality data representing baseflow and storm flow conditions from within the S Lander Street storm drain system were available. Arsenic was detected in most of the samples, with an average concentration of 2.7 µg/L under storm flows; other contaminants, such as mercury and PCBs, were not detected at detection limits of 0.2 µg/L.
- CSO water quality data were available for Hanford #2 and Lander CSOs. In both datasets, arsenic concentrations averaged approximately 2 µg/L, mercury averaged 0.054 and 0.071 µg/L, and PCBs averaged 63 and 52 ng/L. A comparison of the CSO water quality data indicates that contaminant concentrations are generally similar between the datasets, with the exception of 1,4-dichlorobenzene, which averaged 183 µg/L at Hanford #2, compared to 0.44 µg/L in Lander. As discussed in Appendix F, the major source of the of 1,4-dichlorobenzene for the Hanford #2 CSO was found through source-tracing efforts by King County, and the product that resulted in high levels of 1,4-dichlorobenzene is no longer being used by the identified source.

9.5.3 Summary of Groundwater Pathway

Extensive information is available for nearshore cleanup sites to evaluate the potential for groundwater discharging (including seep results at Pier 34) to the EW to impact sediment quality. These data were developed during previous investigation and cleanup activities conducted at many properties. Of the properties evaluated, three areas were identified with exceedances of groundwater reference values relevant to the evaluation of potential sediment recontamination. These areas included the following:

- **Zinc in One Harbor Island Well:** Elevated levels of zinc have been detected in one well (HI-12) located along the shoreline of Harbor Island. Concentrations of zinc fluctuate seasonally in this well, with the zinc concentration exceeding the reference value only part of the year. Average groundwater concentrations in this well are only slightly above the groundwater reference value, and no zinc contamination has been detected in nearby EW sediments as shown in Map 9-20. Groundwater monitoring continues for this well as part of the compliance monitoring program for the Harbor Island Soil and Groundwater OU.
- **Selected PAH Compounds at Selected Terminal 30 Wells:** The Port of Seattle is conducting ongoing investigation and cleanup activities at the T-30 site under a MTCA Agreed Order overseen by Ecology. Extensive cleanup activities have already been completed at this petroleum cleanup site, and none of the nearshore wells show potential migration of petroleum or BTEX contaminants to EW sediments. Acenaphthene, fluorene, and phenanthrene were detected above groundwater reference values in some nearshore wells. With the exception of further evaluation of groundwater concentrations as directed by Ecology, these detections are not associated with mobile phase except acenaphthene. The Port of Seattle and Ecology are evaluating these data as part of the ongoing investigation and cleanup of this site.
- **Arsenic at Pier 35 (USCG):** Elevated levels of arsenic were detected in one well (SB-SC-05) located at the USCG property. The detected arsenic value exceeded the groundwater reference value based on protection of sediment quality, and arsenic contamination has been detected in nearby EW sediments as shown in Map 9-23. No groundwater monitoring is ongoing at the USCG facility.

Inland cleanup sites are located within EW stormwater and combined sewer service areas. These sites are of interest for EW sediment recontamination to the extent that they could

potentially contribute to elevated contaminant levels in stormwater or CSO discharges. The quality and quantity of stormwater and CSO discharges have been directly evaluated as part of EW source-tracing activities. The SRI includes an inventory of cleanup sites, and that information helps to inform business inspections and source-tracing activities conducted by EWG members.

9.5.4 Summary of Bank Erosion

Based on the efforts undertaken to review bank erosion potential, two areas have been identified for further consideration during the FS:

- Bank 8B, which underlies the Spokane Street Bridge, is a non-engineered mud bank. The quality of the intertidal sediments located within this area have been characterized as part of the SRI. Surface sediments in this area contained elevated concentrations of di-n-butyl phthalate and PCBs as discussed in Section 4.2.1.2.
- Banks 1 and 2B, which are adjacent to the USCG facility, are steep rubble-armored sloping shorelines. Results of soils testing performed in 1988 by EPA on behalf of USCG identified the presence of soils contaminated with PCBs, heavy metals, and PAH compounds in nearshore fill soil located adjacent to this area.

9.5.5 Summary of Treated-Wood Structures

Some remaining wood structures treated with creosote or other wood preservatives are located within the EW. The remaining wooden structures include some older docks, older fender-piling systems, stub pilings remaining in areas where structures or pilings were previously removed, or short sections of wooden bulkheads. The areas with the largest number of remaining creosote-treated pilings include the foundation for the rail bridge along the east side of Harbor Island, the foundation pilings supporting the wooden pedestrian bridge and public access area adjacent to Spokane Street, pilings formerly supporting a dock structure at T-25, the existing dock structure adjacent to Pier 34, and the southeastern pier at the USCG facility. The introduction of new treated-wood structures is restricted through state and federal permitting activities. Treated-wood structures may cause sediment contamination through leaching and abrasion. Sediment exceedances for PAH compounds have been observed adjacent to creosote-treated structures in one area adjacent to T-25. No exceedances of arsenic or copper were noted near areas with CCA-treated pilings or fender pilings.

9.5.6 Summary of Atmospheric Deposition

Multiple studies are currently available in the Puget Sound Basin and in the vicinity of the EW that have measured or estimated rates of atmospheric deposition for contaminants including PAH compounds, PCBs, phthalates, and heavy metals. Additional studies are ongoing in the region, including a King County atmospheric deposition study, which includes the evaluation of dioxin/furan compounds. These studies are available for use during the FS to evaluate the contribution of atmospheric deposition to sediment quality within the EW.

Ecology's study of atmospheric deposition in Puget Sound (Brandenberger et al. 2010) concluded that direct atmospheric deposition contributes about 1 to 5% of the total input of trace metals and PAHs to sediment. It is likely that direct atmospheric deposition to the surface waters of the EW plays a similar role in the EW.

10 KEY FINDINGS

This section highlights the important findings of the RI and synthesizes these findings into a unified CSM. The physical, chemical, and ecological processes that have been examined in the SRI are interrelated and must be considered in combination when assembling and analyzing alternatives in the FS, and when making remedy and risk management decisions for the EW.

10.1 Physical Characteristics of the EW

The EW is a channelized portion of the Duwamish River delta. It is located at the north end of the Greater Duwamish Valley, and rests in a north-south trending, glacially scoured trough bounded by glacial drift uplands deposited during repeated Pleistocene glaciations (approximately 15,000 years ago). The trough contains post-glacial alluvium up to 200 ft thick (Weston 1993b) and includes the waters of the Duwamish River, EW, and WW.

The EW is influenced by the freshwater flows from the Green/Duwamish River and the tidal conditions of Elliott Bay (Anchor and Windward 2008a). The outflow of fresh water from the Green/Duwamish River along with the marine tidal waters entering the EW from Elliott Bay produces predominately marine conditions in the EW with more variable salinities under high flow conditions and net outflow to Elliott Bay. The flows are characterized by an outflow to Elliott Bay in the surface layer and inflow to the EW near the bottom. These conditions influence the hydrodynamic and sediment transport processes in the system (Anchor QEA and Coast & Harbor Engineering 2012). The freshwater input from the Green/Duwamish River system flows over the saline waters from Elliott Bay, producing two layer flow in the EW of saltwater and a thin surface layer of slightly lower salinity water.

For the purposes of the SRI, three reaches have been identified in the EW, including the Junction Reach (Station 7200 to 7650), Sill Reach (Station 6800 to 7200), and Main Body Reach (Station 0 to 6800; Map 2-2). The Main Body Reach has been further subdivided into two sections: the Deep Main Body Reach (Station 0 to 4950) and the Shallow Main Body Reach (Station 4950 to 6800), which is located south of regular historical maintenance dredging activities. The main body of the EW is maintained as a federal navigation channel by USACE. Elevations within the northern portion (i.e., the Deep Main Body) of the navigation channel have been maintained at -51 ft MLLW. There are also two slips present

along the eastern side of the EW; Slip 27 and Slip 36. Currently, berths are maintained along Terminals 18, 30, and 25 and in portions of Slips 27 and 36.

10.2 Human Use and Biological Resources of the EW

The EW is a commercial waterway used primarily for container loading and transport. The majority of the EW shoreline consists of riprap, pier aprons, or sheet pilings. Land use, zoning, and land ownership along the EW are consistent with an active commercial waterway. The east and west sides of the EW primarily contain hardened shorelines with extensive overwater structures, commercial and industrial facilities, and other development. The EW provides a critical connection for cargo and other materials moving between water and land. Most vessel traffic consists of shipping companies that move container vessels and assorted tugboats into and out of the EW. While EW is also used for some recreational activities such as boating and fishing, there is limited public access to the EW. There is one public access park, Jack Perry Park, within the EW and a public fishing pier in the southern portion of the waterway. The EW is frequently used by tribes as a resource and for cultural purposes. Tribal treaties guarantee members of the Muckleshoot and Suquamish Tribes the right to harvest seafood from the EW. Currently, the Muckleshoot Tribe conducts commercial netfishery in EW for salmon. Tribal fishermen can also engage in clamming activities (by means of boat access) in all intertidal areas of the EW.

The aquatic habitats in the EW include the water column and intertidal and subtidal substrates (typically mud, sand, gravel, cobble, or riprap). The habitat within EW is predominately deep water habitat with relatively little shallow subtidal and intertidal habitat which is found primarily in the Junction/Sill reach, within Slip 27, and south of Slip 36. Despite the highly modified waterway habitat, the EW is home to a diverse assemblage of aquatic species. Although no quantitative characterization of the benthic invertebrate community in the EW has been conducted, benthic invertebrate assemblages observed in studies in EW comprise a variety of species from diverse phyla (e.g., Mollusca, Arthropoda, Annelida, and Echinodermata). In addition, a variety of demersal, benthopelagic, and pelagic fish species have been observed in the EW. However, there is relatively little EW-specific information on wildlife populations. Surveys of wildlife communities have been conducted primarily upstream of the EW in the LDW, where there is a greater diversity of habitats.

Sixteen aquatic and aquatic-dependent species reported in the vicinity of Elliott Bay area are listed either under ESA or by WDFW as candidate species, threatened species, endangered species, or species of concern Of these species, Chinook salmon, coho salmon, steelhead salmon, brown rockfish, bald eagle, western grebe, and Pacific herring are commonly observed in the EW.

10.3 Conceptual Site Model

A CSM for the EW that describes key features and processes of the waterway was developed as part of the SRI. The CSM will aid in the assembly and evaluation of remedial action alternatives in the FS and in future decision-making for the site. The CSM is considered a working model throughout the SRI/FS process, and may continue to be refined as new information and analyses are developed.

The EW CSM provides a synthesis of the major processes governing the movement and distribution of contaminants at the site as well as potential exposure pathways for the people (Figure 6-1) and animals (Figures 5-1 and 5-2) that use the site. Three key components of the EW CSM are worthy of discussion because of their importance:

- **Physical CSM –** The influence of hydrodynamic and sediment transport processes on the physical distribution of sediment within EW
- **Chemical CSM –** Patterns in the distribution of contaminants in EW
- **Exposure CSM –** Exposure of human and ecological receptors to contaminants within EW

10.3.1 Physical Processes CSM

The Physical Processes CSM focuses on the important processes that affect hydrodynamic and sediment transport processes in the EW. Information used to develop the Physical Processes CSM included site-specific empirical data and output from hydrodynamic, sediment deposition, and prop wash modeling (Anchor QEA and Coast & Harbor Engineering 2012).

Hydrodynamic circulation in the EW is controlled by tidal exchange with Elliott Bay to the north and freshwater inflow from the Green River (through the LDW). Direct discharges of stormwater or CSOs from the contributing drainage basins have a negligible influence on

large-scale circulation in the EW. Water circulation in the EW can be generally described as two-layer flow, with saltwater extending from Elliott Bay upstream through the EW and into the LDW underneath a thin layer of fresher water flowing from the Green/Duwamish River system (see Maps 3-1a and b and 3-2). In general, as upstream inflow increases, predicted surface velocities within the EW increase. Average surface velocities range from 20 to 25 cm/s, and maximum surface velocities range from 90 to 95 cm/s (2- and 100-yr flows, respectively). Average and maximum predicted surface velocities at mean annual flow (1,330 cfs) are 10 and 70 cm/s, respectively (Anchor QEA and Coast & Harbor Engineering 2012). Predicted average near-bed velocities are relatively constant over the range of flows, from the mean annual to the 100-yr upstream flow, at 5 cm/s. Maximum near-bed velocities increase with increasing upstream flow, from 18 cm/s for mean annual flows to 28 cm/s for 100-yr flows. Maximum predicted surface velocities are directed out of the EW (downstream), while maximum predicted near-bed velocities are directed into the EW (upstream). The vertical gradient in salinity in the EW is directly related to upstream flow into the EW, where the range of salinity between surface water and bottom water increases with increasing upstream flow. The split in flow between the EW and WW is predicted (through modeling) to be about equal during normal flow events (annual average) but approximately 30%:70% (EW:WW) during 2-year flows and higher-flow events. The split in flow was validated over a range of tidal conditions during a higher-flow event (4,000 cfs) using ADCP transect data collected within the EW as part of the STE.

Sediment sources to the EW include the upstream sources (Green River, LDW bed sediments, and LDW lateral load sediments), downstream sources (Elliott Bay), and local sources (lateral sources that drain directly to the EW). Geochronology cores were collected in the EW to evaluate net sedimentation rates (Anchor QEA and Coast & Harbor Engineering 2012). Cores were placed in areas that had not been dredged recently[139] (see Map 2-7) and in areas representative of different hydrodynamic regimes (Anchor QEA 2009). Of the 22 cores attempted, 18 were successfully recovered. Evaluation of the 18 recovered geochronology cores collected within the EW (Maps 3-11a and 3-12b) suggests that the majority of the Shallow Main Body Reach (between Stations 5000 and 6800) and the interior

[139] Dredged areas within the EW were expected to have a non-detect for the Cs-137 peak due to the depth of sediment below mudline removed during dredging actions.

of Slip 27 (Map 2-2) are net depositional. Measured net sedimentation rates for sampled areas range between 1.1 and 2.0 cm/yr for Cs-137 data and 0.1 to 4.2 cm/yr for Pb-210 data, and the average of these data are 1.6 cm/yr for Cs-137 and 0.5 cm/yr for Pb-210. Cores were not collected in the Deep Main Body Reach between Stations 2800 and 5000 because this area had been recently dredged. However, cores collected in the Deep Main Body Reach between Stations 0 and 2800 suggest that this area is net depositional but influenced by localized episodic mixing and/or erosion events due to propwash from vessel operation. Results of the hydrodynamic model and propwash modeling show that the entire Deep Main Body Reach (Stations 0 to 5000) is subject to similar estuarine and propwash velocities. Therefore, it is possible that the entire Deep Main Body Reach has similar sedimentation characteristics as the sampled area between Stations 0 and 2800 (when dredging events are excluded). It is likely that measured net sedimentation rates in discrete locations within the EW would be different than the average net sedimentation rate if there were no vessel activity in the EW.

There are areas within EW that may not be net depositional, likey due to anthropgenic forces such as prop wash. Four geochronology cores could not be recovered due to the presence of sand and gravel sediments: two in the Juction Reach (GC-21 and -22), one in the Shallow Main Body Reach (GC-17), and one in the Deep Main Body Reach (GC-04). Net sedimentation rates at these core locations are assumed to be 0 based on the presence of sand/gravel sediments. Therefore, the range net sedimentation rate for all geochronological data, including unrecovered cores, is assumed to be 0 to 4.2 cm/yr. There is uncertainty in the extent of these these areas within the EW.

Geochronology cores were not retrieved in the Sill and Junction Reaches due to the presence of sand and gravel surface sediments. Presence of sample locations where geochronology cores could not be collected indicates that physical processes are occurring in these reaches that do not permit long-term sedimentation to occur.

Results of the sediment transport modeling completed for the LDW FS (QEA 2008) and results of PTM modeling of initial deposition of lateral sources within the EW completed for this study (Anchor QEA and Coast & Harbor Engineering 2012) suggest that 99% of the solids entering the EW are from the Green River, approximately 0.7% is from the LDW (bed sediments and lateral loads), and less than 0.3% is from lateral loads within the EW itself (see Section 3.4). Solids entering the EW from Elliott Bay are assumed to be negligible compared

to the other sources. Based on estimates of average annual inputs of upstream solids (from the LDW model), and EW lateral solids (from the EW STE), and average net sedimentation rates in the EW (from geochronology cores), between 25 and 60% of the incoming solids are predicted to deposit in the EW and between 40 and 75% of incoming solids are predicted to leave the EW (see Section 3.4.3.3). Initial mass deposition patterns within the EW from local lateral sources (evaluated through PTM) averaged over the entire EW site are less than 0.01 cm/yr, which is small compared to average net sedimentation rates within the EW predicted by recovered geochronological cores. Localized initial deposition rates from EW lateral sources are less than 0.1 cm/yr over a majority of the area where deposition was predicted by the PTM model. Isolated areas (usually near outfalls) show initial deposition rates greater than 0.1 cm/yr; however, these isolated areas represent approximately 3% of the total deposition footprint

Riverine and tidal currents in the EW are not expected to cause significant erosion of *in situ* bed sediments, as the maximum predicted bed shear stress for a 100-year high-flow event is less than the average critical shear stress[140] of the bed sediment (estimated from site-specific Sedflume data). Bed shear stress due to large vessel operations (e.g., prop wash) in portions of the Deep Main Body Reach (north of Station 4200) is significantly greater than bed shear stress due to natural forces and is regularly above the critical shear stress for bedded sediments. Consequently, these areas are likely subject to episodic mixing, erosion and re-suspension of bed sediments due to prop wash. The remainder of the Deep Main Body Reach (between Stations 4200 and 4900), the Shallow Main Body Reach, and the Junction Reach are also subject to impacts from vessel operations; however, the vessels that operate in these areas are smaller in size and operate less frequently than in the Deep Main Body Reach (north of Station 4200). Therefore, these areas may be subject to less-frequent mixing, erosion or the re-suspension of surface sediment as a result of prop wash. The influence of vessel operations (e.g., propwash) on bed sediments in portions of the EW result in additional uncertainty when extrapolating net sedimentation rates measured at discrete core locations to the entire EW area.

[140] In this report, critical shear stress is defined as a property of the in situ bed sediments. It represents the value of shear stress (applied to that bed due to current velocities) at which the bed sediment would begin to mobilize (e.g., erode).

10.3.2 Chemical CSM for Sediment

The extensive SRI dataset for both surface sediment (e.g., 0 to 10 cm in depth) and subsurface sediment provides a characterization of sediment contamination patterns within the EW. The observed patterns in the horizontal and vertical distributions of contaminants in surface and subsurface sediment, respectively, are the result of interactions among several factors, including the proximity and status of contaminant sources (present-day and historical), mixing of the surface sediment layer, transport and deposition of sediment within the EW over time, and localized conditions that affect sediment mixing (e.g., prop wash). Dredging also affects the horizontal and vertical contaminant distributions.

Four risk driver contaminants were identified in the HHRA for the EW based on risks associated with seafood consumption or direct sediment contact: total PCBs, arsenic, cPAHs, and dioxins and furans. Total PCBs and TBT were also identified in the ERA as a risk driver for fish and benthic invertebrates respectively. In addition, 29 chemicals were identified as risk drivers for benthic invertebrates because detected concentrations of these 29 chemicals exceeded the SQS of the Washington State SMS at one or more locations (Table 4-15). Total PCB concentrations in surface sediment exceeded the SQS at more locations than any other chemical. The chemical with the next highest number of locations with detected concentrations in surface sediment greater than the SQS was mercury. The distributions of these risk driver chemicals in sediment are discussed below.

10.3.2.1 Surface Sediment Patterns

PCBs are widely distributed in surface sediment throughout the EW. Total PCBs were detected in 95% of the 235 surface sediment samples in which they were analyzed, at concentrations ranging from 6.0 to 8,400 µg/kg dw, with a mean concentration of 490 µg/kg. The highest total PCB concentrations in the southern portion of the waterway were located in Slip 27 (3,200 µg/kg dw), the mound area outside of Slip 27 (2,000 µg/kg dw), and the area off of the T-25 (1,600 µg/kg dw) (close to the Hanford #2 CSO and two SD outfalls) (Map 4-16). In the northern portion of the waterway, the highest total PCB concentrations (1,000 and 1,900 µg/kg dw) were located off the northern portion of T-18 between Stations 600 and 1500 (Map 4-16).

Dioxins and furans were measured in subtidal composite sediment samples created for 13 subareas throughout the waterway and in four intertidal MIS composite sediment

samples. Dioxin and furans were detected in all 13 subtidal composite samples with TEQ concentrations ranging from 4.02 to 30.6 ng TEQ/kg dw, and in all four intertidal MIS composite samples with concentrations ranging from 9.2 to 13.8 ng TEQ/kg dw. The subtidal composites and MIS composite samples were designed to provide spatially representative estimates of the mean dioxin and furan concentrations throughout the waterway.

Dioxins and furans were also analyzed in a limited number of individual grab samples. Dioxin and furans were detected in all 11 grab samples with TEQ concentrations ranging from 2.78 to 49.7 ng TEQ/kg dw. The highest dioxin and furan concentrations in grab samples were in samples collected in the southern portion of the waterway in Slip 27, the western portion of the shallow main body, and the Junction/Sill reach (Map 4-23). Slip 27 also had the highest subtidal composite dioxin TEQ (30.6 ng TEQ/kg dw).

At least one cPAH compound was detected in 97% of the 240 surface sediment grab samples, with concentrations ranging from 15 to 10,000 µg TEQ/kg dw and a mean concentration of 460 µg TEQ/kg dw. In addition to the surface sediment grab samples, cPAHs were measured in intertidal MIS composite samples and intertidal composite samples created to characterize cPAHs in each intertidal sampling area. The highest surface sediment cPAH concentration was 17,000 µg TEQ/kg dw in an intertidal composite sample from the small intertidal area located off of the historic Pier 24. The subtidal area with the highest cPAH concentrations in the southern portion of the waterway was the area off of the historic Pier 24 (Station 6200) (Map 4-26). In the northern portion of the waterway, the highest cPAH concentrations were in samples collected offshore of the former GATX and Rabanco barge-loading facilities located south of Slip 36 (3,300 and 3,700 µg TEQ/kg dw, respectively) and at the head of Slip 36 (3,800 µg TEQ/kg dw) (Map 4-26).

Arsenic was detected in 70% of the 231 surface sediment grab samples with a range of concentrations from 2.3 to 241 mg/kg dw with a mean concentration of 9.0 and a 95th percentile of 17 mg/kg dw. The two highest surface sediment arsenic concentrations (163 and 241 mg/kg dw) were in samples collected offshore of the former GATX and Rabanco barge-loading facilities on the east side of the EW, just south of Slip 36 (Map 4-30). Samples from all other locations had arsenic concentrations below 30 mg/kg dw.

Mercury was detected in 98% of the 239 surface sediment grab samples with concentrations ranging from 0.02 to 1.07 mg/kg dw and a mean concentration of 0.30 mg/kg dw. The areas

with the highest surface sediment mercury concentrations in the southern portion of the waterway were the area off of historic Pier 24 (0.75 mg/kg dw) and T-25 (0.67 mg/kg dw) (near area Hanford #2 CSO and two SD outfalls). In the northern portion of the waterway the highest surface sediment mercury concentrations were located in the deep main channel between Stations 2700 and 3400 (0.91 mg/kg dw) and the head of Slip 36 (0.70 mg/kg dw) (Map 4-35).

TBT was detected in 90% of the 67 surface sediment samples analyzed for TBT, with concentrations ranging from 1.6 to 6,000 µg/kg dw and a mean concentration of 180 µg/kg dw. The highest surface sediment TBT concentrations were located along T-18 on the western side of the deep main channel. The three locations with the highest surface sediment TBT concentrations were collected from locations along the shoreline of T-18 near Station 4400 (610 µg/kg dw), Station 1800 (1,600 µg/kg dw), and Station 800(6,000 µg/kg dw) (Map 4-40). Fewer samples were analyzed for TBT than for other contaminants, which may result in greater uncertainty in the spatial distribution of TBT. The locations selected for the analysis of TBT were areas where existing data indicated the presence of elevated concentrations of TBT in sediment.

Twenty-nine chemicals exceeded the SMS criteria in surface sediment samples. Total PCB concentrations exceeded the SQS or CSL in 65% of the samples. Mercury and 1,4-dichlorobenzene concentrations exceeded the SQS or CSL in 19 and 13% of the samples respectively. In addition, 4 PAH compounds (i.e., acenaphthene, fluoranthene, fluorene, phenanthrene) exceeded the SQS or CSL in 5 to 10% of the samples, and 22 contaminants exceeded the SQS or CSL in less than 5% of the samples, including 6 contaminants that exceeded the SQS or CSL in only one sample.

10.3.2.2 Subsurface Sediment Patterns

Data from subsurface sediment collected from cores provide information on the nature and extent of contamination at depth. The data also provide important information and offer insight into processes that contributed to present-day contaminant distributions in EW. Physical events, such as dredging, are recorded in the geological structure of subsurface sediment. Physical and chemical markers within sediment cores can be used to reconstruct historical records of contamination and estimate the age of subsurface sediment.

Subsurface sediment chemistry data, radioisotope data, and physical characteristics of the material retained in the cores, when combined with the history of industrial development in the waterway allow for interpretation of the history of sedimentation in EW. Based on subsurface sediment stratigraphy in sediment cores, EW sediment can be divided into the following three relatively distinct zones:

- **Recent sediment –** This upper zone represents the sediment deposited in EW over approximately the last 50 years and generally provides a record of the more recent activities that have occurred within EW.
- **Transition zone–** The second zone, located beneath the recent sediment, represents sediment deposited in EW following the construction of the waterway in the early 20th century. This layer contains the record of activities that occurred within EW through much of the early commercial and industrial development along the EW.
- **Lower Alluvium –** The deepest zone, located beneath the transition zone, represents historical sediment deposits that predate construction of EW.

The recent sediment zone and the transition zone consist of material that has been deposited in the EW since its construction. The lower alluvium unit is predominantly sand with laminated and stratified beds of slightly silty to silty sand and silt that was deposited prior to the industrialization of the area. The depth from the sediment surface to the surface of the lower alluvium unit ranged widely from 0 to 11.5 ft, with an average depth of 2.1 ft, and is discussed in greater detail in Section 2.5.2.

The areas in the deep main channel that have been recently dredged have the shallowest sediment depths to the lower alluvium unit as a result of the removal of the upper alluvium unit during dredging. In this area, the depths to the lower alluvium ranged from 0 to 9.4 ft, with an average depth of 3 ft. The maximum depth was associated with a core collected from the mouth of Slip 27 outside the Phase 1 dredge prism. The greatest depths from the sediment surface to the surface of the lower alluvium unit were in the shallow main body (Station 4900 to Station 6800) and ranged from 3.4 to11.8 ft, with an average depth of 7 ft due to the lack of recent dredging activity in this area. Slip 27 has not been dredged since 1970, and the depth to the lower alluvium unit within Slip 27 ranged from 5 to 10 ft. Slip 36 was dredged in 2005, and the depth to the lower alluvium unit within Slip 36 was consistently less than 2 ft.

In general, elevated subsurface contaminant concentrations were co-located with areas of elevated surface sediment contaminant concentrations. However, there were areas with subsurface sediment concentrations that exceeded the surface sediment concentrations. In Slip 27, concentrations of total PCBs, cPAH, arsenic, and mercury were generally higher in subsurface sediment as compared with those in surface sediment, and the shallow main body had higher concentrations of total PCBs and mercury in subsurface sediment relative to those in surface sediment (Maps 4-21a and 4-39a). The analysis of vertical patterns of chemicals in subsurface sediment showed that elevated contaminant concentrations were mostly detected in deeper core intervals in areas that have not been dredged since the 1960s.

Overall, 95% of the cores collected from the EW during SRI sampling events had contaminant concentrations that were less than the SQS in the lowest interval of the core that was analyzed (Maps 4-13a through 4-13k). In the cores where the lower alluvium was analyzed (74% of the cores), only three locations had SQS exceedances[141] in that zone (Maps 4-14a though Map 4-14d).

10.3.3 Exposure CSM

One of the key components of the SRI is the assessment of risks for people and ecological receptors that may be exposed to site-related contaminants. This section discusses the pathways of exposure that may lead to unacceptable risks. The risk assessments are summarized in Section 10.4.

The physical and chemical CSMs discussed above provide an overview of the distribution and movement of contaminants in EW, which influence the exposure of receptors to these contaminants. The exposure CSM includes contaminant sources, transport mechanisms, exposure pathways, exposure routes, and potentially exposed receptors. Figures 5-1 and 5-2 present the exposure pathways for ecological receptors, and Figure 6-1 presents the exposure pathways for people. Potential sources and contaminant transport pathways are discussed in Section 9.

[141] The comparison to SQS was made for the purposes of evaluating concentrations and is not intended to be an evaluation of risk to ecological receptors or human health.

The characteristics of each exposure pathway are dependent on the contaminant and the receptor of interest (e.g., people, fish), but the principal pathways for exposure to contaminated sediment in the EW are: 1) indirectly through diet, primarily through ingestion of contaminated seafood; and 2) direct contact. Other pathways of exposure were also included in the risk assessments, but generally had lower risks associated with them.

10.3.3.1 Dietary Exposure

People and wildlife can be exposed to contaminants in the EW through ingestion of contaminated seafood, such as fish, crabs, and clams. Most resident fish, with the exception of brown rockfish, integrate their exposure throughout their foraging ranges in the EW, and are primarily exposed through the ingestion of benthic invertebrates, which have very localized exposures, or the ingestion of other fish that have a broader exposure.

Aquatic species that serve as food for other ecological receptors are exposed to sediment-associated chemicals through various pathways (Figures 5-1 and 5-2). Dietary exposures in the risk assessments were estimated based primarily on consumption rates and contaminant concentrations in prey tissues, although other factors were also included. Consumption rates for people were estimated for various scenarios. EPA required the application of seafood consumption rates that have been developed for adult and child consumers based on seafood harvest from King County or Puget Sound. There is considerable uncertainty about the applicability of some of the seafood consumption rates to this HHRA, particularly for clams, given the presence of low-quality shellfish habitat in areas that have riprap and armored slopes, as well as small pockets of higher-quality shellfish habitat such as intertidal sediment. However, in evaluating risks and exposures in smaller sites (such as the EW) that are within larger bodies of water (such as Elliott Bay or Puget Sound), EPA Region 10 believes that using a holistic approach is appropriate, and thus using consumption rates associated with larger water bodies is necessary (EPA 2011a). This will support remedial actions that result in the uniform protection of public health throughout the larger water body.

To estimate exposure, chemical concentrations in tissues have been analyzed in various fish and invertebrate species that have been collected from throughout EW. Most of the tissue data are for English sole, shiner surfperch, brown rockfish, juvenile Chinook salmon, Dungeness and red rock crabs, clams, mussels, shrimp, and small invertebrates that live in the sediment, such as amphipods and marine worms. These species were selected because

they were assumed to be representative of species within the EW that could be consumed by people, fish, or wildlife. Their tissues were analyzed for a wide variety of chemicals.

Mean total PCB and dioxin and furan TEQ concentrations were highest for brown rockfish, English sole, shiner surfperch, and crab hepatopancreas tissue (concentrations in edible crab meat were lower). Mean total PCB and dioxin and furan TEQ concentrations were lowest in shellfish including clams and geoducks. The highest cPAH concentrations in tissue were detected in clams, mussels, and benthic invertebrates. cPAH concentrations were not as high in fish because fish metabolize PAHs. Other SVOCs were infrequently detected in tissue. The highest mean concentrations of inorganic arsenic were in clams and for other metals (including TBT) the highest mean concentrations were detected in benthic invertebrates.

10.3.3.2 Direct Contact with Sediment

People are also exposed to chemicals in contaminated sediment through direct contact (dermal adsorption and incidental ingestion of sediment). The HHRA evaluated several scenarios for this pathway (including netfishing, habitat restoration work, and clamming) where people would come into direct contact with sediment. While many ecological receptors can be exposed through direct contact with sediment, the benthic invertebrate community is most closely related to direct sediment exposure pathways because they are constantly in direct contact with sediment.

10.3.3.2 Direct Contact with Surface Water

People are exposed to chemicals in surface water when swimming through direct contact (dermal adsorption and incidental ingestion of surface water). Exposure to surface water in the EW was assessed for swimming exposure based on the adult swimming scenarios presented in a previous King County assessment (King County 1999a). These levels of exposure are likely significant overestimates of swimming exposure levels for the EW, given that they were developed for areas that include a greater number of recreational access points (e.g., Elliott Bay) than does the EW, and areas that do not have the EW's high concentration of large ship and tug boat traffic. Ecological receptors such as fish and crabs were also evaluated for direct contact with surface water (e.g., gill uptake).

10.4 Risk Assessment Results

Baseline risk assessments were conducted to evaluate the potential for adverse effects for people and ecological species that may be exposed directly or indirectly to contaminated sediment in EW, as discussed above. Key findings from these assessments are presented in this section. The risk assessments are presented in full in Appendices A and B and summarized in Sections 5 and 6.

10.4.1 Ecological Risks

The ERA assessed risks to receptors that were selected to be both representative and protective of the range of species found in EW, either as resident species or transient/migratory species. Nine ROCs were evaluated; including the benthic invertebrate community, fish, crabs, and aquatic dependent birds and mammals. A summary of COCs and the risk driver contaminants for each ROC are presented in Table 10-1.

Table 10-1
Summary of Ecological COCs and Risk Drivers

Receptor	Evaluation Type	COCs	Risk Driver
Benthic Invertebrate Community	sediment	30 COCs[a]	29 SMS chemicals[b]
	tissue residue	TBT	TBT
	surface water	TBT	none
	porewater	naphthalene	none
Crab	tissue residue	cadmium, copper, zinc	none
	surface water	None	none
Fish	dietary	cadmium, copper, vanadium	none
	tissue residue	total PCBs, TBT	total PCBs
	surface water	None	none
Birds	dietary dose	None	none
Mammals	dietary dose	None	none

[a] Arsenic, cadmium, mercury, zinc, acenaphthene, benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, dibenzo (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3,-c,d)pyrene, phenanthrene, pyrene, total benzofluoranthenes, HPAH, LPAH, bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, 1,4-dichlorobenzene, 2-methylnaphthalene, 2,4-dimethylphenol, dibenzofuran, n-nitrosodiphenylamine, phenol, and total PCBs and total DDTs. All COCs had exceedances of SMS chemical criteria except total DDTs, which was based on exceedances of DMMP guideline.

[b] Anthracene was inadvertently omitted from the list of COCs and risk drivers in the ERA. Anthracene exceeded the SQS in one sediment sample and has been included as a COC and risk driver in the SRI.

COC – contaminant of concern
DDT – dichlorodiphenyltrichloroethane
DMMP – Dredge Material Management Program
SMS – Washington State Sediment Management Standards
SQS – sediment quality standard
SVOC – semivolatile organic compound

PAH – polycyclic aromatic hydrocarbon
PCB – polychlorinated biphenyl
TBT – tributyltin
TEQ – toxic equivalent

For the benthic invertebrate community, 30 COCs were identified based on concentrations in at least one surface sediment sample exceeding their SQS or toxicologically based DMMP guidelines. Sediment toxicity tests were conducted primarily at locations where chemical concentrations predicted adverse impacts to benthic invertebrates could occur. The toxicity tests serve to confirm or refute those predictions based on chemistry alone.

Using the final SMS designation based on both sediment chemistry and toxicity test results, approximately 40% of the EW is designated as having no adverse effects to benthic community (all less than SQS), while approximately 21% are expected to have minor adverse affects (greater than or equal to CSL). Approximately 39% of the area was between the SQS and the CSL and is generally interpreted as having a potential for minor adverse effects on the benthic community. Map 4-12 shows the final designation of each area, as represented by Thiessen polygon, according to SMS rules.

Benthic invertebrate community risks were evaluated using a tissue-residue approach for total PCBs, mercury, and TBT. TBT tissue residue concentrations were above the tissue TRV in two areas and therefore, there is a potential for risk to the benthic invertebrate community in these two areas. Based on this assessment, TBT was identified as a COC.

For most ecological receptors, risks were estimated to be low. COCs were defined as contaminants with LOAEL-based HQs greater than or equal to 1, which indicates a potential for adverse effects. For the juvenile Chinook salmon ROC, a listed species, COCs were identified if a COPC exceeded the NOAEL to be protective of individuals. Cadmium was the only COC identified for juvenile Chinook salmon. Three COCs (cadmium, copper and zinc) were identified for crabs and five COCs (total PCBs, cadmium, copper, TBT and vanadium) were identified for English sole or brown rockfish (Table 10-1). No COCs were identified for aquatic-dependent wildlife receptors (river otters, harbor seals, pigeon guillemot and osprey).

In surface water, TBT was identified as the only COC, and that was for exposure of benthic invertebrates. VOCs were analyzed in porewater at two intertidal locations for the exposure of benthic invertebrates and naphthalene was the only porewater COC.

A subset of COCs were identified as risk drivers for ROCs based on the risk estimates, uncertainties discussed in the ERA, and regional background concentrations in accordance with EPA guidance. Total PCBs was selected as a risk driver for English sole and brown rockfish and TBT and 29 SMS chemicals for benthic invertebrate community (see Table 10-1).

10.4.2 Human Health

For the HHRA, risks were evaluated for various seafood consumption scenarios, direct sediment exposure scenarios (i.e., netfishing, restoration work, and clamming), and for surface water exposure scenarios (i.e., swimming). Because knowledge of current and future site use is imperfect, the scenarios evaluated in this assessment have been selected in an attempt to not underestimate risks (i.e., to be health protective) and, as such, may overestimate risks for many site users. The following briefly summarizes key findings from the HHRA:

- **Seafood consumption scenarios** – Although the collection and consumption of seafood from the EW are known to occur, no seafood consumption surveys that focused solely on the EW were available. Therefore, the rates of seafood ingestion were selected by EPA from several regional surveys that cover areas larger than the EW, including surveys of Puget Sound tribes and API populations.
- **Direct sediment exposure scenarios** – As with the seafood consumption scenarios, there are no site-specific data to estimate direct exposures to EW sediment via restoration work or clamming; exposure scenarios for these activities were developed for health-protective estimation of risks. The tribal netfishing scenario reflects exposure conditions that could occur under current tribal fishing activities within the Duwamish River (including EW).

Surface water exposure scenarios – Exposure to surface water in the EW was assessed for three levels of swimming exposure that were likely significant overestimates of exposures for the EW, given that they were developed for areas that include a greater number of recreational access points and do not have the EW's high concentration of large ship and

tugboat traffic and the fact that water temperatures in the EW are generally quite cold.[142] Future uses of the EW are expected to include similar levels of vessel traffic, so there is very little uncertainty associated with changes in surface water exposure. Excess cancer risk estimates and non-cancer hazards in the EW were found to be higher for the seafood consumption scenarios than for the direct sediment or surface water exposure scenarios. Table 10-2 identifies contaminants selected as COCs and indicates whether they were selected as risk drivers for the RME scenarios evaluated in the HHRA.

Table 10-2
Summary of COCs and Risk Drivers from the Baseline HHRA

COC[a]	Seafood Consumption RME Scenarios	Direct Sediment Exposure	
		Netfishing RME Scenario	Tribal Clamming RME Scenario
Arsenic	X[b]	**X**	**X**
Cadmium	X		
cPAHs	**X**	**X**	**X**
Pentachlorophenol	X		
PCBs (total PCBs or PCB TEQ)	**X[c]**		X[d]
alpha-BHC	X		
Total chlordane	X		
Dieldrin	X		
Heptachlor epoxide	X		
Mirex	X		
Dioxins/furans	**X**	X	
Total TEQ[e]			X

Note: COCs are indicated by "X" in the table. COCs selected as risk drivers are indicated by bold text and shaded cells.

[a] COCs were defined in the HHRA based on risk estimates only for RME scenarios.

[b] Arsenic was not identified as a risk driver for seafood consumption because it was determined that the site did not contribute any incremental risk above background (Section B.5.5.1.2).

[c] Risk estimates for total PCBs were higher than those for PCB TEQ, and thus while both total PCBs and PCB TEQ were identified as COCs for the seafood consumption scenarios, total PCBs are the focus of risk driver discussions.

[d] Total PCBs were identified as COC for direct contact.

[e] Total TEQ is equal to the sum of PCB TEQ and dioxin/furan TEQ. When excess cancer risks for PCB TEQ and dioxin/furan TEQ were not independently greater than the risk threshold, total TEQ was identified as a COC if the excess cancer risk was greater than 1×10^{-6}.

[142] Temperatures for water samples collected in 2008 and 2009 ranged from 5.1 to 14.1°C (41 to 57°F), with a mean temperature of approximately 10°C (50°F).

BHC – benzene hexachloride
COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
TEQ – toxic equivalent
HHRA – human health risk assessment
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure

For all three RME seafood consumption scenarios, total excess cancer risks were greater than 1×10^{-4} and at least one COPC had an HQ greater than 1.The majority of the total excess cancer risk (over 95%) was associated with a few contaminants: arsenic, cPAHs, PCBs, and dioxins/furans. Elevated risk estimates associated with inorganic arsenic and cPAHs are largely attributed to consumption of clams. In contrast, the seafood types that contribute the majority of the risk for PCBs and dioxin/furan TEQ are more variable by scenario. For PCBs, risks are primarily attributable to benthic fish fillet, perch, and rockfish. For dioxin/furan TEQ, risks are primarily attributable to clams, crab (both edible meat and whole body), and rockfish. With the exception of arsenic, these COCs were designated as risk drivers (Table 10-2). Arsenic was not designated as a risk driver because there was no site-related risk for the RME scenarios (i.e., tissue concentrations collected from the EW and from background areas were similar, as were the risk estimates based on these data).[143]

For the direct sediment exposure RME scenarios, total excess cancer risks were lower than those for the seafood consumption RME scenarios (total risks were between 1×10^{-6} and 1×10^{-4}). The majority of the total excess cancer risk (over 80%) was attributable to arsenic and cPAHs, and these COCs were identified as risk drivers for direct sediment exposure. Other COCs included PCBs and dioxins/furans. Non-cancer health effects were not predicted for the direct sediment exposure scenarios. No COCs or risk drivers were identified for exposure to surface water since no RME scenarios were identified.

10.5 Risk Management Considerations

This section summarizes key findings of the RI that are related to risk management decisions that may be made for the EW site. Key findings are presented on RBTCs and preliminary background concentrations of the human health risk drivers, both of which may influence the selection of cleanup levels, and the relationship between the spatial distribution of risk driver COCs in sediment and EW sediment dynamics.

[143] The details of this evaluation are provided in Appendix B (Section B.5.5.1.2).

10.5.1 Sediment RBTCs and Chemical Concentrations in Sediment Collected from EW and Areas Outside of the EW

Risk estimates presented in the baseline risk assessments have been translated into sediment RBTCs that will be considered in developing PRGs in the FS in combination with background concentrations and other factors. Sediment RBTCs were derived for direct sediment contact scenarios and seafood ingestion scenarios for humans, and for protection of fish, as appropriate, for four risk driver COCs: total PCBs, arsenic, cPAHs, and dioxins and furans.

Sediment RBTCs for total PCBs for RME seafood consumption scenarios and for fish ROCs were estimated using a FWM calibrated to EW environmental conditions and empirical data for fish, crab, clam, and other invertebrate species collect from the EW. Sediment RBTCs for cPAHs associated with the human consumption of clams could not be derived because a clear relationship could not be established between concentrations of this contaminant in clams[144] and in sediment (Section 8.3.3). Sediment RBTCs for dioxins and furans were derived for seafood consumption pathways based on site-specific BSAFs calculated for four individual dioxin and furan congeners (Section 8.3.2).

A range of sediment RBTCs for total PCBs were derived for the seafood consumption scenarios (Tables 8-8 and 8-9). Sediment RBTCs could not be derived for the RME seafood consumptions scenarios for 1×10^{-5} and 1×10^{-6} excess cancer risks and for non-cancer hazards because the contribution from PCBs in water alone resulted in estimated total PCB concentrations in tissue greater than the risk level, even in the absence of any contribution from sediment. Therefore, the sediment RBTCs for total PCBs are listed as < 1 µg/kg dw.

The sediment RBTCs for human health seafood consumption and for the protection of fish are summarized in Table 10-3 and Figures 10-1 through 10-4. Sediment RBTCs were also developed for benthic invertebrates and were set equal to SMS criteria for 29 risk drivers; and for TBT, a sediment RBTC of 7.5 mg/kg OC was derived based on benthic invertebrate TBT tissue concentrations using a BSAF approach.

[144] For cPAHs, the majority (73 to 90%) of the cPAH excess cancer risk was attributable to the consumption of clams.

Table 10-3
Comparison of Sediment RBTCs for Select Risk Driver COCs and Preliminary Background Sediment Concentrations[a] from Puget Sound Reference Areas, Upstream of the LDW, the LDW Upper Turning Basin, and the EW

Risk Driver COC	Unit	Risk Level	Sediment RBTCs for RME Direct-Contact Scenarios	Sediment RBTCs for RME Seafood Consumption Scenarios and Fish ROCs	EW SurfaceSediment			*OSV Bold* Puget Sound 2008 Survey Data[b]		Upstream Sediment			
										Surface Sediment Data: Green River[c]		Subsurface Sediment: LDW Upper Turning Basin[d]	
					Mean	SWAC	90th	Mean	90th	Mean	90th	Mean	90th
Arsenic	mg/kg dw	1×10^{-6}	Netfishing (site wide): 3.7	na	Site wide: 9.3	8.8	17	6.5	11	Ecology: 6.8 LDW RI: 7	Ecology: 10 LDW RI: 11	7	12
			Tribal clamming (intertidal): 1.3										
		1×10^{-5}	Netfishing (site-wide): 37	na									
			Tribal clamming (intertidal): 13										
		1×10^{-4}	Netfishing (site-wide): 370	na	Intertidal: 10.1[e]	na[f]	na[f]						
			Tribal clamming (intertidal): 130										
		HQ = 1	na	na									
cPAHs	µg TEQ/kg dw	1×10^{-6}	Netfishing (site wide): 380	nc[g]	Site wide: 440	420	1,100	7.9	15	Ecology: 18LDW RI: 55	Ecology: 57 LDW RI: 135	73	180
			Tribal clamming (intertidal): 150										
		1×10^{-5}	Netfishing (site wide): 3,800	nc[g]									
			Tribal clamming (intertidal): 1,500										
		1×10^{-4}	Netfishing (site wide): 38,000	nc[g]	Intertidal: 1,000[d]	na[f]	na[f]						
			Tribal clamming (intertidal): 15,000										
		HQ = 1	na	na									
Dioxin and furan TEQ	ng TEQ/kg dw	1×10^{-6}	na	0.18 – 0.94[h]	15.7[i]	na	nc	1.4	2.3	Ecology: 1.0 LDW RI: 2.0	Ecology: 3 LDW RI:: na	nc	2.8[j]
		1×10^{-5}	na	1.8 – 9.4[h]									
		1×10^{-4}	na	18 – 94[h]									
		HQ = 1	na	8.2									
Total PCBs	µg/kg dw	1×10^{-6}	na	< 1[k]	490	460	1,300	1.2[l]	2.8[l]	Ecology:3LDW RI: 23	Ecology: 6 LDW RI:40	36	56
		1×10^{-5}	na	< 1[k]									
		1×10^{-4}	na	2.0 – 250[h]									
		HQ = 1 (human health)	na	< 1[k]									
		HQ = 1 (fish)	na	39->470[m]									

[a] Final determinations of background concentrations will be provided by EPA in the EW ROD
[b] The *OSV Bold* Puget Sound 2008 survey data (DMMP 2009) is the primary dataset for natural background. The values presented in this table represent the mean and 90th percentile concentrations of this dataset.
[c] Information relevant to upstream concentrations in sediment is presented in Section 7.2. The concentrations presented in this table represent the mean and 90th percentile concentrations in the surface sediment samples from the Ecology upstream surface sediment data (2008) and surface sediment samples collected upstream of the LDW Superfund site collected as part of the LDW RI studies (1994-2006).
[d] Subsurface sediment data from the LDW Upper Turning Basin represent solids from the Green/Duwamish River upstream of the LDW and are presented in Section 7.2.2.1. The concentrations presented in this table (for informational purposes only) represent the mean and 90th percentile concentrations in sediment cores collected between RM 4.3 and RM 4.75 of the LDW.
[e] The intertidal mean is the average of the site-wide intertidal MIS samples. This value is consistent with the intertidal SWAC calculated using the intertidal area composite samples (1,200 µg TEQ/kg dw).
[f] SWAC and 90th percentile values are not calculated for the intertidal sediment because these areas were characterized using MIS samples.
[g] Although identified as a COC for seafood consumption, sediment RBTCs were not calculated for cPAHs for seafood consumption scenarios because a clear relationship has not been established between cPAH concentrations in surface sediment and clam tissues, which would be needed to develop an RBTC.
[h] Sediment RBTCs developed from the human health seafood consumption RME scenarios.
[i] The mean of the subtidal composite samples analyzed for dioxins and furans.
[j] Because of the small dataset, mean and 90th percentiles were not calculated for dioxin and furan TEQs. The dioxin and furan TEQ values represent the maximum measured TEQ values.
[k] A sediment RBTC could not be calculated; even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, FWM-estimated total PCB concentrations in tissue would be greater than the tissue RBTC for the applicable risk level because of the contribution of PCBs from water alone.
[l] Value is the mean or 90th percentile of the total PCBs sum of congeners.
[m] RBTCs developed for brown rockfish and English sole, estimated through the FWM.

COC – contaminant of concern
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
FWM – food web model
HI –hazard index
HQ – non-cancer hazard quotient
LDW – Lower Duwamish Waterway
na – not available or applicable
nc – not calculated
nd – no data
PCB – polychlorinated biphenyl
RBTC – risk-based threshold concentration
RI – remedial investigation
RM – river mile
RME – reasonable maximum exposure
ROC – receptor of concern
SWAC – spatially weighted average concentration
TEQ – toxicity equivalent quotient

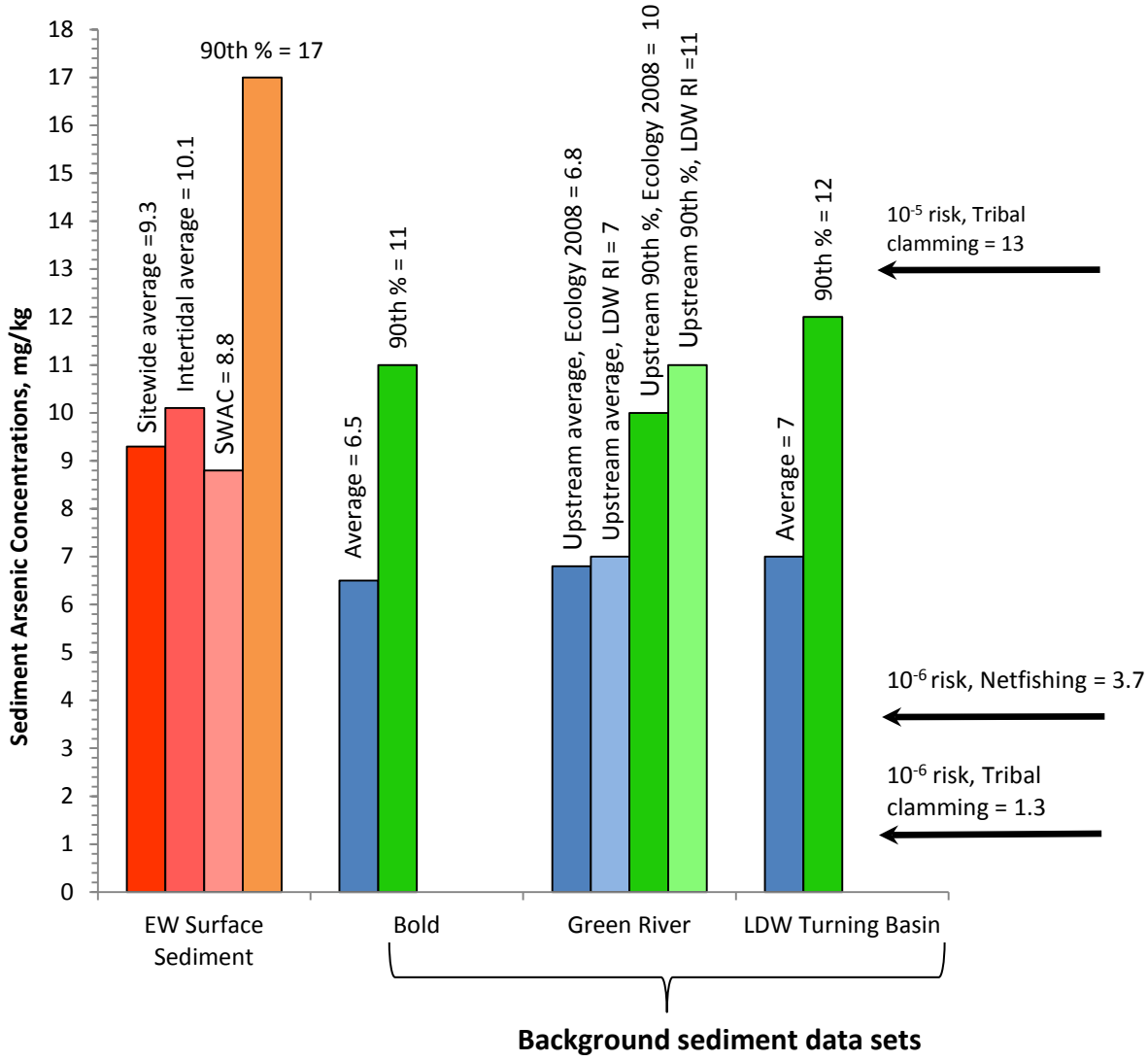


Figure 10-1.
Comparison of Sediment RBTCs for Arsenic and Preliminary Background Sediment Concentrations from Puget Sound Reference Areas, Upstream of the LDW, the LDW Upper Turning Basin, and the EW

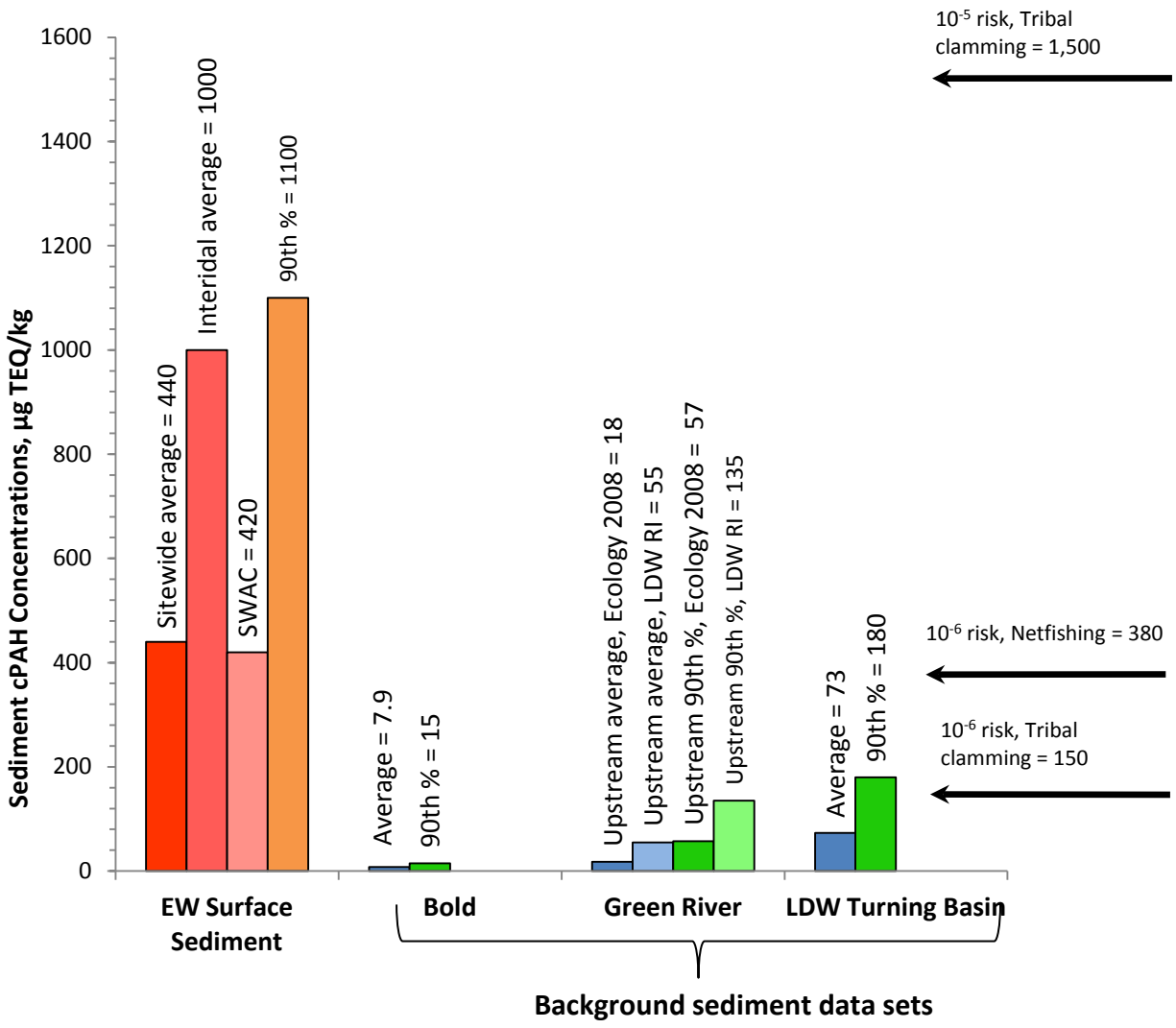


Figure 10-2

Comparison of Sediment RBTCs for cPAH TEQ and Preliminary Background Sediment Concentrations from Puget Sound Reference Areas, Upstream of the LDW, the LDW Upper Turning Basin, and the EW

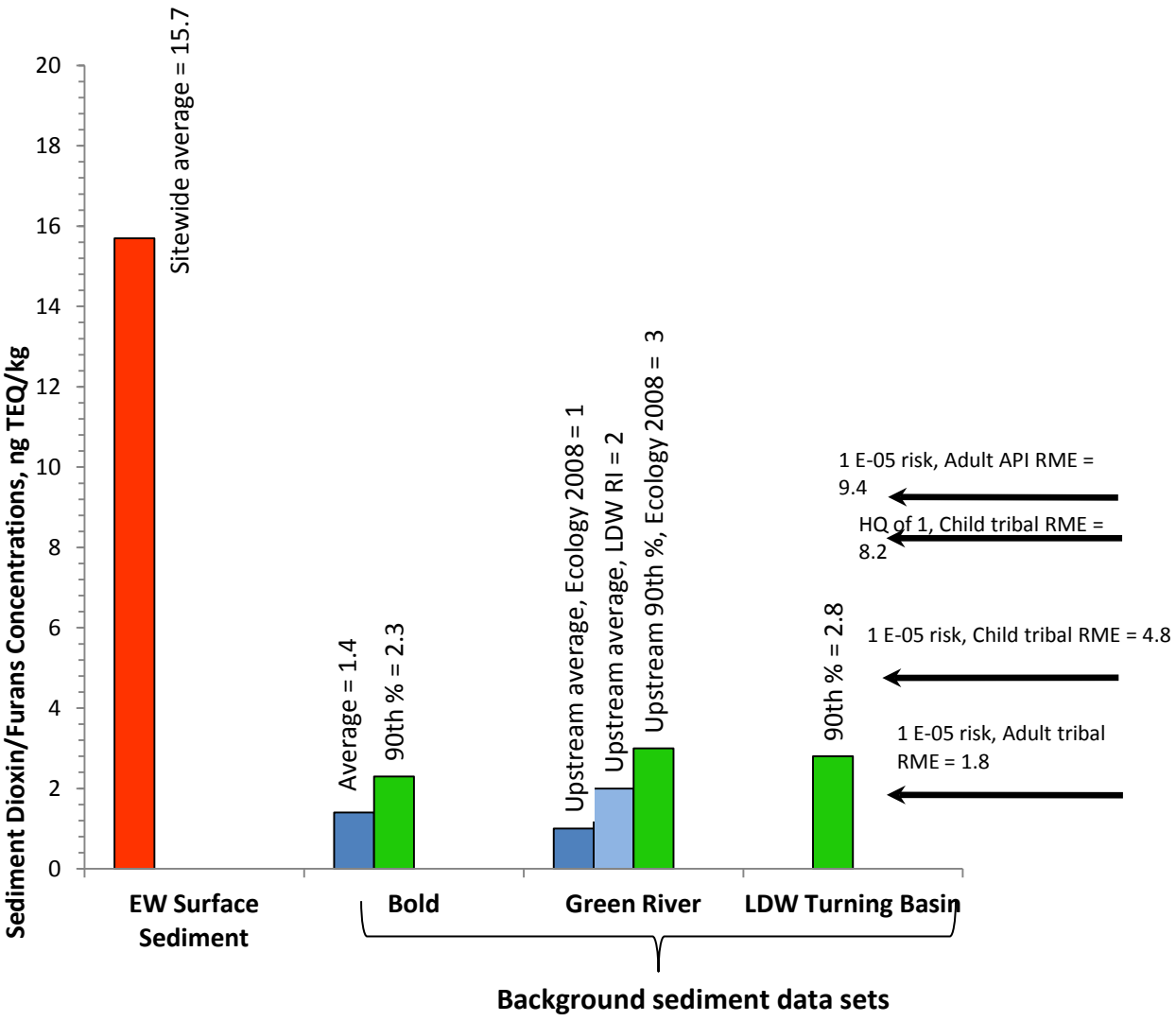


Figure 10-3

Comparison of Sediment RBTCs for Dioxin/Furan TEQ and Preliminary Background Sediment Concentrations from Puget Sound Reference Areas, Upstream of the LDW, the LDW Upper Turning Basin, and the EW

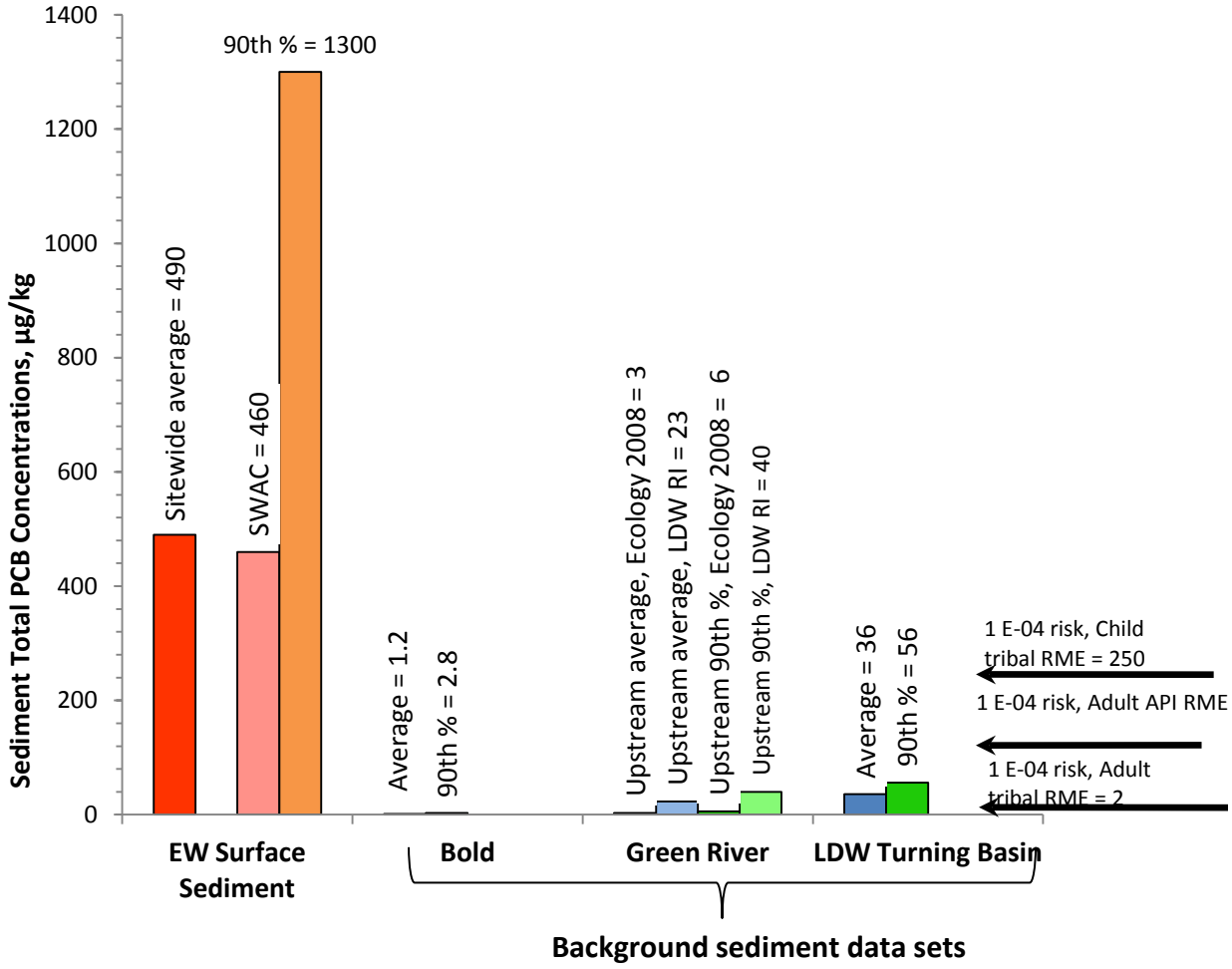


Figure 10-4
Comparison of Sediment RBTCs for Total PCBs and Preliminary Background Sediment Concentrations from Puget Sound Reference Areas, Upstream of the LDW, the LDW Upper Turning Basin, and the EW

Data on background concentrations for the human health risk driver COCs were collected from areas outside of the EW (Section 7). Background concentrations provide important context for RBTCs because EPA generally does not require cleanup below anthropogenic background concentrations in consideration of the potential for recontamination from sources unrelated to the site, cost effectiveness, and technical practicability (EPA 2002a). In

addition, MTCA is a potential ARAR, and MTCA cleanup levels cannot be set at concentrations below natural background (WAC 173-340-705(6)).

Background concentrations of chemicals will be considered in the FS, and their role in determining cleanup levels will be determined by EPA in the ROD. Concentrations of select risk driver COCs from the *OSV Bold* Puget Sound 2008 survey (DMMP 2009) and other Puget Sound reference areas were presented in Section 7.1. The *OSV Bold* Puget Sound 2008 survey (DMMP 2009) data are summarized in Table 10-3. Relevant surface sediment data for upstream environments were presented in Section 7.2 and are summarized in Table 10-3. The sediment datasets are summarized as mean concentrations, SWAC concentrations and 90th percentile values. The SWAC and the mean provide a measure of the central tendency of the datasets and the 90th percentile values provide a measure of the upper bounds of the datasets.

Two risk drivers, arsenic and cPAHs, for the human health direct contact scenarios had sediment RBTCs that were compared with background data and EW data (Table 10-3). RBTCs derived for the human health direct sediment contact scenarios were applied to sediment concentrations averaged over the exposure areas for the specified uses, not on a point-by-point basis. The exposure area for the netfishing RME scenario included all of the intertidal and subtidal areas of the EW. The exposure area for the RME tribal clamming scenario included all intertidal areas because all areas are potentially accessible either from a boat or from the shore. Because of this, EW site-wide mean and intertidal mean concentrations of arsenic and cPAHs were compared with RBTCs. For arsenic, the direct sediment contact RBTCs at the 1×10^{-6} risk level were below the 90th percentile of the *OSV Bold* Puget Sound survey data (DMMP 2009). The EW mean surface sediment arsenic concentration and the arsenic SWAC were between the mean and the 90th percentile of the arsenic concentrations in the OSV Bold Puget Sound survey data (DMMP 2009). The cPAH sediment RBTCs for netfishing and clamming at the 1×10^{-6} risk level were greater than the 90th percentile of the *OSV Bold* Puget Sound 2008 survey dataset concentrations (DMMP 2009). The cPAH SWAC and the EW mean cPAH concentrations (both EW-wide and intertidal) were all above the 90th percentile for the *OSV Bold* Puget Sound survey data (DMMP 2009) and were between the RBTCs at the 1×10^{-5} and 1×10^{-6} excess cancer risk levels.

Sediment RBTCs for two risk drivers, total PCBs and dioxins/furans, for the human health seafood consumption scenarios as well as total PCBs for two fish receptors were compared with background data and EW data (Table 10-3). Sediment RBTCs estimated for human seafood consumption scenarios and for fish exposures were applied as average concentrations over the relevant exposure area (site-wide), not on a point-by-point basis. Hence, comparisons of RBTCs with the EW mean and SWAC concentrations of PCBs and dioxins/furans were made. For human health RBTCs, the values at the risk thresholds of 1×10^{-6} excess cancer risk and non-cancer HQ of 1 are all below the 90th percentile of the *OSV Bold* Puget Sound 2008 survey data for total PCBs (DMMP 2009). The total PCB RBTCs for fish exposures are above the 90th percentile of the *OSV Bold* Puget Sound 2008 survey data (DMMP 2009). The EW mean total PCB concentration and the SWAC were above both the 90th percentile of the *OSV Bold* Puget Sound 2008 survey data (DMMP 2009) and the human health-based sediment RBTCs. The EW mean total PCB concentration was slightly above the higher fish RBTC, whereas the SWAC was just below the higher fish RBTC; both were above the lower fish RBTC value. The dioxin/furan sediment RBTC at the 1×10^{-6} excess cancer risk was also below the 90th percentile of the *OSV Bold* Puget Sound 2008 survey data for dioxins/furans (DMMP 2009). The mean dioxin and furan TEQ for EW surface sediment was above the 90th percentile of the *OSV Bold* Puget Sound 2008 survey data. The RBTCs based on both 1×10^{-5} excess cancer risk level and the non-cancer HQ were also above the 90th percentile of the *OSV Bold* Puget Sound 2008 survey data (DMMP 2009). However, the EW mean was below the RBTCs at the 1×10^{-4} excess cancer risk level.

Sediment RBTCs for benthic invertebrates were developed based on point concentrations, and therefore the surface sediment data can be compared with the RBTCs on a location basis. A comparison of the sediment concentrations with both SMS criteria and the TBT sediment RBTC is presented on Map 10-1. Exceedances of the SMS criteria were observed throughout the EW. The 10 locations with TOC-normalized TBT concentrations above the sediment RBTC also exceeded the SMS for another contaminant.

10.5.2 Tissue RBTCs and Chemical Concentrations in Tissue Collected from Non-Urban Areas of Puget Sound

Tissue RBTCs were calculated for total PCBs, dioxins and furans, and cPAHs (the risk drivers identified in the HHRA) at several risk levels based on the RME seafood consumption

scenarios evaluated in the HHRA.[145] For example, the total PCB concentration in seafood that would be necessary to achieve an excess cancer risk of 1×10^{-5} would be 4.2 µg/kg ww for the adult tribal RME scenario (Table 10-4) and 14 µg/kg ww for the API RME scenario. Just as it is important to put sediment RBTCs in the context of sediment background levels, it is important to put tissue RBTCs in the context of the PCB concentrations found in seafood from non-urban locations within Puget Sound. There are limited data for some species and contaminants for comparison with the tissue RBTCs.

Table 10-4
Total PCB Concentrations in Non-urban Puget Sound Tissue for Select Species Compared with Tissue RBTCs

EPC or RBTC	Total PCB Concentration (µg/kg ww)			
	Benthic fish (fillet)	Rockfish (fillet)	Clam (soft tissue)	Crab (edible meat)
Empirical Tissue Concentrations				
Non-urban Puget Sound (range of mean values)[a]	nd – 11.6	4.5 – 32.3	nd – 1.66[b]	0.62 – 1.3[c]
Tissue RBTCs for the RME Scenarios Based on Tulalip Data[d]				
1×10^{-4} risk level	42 (adult tribal); 230 (child tribal); 140 (adult API)			
1×10^{-5} risk level	4.2 (adult tribal); 23 (child tribal); 14 (adult API)			
1×10^{-6} risk level	0.42 (adult tribal); 2.3 (child tribal); 1.4 (adult API)			
HQ of 1	17 (adult tribal); 8 (child tribal); 24 (adult API)			

[a] Range of mean total PCB concentrations from non-urban Puget Sound sampling areas, as presented in Table 7-13.

[b] The only detected results were for horse clam tissue and gut balls collected from Dungeness Bay and Freshwater Bay.

[c] Dungeness crab edible meat collected from Padilla/Fidalgo Bay, Dungeness Bay, and Freshwater Bay.

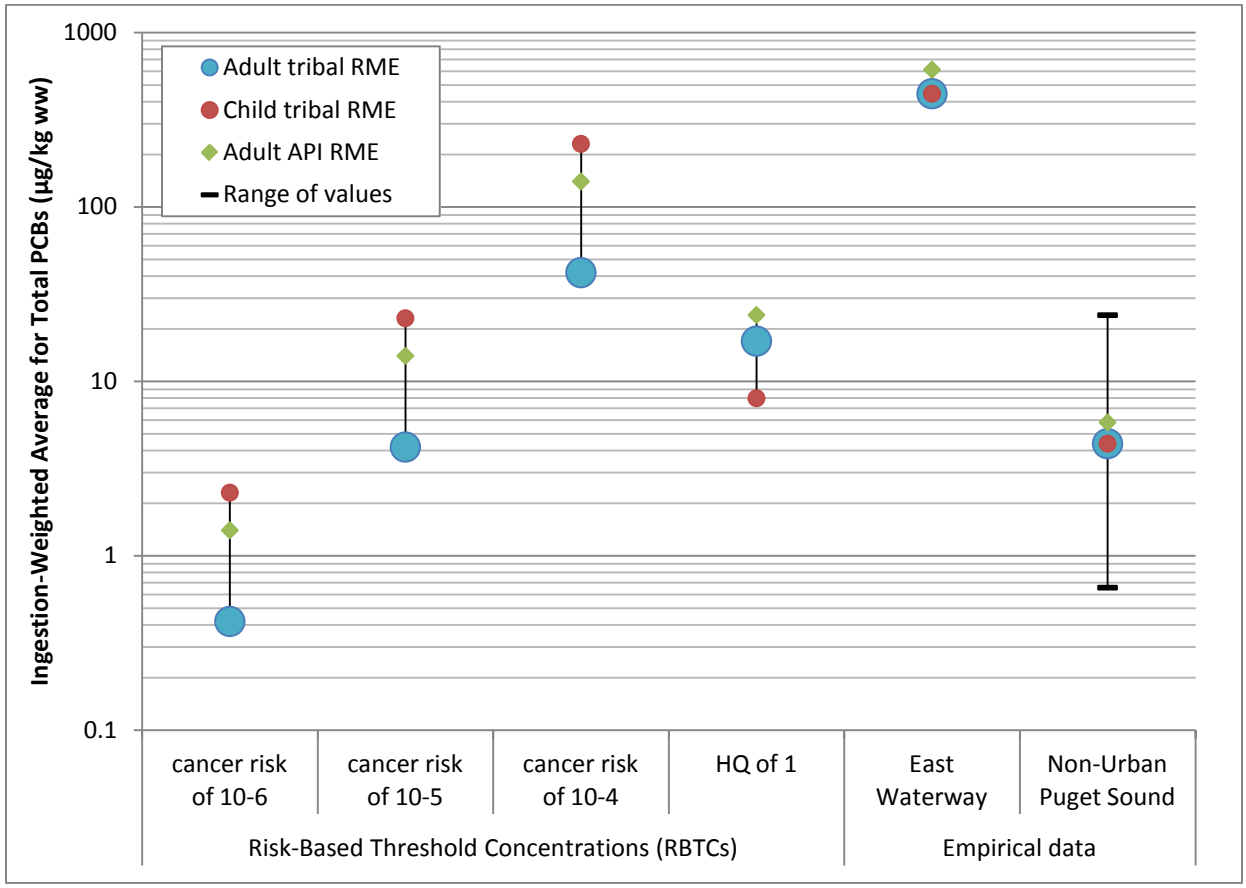
[d] Tissue RBTCs represent the ingestion-weighted average concentrations in tissue (across all seafood types) that correspond to a certain risk threshold for each scenario.

API – Asian and Pacific Islander
EPC – exposure point concentration
EW – East Waterway
HQ – hazard quotient
nd – not detected
PCB – polychlorinated biphenyl
RME – reasonable maximum exposure
RBTC – risk-based threshold concentration
UCL – upper confidence limit on the mean
ww – wet weight

As described in Section 7.4.1 and in WSDOH (2006), PCBs are frequently detected in many different seafood species throughout non-urban areas of Puget Sound at concentrations

[145] Tissue RBTCs were also estimated for fish ROCs for total PCBs and benthic invertebrates for TBT. These are not discussed here because the RBTCs are expected to be above non-urban Puget Sound background levels.

similar to tissue RBTCs, with mean total PCB concentrations ranging from 4.5 to 32.3 µg/kg ww in rockfish, 2.8 to 11.6 µg/kg ww in English sole fillet, 0.62 to 1.3 µg/kg ww in crab edible meat, and not detected to 1.66 µg/kg ww in clams (Table 10-4). As shown in Table 10-4 and Figure 10-5, tissue RBTCs at the 1×10^{-6} excess cancer risk threshold for the adult tribal RME scenario are below the non-urban Puget Sound tissue data and are similar to or below tissue data at the 1×10^{-5} excess cancer risk threshold.



Notes: Ingestion-weighted averages for the East Waterway were calculated using the EPCs used in the HHRA. Ingestion-weighted averages for the non-urban Puget Sound dataset were calculated using average values, with the range defined by minimum and maximum values. Detection frequencies for the empirical data are 100% for the East Waterway dataset (n = 107) and 66% for the non-urban Puget Sound dataset (n = 490).

Figure 10-5

Comparison of Total PCBs Tissue RBTCs for Concentrations of Total PCBs in East Waterway and Non-Urban Puget Sound Tissue Samples

Dioxin and furans have been detected in several seafood species throughout Puget Sound at concentrations similar to and greater than dioxin/furan tissue RBTCs estimated for the three RME scenarios at different risk thresholds (Table 10-5). The non-urban Puget Sound dataset for dioxins and furans contain a limited number of samples compared to the number of samples in the PCB datasets. Therefore, there is greater uncertainty in the comparison of the dioxins and furans datasets to the tissue RBTCs. As shown in Table 10-5 and Figure 10-6, tissue RBTCs at the 1×10^{-6} excess cancer risk threshold are below the non-urban Puget Sound tissue concentrations and are similar to or below tissue concentrations at the 1×10^{-5} excess cancer risk threshold.

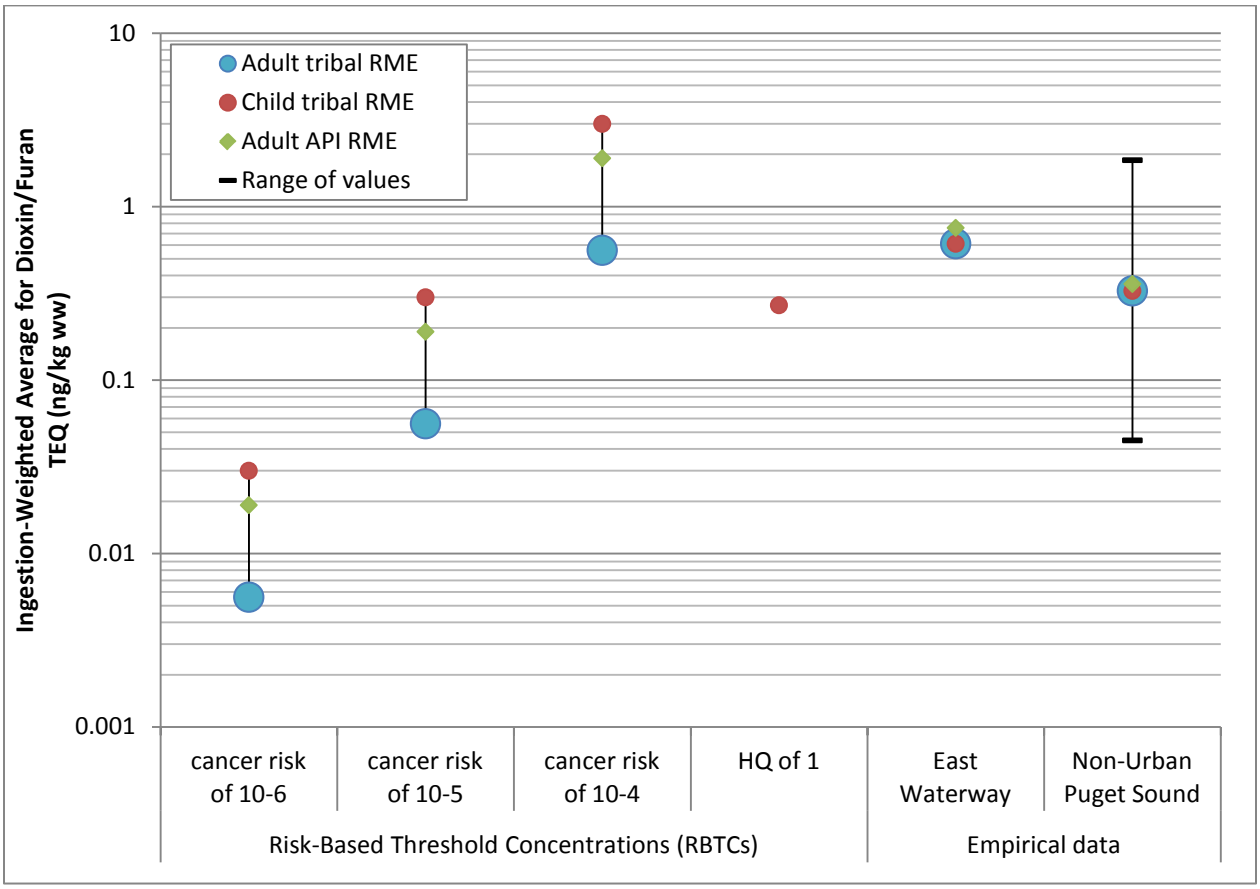
Table 10-5
Dioxin and Furan TEQ in EW and Non-urban Puget Sound Tissue for Select Species Compared with Tissue RBTCs

EPC or RBTC	Dioxin and Furan TEQ Concentration (ng TEQ/kg ww)			
	Benthic Fish (whole body)	Rockfish (whole body)	Clam (soft tissue)	Crab (edible meat)
Empirical Tissue Concentrations				
Non-urban Puget Sound (range of values)[a]	0.152 – 0.320	no data	0.033 – 1.63	0.102 – 1.72
Tissue RBTCs for the RME Scenarios[b]				
1×10^{-4} risk level	0.56 (adult tribal); 3.0 (child tribal); 1.9 (adult API)			
1×10^{-5} risk level	0.056 (adult tribal); 0.3 (child tribal); 0.19 (adult API)			
1×10^{-6} risk level	0.0056 (adult tribal); 0.03 (child tribal); 0.019 (adult API)			
HQ of 1	0.27 (child tribal)			

[a] Range of dioxin and furan TEQs from non-urban Puget Sound sampling areas, as presented in Table 7-14.UCLs could not be calculated for dioxins/furans for these species because of the small dataset size.

[b] Tissue RBTCs represent the ingestion-weighted average concentrations in tissue (across all seafood types) that correspond to a certain risk threshold for each scenario.

API – Asian and Pacific Islander
EPC – exposure point concentration
HQ – hazard quotient
EW – East Waterway
na – not applicable
RBTC – risk-based threshold concentration
RME – reasonable maximum exposure
TEQ – toxic equivalent
ww – wet weight



Notes: Ingestion-weighted averages for the East Waterway were calculated using the EPCs used in the HHRA. Ingestion-weighted averages for the non-urban Puget Sound dataset were calculated using average values, with the range defined by minimum and maximum values. Detection frequencies for the empirical data are 100% for the East Waterway dataset (n = 28 supercomposites) and 100% for the non-urban Puget Sound dataset (n = 106). An RBTC for the HQ of 1 risk level is shown only for the child tribal RME scenario because HQs for the two adult scenarios did not exceed the threshold of 1 in the HHRA.

Figure 10-6

Comparison of Dioxin/Furan TEQ Tissue RBTCs for Dioxin/Furan TEQs in East Waterway and Non-Urban Puget Sound Tissue Samples

cPAHs were detected infrequently in samples collected from non-urban areas of Puget Sound (Table 10-6).The dataset was limited to three detected results for littleneck clam tissue, three detected results for geoduck tissue, and one detected result for mussel tissue. Although the consumption of clams was the primary contributor to the cPAH risk as calculated in the HHRA, the tissue RBTCs are based on ingested weighted-average seafood consumption rates. As shown in Table 10-6 and Figure 10-7, tissue RBTCs at the 1×10^{-6} excess cancer risk threshold are lower than the non-urban Puget Sound tissue concentrations for clams.

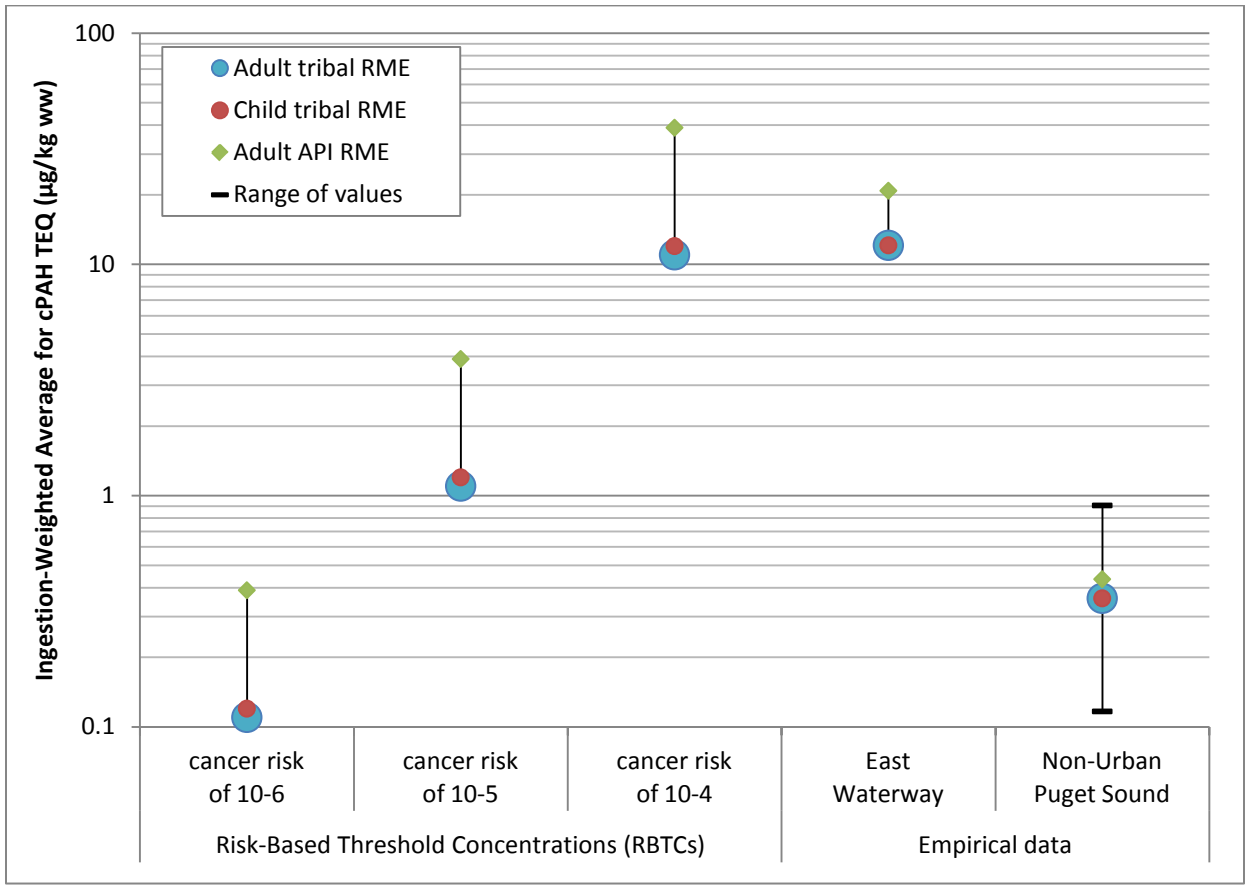
Table 10-6
cPAH TEQ in EW and Non-Urban Puget Sound Tissue Compared with Tissue RBTCs for Select Species

EPC or RBTC	cPAH TEQ Concentration (µg TEQ/kg ww)			
	Benthic Fish (fillet)	Rockfish (whole body)	Clam (soft tissue)	Crab (edible meat)
Empirical Tissue Concentrations				
Non-urban Puget Sound (range of values)[a]	nd	no data	nd – 1.05	nd
Tissue RBTCs for the RME Scenarios[b]				
1×10^{-4} risk level	11 (adult tribal); 12 (child tribal); 39 (adult API)			
1×10^{-5} risk level	1.1 (adult tribal); 1.2 (child tribal); 3.9 (adult API)			
1×10^{-6} risk level	0.11 (adult tribal); 0.12 (child tribal); 0.39 (adult API)			
HQ of 1	na			

[a] Range of cPAH TEQs from non-urban Puget Sound sampling areas, as presented in Table 7-15.

[b] Tissue RBTCs represent the ingestion-weighted average concentrations in tissue (across all seafood types) that correspond to a certain risk threshold for each scenario.

API – Asian and Pacific Islander
cPAHs – carcinogenic polycyclic aromatic hydrocarbons
EPC – exposure point concentration
EW – East Waterway
HQ – hazard quotient
na – not applicable
nd – not detected
RME – reasonable maximum exposure
RBTC – risk-based threshold concentration
TEQ – toxic equivalent
ww – wet weight



Notes: Ingestion-weighted averages for the East Waterway were calculated using the EPCs used in the HHRA. Ingestion-weighted averages for the non-urban Puget Sound dataset were calculated using average values, with the range defined by minimum and maximum values. Detection frequencies for the empirical data are 71% for the East Waterway dataset (n = 96) and 11% for the non-urban Puget Sound dataset (n = 28).

Figure 10-7

Comparison of cPAH TEQ Tissue RBTCs for cPAH TEQs in East Waterway and Non-Urban Puget Sound Tissue Samples

10.6 Pathways, and Potential Contaminant Sources, and Ongoing Source Control Efforts

Understanding pathways, identifying potential sources of contamination and controlling on-going sources is critical to the long-term success of any remedial action. As such, source characterization and control efforts have been conducted to characterize potential sources and pathways by which contaminant inputs can reach the EW. The data developed during this work provides the information necessary to support the future evaluation of potential sediment recontamination as part of the FS.

A variety of source control programs operate in and around the EW. These programs include activities of various regulatory agencies and the work of individual EWG members and other parties. Information available from these ongoing source control programs has been compiled and supplemented with other data and evaluations to characterize potential source inputs to the EW.

Sources of contaminants to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the EW through various potential pathways. These potential pathways include the following:

- Direct discharge into the EW (e.g., CSOs and SDs, or sheet flow from properties immediately adjacent to the waterway)
- Groundwater migration/discharge
- Bank erosion
- Abrasion and leaching of treated piling structures
- Atmospheric deposition
- Spills and/or leaks to the ground, surface water, or directly into the EW (may be a potential source or pathway)
- Transport of resuspended contaminated sediment

Direct discharges to the EW include discharges from both CSO and stormwater outfalls as well as sheet flow from adjacent properties. CSO discharge volumes and frequencies are routinely monitored by the City of Seattle and King County; however, stormwater discharges are not routinely monitored. Therefore, stormwater discharge volumes have been estimated based on land use and rainfall. Extensive monitoring has been conducted as part of ongoing source tracing efforts to characterize the chemical quality of SD and CSO solids discharged to the EW. A number of source control actions have been completed in parallel with the SRI to reduce contaminant inputs to these systems. King County and City of Seattle CSO control programs continue to reduce overflow events. In addition, the City of Seattle and Port of Seattle stormwater management programs reduce chemical and solids loadings to the stormwater and combined sewer as detailed in Section 9.3.2.

The majority of source control samples had contaminant concentrations below screening levels[146] with the exception of BEHP, which was found to be ubiquitous within a variety of drainage basins. The highest concentrations of PCBs and mercury were found in a few nearshore SDs and a few locations in the Hanford #2 CSO system whereas the highest concentrations of HPAHs were found in S. Lander Street SD and one location in Hanford #2 CSO system. Source-tracing and control efforts for the highest concentrations of various contaminants (e.g., arsenic, mercury, total PCBs, dioxins/furans and 1,4-dichlorobenzene) have been completed by the City of Seattle, King County, and the Port of Seattle.

Extensive investigation and cleanup activities and monitoring have been conducted at the nearshore cleanup sites located along the EW under state and federal cleanup programs and are ongoing at several of these sites. Extensive data were used to characterize the groundwater conditions and evaluate this pathway from a source control perspective. These data have been compared to appropriate reference values to assess the potential for contaminant concentrations in groundwater to impact EW sediment.

Bank erosion is another pathway by which contaminants could potentially impact EW sediment. Investigations conducted as part of the SRI verified that nearshore banks of the EW generally consist of engineered slopes with armoring that reduces the potential for bank erosion.

Abrasion and leaching are pathways by which treated-wood pilings can introduce contaminants into the EW. Most pilings and marine structures present in the EW are constructed of alternative materials (e.g., concrete or steel), and ongoing programs exist to reduce the use and presence of treated wood for waterway structures. Some treated-wood structures remain within the EW and represent potential sources of metals and PAHs.

Spills from over-water and nearshore uses can represent a source by which contaminants can be introduced into the EW. Documented spills to the EW have occurred and most have consisted of relatively small releases of petroleum with the exception of one large spill that released metals to EW. A significant spill occurred in 2008 at the Industrial Plating

[146] There are no regulatory standards for solids collected from catch basins or in the lines of SD or CSO conveyance systems. State and local source control programs typically compare storm drain solids data to the SMS to provide a rough indication of overall quality.

Corporation. The spill event occurred due to the rupture of a 50,000-gallon wood-stave storage tank that contained wastewater and sludge from electroplating operations. Although a large portion of the spill was contained onsite, some of this material, which contained very high concentrations of cadmium, chromium, copper, and zinc, did reach the EW via the S Lander Street storm drain system.

Data are available for some contaminants (PCBs, metals and selected SVOCs) to characterize the direct atmospheric deposition pathway by which airborne contamination can be deposited into the EW (the indirect atmospheric deposition pathway is considered as part of the direct discharge pathway [i.e., stormwater, CSO, and sheet flow]). The atmospheric deposition data provide information necessary to support predictions of sediment recontamination during development of the FS.

10.7 Key Observations and Findings

Key observations and findings for the SRI are summarized below.

- Over the past 100 years, the EW has been highly modified from its natural configuration of a river mouth delta to support urban and industrial development. Changes have included reductions and control of water flow, channel deepening, significant shoreline modifications and fill, loss of intertidal habitat, and installation of riprap, pier aprons and sheet pile walls.
- Commercial facilities are the predominant use of the shoreline.
- The EW is currently and expected to continue to be used as a commercial navigational corridor. In addition to commercial activities, the EW supports the collection of seafood by tribal members, who have tribal treaty rights to harvest seafood from EW, as well others such as recreational fishers or individuals collecting seafood to supplement their diet.
- Despite significant habitat alterations and the presence of areas with elevated contaminant concentrations in sediment, the EW contains a diverse assemblage of aquatic species and a robust food web that includes top predators.
- The range of measured rates of net sediment deposition in the deeper areas of the EW (the Shallow and Deep Main Body Reaches) are between 0.1 and 4.2 cm/yr (based on Cs-137 and Pb-210 data), with the majority of these areas being net depositional

(meaning more material is deposited than eroded). Average net sedimentation rates in these areas (based on all interpretable core data) are 1.6 cm/yr and 0.5 cm/yr based on Cs-137 and Pb-210 data, respectively. Net sedimentation rates could not be quantified for the Sill or Junction Reaches, due to consolidated sand and gravel surface sediments at proposed sampling locations in these areas.

- Results of the sediment transport modeling completed for the LDW FS and results of PTM modeling of lateral sources within the EW completed for this SRI suggest that 99% of the sediment load into the EW is from the Green River, approximately 0.7% is from the LDW (bed/bank sediment and lateral loads), and less than 0.3% is from lateral loads within the EW.
- Portions of the Deep Main Body Reach (from approximately Slip 27 north towards the mouth of the waterway) are likely subject to episodic erosion and re-suspension of bed sediments due to prop wash. The remainder of the Deep Main Body Reach (between Stations 4200 and 4900), the Shallow Main Body Reach, and the Junction Reach may be subject to only occasional erosion or re-suspension of surface sediments due to prop wash.
- Sediment concentrations above SMS values were observed throughout the EW. The majority of the contaminant concentrations above the CSL in surface sediment were located in areas within the EW that have not recently been dredged (i.e. the shallow main body, the perimeter of the deep main body and the slips). The locations of the highest total PCB, cPAH, arsenic, mercury, and TBT concentrations were varied.
- Most of the human health risks are associated with PCBs, arsenic, cPAHs, and dioxins and furans.
- The highest risks to people are associated with consumption of fish, crabs, and clams, with lower risks associated with activities that involve direct contact with sediment, such as clamming and netfishing.
- Based on surface sediment chemistry and toxicity test results, sediment contamination in approximately 40% of the EW (29 ha) is predicted to have no adverse effects on the benthic invertebrate community; sediment contamination in approximately 21% (15 ha) is predicted to have minor adverse effects on the benthic invertebrate community, and sediment contamination in the remaining 39% of the EW (28 ha) is

predicted to have a potential for minor adverse effects on the benthic invertebrate community. Most these predicted effects were due to PCBs and mercury; however, 29 different chemicals have a potential for minor adverse effects in at least one location.

- In addition, potential risks to benthic invertebrates were found from exposure to TBT in two areas within EW.
- There are potential risks to fish from exposures to total PCBs, cadmium, copper, vanadium and TBT and to crab from cadmium, copper and zinc. Unacceptable risks are not expected for aquatic-dependent wildlife based on their exposure within EW.
- Puget Sound sediment data and data from other lines of evidence are available for consideration in the derivation of natural and anthropogenic background concentrations in the FS. A comparison of preliminary background concentrations with risk-based goals in sediment (represented by sediment RBTCs) will be used in the FS to provide important support for risk management decisions by EPA.
- Sediment RBTCs were calculated for risk drivers identified in the ERA (TBT and PCBs) and in the HHRA (arsenic and cPAHs for direct sediment exposure; PCBs and dioxins/furans for seafood consumption[147]). SMS criteria (i.e., SQS and CSL) were also used as sediment RBTCs for benthic invertebrates. The following summarizes the comparison of RBTCs based on the human health exposure scenarios with upstream or background concentrations (Table 10-3):
  - PCB RBTCs for the human health seafood consumption scenarios are estimated to be less than natural background (e.g., *OSV Bold* Puget Sound 2008 survey (DMMP 2009)) for the 1×10^{-6} and 1×10^{-5} excess cancer risk thresholds and non-cancer risks based on HQ of 1.
  - Dioxin/furan RBTCs for the human health seafood consumption scenarios are estimated to be less than natural background at the 1×10^{-6} excess cancer risk threshold.

[147] cPAHs were also identified as a risk driver for the seafood consumption RME scenarios, but sediment RBTCs could not be calculated because a clear relationship could not be established between cPAH concentrations in surface sediment and clam tissues.

  - Arsenic RBTCs for the human health direct contact RME scenarios are estimated to be less than natural background at the 1×10^{-6} excess cancer risk threshold.
  - cPAHs RBTCs for the human health direct contact RME scenarios are above natural background levels but similar to some anthropogenic background data (e.g., urban bays and streams) at the 1×10^{-6} excess cancer risk threshold.

- Tissue RBTCs were calculated for risk drivers for the human health seafood consumption RME scenarios presented in the HHRA (PCBs, dioxins/furans, and cPAHs). Tissue RBTCs represent an ingestion-weighted average based on the dietary assumptions from the HHRA, and thus are not directly comparable to non-urban Puget Sound background concentrations for specific tissue types. However, this initial comparison indicated that RBTCs for the 10^{-6} risk level (and 10^{-5} risk level for some risk drivers) are similar to or lower than non-urban Puget Sound background levels.
- Key pathways and potential sources of contaminants were identified with potential sources of contaminates being the result of both historic and on-going inputs. Source control data are available for the different pathways to evaluate recontamination potential of sediment in the FS. The evaluation of recontamination potential will inform future source control actions in EW.

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