HUMAN HEALTH AND ECOLOGICAL EFFECTS RISK ASSESSMENT

Imazapyr Risk Assessment
Washington State

Submitted to:
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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACGIH	American Conference of Governmental Industrial Hygienists
a.e.	acid equivalents
a.i.	active ingredient
ALS	acetolactate synthase
AMS	Ammonium sulfate
BCF	bioconcentration factor
BMI	Benthic macroinvertebrates
bw	body weight
°C	Degrees Celsius
CAS	Chemical Abstracts Service
CI	confidence interval
cm	centimeter
CNS	central nervous system
CRLF	California red-legged frog
EC_{25}	concentration causing 25% inhibition of a process
EC_{50}	concentration causing 50% inhibition of a process
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
EXAMS	Exposure Analysis Modeling System
F	female
FIFRA	Federal Insecticide Fungicide and Rodenticide Act
g	gram
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
GRAS	Generally Regarded as Safe
ha	hectare
HDT	Highest tested dose
HQ	hazard quotient
IRIS	Integrated Risk Information System
k_a	absorption coefficient
K_d	Soil adsorption coefficient
kg	kilogram
Koc	organic carbon partition coefficient
Kow	octanol-water partition coefficient
K_p	skin permeability coefficient
L	liter
Lb	pound
LC_{50}	lethal concentration, 50% mortality
LD_{50}	lethal dose, 50% mortality

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (continued)

LOAEL	lowest-observed-adverse-effect level
LOC	level of concern
m	meter
M	male
MATC	Maximum allowable toxic concentration
mg	milligram
mg/kg/day	milligrams of agent per kilogram of body weight per day
mL	milliliter
mM	millimole
MRID	Master Record Identification Number
MSDS	material safety data sheet
Mw	molecular weight
NAWQA	National Water Quality Assessment
NCAP	Northwest Coalition for Alternatives to Pesticides
NIOSH	National Institute for Occupational Safety and Health
NIS	non-ionic surfactant
NOAEC	no-observed-apparent-effect concentration
NOAEL	no-observed-apparent-effect level
NOEC	no-observed-effect concentration
NOEL	no-observed-effect level
NPE	nonylphenol polyethoxylate
NRC	National Research Council
OSHA	Occupational Safety and Health Administration
pK_a	acid dissociation constant
ppm	parts per million
PRZM	Pesticide Root Zone Model
RfD	reference dose
RQ	risk quotient
SERA	Syracuse Environmental Research Associates
U.S.	United States
USFS	U.S. Forest Service
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WCR	water contamination rates
WHO	World Health Organization
WSDA	Washington State Department of Agriculture
µ	micron
>	greater than
<	less than

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EXECUTIVE SUMMARY

The (WSDA) has legislative mandate to control noxious and invasive weeds in the State of Washington. Noxious weeds are plants that when established are highly destructive, competitive, or difficult to control by cultural or chemical practices (RCW 17.10.010). The WSDA is proposing the use of imazapyr formulations for weed control along riparian corridors within Washington State. This document provides risk assessments for human health effects and ecological effects to support an assessment of the environmental consequences of using imazapyr to control vegetation in riparian corridors.

Imazapyr is a broad-spectrum herbicide that is used to control a variety of grasses, broadleaf weeds, vines, and brush species, site preparation and conifer release, and rights-of-way maintenance. While imazapyr formulations can be used in pre-emergence applications, the most common and effective applications are post-emergent when the vegetation to be controlled is actively growing. Imazapyr acts as an enzyme inhibitor in plants, disrupting the biosynthesis of the three branched-chain aliphatic amino acids valine, leucine, and isoleucine. Because animals do not synthesize branched-chained aliphatic amino acids but obtain them from their diet, the mechanism for plant toxicity, i.e., the interruption of protein synthesis is not generally relevant to birds, mammals, fish, or invertebrates.

PROGRAM DESCRIPTION

Two years (817 records) of WSDA herbicide application records were reviewed to determine typical imazapyr application rates in riparian and upland vegetation. Summary statistics of the records resulted in an arithmetic mean imazapyr application rate of 0.24 lb a.e./acre, with a 95 percent confidence interval of 0.02 lb a.e./acre. The exposure point concentration for imazapyr used in both the human health and ecological risk assessments is the 95 percent upper confidence interval, or 0.26 lb a.e./acre.

Adverse effects in workers, the general public, as well as terrestrial or aquatic animals do not appear to be likely. The weight of evidence suggests that no adverse effects in these organisms are plausible using typical or worst-case exposure assumptions at the typical application rate of 0.45 lb/acre or the maximum application rate of 1.25 lb/acre.

HUMAN HEALTH RISK ASSESSMENT

Exposure assessments are conducted for both workers and the general public for the typical application rate of 0.26 lb a.e./acre. Three exposure scenarios were modeled for workers: directed ground, broadcast ground, and aerial. Exposure scenarios modeled for the general public include direct spray; dermal exposure to contaminated vegetation; and consumption of contaminated water, vegetation, and fish.

The results of the risk characterization indicate that, under the conditions modeled, neither workers nor the general public will be exposed to concentrations of imazapyr that exceed levels of concern at the typical application rate of 0.26 lb a.e./acre.

Although there are some uncertainties associated with the risk assessment for human exposure to imazapyr, the highest hazard quotients associated with imazapyr exposures are substantially below levels of concern, indicating that human exposure to imazapyr poses little risk.

ECOLOGICAL RISK ASSESSMENT

Exposure assessments are conducted for terrestrial animals (mammals, birds, amphibians, and invertebrates), terrestrial plants, aquatic animals (fish and invertebrates), and for aquatic plants at the typical application rate of 0.26 lb a.e./acre. Exposure scenarios for terrestrial animals include direct application and ingestion of contaminated water and prey. Exposure scenarios for terrestrial plants include that from runoff and from spray drift. Aquatic animals and plants are exposed via a modeled spill scenario and via runoff.

The risk characterization indicates that terrestrial and aquatic animals are not likely to be adversely affected by imazapyr under the modeled conditions. The weight of the toxicological evidence supports this conclusion that no adverse effects are likely in mammals, birds, fish, and terrestrial or aquatic invertebrates.

Off-site movement of imazapyr could affect sensitive plant species via drift or runoff, depending on site-specific conditions. When applied to areas in which runoff is favored, runoff appears to pose a greater hazard than drift. Residual soil contamination with imazapyr could be prolonged in some regions. In relatively arid areas where microbial metabolism may be the predominant degradation mechanism of imazapyr in soil, residual toxicity could last for several months to several years, especially for sensitive plant species. In areas of relatively high precipitation, soil persistence would be expected to be much shorter and residual plant toxicity less.

Characterizing risk to plants attributable to residual soil contamination is difficult because of the many variables controlling the persistence of imazapyr in soil. Given that this risk assessment is to address the potential risks to ecological receptors potentially exposed to imazapyr throughout the state of Washington, characterizing risk to plants exposed to residual soil concentrations of imazapyr is very general. The actual degree of risk to plants exposed to residual soil concentrations of imazapyr will very across the state depending on precipitation rates, soils types, and many other factors.

The risk characterization also indicates that aquatic macrophytes are more sensitive to imazapyr than unicellular algae. Peak concentrations of imazapyr in surface water modeled in this risk assessment could adversely affect some aquatic macrophytes.

Imazapyr could have indirect effects on sensitive animal and plant species, particularly those listed under the federal Endangered Species Act, through habitat alteration. Although the ecological risk assessment determined that there is very low risk to terrestrial and aquatic animal species due to direct toxic effects from imazapyr exposure, the herbicide could potentially cause habitat alterations that could, ultimately, affect sensitive species. This is especially true in riparian areas where riparian areas where riparian vegetation performs important ecological functions, including serving as terrestrial and aquatic habitat, stabilizing stream banks, providing shade to streams, and providing large woody debris to increase complexity of in-stream habitat.

As in any ecological risk assessment, the risk characterization results must be qualified. Imazapyr has been tested in only a limited number of species and under conditions that may not adequately represent ecological receptor populations. Data gaps and uncertainties associated with the ecological risk assessment are discussed in the ecological risk assessment.

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1.0 INTRODUCTION

The Washington State Department of Agriculture (WSDA) has legislative mandate to control noxious and invasive weeds in the State of Washington. Noxious weeds are plants that when established are highly destructive, competitive, or difficult to control by cultural or chemical practices (RCW 17.10.010). On behalf of the WSDA, Entrix (2003) prepared an ecological risk assessment (ERA) evaluating the potential environmental risks of imazapyr used to control cordgrass (*Spartina* spp.), a dominant invasive weed spreading throughout many of Washington's most productive estuarine tideflats. The ERA was prepared as a supplement to the original environmental impact statement (EIS) that evaluated the potential benefits and risks associated with the use of the herbicide glyphosate (i.e., Rodeo®) and other mechanical management alternatives to control *Spartina* (Ebasco, 1993).

The WSDA is proposing the use of imazapyr formulations for weed control along riparian corridors within Washington State. This document provides risk assessments for human health effects and ecological effects to support an assessment of the environmental consequences of using imazapyr to control vegetation in riparian corridors. As with the 2003 imazapyr ERA, the human health and ecological risk assessments will serve as supplements to the 1993 EIS.

The goals of the human health risk assessment (HHRA) and ERA are to:

1. Summarize current knowledge concerning the toxicity of imazapyr to humans and to target and non-target ecological receptors;

2. Estimate potential exposure to human and ecological receptors relevant to the riparian environments where the herbicide may be applied; and

3. Characterize risks from that exposure to humans and individual species and ecosystems where imazapyr formulations may be applied.

This document has four chapters, including the introduction, program description, risk assessment for human health effects, and risk assessment for ecological effects or effects on wildlife species. Each of the two risk assessment chapters has four major sections, including an identification of the hazards associated with imazapyr, an assessment of potential exposure to this compound, an assessment of the dose-response relationships, and a characterization

of the risks associated with plausible levels of exposure. These are the basic steps recommended by the National Research Council of the National Academy of Sciences (NRC, 1983) for conducting and organizing risk assessments.

The HHRA and ERA are not, and are not intended to be, comprehensive summaries of all of the available information about the toxicity and environmental fate of imazapyr. Previous HHRA and ERA documents have been published regarding the human health or ecological effects of imazapyr and were used in the preparation of this risk assessment (Entrix, 2003; SERA, 2004; EPA, 2005a, 2005b). Almost all of the mammalian toxicology studies and most of the ecotoxicology studies are contained in unpublished reports submitted to the U.S. Environmental Protection Agency (EPA) as part of the registration process for this compound. The results of these studies have been summarized in human health and ecological risk assessments prepared by EPA (2005a, 2005b), as well as by Entrix (2003) and Syracuse Environmental Research Associates (SERA) (2004) used in the preparation of this document. Additionally, a comprehensive literature review was conducted to locate more recent studies published in the scientific literature that investigated the toxicity and environmental fate and effects of imazapyr.

Risk assessments are usually expressed with numbers; however, the numbers are far from exact. Variability and uncertainty may be dominant factors in any risk assessment, and these factors should be expressed. Within the context of a risk assessment, the terms variability and uncertainty signify different conditions. Variability reflects the knowledge of how things may change. Variability may take several forms. For this risk assessment, three types of variability are distinguished: statistical, situational, and arbitrary. Statistical variability reflects random patterns in data. For example, various types of estimates used in this risk assessment involve relationships of certain physical properties to certain biological properties. In such cases, best or maximum likelihood estimates can be calculated as well as upper and lower confidence intervals that reflect the statistical variability in the relationships (SERA, 2004).

Situational variability describes variations depending on known circumstances. For example, the application rate or the applied concentration of a herbicide will vary according to local conditions and goals. As discussed in the following section, the limits on this variability are known and there is some information to indicate what the variations are. In other words, situational variability is not random (SERA, 2004).

Arbitrary variability represents an attempt to describe changes that cannot be characterized statistically or by a given set of conditions that cannot be well defined. This type of variability dominates some spill scenarios involving either a spill of a chemical on to the surface of the skin or a spill of a chemical into the environment. In either case, exposure depends on the

amount of chemical spilled and the area of skin or volume of water that is contaminated (SERA, 2004).

Variability reflects an awareness of how things may change, while uncertainty reflects a lack of such knowledge. For example, the focus of the human health dose-response assessment is an estimation of an "acceptable" or "no adverse effect" dose that will not be associated with adverse human health effects. For imazapyr, and for most other chemicals, this estimation about human health effects is based on data from experimental animal studies, which cover only a limited number of effects. Professional judgment is the basis for the methods used to make the assessment. Although the judgments may reflect a consensus (i.e., be used by many groups in a reasonably consistent manner), the resulting estimations of risk cannot be proven analytically. The estimates regarding risk involve uncertainty. The primary functional distinction between variability and uncertainty is that variability is expressed quantitatively, while uncertainty is generally expressed qualitatively (SERA, 2004).

In considering different forms of variability, almost no risk estimate presented in this document is given as a single number. Usually, risk is expressed as a central estimate and a range, which is sometimes very large. Because of the need to encompass many different types of exposure as well as the need to express the uncertainties in the assessment, this risk assessment involves numerous calculations. Some of the calculations are relatively simple and are included in the body of the document. Some sets of the calculations, however, are cumbersome. Those calculations are included in Appendix B to this risk assessment. Appendix B provides the detail for the estimates cited in the body of the document.

2.0 IMAZAPYR APPLICATION IN FRESHWATER RIPARIAN AREAS

Imazapyr formulations (Habitat® and Polaris™ AQ [now Polaris®]) have been used by the WSDA since 2004 to control cord grass (*Spartina* spp.), a dominant invasive weed spreading throughout many of Washington's most productive estuarine tideflats. Invasive weed infestations (e.g., Japanese knotweed [*Polygonum cuspidatum*], purple loosestrife [*Lythrum salicaria*], and giant hogweed [*Heracleum mantegassianum*]) along Washington's freshwater riparian corridors have prompted the WSDA to propose the use of imazapyr to control invasive species along streams and rivers. Both Habitat® and Polaris® are licensed for applications in aquatic environments consisting of standing and flowing waters, estuarine/marine areas, wetlands, and riparian areas.

Imazapyr is a broad-spectrum herbicide that is used in the control a variety of grasses, broadleaf weeds, vines, and brush species, site preparation and conifer release, and rights-of-way maintenance. While imazapyr formulations can be used in pre-emergence applications, the most common and effective applications are post-emergent when the vegetation to be controlled is actively growing. Imazapyr acts as an enzyme inhibitor in plants, disrupting the biosynthesis of the three branched-chain aliphatic amino acids valine, leucine, and isoleucine. (Pless, 2005) Because animals do not synthesize branched-chained aliphatic amino acids but obtain them from their diet, the mechanism for plant toxicity, i.e., the interruption of protein synthesis, is not generally relevant to birds, mammals, fish or invertebrates (Pless, 2005).

Syracuse Environmental Research Associates conducted human health and ecological risk assessments for the U.S. Forest Service (USFS) in 2004 to evaluate risks to human and ecological receptors exposed to imazapyr formulations for vegetation control in national forests. SERA reviewed USFS herbicide application records for 2001. Based on their review, they determined that application rates used to construct the various exposure scenarios ranged from 0.03 lb acid equivalents (a.e.)/acre to 1.25 lbs a.e./acre with a typical rate taken as 0.45 lb a.e./acre. SERA (2004) reported that the typical application rate was about the average application rate that the Forest Service used in 2001 for noxious weed control and was near the geometric mean of the recommended range of application rates, 0.125 to 1.25 lbs a.e./acre.

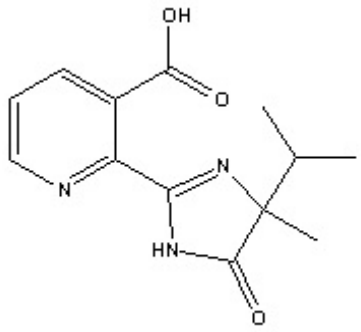
Two years of WSDA herbicide application records were reviewed to determine typical imazapyr application rates. Review of the application records revealed that imazapyr was used to control *Spartina* spp. in estuarine areas and to control invasive plants such as knotweed (*Polygonum* spp.) and purple loosestrife (*Lythrum salicaria*) primarily along riparian corridors. Application rates differed substantially for imazapyr, depending on the target species. Imazapyr formulations applied to control *Spartina* spp. were applied at 5 to 6 pints

per acre, which is equivalent to 1.25 to 1.5 lbs a.e./acre. When used to control other species along riparian areas, application rates varied considerably. Because the intent of the risk assessments is to evaluate potential human health and environmental risks associated with applying imazapyr formulations along riparian corridors, we conducted summary statistics of 817 herbicide application records where imazapyr was used to control species other than *Spartina* spp. Applications records for the use of imazapyr to control *Spartina* spp. were not included in the statistical analysis.

The arithmetic mean imazapyr application rate was 0.24 lb a.e./acre, with a 95 percent confidence interval (CI) of 0.02 lb a.e./acre. According to EPA (2001), the exposure point concentration is usually calculated as the 95 percent upper CI (UCI) of the arithmetic mean because of the uncertainty associated with estimating the true population mean. Therefore, the exposure point concentration for imazapyr used in both the human health and ecological risk assessments is the 95 percent UCI, or 0.26 lb a.e./acre.

2.1 CHEMICAL DESCRIPTION AND COMMERCIAL FORMULATIONS

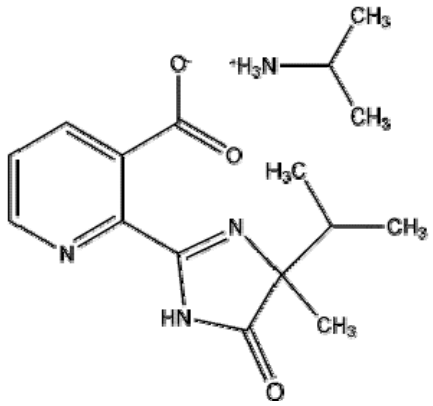
Imazapyr is the common name for 2-(4,5-dihydro-4-methyl-4-[1-methylethyl]-5oxo-1*H*imidazol-2-yl)-3-pyridinecarboxylic acid:



The non-selective herbicide imazapyr is an anionic, organic acid that is non-volatile and is both persistent and mobile in soil. Commercial formulations contain either imazapyr acid or the imazapyr isopropylamine salt, both of which are generally dissolved in a water solution. Imazapyr is mainly in anionic form at typical environmental pHs, and the behavior of the acid and salt forms are expected to be similar. Aqueous photolysis is the only identified route of degradation for imazapyr in the environment. Imazapyr degraded through photolysis in water with half-lives ranging between 2.5 and 5.3 days. The two major degradates have been identified as: 2,3-pyridinecarboxylic acid and 7-hydroxy-furo(3,4-b)pyridin-5(7H)-one. Laboratory studies show imazapyr is essentially stable to hydrolysis, aerobic and anaerobic soil degradation, as well as aerobic and anaerobic aquatic metabolism. Field study

observations are consistent with laboratory studies indicating that imazapyr will persist in soils and move via runoff to surface water and leach to groundwater. Imazapyr does not bioconcentrate (EPA, 2005a).

The imazapyr formulations Habitat® and Polaris® consist of the isopropylamine salt of imazapyr:



Information about the chemical and physical properties is summarized in Table 1.

The Habitat® and Polaris® formulations contain imazapyr at 2 lbs a.e./gallon. Information on inert ingredients and impurities in imazapyr formulations is considered proprietary under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Section 10. Inert ingredients are defined by EPA (2008) as follows:

> An inert ingredient means any substance (or group of structurally similar substances if designated by the Agency), other than an active ingredient, which is intentionally included in a pesticide product. Inert ingredients play a key role in the effectiveness of a pesticidal product. For example, inert ingredients may serve as a solvent, allowing the pesticide's active ingredient to penetrate a plant's outer surface. In some instances, inert ingredients are added to extend the pesticide product's shelf-life or to protect the pesticide from degradation due to exposure to sunlight. Pesticide products can contain more than one inert ingredient, but federal law does not require that these ingredients be identified by name or percentage on the label.

The potential significance of inert ingredients in imazapyr can be inferred based on differences in the toxicity of the formulations and technical grade imazapyr.

As reported in SERA (2004), the Northwest Coalition for Alternatives to Pesticides (NCAP) has obtained information on the identity of the inert ingredients in the imazapyr formulation Arsenal® AC from EPA under the Freedom of Information Act and has listed this information on the NCAP Web site (http://www.pesticide.org/FOIA). The only inert ingredient listed for

Arsenal® AC, other than water, is glacial acetic acid (CAS No. 64-19-7). Dilute acetic acid is an approved food additive and is also classified as a Generally Recognized as Safe (GRAS) compound (SERA, 2004). Acetic acid is a major component of vinegar and is a List 4B inert (SERA, 2004).

2.2 APPLICATION METHODS

Habitat® and Polaris® are licensed for the control of undesirable emergent and floating aquatic vegetation in estuarine and marine surface waters, as well as to control undesirable wetland, riparian and terrestrial vegetation growing in or around surface waters when applications may result in inadvertent applications to surface water. Both formulations can also be used to control undesirable vegetation in fencerows, non-irrigation ditch banks, wildlife openings, and industrial non-cropland areas including railroad, utility, pipeline and utility plant sites, petroleum tank farms, pumping installations, storage areas, non-irrigation ditchbanks, roads, transmission lines, and industrial bare-ground areas (BASF, 2008; Nufarm, 2008).

The most common methods of ground application for imazapyr formulations involve backpack (selective foliar) and boom spray (broadcast foliar) operations. Habitat® and Polaris® may also be applied aerially.

2.3 APPLICATION RATES

Application rates of 2 to 6 pints Habitat® or Polaris® /acre /year are recommended on the product labels (BASF, 2009; Nufarm, 2008). This is equivalent to 1 to 3 quarts of formulation per acre or 0.25 to 0.75 gallons formulation per acre. Given that there is 2 lbs a.e./gallon in both Habitat® and Polaris®, these rates correspond to 0.5 to 1.5 lbs a.e./acre.

Post-emergence applications of both formulations require the addition of a spray adjuvant for optimum herbicide performance. Only spray adjuvants that are approved or appropriate for aquatic use should be utilized. Adjuvants recommended by the manufacturers include:

- **Non-Ionic Surfactants.** Added at the rate of 0.25 percent volume/volume (v/v) or higher of the spray solution (0.25 percentv/v is equivalent to 1 quart in 100 gallons);
- **Methylated Seed Oil or Vegetable Oil Concentrate.** Instead of a surfactant, a methylated seed oil or vegetable-based seed oil concentrate may be used at the rate of 1.5 to 2 pints per acre; and
- **Silicone-Based Surfactants.** These surfactants are to be added according to a specific manufacturer's recommendations

Other adjuvants may include antifoaming agents, spray pattern indicators or drift-reducing agents (Nufarm, 2008).

Some of the adjuvants used by WSDA for its imazapyr applications include AgriDex® and Dyne-Amic® (B. Stuart, Biologist, AMEC Geomatrix, Inc., and M. Udo, WSDA, pers. comm., June 6, 2009). For additional information about these adjuvants, please refer to Section 3.2.13.

For this risk assessment, the typical application rate will be taken as 0.26 lb a.e./acre. The typical application rate represents the 95 percent UCI for the application rate for imazapyr used by the WSDA to control noxious weeds in riparian areas. The maximum application rate will be taken as to 1.5 lbs a.e./acre, which is the maximum application rate specified on the labels for Habitat® and Polaris® (BASF, 2008; Nufarm, 2008). The tables in Appendix B are based on the typical application rate of 0.26 lb/acre rather than the full range of application rates. The consequences of varying application rates up to the maximum of 1.5 lbs a.e./acre is considered in the risk characterization for human health (Section 3.5) and ecological effects (Section 4.5).

The extent to which imazapyr formulations are diluted prior to application primarily influences dermal and direct spray scenarios, both of which are dependent on the "field dilution" (i.e., the concentration of imazapyr in the applied spray). In all cases the higher the concentration of imazapyr, the greater the risk. For this risk assessment, the lowest dilution will be taken at 5 gallons/acre. The highest dilution (i.e., that which results in the lowest risk) will be based on 20 gallons of water per acre. This is a conservative approach in that some applications of imazapyr formulations will involve more dilute solutions that consequently present a lesser risk. The central estimate will be taken as 10 gallons of water per acre, the geometric mean of the range of 5 to 20 gallons per acre (SERA, 2004). These values are entered into Table B-1 in Appendix B.

It should be noted that the selection of application rates and dilution volumes in this risk assessment is intended to simply reflect typical or central estimates as well as plausible lower and upper ranges. The tables in Appendix B are based on the typical application rate of 0.26 lb a.e./acre rather than the full range of application rates.

2.4 ENVIRONMENTAL PERSISTENCE AND MOBILITY

Commercial formulations of imazapyr contain either imazapyr acid or the imazapyr isopropylamine salt, both of which are generally dissolved in a water solution. Imazapyr is mainly in anionic form at typical environmental pHs, and the behavior of the acid and salt forms are expected to be similar (EPA, 2005a). The persistence and movement of imazapyr in the environment, particularly in soils, is highly complex and substantially different estimates of persistence and transport can be made under different site-specific conditions. This section

presents a summary of available information about the environmental fate and transport of imazapyr in water, soil, and tissues.

2.4.1 Persistence and Mobility of Imazapyr in Aquatic Environments

Aqueous photolysis is the only identified route of degradation for imazapyr in the environment. In laboratory studies, imazapyr degraded through photolysis in water with half-lives ranging between 2.5 and 5.3 days. The two major degradates were: 2,3-pyridinecarboxylic acid, and 7-hydroxy-furo(3,4-b)pyridin-5(7H)-one. Laboratory studies show imazapyr is essentially stable to hydrolysis (EPA, 2005a).

In field studies, Arsenal® 2AS, the isopropylamine salt of imazapyr (22.6 percent a.e. in aqueous solution), rapidly dissipated from shallow ponds in Florida and Louisiana during summer months. In Florida, Arsenal® 2AS applied at the proposed maximum label rate of 1.5 lbs a.e./acre dissipated with half-lives of 3 and 4 days in pond water and sediment, respectively. In the Louisiana study, Arsenal® 2AS dissipated with half-lives of 2 and 4 days in pond water and sediment, respectively (EPA, 2005a).

Mangels and Ritter (2000) conducted bioaccumulation studies with imazapyr as part of the product registration process. Freshwater ponds in Missouri and Florida containing bluegill, tilapia, catfish, and crayfish were treated with imazapyr. Arsenal® was applied to the banks and outer edges of the ponds at a rate of 1.6 lbs a.e./acre. Imazapyr concentrations were monitored in surface water and sediments. Reported half-lives for imazapyr in water ranged from 3.9 to 14.5 day, while the only reported half-life for imazapyr in sediment was 9.2 days (Table 2).

Patten (2003) investigated imazapyr persistence when applied under tidal estuary conditions in Willapa Bay, Washington. Imazapyr was applied at a rate of 1.68 kg a.e./hectare (ha) (1.5 lbs a.e./acre) to a 30- by 33-meter (m) area of bare mudflat on the upper intertidal zone of Willapa Bay and to three replicate plots (3-m X 4-m) of smooth cordgrass (*Spartina alterniflora*). Agridex® at 1 percent (v/v) was used as a surfactant. Water and sediment temperatures at application were 13°C and 19°C, respectively. The sediment parameters at the bare mudflat study site were as follows: 49 percent moisture; pH 7.9; organic matter 5.4 percent; and 18.3, 65.5, 16.2 percent sand, silt, clay, respectively. Water and sediment samples were collected after application and after the 1st, 2nd, 6th, 14th, 28th, and 56th tidal sequences following application (1, 14, 27, 77, 184, 366, and 703 hours after treatment).

Patten (2003) reported that the persistence of imazapyr in water and sediment followed exponential decay upon application to estuary mud. The maximum concentrations found in water and sediment after application was 3.4 micrograms/milliliter (µg/mL) (parts per million

[ppm]) and 5.4 µg/gram (g) (ppm), respectively. Water and sediment concentrations approached the zero asymptote at 40 and 400 hours after treatment, respectively. This represents water and sediment half lives of <0.5 and 1.6 days, respectively. Imazapyr concentration in water decreased rapidly within a short distance away from the spray zone. Water collected just 6 or 60 m from outside the spray zone at the first incoming tide had imazapyr concentration equivalent to water collected at the seventh tidal sequence at the immediate edge of the spray zone. In comparison to imazapyr applied to bare mud, an application to a smooth cordgrass canopy resulted in a sediment concentration of 1.4 µg/g in underlying sediments, a concentration nearly four times lower than that for imazapyr applied directly to sediments.

2.4.2 Persistence and Mobility of Imazapyr in Soil

Please refer to Appendix A for a discussion of the persistence and mobility of imazapyr in soil.

2.4.3 Persistence of Imazapyr in Tissues

Relatively few studies have been conducted examining biological uptake (bioaccumulation) and persistence of imazapyr in tissues. Mangels and Ritter (2000) conducted bioaccumulation studies with imazapyr as part of the product registration process. Freshwater ponds in Missouri and Florida containing bluegill, tilapia, catfish, and crayfish were treated with imazapyr. Arsenal® was applied to the banks and outer edges of the ponds at a rate of 1.6 lbs a.e./acre. Imazapyr concentrations were monitored in the ponds and fish tissue samples were collected to measure uptake by test animals. The results of the studies are summarized in Table 2. As can be seen from Table 2, imazapyr was detected in tissues of test animals at three hours post-treatment in only one of the four treatment ponds. Thereafter, tissue imazapyr concentrations were below the method detection limit of 50 µg/kilogram (kg) (parts per billion [ppb]), indicating a very low potential for tissue bioaccumulation.

Christensen (1999) examined the potential for bioconcentration and persistence in the freshwater clam (*Corbicula fluminea*) exposed to Arsenal® in a pond mesocosm treated at a nominal concentration 0.091 lb a.e./acre. Similar to the study results reported above, no imazapyr was detected in the clam tissue at or above the 50 µg/kg (ppb) method detection limit. Over the 28-day study, the concentration of imazapyr in the water declined only minimally, from 81 to 75.1 ppb, while the sediment concentration increased from non-detectable to 29.2 ppb at the end of the experiment.

3.0 HUMAN HEALTH RISK ASSESSMENT

This section presents the human health risk assessment (HHRA) that evaluates the potential risks to human receptors exposed to imazapyr. The HHRA will be discussed in the following subsections:

- Overview of approach;
- Hazard identification;
- Exposure assessment;
- Dose-response assessment;
- Risk characterization; and
- Data gaps and uncertainty.

3.1 OVERVIEW OF APPROACH

The human health risk assessment follows the methodology recommended by EPA for the assessment of chemicals with non-cancer health endpoints (EPA, 1997). This methodology generally includes the following four steps:

- **Hazard Identification** – Identifying the Imazapyr formulations that will be addressed in the risk assessment and the toxicological hazards posed by these products.
- **Exposure Assessment** – Characterizing the magnitude, frequency, and duration of exposure to Imazapyr for workers and members of the general public.
- **Dose-Response Assessment** – The quantitative relationship between the chemical dose and the incidence of adverse health effects in humans.
- **Risk Characterization** – Estimating the potential for adverse health effects by integrating the information from the dose-response assessment with the exposure assessment.

Each of these steps is discussed in greater detail in subsequent sections.

3.2 HAZARD IDENTIFICATION

This section discusses the toxicity of imazapyr to mammalian test species (e.g., rats and rabbits) used as surrogates to assess the potential toxicity of imazapyr to humans.

3.2.1 Overview

The toxicity of imazapyr has been relatively well-characterized in laboratory studies using mammalian test species. All of the mammalian toxicity information is contained in unpublished studies that were submitted to EPA as part of the imazapyr registration process. Several

clinical cases of human ingestion of large amounts of Arsenal® have been reported in the literature (see Lee et al., 1999). Symptoms include vomiting, impaired consciousness, and respiratory distress. No fatal cases of imazapyr ingestion have been reported (SERA, 2003; EPA, 2005a).

The mode of action of imazapyr in mammals is unclear; however, mammalian toxicity studies indicate low and essentially undetectable acute and chronic systemic toxicity for imazapyr. The acute oral LD_{50} (lethal dose causing mortality in 50 percent of test population) of unformulated imazapyr is greater than 5,000 mg/kg (ppm – 0.5 percent) and the chronic dietary no-observed-apparent-effect level (NOAEL) for imazapyr is 10,000 ppm (1 percent) in dogs, rats, and mice. In the dog, this dietary concentration is equivalent to a daily dose of 250 mg active ingredient (a.i.)/kg/day. In the other test species, the equivalent daily doses are higher than 250 mg/kg/day. Multi-generation reproductive and developmental studies have demonstrated no adverse effects on reproductive capacity or normal development. No adverse carcinogenic or mutagenic effects have been reported, and EPA has categorized the carcinogenic potential of imazapyr as *Class E: evidence of non-carcinogenicity* (SERA, 2004).

Chronic toxicity studies in which imazapyr was added to the diets of male and female mice, as well as female rats, reported increased food consumption. It is unclear if this effect is attributable to imazapyr toxicity or whether imazapyr in the feed may have affected chow palatability. The weight of evidence suggests that imazapyr is not directly neurotoxic, nor do available data suggest systemic toxic effects after dermal or inhalation exposures to imazapyr. Similarly, while the available data are limited, there is no indication that impurities or adjuvants in or metabolites of imazapyr pose a risk of toxicity to mammals. Imazapyr and imazapyr formulations can be mildly irritating to the eyes and skin (SERA, 2004).

3.2.2 Mechanism of Action

Imazapyr inhibits the enzyme acetolactate synthase in plants, which is required for the synthesis of essential amino acids (valine, leucine, and isoleucine). This enzyme is not present in animals, and the mechanism of action in animals and man is unknown (EPA, 2005a, 2005b; SERA, 2004).

3.2.3 Kinetics and Metabolism

Mallipudi et al. (1983) and Zdybak (1992) investigated the metabolism and kinetics of imazapyr in rats and lactating goats, respectively. Data from these studies suggest that orally-administered imazapyr is well absorbed and that the majority of the administered dose is rapidly excreted, unchanged, in urine and feces. ^{14}C-labeled imazapyr was administered to 15 male Sprague Dawley rats (body weight = 225 g) by gavage at a dose of 4.4 mg/kg. Approximately 98 percent of the administered dose was recovered as parent compound in the

urine and feces after 8 days with no residues in liver, kidneys, muscle, or blood (Mallipudi et al., 1983; Miller et al., 1991). No metabolites were identified (Mallipudi et al., 1983). Similar results were reported in lactating goats administered ^{14}C-imazapyr acid in amounts equivalent to dietary exposures of 0, 17.7, and 42.5 mg/kg for 7 days (Zdybak, 1992). Sixty to 65 percent of the administered dose was excreted in the urine as parent compound; while 16 percent to 19 percent of the administered dose was recovered from feces. Only very small amounts were recovered from milk, blood, kidneys, liver, muscle, and fat.

Tsalta (1995), studying imazapyr metabolism in white leghorn chickens, reported results similar to those for mammalian studies. Imazapyr was excreted as the parent compound.

3.2.4 Acute Oral Toxicity

Only limited information is available about the toxicity of imazapyr in humans. Lee et al. (1999) reported six cases of acute imazapyr poisoning in Taiwan. Five of the cases were adults (4 men, 1 woman) who attempted suicide by ingesting concentrated (undiluted) Arsenal® (23.1 percent w/w imazapyr as the isopropylamine salt) in approximate amounts of 75, 100, 120, 300, and 500 mL. The sixth case was a 4-year-old boy who was forced to swallow approximately 2 mL of Arsensal®. None of the cases resulted in death. Lee et al. (1999) reported copious vomiting following ingestion in all six cases. Three of the five adults had severe symptoms including impaired consciousness and respiratory distress requiring intubation. Other effects in the adults included oral mucosal and gastrointestinal irritation and transient liver and renal dysfunction. Vomiting was the only effect observed in the child. The authors concluded that the clinical observations constituted a toxic syndrome resulting from ingestion of a large amount (>100 mL) of Arsenal®, although the specific component(s) in the Arsenal® formulation responsible for the toxic reactions are unknown.

Little information is available on the acute toxicity of imazapyr in mammals. An acute oral toxicity study was required as part of the pesticide registration process for imazapyr. As summarized in Table 3, single oral doses of 5,000 mg/kg of a 2 lbs a.e./gallon formulation of imazapyr (corresponding to 25 mL formulation/kg body weight) was administered to groups of five male and female rats. Over the 14-day observation period, one male rat died. Abnormal findings in this rat included congestion of liver, kidney, and intestinal tract, as well as hemorrhagic lungs (Fischer, 1983). None of the surviving rats showed signs of toxicity. It is unclear if the death of the one male rat was associated with treatment. In a similar study using a mixture of imazapyr and a related herbicide, imazethapyr, at a total dose of 5,000 mg/kg, no effects were noted (Lowe, 1988). A review of unpublished studies of imazapyr sponsored by American Cyanamid (Peoples, 1984) indicates that the oral LD_{50} of unformulated imazapyr (i.e., presumably technical grade imazapyr) is greater than 5,000 mg/kg. No further

information on the acute oral toxicity of imazapyr has been encountered in EPA's files on this compound or other reviews in the published literature (Cox, 1996; Gagne et al., 1991).

3.2.5 Subchronic or Chronic Toxicity

Chronic toxicity studies on imazapyr have been conducted in three species: dogs (Shellenberger, 1987), mice (Auletta, 1988; Hess, 1992), and rats (Daly, 1988; Hess, 1992). These studies were submitted to EPA in support of the registration of imazapyr; none of the studies are published in the open peer-reviewed literature. The studies do not suggest any toxicity at dietary concentrations of up to 10,000 ppm. In the rat feeding study (Daly, 1988), a slight decrease in survivorship is apparent with increasing dose; however, these changes are not statistically significant at any of the observation intervals (i.e., 6 months, 12 months, 18 months, and 24 months). Consequently, the dietary NOAEL of 10,000 ppm from the 1-year dog feeding study (Shellenberger, 1987) is used as the basis for EPA's reference dose (RfD), as discussed further in Section 3.4.2. EPA (1997) calculated that the dietary concentration of 10,000 ppm resulted in an average daily dose of about 250 mg/kg/day in dogs, based on midpoint food consumption and body weights reported by Shellenberger (1987).

The rat (Daly 1988) and mouse (Auletta, 1988) chronic dietary studies indicated a slight, and in some cases statistically significant, increase in food consumption with no corresponding increase in body weight. Three classes of mechanisms could produce this effect: a biochemical basis, such as uncoupling of oxidative phosphorylation; an endocrine basis – e.g., changes in thyroid hormone secretion, or increased corticosteroid levels – or a neurological basis involving hyperactivity (SERA, 2004). Imazapyr has been implicated in the development of thyroid tumors (Section 3.2.10). While a detailed review of the carcinogenicity studies do not support the assertion that imazapyr is carcinogenic, changes in appetite could be associated with effects on the thyroid (SERA, 2004). Without additional mechanistic studies, the basis for the observed effects on food consumption remain speculative (SERA, 2004).

Hess (1992) conducted a 13-week subchronic study using rats exposed to imazapyr at dietary concentrations higher than the maximum tested in the chronic studies summarized above. Exposure to levels of 15,000 or 20,000 ppm caused no toxicity in either sex. The 13-week study established a subchronic dietary NOAEL at the highest tested dose of 20,000 ppm in rats, which corresponded to daily doses of about 1,700 mg/kg/day. This NOAEL in rats is twice that in dogs reported by Shellenberger (1987).

Two standard teratology studies in Charles River rats involving gavage administration (discussed further in Sections 3.2.6 and 3.2.8) reported dose-related increases in salivation in treated dams (Salamon et al., 1983a, 1983b). Salivation can be a sign of a neurologic involvement (SERA, 2004). This effect, however, was not reported in a dietary reproduction

study involving Sprague-Dawley rats (Robinson, 1987) and was not noted in any of the acute toxicity studies summarized in Section 3.2.4 or in the chronic toxicity studies discussed above.

3.2.6 Endocrine System Effects

Imazapyr has not been tested for activity as an agonist or antagonist of the major hormone systems (e.g., estrogen, androgen, thyroid hormone), nor have the levels of these circulating hormones been measured following imazapyr exposures. Any judgments concerning the potential effect of imazapyr on endocrine function must be based on inferences from standard toxicity studies (SERA, 2004).

The available toxicity studies have not reported any histopathologic changes in endocrine tissues that have been examined as part of the standard battery of tests. As discussed in Section 3.2.5, the increased food consumption noted in some chronic feeding studies in rodents (Auletta, 1988; Daly, 1988) could be associated with endocrine function – i.e., a change in thyroid status. However, none of the animal studies reported abnormal thyroid histology or hormone levels in the standard clinical chemistry results that were attributed to imazapyr exposure (SERA, 2004). Auletta (1988) noted an increase in the incidence of elevated seminal vesicle weight, suggesting that this is a *"common findings in old mice."* The response appears to be dose related and the development of the seminal vesicles is stimulated by androgenic hormones (SERA, 2004)

3.2.7 Immune System Effects

No studies were located that addressed the immunotoxic potential of imazapyr. The toxicity of imazapyr has been examined in numerous acute, subchronic, and chronic bioassays, but none of these studies focused on imazapyr's toxicity to the immune system. Changes in the immune system were not observed in any of the available long-term animal studies (SERA, 2004).

3.2.8 Nervous System Effects

Virtually any chemical will cause signs of neurotoxicity in severely poisoned animals and, thus, can be classified as an indirect neurotoxin. This is the case for imazapyr. At high doses that produce a broad spectrum of toxic effects, clinical signs of poisoning include neurotoxicity, manifested as impaired consciousness and respiratory distress in humans (Lee et al., 1999), decreased activity in rats (Fischer, 1986b), and loss of equilibrium and inactivity in fish (Cohle and McAllister, 1984b, 1984c). These reports from acute high-dose exposures, however, do not implicate imazapyr as a direct neurotoxin.

General pharmacology studies with imazapyr isopropylamine revealed central nervous system (CNS) effects following oral exposure (SERA 2004). Imazapyr isopropylamine was

administered orally to male mice and male rabbits at concentrations of 1,000, 3,000, or l0,000 mg/kg to define effects on gross behavior, the central nervous system, and the digestive system. Imazapyr isopropylamine was also administered intravenously to male rabbits and male rats at does of 100, 300, 1,000, or 3,000 mg/kg to assess the effects on skeletal muscle and respiratory and circulatory systems. The chemical produced a stimulant effect on gross behavior and increased the sleeping time induced by hexobarbital (an anesthetic and sedative) at high doses in mice, slightly increased muscle contractility in rats, depressed gross behavior at high doses in rabbits, slightly changed respiratory rate, blood pressure, and heart rate in rabbits, and increased the volume of urine at high doses in both mice and rabbits. No effect on the digestive system was observed. These data suggest that exposure to imazapyr isopropylamine at the reported doses produces CNS effects.

Neurotoxicity has not been noted in other studies investigating reproductive or developmental effects of imazapyr, nor has neurotoxicity been reported in standard acute and chronic toxicity studies. None of the toxicity studies with the imazapyr have reported histopathological changes in nervous tissue. Thus, the weight of evidence does not indicate that imazapyr is directly neurotoxic.

3.2.9 Reproductive and Teratogenic Effects

No studies on potential reproductive or teratogenic effects are available in the published literature. Several studies, summarized in Table 3, investigating the reproductive effects of imazapyr in rats and rabbits have been conducted by the manufacturer (American Cyanamid) and submitted to EPA in support of the registration of imazapyr. These studies were reviewed by EPA (1997) and were classified as acceptable and adequate. Even at dose levels that cause signs of maternal toxicity (including death), the studies did not indicate that imazapyr causes adverse reproductive or developmental effects.

3.2.10 Carcinogenicity and Mutagenicity

EPA (1997) reviewed a number of assays for mutagenicity, as well as chronic studies in mice (Auletta, 1988) and rats (Daly, 1988), that assessed the carcinogenic potential of imazapyr. Some of the observations from the chronic rat study (Daly, 1988) raised concerns for potential carcinogenic activity. Histopatholgoical examination of test animals revealed an increased incidence of C-cell carcinomas in the thyroid glands of male rats exposed to10,000 ppm for up to 2 years, compared with male rats in the middle-dose, low-dose (1,000 ppm), and matched control (0 ppm) groups. The incidences of C-cell carcinomas for all groups of male rats in the Daly (1988) study are within the range of the historical control data (13.7 percent), although the incidence in high-dose male rats (7.69 percent) was almost twice the average incidence (4.10 percent) reported in the historical control data (Daly, 1988; Daly et al., 1991).

Further examination was conducted to review the data on 260 thyroid glands from male rats in the study. The examination concluded that the difference in C-cell carcinomas between the treated and untreated rats was not statistically significant at $p<0.05$ and that the difference between the control and high-dose male rats with respect to the incidence of C-cell carcinomas was of no biological significance because it was consistent with that reported in other studies conducted at the same laboratory as the Daly (1988) study and in studies published in the open literature.

The results of two gene mutation studies (*Salmonella typhimurium/Escherichia coli* and Chinese hamster ovary cell gene mutation) and chromosomal aberration studies (Chinese hamster ovary cells) were reviewed by EPA (1997) and classified as acceptable and negative for potential mutagenic activity. Based on these studies, EPA (1997) has categorized imazapyr as *Class E: evidence of non-carcinogenicity*. Further support for lack of genotoxic activity comes from other mutagenicity studies that have been conducted and submitted to EPA in support of the registration of imazapyr (Allen et al., 1983; Cortina, 1984; Enloe et al., 1985; Johnson and Allen, 1984; Sernau, 1984). All of these studies demonstrated a negative response.

3.2.11 Dermal Exposure Effects

Several studies, summarized in Table 3, on the effects of dermal exposure to imazapyr in experimental animals have been conducted and submitted to EPA in support of the registration of imazapyr. The available data suggest that dermal exposure to 2,000 mg/kg imazapyr was not associated with any signs of systemic toxicity in rabbits based on standard acute/single application bioassays with 14-day observation periods. A single dose of Arsenal® AC at 5,000 mg/kg was not associated with mortality, signs of toxicity or changes in body weight (Lowe and Bradley, 1996).

There are no data concerning the dermal absorption kinetics of imazapyr; however, absorption is typically less rapid than absorption after oral exposure and dermal LD_{50}'s are typically higher than oral LD_{50}'s (SERA, 2004). Because the acute oral LD_{50} of imazapyr is more than 5,000 mg/kg (Fischer, 1983), the lack of apparent toxicity at dermal doses of up to 2,000 mg/kg/day is to be expected and these studies add little to the assessment of risk for imazapyr after dermal contact.

Most of the occupational exposure scenarios and many of the exposure scenarios for the general public involve the dermal route of exposure. For these exposure scenarios, dermal absorption is estimated and compared with an estimated acceptable level of oral exposure based on subchronic or chronic toxicity studies. Thus, it is necessary to assess the

consequences of dermal exposure relative to oral exposure and the extent to which imazapyr is likely to be absorbed from the surface of the skin (SERA, 2004).

According to SERA (2004), dermal exposure scenarios involving immersion or prolonged contact with chemical solutions use Fick's first law and require an estimate of the permeability coefficient, K_p, expressed in centimeters (cm)/hour. Because no kinetic data are available for the dermal absorption of imazapyr, the method for estimating a zero-order absorption rate (EPA, 1992) is used in this risk assessment. Using this method, a dermal permeability coefficient for imazapyr is estimated at 0.000056 cm/hour with a 95 percent confidence interval of 0.000028 to 0.00011 cm/hour. These estimates are used in all exposure assessments that are based on Fick's first law. The calculations for these estimates are presented in Appendix B, Table B-8. For exposure scenarios like direct sprays or accidental spills, which involve deposition of the compound on the skin's surface, dermal absorption rates (proportion of the deposited dose per unit time) rather than dermal permeability rates are used in the exposure assessment. Using the methods detailed in Durkin et al. (1995), the estimated first-order dermal absorption coefficient is 0.0011 hour-1 with 95 percent confidence intervals of 0.00044 to 0.0029 $hour^{-1}$. The calculations for these estimates are presented in Appendix B, Table B-9.

3.2.12 Inhalation Exposure Effects

Three studies investigated the inhalation toxicity of imazapyr (Table 3). No toxic effects were observed during or after 4-hour exposures to either imazapyr or imazapyr formulations at aerosol concentrations of >5 mg/L (Peoples, 1984). In post-treatment burns, brown-and-burn operations conducted 30 to 180 days after imazapyr treatment, McMahon and Bush (1992) found no detectable concentrations of imazapyr in the breathing zone of workers during operations in plots that had been treated with imazapyr 69 or 106 days earlier at application rates of up to 3.5 L/ha (0.92 gal/ha or 1.84 lbs imazapyr a.e./ha or about 0.77 lb a.e./acre).

3.2.13 Inert Ingredients and Adjuvants

The inert ingredients used by pesticide manufacturers in specific formulations are considered proprietary under FIFRA. Other than to state that no apparently hazardous materials have been identified, this information cannot be detailed. All of the technical formulations of imazapyr covered in this risk assessment involve the isopropyl or isopropanolamine salts of imazapyr. Little toxicity information is available on these compounds. Isopropanolamine is classified by EPA (1998) as a List 3 inert, which are compounds that EPA cannot classify as hazardous or non-hazardous based on the available information. Isopropylamine, and a large number of other derivatives of isopropanol, are used as food additives and classified as GRAS compounds. None of the inert ingredients used in any of the imazapyr formulations have been classified by EPA as hazardous (List 1 or List 2) (SERA, 2004).

The Northwest Coalition for Alternatives to Pesticides (NCAP) has obtained information on the identity of the inert ingredients in Arsenal® AC from EPA under the Freedom of Information Act has listed this information on the NCAP web site (http://www.pesticide.org/FOIA/imazapyr.html). The only inert listed at this site other than water is glacial acetic acid (CAS No. 64-19-7). Dilute acetic acid, major component of vinegar, is an approved food additive and is also classified as a GRAS compound (SERA, 2004).

Adjuvants are spray-solution additives that are mixed with an herbicide solution to improve performance of the spray mixture. Adjuvants can either enhance activity of an herbicide's active ingredient (activator adjuvant) or offset any problems associated with spray application, such as adverse water quality or wind (special purpose or utility modifiers). Activator adjuvants include surfactants, wetting agents, sticker-spreaders, and penetrants (Bakke, 2007).

Adjuvants are not under the same registration guidelines as are pesticides. EPA does not register or approve the labeling of spray adjuvants. All adjuvants are generally field tested by the manufacturer with several different herbicides and under different environments. Surfactants, or surface-acting agents, are a broad category of activator adjuvants that facilitate and enhance the absorbing, emulsifying, dispersing, spreading, sticking, wetting, or penetrating properties of herbicides (Bakke, 2007).

The labels for the imazapyr formulations Habitat® and Polaris® recommend the addition of adjuvants to the spray mixture, including non-ionic surfactants, methylated seed oils or vegetable oil concentrates, or silicone-based surfactants. Other adjuvants may include antifoaming agents, spray-pattern indicators, and drift-reducing agents.

Surfactants are the most common adjuvants added to herbicide spray mixes. A review of two years (2004 and 2007) of WSDA imazapyr application records revealed that the surfactants most commonly used with imazapyr formulations are R-11®, Agri-Dex®, Dyne-Amic®, and Class Act® NG. Brief descriptions of each of these surfactants are provided below.

3.2.13.1 Agri-Dex®

Agri-Dex® is classified as a crop oil/crop-oil concentrate. These are normally derivatives of paraffin-based petroleum oil. Crop oils are generally 95 to 98 percent oil with 1 to 2 percent surfactant/emulsifier. Crop oils also promote the penetration of a pesticide spray. Traditional crop oils are more commonly used in insect and disease control than with herbicides. Crop oil concentrates are a blend of crop oils (80 to 85 percent) and a non-ionic surfactant (15 to 20 percent). The purpose of the non-ionic surfactant in this mixture is to emulsify the oil in the spray solution and lower the surface tension of the overall spray solution (Bakke, 2007).

Agri-Dex® is a non-ionic surfactant consisting of a mixture of heavy and light range paraffin-based petroleum oils (82 percent), polyol fatty acid esters and polyoxyethylated polyol fatty acid esters (not identified further) (17 percent) (EPA List 3 surfactant/emulsifier), and inert ingredients (1 percent) (Bakke, 2007).

Agri-Dex® may be mildly irritating to the skin and eyes. The primary ingredient, paraffin-based oils, is described as a solvent refined paraffinic distillate containing a mixture of hydrocarbons having carbon numbers predominantly in the range C20-C50 (heavy paraffinic) or C15-30 (light paraffinic). The light paraffin oil is also identified as a horticultural spray oil. It is of low oral and dermal acute toxicity. The paraffin oil mixtures are not on the EPA inerts list, although other paraffinic oils are on List 2 and List 3. The reason why certain paraffinic oils are on the EPA inerts list and others are not is not apparent (Bakke, 2007).

The name polyol fatty acid ester refers to unspecified fatty acid esters of unspecified alcohols. Similarly, the name polyethoxylated polyol fatty acid ester refers to a group of chemicals that consist of unspecified fatty acid esters of unspecified polyethoxylated alcohols. Without further identity, no definitive statements can be made concerning the toxicity of these compounds (Bakke, 2007).

Agri-Dex® contains ethoxylated ingredients. Ethoxylates are formed by reactions of ethylene oxide. In the manufacturing process, some unreacted ethylene oxide, as well as the contaminant 1,4-dioxane, can become part of the final formulation. Both of these chemicals are considered likely human carcinogens (Bakke, 2007).

3.2.13.2 Class Act® NG

Class Act® NG is described as a water-conditioning agent/non-ionic surfactant. It is classified as a fertilizer/surfactant mixture. These products typically add nitrogen fertilizers (ammonium sulfate and ammonium nitrate) to adjuvants to increase herbicide activity. Ammonium-based fertilizers and, in particular, ammonium sulfate (AMS) are also being promoted to reduce potential antagonism with hard water (Bakke, 2007).

The active ingredients (50.5 percen6t) in Class Act® NG include alkyl polyglycoside (corn sugar derivative used as a wetting agent) (EPA List 3), corn syrup (EPA List 4A), and ammonium sulfate (32 to 36 percent) (EPA List 4B, source of N fertilizer). The inert ingredients (40.5 percent) comprising Class Act® NG have not been identified by the manufacturer (Bakke, 2007).

Class Act® NG is considered mildly irritating to the skin and eyes. The wetter/spreader alkyl polyglycoside is the same surfactant product sold under the trade name of Dow Triton™

CG110. According to the Material Safety Data Sheet (MSDS) for Dow Triton™ CG-110, this material is of low acute toxicity (oral LD_{50} > 5,000 mg/kg, dermal LD_{50} >5,000 mg/kg), although it is an eye irritant. It is used as a detergent and wetter/spreader in personal care products such as shampoo and skin cream because of its mild skin effects. It is of low aquatic toxicity, with a 48-hour NOEC for *Daphnia* of 150 mg/L and a 96-hour NOEC for fathead minnow of 125 mg/L (Bakke, 2007).

The Class Act® NG label specifically identifies corn syrup as a component of the product. Corn syrup is a common ingredient in foods (Bakke, 2007).

The source of nitrogen in Class Act® NG is ammonium sulfate, an EPA List 4B chemical, is a commonly used fertilizer in commercial garden products (Bakke, 2007). Ammonium sulfate is a water-soluble compound that is mildly irritating to the skin and eyes. It is of low oral toxicity, with a mouse LD_{50} of 640 mg/kg. In limited testing, ammonium sulfate has not been shown to be a mutagen or carcinogen. It is of low aquatic toxicity, with a rainbow trout 96-hour LC_{50} of 173 mg/L, a 96-hour EC_{50} for *Daphnia* >100 mg/L, and an 18-day EC_{50} for green algae of 2,700 mg/L. A recent study with three amphibian species showed that ammonium sulfate was more toxic to amphibians than the tested fish, with a 10-day NOEAC of 17 to 83 mg/L ammonium-nitrogen equivalent for the amphibians and 67 to 134 mg/L for fathead minnow (Bakke, 2007).

3.2.13.3 Dyne-Amic®

Dyne-Amic® is classified as a silicone-based wetter/spreader. These compounds, also known as organosilicones, are increasing in popularity because of their superior spreading ability. This class contains a polysiloxane chain. Some of these are a blend of non-ionic surfactants (NIS) and silicone while others are entirely silicone. The combination of NIS and a silicone surfactant can increase absorption into a plant so that the time between application and rainfall can be shortened. This is known as rainfastness. The surfactants extreme spreading ability may lead to droplet coalescence and subsequent runoff if applied at inappropriately high rates (Bakke, 2007).

Dyne-Amic® is a mixture of a silicone-based surfactant, esterified vegetable oil, and an alkylphenol ethoxylate; however the exact formulation of these ingredients is unknown. It is likely that the alkylphenol ethoxylate is nonylphenol ethoxylate, but that is not certain. The active ingredients (99 percent) in Dyne-Amic® consist of the silicone surfactant polyalkyleneoxide-modified polydimethylsiloxane (not further identified), alkylphenol ethoxylates (not further identified, likely is nonylphenol polyethoxylate, a non-ionic surfactant), methyl esters of C16-C18 fatty acids (not further identified, but described as a highly refined methylated vegetable oil), polyoxypropylene oleate butyl ether (EPA List 3 - likely being used

as an antifoam agent, a minor component), and polyoxyethylene-polyoxypropylene copolymer (Poloxalene, an EPA List 4B chemical, also likely being used as an antifoam agent, a minor component) (Bakke, 2007).

Dyne-Amic® is mildly or non-irritating to the skin (Category IV), and may be slightly irritating to the eyes (Category IV). There are two Chemical Abstract Service (CAS) numbers on the Dyne-Amic® label, one that corresponds to polyoxypropylene oleate butyl ether, while the other indicates poloxalene. The exact identity of the silicone-based components of Dyne-Amic® is unspecified. Silicone-based compounds are generally of low acute toxicity (Bakke, 2007).

Nonylphenol polyethoxylate has been linked to estrogenic effects in wildlife, including fish and amphibians (Bakke, 2007). A human health and ecological risk assessment prepared by Bakke (2003) summarized the risk of NPE exposure in workers and the general public. Bakke (2003) concluded that, based on the available information and under the foreseeable conditions of application, there is no route of exposure or scenario suggesting that workers or the general public will be at any substantial risk from longer-term exposure to NPE-based surfactants.

Poloxalene is of low toxicity on an acute oral basis, with an LD_{50} value in rats, mice, and rabbits exceeding 3,000 mg/kg. It is used as an oral veterinary treatment in cattle to cure legume bloat or as a feeding supplement to prevent bloat. It may be used here as an anti-foam agent or as a non-ionic surfactant (Bakke, 2007).

Polyoxypropylene oleate butyl ether is probably a minor component of Dyne-Amic®, likely used as an antifoam agent. It is a product recognized by the US Food and Drug Administration as being generally safe when used as an antifoam agent in food packaging (Bakke, 2007).

Dyne-Amic® contains ethoxylated ingredients. Ethoxylates are formed by reactions of ethylene oxide. In the manufacturing process, some unreacted ethylene oxide, as well as the contaminant 1,4-dioxane, can become part of the final formulation. Both of these chemicals are considered likely human carcinogens. For a comprehensive review at the risks of ethylene oxide in ethoxylated surfactants, please refer to Bakke (2003).

3.2.13.4 R-11®

R-11® is a non-ionic surfactant described as an alkylphenol ethoxylate-based wetter/spreader. Wetter/spreaders are most often used with herbicides to help them spread over and penetrate the waxy cuticle (outer layer) of a leaf or to penetrate through the small hairs present on the leaf surface. Because of the high surface tension of water, spray-mixture droplets can

maintain their roundness and sit on the leaf hairs or waxy surface without much of the herbicide actually contacting the leaf. The primary purpose of a wetter/spreader is to reduce the surface tension of the spray solution to allow more intimate contact between the spray droplet and the plant surface. They may also act to change the permeability of the leaf surface.

Most wetter/spreaders used with herbicides are considered non-ionic surfactants. This means that these compounds have no electrical charge and are compatible with most pesticides. There are cationic (positive charge) and anionic (negative charge) surfactants, but they are not as commonly used. Wetter/spreaders have the physical characteristics of both oil and water. Most wetter/spreader molecules contain a hydrophilic head and a long-chain hydrocarbon lipophilic tail (Bakke, 2007).

The active ingredients of R-11® (90 percent) consist of nonylphenol polyethoxylate (NPE) (80 percent) (EPA List 4B), 1-butanol (10 percent) (EPA List 4B), compounded silicone, dimethylpolysiloxane (<1 percent - antifoaming agent) (EPA List 4B), and water (Bakke, 2007).

R-11® may cause skin irritation and may be mildly irritating to the eyes. The active ingredient, NPE, has been linked to estrogenic effects in wildlife, including aquatic species, such as fish and amphibians. A human health and ecological risk assessment prepared by Bakke (2003) summarized the risk of NPE exposure in workers and the general public. Bakke (2003) concluded that, based on the available information and under the foreseeable conditions of application, there is no route of exposure or scenario suggesting that workers or the general public will be at any substantial risk from longer-term exposure to NPE-based surfactants. For a comprehensive summary of the human health risk of nonylphenol ethoxylate surfactants, refer to Bakke (2003).

1-Butanol and compounded silicone are both on the EPA List 4B. 1-Butanol is slightly more orally acutely toxic than the nonylphenol polyethoxylate. The compounded silicone is practically non-toxic on an acute oral basis (rat LD_{50} >17 g/kg) (Bakke, 2007).

3.2.14 Impurities

There is no information in the published literature on the manufacturing impurities in imazapyr; however, chemical manufacturing processes typically do not yield pure product. It is expected that technical grade imazapyr, as with other technical grade products, contains some impurities. These impurities have been disclosed to EPA as part of the registration process for imazapyr formulations (SERA, 2004). Because specific information concerning product impurities may provide insight into the manufacturing process used to synthesize imazapyr, such information is considered proprietary, and is protected under FIFRA (Section 10).

Concerns about the potential toxicity of impurities in technical grade imazapyr may be alleviated, to some extent, by the fact that toxicity testing with imazapyr was conducted with the technical grade product, which would include any manufacturing impurities. If toxic impurities are present in the technical grade product, their contribution to product toxicity would likely be encompassed within the toxicity studies on the technical grade product (SERA, 2004).

3.2.15 Metabolites

The metabolism and kinetics of imazapyr have been studied in rats (Mallipudi et al., 1983b), lactating goats (Zdybak, 1992), and white leghorn chickens (Tsalta, 1995). Only the parent compound (imazapyr) was reported to be excreted in these studies.

Quinolinic acid is a photolytic breakdown product of imazapyr that has been associated with neurologic effects in experimental animals (Schwarcz et al., 1983). Quinolinic acid is a metabolite of tryptophan, a naturally occurring and essential amino acid in mammals. Concentrations of quinolinic acid are controlled in mammals by an active transport system which helps to regulate the concentrations of a large number of weak acids in the central nervous system as well as transport systems involved in the urinary excretion of weak acids (Morrison et al., 1999).

3.3 EXPOSURE ASSESSMENT

The exposure assessment characterizes the magnitude, frequency, and duration of exposure to Imazapyr for workers and members of the general public. Figure 1 presents a conceptual model outlining the primary exposure pathways modeled for potential human exposure. The model is not intended to depict all potential exposure routes, but only those with complete exposure pathways that may lead to toxicity and those with complete exposure pathways that are unlikely to result in toxicity. As an example, the available toxicity data indicate that imazapyr does not bioaccumulate, so that consumption of plants or animals from contaminated environments is unlikely to result in toxicity.

The conceptual site model (Figure 1):

- Identifies the primary source of contamination in the environment;
- Shows how imazapyr at the original point of release might move in the environment;
- Identifies the different types of human populations (e.g., workers, general public, subsistence fishers) who might come into contact with contaminated media; and

- Lists the potential exposure pathways (e.g., ingestion of contaminated water, inhalation of chemicals in air, dermal contact with contaminated soil) that may occur for each population.

3.3.1 Overview

Exposure assessments are conducted for both workers and members of the general public for the typical application rate of 0.26 lb a.e./acre. The consequences of using the maximum application rate that might be used by the WSDA, 1.5 lb/acre, are discussed in the risk characterization.

For workers, three types of application methods are modeled: directed ground, broadcast ground, and aerial. The central estimate of exposure for broadcast ground spray workers is about 0.006 mg/kg/day. The central estimates of exposures for backpack and aerial workers are somewhat lower, about 0.003 and 004 mg/kg/day, respectively. The upper range of exposures is approximately 0.02 mg/kg/day for backpack and aerial applications and 0.04 mg/kg/day for broadcast ground spray. All of the accidental exposure scenarios for workers involve dermal exposures and all of these accidental exposures lead to estimates of dose that are either in the range of or substantially below the general exposure estimates for workers.

For the general public, the estimates of acute exposures range from approximately 1.19 X 10^{-6} (1.19E -06) mg/kg associated with the lower range for the consumption of contaminated water from a stream by a child to 0.06 mg/kg associated with the upper range for consumption of contaminated water by a child following an accidental spill of imazapyr into a small pond. High dose estimates are also associated with the direct spray of a child (an upper range of 0.0.65 mg/kg/day). Other acute exposures are lower by about an order of magnitude or greater. For chronic or longer term exposures, the modeled exposures are much lower than for acute exposures, ranging from approximately 1.9E -09 mg/kg/day associated with the lower range for the normal consumption of fish to approximately 0.023 mg/kg/day associated with the upper range for consumption of contaminated fruit.

3.3.2 Workers

A summary of the exposure assessments for workers is presented in Appendix B, Table B-34. Two types of exposure scenarios are considered: general and accidental/incidental. The term general exposure scenario is used to designate those exposures that involve estimates of absorbed dose based on the handling of a specified amount of a chemical during specific types of applications. The accidental/incidental exposure scenarios involve specific types of events that could occur during any type of application. The exposure scenarios developed in this section as well as other similar scenarios for the general public (Section 3.3.3) are based on the typical application rate of 0.26 lb a.e./acre.

3.3.2.1 General Exposures

Worker exposure rates are expressed in units of mg of absorbed dose per kilogram of body weight per pound of chemical handled (SERA, 2004). Based on analyses of several different pesticides using a variety of application methods, default exposure rates are estimated for three different types of applications: directed foliar (backpack), boom spray (hydraulic ground spray), and aerial (SERA, 2004).

The specific assumptions used for each application method are detailed in Appendix B, Tables B-10 (directed foliar), B-11 (broadcast foliar) , and B-12 (aerial). The central estimate of the amount handled per day is calculated as the product of the central estimates of the acres treated per day and the application rate (SERA, 2004).

No worker exposure studies involving imazapyr were found in the literature. Exposure rates are based on worker exposure studies of nine different pesticides with molecular weights ranging from 221 to 416 and log K_{ow} values at pH 7 ranging from -0.75 to 6.50 (SERA, 2004). The estimated exposure rates are based on estimated absorbed doses in workers as well as the amounts of the chemical handled by the workers. As summarized in Table1, the molecular weight of imazapyr is 261.3 and the K_{ow} is 1.3, which corresponds to a log K_{ow} of 0.11. These values are within the range of the herbicides evaluated in SERA (2001). As described in SERA (2001), the ranges of estimated occupational exposure rates vary substantially among individuals and groups, (i.e., by a factor of 50 for backpack applicators and a factor of 100 for mechanical ground sprayers). Much of the variability can be attributed to the hygienic measures taken by individual workers (i.e., how careful the workers are to avoid unnecessary exposure); however, pharmacokinetic differences among individuals (i.e., how individuals absorb and excrete the compound) also may be important (SERA, 2004).

An estimate of the number of acres treated per hour is needed to apply these worker exposure rates. These values are taken from previous U.S. Department of Agriculture (USDA) risk assessments (SERA, 2004). The number of hours worked per day is expressed as a range, the lower end of which is based on an 8-hour work day with 1 hour at each end of the work day spent in activities that do not involve herbicide exposure. The upper end of the range, 8 hours per day, is based on an extended (10-hour) work day, allowing for 1 hour at each end of the work day to be spent in activities that do not involve herbicide exposure (SERA, 2004).

The use of 6 hours as the lower range of time spent per day applying herbicides may not be a true lower limit. It is conceivable and perhaps common for workers to spend much less time in the actual application of herbicide if they are engaged in other activities. Thus, using 6 hours may overestimate exposure. In the absence of any published or otherwise documented work

practice statistics to support the use of a lower limit, this approach is used as a conservative assumption (SERA, 2004).

The range of acres treated per hour and hours worked per day is used to calculate a range for the number of acres treated per day. For this calculation, as well as others in this section involving the multiplication of ranges, the lower end of the resulting range is the product of the lower end of one range and the lower end of the other range. Similarly, the upper end of the resulting range is the product of the upper end of one range and the upper end of the other range. This approach is taken to encompass as broadly as possible the range of potential exposures (SERA, 2004)

The central estimate of the acres treated per day is taken as the arithmetic average of the range. Because of the relatively narrow limits of the ranges for backpack and boom spray workers, the use of the arithmetic mean rather than some other measure of central tendency, like the geometric mean, has no marked effect on the risk assessment (SERA, 2004).

3.3.2.2 Accidental Exposures

Typical occupational exposures may involve multiple routes of exposure (i.e., oral, dermal, and inhalation); although, dermal exposure is generally the predominant exposure route for herbicide applicators (Ecobichon, 1998; van Hemmen, 1992). Typical multi-route exposures are encompassed by the methods used in Section 3.3.2.1 on general exposures. Accidental exposures are most likely to involve splashing a solution of herbicides into the eyes or to involve various dermal exposure scenarios.

Imazapyr is a mild skin and eye irritant. The available literature does not include quantitative methods for characterizing exposure or responses associated with splashing a solution of a chemical into the eyes; furthermore, there appear to be no reasonable approaches to modeling this type of exposure scenario quantitatively. Consequently, accidental exposure scenarios of this type are considered qualitatively in the risk characterization (Section 3.5) (SERA, 2004).

There are various methods for estimating absorbed doses associated with accidental dermal exposure (EPA, 1992; SERA, 2001). Two general types of exposure are modeled: those involving direct contact with a solution of the herbicide and those associated with accidental spills of the herbicide onto the skin. Any number of specific exposure scenarios is possible for direct contact by varying the amount or concentration of the chemical in contact with the skin and by varying the surface area of the skin that is contaminated (SERA, 2004).

For this risk assessment, two exposure scenarios are developed for each of the two types of dermal exposure, and the estimated absorbed dose for each scenario is expressed in units of mg chemical/kg body weight. Both sets of exposure scenarios are summarized in Appendix B, Table B-33, which references other Appendix B tables in which the specific calculations are detailed.

Exposure scenarios involving direct contact with solutions of imazapyr are characterized by immersion of the hands for 1 minute or wearing contaminated gloves for 1 hour. Generally, it is not reasonable to assume or postulate that the hands or any other part of a worker will be immersed in an herbicide solution for any period of time. Contamination of gloves or other clothing is quite plausible. For occupational exposure scenarios, the key assumption is that wearing gloves grossly contaminated with imazapyr solution is equivalent to immersing the hands in a solution. In either case, the concentration of the chemical in solution that is in contact with the surface of the skin and the resulting dermal absorption rate are expected to be comparable (SERA, 2004).

For both scenarios (the hand immersion and the contaminated glove), the assumption of zero-order absorption kinetics is appropriate. Following the general recommendations of EPA (1992), Fick's first law is used to estimate dermal exposure. As discussed in Section 3.2.3, an experimental dermal permeability coefficient (Kp) for imazapyr is not available. Thus, the Kp for imazapyr is estimated using the algorithm from EPA (1992). The application of this algorithm to imazapyr, based on molecular weight and the K_{ow}, is given in Appendix B, Table B-8.

Exposure scenarios involving chemical spills onto the skin are characterized by a spill on to the lower legs as well as a spill on to the hands. In these scenarios it is assumed that a solution of the chemical is spilled on to a given surface area of skin and that a certain amount of the chemical adheres to the skin. The absorbed dose is then calculated as the product of the amount of the chemical on the skin (i.e., the amount of liquid per unit surface area multiplied by the surface area of the skin over which the spill occurs and the concentration of the chemical in the liquid) the first-order absorption rate, and the duration of exposure (SERA, 2004).

For both scenarios, it is assumed that the contaminated skin is cleaned after 1 hour. As with the exposure assessments based on Fick's first law, this product (mg of absorbed dose) is divided by body weight (kg) to yield an estimated dose in units of mg chemical/kg body weight. The specific equation used in these exposure assessments is specified in Appendix B, Table B-6. Confidence in these exposure assessments is diminished by the lack of experimental data on the dermal absorption of imazapyr (SERA, 2004).

3.3.3 General Public

This section describes the modeled scenarios for exposure of the general public to imazapyr.

3.3.3.1 General Considerations

The two types of exposure scenarios developed for the general public include both acute and chronic exposure. The acute exposure scenarios are primarily accidental. They assume that an individual is exposed to imazapyr either during or shortly after application. Specific scenarios are developed for direct spray, dermal contact with contaminated vegetation, as well as the consumption of contaminated fruit, water, and fish. Most of these scenarios should be regarded as extreme, some to the point of limited plausibility. The longer-term or chronic exposure scenarios parallel the acute exposure scenarios for the consumption of contaminated fruit, water, and fish but are based on estimated levels of exposure for longer periods after application.

The exposure scenarios developed for the general public are summarized in Appendix B, Table B-35. As with the worker exposure scenarios, details of the assumptions and calculations involved in these exposure assessments are given in Appendix B (Tables B-17 to B-32). The remainder of this section focuses on a qualitative description of the rationale for these exposure scenarios and the quality of the data supporting the exposure scenarios.

A quantitative summary of the risk characterization for workers associated with exposure to imazapyr is presented in Appendix B, Table B-34. The quantitative risk characterization is expressed as the hazard quotient, the ratio of the estimated doses from Appendix B, Table B-33 to the RfD. For both acute exposures (i.e., accidental or incidental exposures) and general exposures (i.e., daily exposures that might occur over the course of an application season), the chronic RfD of 2.5 mg/kg/day is used to characterize risk.

3.3.3.2 Direct Spray

Direct spray involving ground applications is modeled in a manner similar to accidental spills for workers (Section 3.3.2.2). It is assumed that the individual is sprayed with a solution containing imazapyr and that some of the compound remains on the skin and is absorbed via first-order kinetics. For these exposure scenarios, it is assumed that during a ground application, an unclothed child is sprayed directly with imazapyr. These scenarios also assume that the child is completely covered (100 percent of the surface area of the body is exposed). These exposure scenarios are likely to represent upper limits of exposure. An additional set of scenarios are included involving a young woman who is accidentally sprayed over the feet and legs. For each of these scenarios, some assumptions are made regarding the surface area of the skin and body weight, as detailed in Appendix B, Table B-3.

3.3.3.3 Dermal Exposure from Contaminated Vegetation

The dermal exposure scenario assumes that the herbicide is sprayed at a given application rate and that an individual comes in contact with sprayed vegetation or other contaminated surfaces at some period after spray application. Some estimates of dislodgeable residue and the rate of transfer from the contaminated vegetation to the surface of the skin must be assumed; however, data are unavailable on dermal transfer rates for imazapyr. Therefore, the estimation methods of Durkin et al. (1995) are used (Appendix B, Table B-19) (SERA, 2004). The exposure scenario assumes a contact period of one hour and that imazapyr is not removed by washing for 24 hours. Other estimates used in this exposure scenario involve estimates of body weight, skin surface area, and first-order dermal absorption rates, as discussed in the previous section.

3.3.3.4 Contaminated Water

Surface waters can be contaminated from runoff, as a result of leaching from contaminated soil, from a direct spill, or from unintentional contamination from herbicide applications. The two types of estimates made for the concentration of the compound in surface water are acute/accidental exposure from an accidental spill and longer-term exposure to imazapyr in surface water that could be associated with the application of this compound to a 10-acre area that is adjacent to and drains into a small stream or pond.

Acute Exposure – Two exposure scenarios are presented for the acute consumption of contaminated water: an accidental spill into a small pond (0.25 acres in surface area and 1-meter deep) and the contamination of a small stream by runoff or percolation. The accidental spill scenario assumes that a young child consumes contaminated water shortly after an accidental spill into a small pond. The details of this scenario are provided in Appendix B, Table B-24. This scenario assumes no dissipation or degradation of imazapyr after the spill. The conservative assumptions applied to this scenario are expected to generally overestimate exposure. Under such a scenario, the actual water concentrations of imazapyr would be determined by the amount of compound spilled, the size of the water body receiving the spill, the elapsed time between the spill and water consumption, and the volume of contaminated water consumed. Under this scenario, the concentration of imazapyr in a small pond is estimated to range from about 1.2 mg/L to 4.7 mg/L with a central estimate of about 2.3 mg/L (Appendix B, Table B-24).

The other acute exposure scenario for the consumption of contaminated water involves runoff into a small stream. Two monitoring studies are available reporting imazapyr concentrations streams after aerial applications (Michael and Neary, 1993; Rashin and Graber, 1993). Michael and Neary (1993) applied a liquid formulation of imazapyr at a rate of 2.2 kg a.i./ha (1.9 lbs a.i./acre). The authors did not specify which imazapyr formulation was used, but they

indicated that it was produced by American Cyanamid. It is assumed that an Arsenal® formulation (isopropylamine salt of imazapyr) was applied. Correcting for differences in molecular weight between the acid and isopropylamine salt, an application rate of 1.96 lbs a.i./acre the isopropylamine salt of imazapyr corresponds to 1.59 lbs a.e./acre of the acid (1.96lbs a.i. × [MW acid 261÷MW 320 salt]). The broadcast aerial applications were made in two similar watersheds in Alabama (designated as Sites 12 and 13 in Michael and Neary, 1993). At one site (13), a buffer zone was maintained along streams. The maximum surface water concentration in the site with the buffer zone was 130 micrograms (µg)/L. The maximum surface water concentration in the site without the buffer zone (Site 12) was 680 µg/L, but this was associated with imazapyr falling directly into the stream during application (Michael and Neary, 1993). The maximum concentrations of imazapyr occurred as a pulse immediately after a 30-mm (about 1.2 inches) rainfall and decreased to trace or non-detectable concentrations within 9 hours. Subsequent rainfalls (>10 mm or about 0.4 inch) resulted in maximum imazapyr concentrations of 6 µg/L which decreased to non-detectable or trace levels within 1.5 hours (Michael and Neary, 1993).

A study by Rashin and Graber (1993) involved the aerial application of imazapyr at 0.1 a.i. kg/ha or 0.0892 lb a.i./acre to two watersheds in Washington state. Correcting for molecular weight differences between the acid and isopropylamine salt of imazapyr, the application rate corresponds to 0.073 lb a.e./acre (0.0892 lb a.i. × [MW acid 261÷MW 320 salt]). Buffer zones were maintained at each location, with the maximum concentration in surface water at each site reported as 1 µg/L. It is unknown if this concentration was an actual maximum observed measurement or simply represented the limit of detection.

While actual monitoring data may provide the best estimate of water contamination from herbicide application, such data may not encompass a broad range of environmental conditions occurring during product applications (e.g., extremely heavy rainfall) or they may reflect atypical applications that do not reflect normal application practices. Consequently, for this component of the exposure assessment, the monitored levels in ambient water are compared to modeled estimates based on Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) modeling conducted by SERA (2004). GLEAMS is a root-zone model used to examine the fate of chemicals in various types of soils under different meteorological and hydrogeological conditions (Knisel and Davis, 2000). As with many environmental fate and transport models, the input and output files for GLEAMS can be complex. The general application of the GLEAMS model and the use of the output from this model to estimate concentrations in ambient water are detailed in SERA (2003b).

GLEAMS can be used to examine the fate of chemicals in various types of soils under different meteorological and hydrogeological conditions (Knisel and Davis, 2000). As with many

environmental fate and transport models, the input and output files for GLEAMS can be complex. The general application of the GLEAMS model and the use of the output from this model to estimate concentrations in ambient water are detailed in SERA (2003b).

For the scenario modeled by SERA (2004), the application site was assumed to consist of a 10-acre square area that drained directly into a small pond or stream. The chemical-specific values as well as the details of the pond and stream scenarios used in the GLEAMS modeling are summarized in Appendix A, Table A-2. The GLEAMS modeling yielded estimates of runoff, sedimentation, and percolation that were in turn used to estimate concentrations in the receiving waters adjacent to a treated plot. The results of the GLEAMS modeling for the pond and small stream are summarized in Table 4. These estimates are expressed as both average and maximum water contamination rates (WCR); i.e., the concentration of the compound in water in units of µg/L normalized for an application rate of 0.26 lb a.e./acre.

As indicated in Table 4, no stream contamination is estimated in very arid regions (annual rainfall ≤5 inches to 25 inches). The modeled maximum concentrations in the stream range from about 0.028 µg/L or less (in loam) to somewhat over 0.5 µg/L (clay) at annual rainfall rates from 150 to 250 inches per year, with the highest concentrations associated with clay soils at annual rainfall rates of 200 inches or more. While not detailed in Table 4, the losses from clay are associated almost exclusively with runoff (about 84 percent), with the remaining amount due to sediment loss. For loam, about 88 percent of the loss is associated with percolation and most of the remaining loss with runoff. For sand, the pesticide loss is associated exclusively with percolation. For both clay and loam, the maximum losses occur with the first rainfall after application. For sand, time to maximum loss is attenuated.

The stream concentrations based on the GLEAMS modeling by SERA (2004) appear to underestimate concentrations in streams noted in the monitoring studies. Michael and Neary (1993) indicated peak concentrations of 130 µg/L to 680 µg/L in streams after an application of 1.59 lbs a.e./acre following a rainfall of about 1.2 inches. According to SERA (2004), the higher concentration of 680 µg/L reported by Michael and Neary (1993) was associated with direct application of imazapyr to the stream and likely is not appropriate for comparison to the GLEAMS modeling. The concentration of 130 µg/L may be normalized for the application rate to a water contamination rate of about 80µg/L per lb a.e. applied (130 µg/L ÷ 1.59 lbs a.e./acre = 81.76 µg/L per lb/acre). The highest concentration in streams based on the GLEAMS modeling is only about 2 µg/L, when the modeling results are normalized to an application rate of 1 lb a.e./acre. The GLEAMS modeling was based on a precipitation pattern of rain occurring on the every 10^{th} day. The rainfall rate of 1.2 inches would correspond to an annual precipitation rate of about 44 inches (1.2 inches/event × 36.5 events/year). Based on the GLEAMS modeling (normalized to an application rate of 1 lb a.e./acre) for clay soil, the

estimated peak concentration in streams at an annual rainfall of 44 inches would be about 0.4 µg/L, a factor of about 200 below the normalized peak concentration of 80 µg/L per lb a.e./acre from Michael and Neary (1993).

According to SERA (2004), the reasons for this discrepancy cannot be clearly determined from the available data. One critical factor in the GLEAMS modeling output is the streamflow rate. As specified in Table A-2, the GLEAMS modeling is based on a mean streamflow rate 4.42 million L/day with a flow velocity of 0.08 m/second. Some streams, however, have much lower discharge rates and flow rates for any single stream may be highly variable over time. For example, the flow rate of 4.42 million L/day used in the GLEAM modeling is based on the lower fifth percentile of a database of 55,701 stream reaches, including only those streams with mean discharges >1,000 liters/day. For this database, the lower 0.1 percent of streams have discharge rates of 0.158 million L/day, a factor of about 28 less than the value used in the GLEAMS modeling. In addition to variations in mean discharges among streams, flow rates will vary more substantially over time for an individual stream. For example, the stream with a mean discharge of 4.42 million L/day has a low discharge of less than 1,000 liters/day. Thus, if the stream monitored by Michael and Neary (1993) had a very low discharge, the higher concentrations could be expected.

According to SERA (2004), the GLEAMS modeling for the stream may be compared to a similar modeling effort by Garrett et al. (1999) using the Pesticide Root Zone Model/Exposure Analysis Modeling System (PRZM/EXAMS). PRZM, like GLEAMS, is a root zone model that models edge-of-field pesticide losses that are generally comparable to GLEAMS (SERA, 2004). EXAMS is a model used by EPA that uses outputs from PRZM to estimate concentrations of chemicals in surface water. Garrett et al. (1999) modeled imazapyr concentrations in streams after the application at a rate of 1.5 lb a.e./acre. Peak concentrations of up to 24 µg/L were modeled but concentrations were generally in the range of 1 to 10 µg/L, equivalent to water contamination rates of about 0.7 to 7 µg/L per lb a.e./acre. These are only modestly higher than the peak concentration of 2 µg/L per lb a.e./acre for modeled for clay by the GLEAMS model at an application rate of 1 lb a.e./acre. The concentration of 24 µg/L is equivalent to 16 µg/L per lb a.e./acre, a factor of 5 below the 80 µg/L per lb a.e./acre value from the study by Michael and Neary (1993).

The estimated peak concentrations in ponds based on the GLEAMS modeling (Table 4) are generally similar to those in streams, ranging from about 0.02 or less to0.46 µg/L in clay soil, up to about 0.12 µg/L in sand, and less than 0.018 µg/L in loam. Modeled average concentrations in ponds, however, are substantially higher than those in streams. The highest average concentration is estimated at about 0.1 µg/L (i.e., sandy soil at a rainfall rate of 50 to 100 inches per year). Over all soil types, typical concentrations are in the range of 0.01 or less

to 0.2 µg/L. As with the stream modeling, virtually no contamination is modeled in very arid regions for clay and sand. For loam, no water contamination is estimated at rainfall rates of 25 inches per year or less (SERA, 2004).

The GLEAMS scenarios do not specifically consider the effects of accidental direct spray. For example, the steam modeled using GLEAMS is about 6 feet wide and it is assumed that the herbicide is applied along a 660 foot length of the stream with a flow rate of 4.42 million L/day. At an application rate of 1 lb/acre, accidental direct spray onto the surface of the stream would deposit about 41,252,800 µg (1 lb/acre = 112,100 µg/m², 6 ft x 660 ft = 3,960 ft² = 368 m², 112,100 µg/m² × 368 m² = 41,252,800 µg). This would result in a downstream concentration of about 10 µg/L (41,252,800 µg/day ÷ 4,420,000 L/day). As indicated in Table 4, the expected peak concentrations from runoff or percolation in streams are below this value by a factor of about 5 or more.

Based on SERA (2004), for the current risk assessment, the upper range for the short-term water contamination rate will be 80 µg/L per lb/acre based on the monitoring data from Michael and Neary (1993). This concentration is substantially higher than the estimates from GLEAMS (Table 4), but is based on actual monitoring data from an application scenario analogous to the types of applications that could be made in WSDA programs. The concentration of 0.08 mg/L per lb/acre is used as the upper exposure concentration in Table B-7 in Appendix B, while the central estimated exposure concentration will be 2 µg/L (0.002 mg/L), based on the GLEAMS modeling for the maximum concentration for clay at annual rainfall rates of 100 to 250 inches. While this is the upper range of modeled values, the discrepancies between the modeled estimates and monitoring data suggest that this conservative approach is appropriate for imazapyr. The estimated lower exposure concentration is 0.1 µg/L (0.0001 mg/L), a concentration that might be expected in relatively arid regions with clay soil (i.e., annual rainfall of 20 inches).

Chronic Exposure – The chronic exposure scenario for contaminated water is detailed in Appendix B, Table B-26 and is based on SERA (2004). This scenario assumes that an adult male (70 kg) consumes contaminated surface water from an imazapyr-contaminated pond for a lifetime. The estimated concentrations in pond water are based on the modeled estimates from GLEAMS, discussed in the previous section.

Imazapyr is not included in the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) (USGS, 2003) and no other long-term monitoring studies have been located. Chronic exposure estimates will be based only on the GLEAMS modeling results.

The typical chronic WCR was selected as 0.1 µg/L or 0.0001 mg/L per lb/acre. According to SERA (2004) this is about the average concentration in a pond based on GLEAMS modeling at a precipitation rate of 50 to about 250 inches per year in clay soil, as well as average concentrations modeled for sand at a rainfall rate of about 25 inches per year. The upper range of the WCR could be taken as 0.2 µg/L or 0.0002 mg/L per lb/acre. This is the highest average concentration modeled from sandy soil at an annual precipitation of 50 inches. However, as noted in the previous section, the peak values modeled by GLEAMS did not agree with data from the limited monitoring studies for imazapyr. Thus, a peak concentration of 0.001 mg/L was selected – a factor of 5 higher than the highest modeled average concentration – because of concerns that concentrations higher than those modeled could be plausible under some application conditions. A lower exposure concentration of 0.01 µg/L or 0.00001 mg/L per lb/acre was selected. This selection is somewhat arbitrary but would tend to encompass concentrations that might be found in relatively arid areas.

The WCR values discussed in this section are summarized in Appendix B, Table B-25, and are used for all chronic exposure assessments involving contaminated water. As with the corresponding values for a small stream, these estimates are expressed as the water contamination rates in units of mg/L per lb a.i./acre.

3.3.3.5 Oral Exposure from Contaminated Fish

As part of the registration process for imazapyr, a study was conducted to calculate bioconcentration factors (BCF) for imazapyr (McAllister et al. 1985) and the results of the study were submitted to EPA. McAllister et al. (1985) exposed bluegill sunfish to ^{14}C-labeled imazapyr for 28 days and were unable to find detectable concentrations of imazapyr in fish tissues. The reported bioconcentration factor was less than 0.5, indicating that the concentration of imazapyr in fish tissues was less than the concentration of imazapyr in the water. For exposure assessments based on the consumption of contaminated fish, the measured BCF of 0.5 is used (i.e., the concentration in the fish will be one-half that of the concentration in the water).

For both acute and chronic exposure scenarios involving the consumption of contaminated fish, the water concentrations of imazapyr used are identical to the concentrations used in the contaminated water scenarios (Section 3.4.3.4). The acute exposure scenario is based on the assumption that an adult consumes fish taken from contaminated water shortly after an accidental spill of 200 gallons of a field solution into a pond that has an average depth of 1 m and a surface area of 1,000 m² or about one-quarter acre. It is assumed that no dissipation or degradation of imazapyr occurs. Because of the available and well-documented information indicating that there are substantial differences in the amount of caught fish consumed by the general public and Native American subsistence populations, separate exposure estimates are

made for these two groups, as illustrated in Appendix B, Tables B-27 and B-28, respectively. (general public) and (subsistence populations). Chronic exposure is calculated in a similar way, as detailed in Appendix B, Tables B-29 and B-30, except that estimates of imazapyr concentrations in surface water are based on the estimates of chronic concentrations discussed in Section 3.4.3.4.

3.3.3.6 Oral Exposure from Contaminated Vegetation

None of the WSDA applications of imazapyr will involve the treatment of crops, so that under normal circumstances, imazapyr-contaminated vegetation consumption by humans is unlikely. However, it is possible that accidental spraying of crops or the spraying of edible wild vegetation, like berries, could occur. In most instances, particularly for longer-term scenarios, treated vegetation would probably show signs of damage from exposure to imazapyr (Section 4.4.2.4), likely reducing consumption that could lead to significant levels of human exposure to imazapyr. One plausible scenario involves the consumption of contaminated berries or other edible wild plants after treatment of an area.

Both acute- and chronic-exposure scenarios for consumption of contaminated vegetation are considered and detailed in Appendix B, Tables B-20 through B-23. In both scenarios, the concentration of imazapyr on contaminated vegetation is estimated using the empirical relationships between application rate and concentration on vegetation developed by Fletcher et al. (1995 a, b) and Hoerger and Kenaga (1972). These relationships are defined in Appendix B, Table B-4. For the acute exposure scenario, the estimated residue concentration is calculated as the product of the application rate and the residue rate (Appendix B, Table B-20.

An exposure duration of 90 days is assumed for the chronic exposure scenario (Appendix B, Table B-22). The rate of vegetation-residue-concentration decrease is based on vegetation-residue half-lives reported by Michael and Neary (1993), who reported a range of imazapyr half-lives from 15 to 37 days. This range is used as the upper and lower limit residue decrease. The arithmetic mean of the range, 26 days, is used as the central estimate of residue decrease. The 90-day exposure was selected to represent the consumption of contaminated fruit and vegetation that might be available over one season.

For chronic exposure scenarios, the time-weighted average concentration on fruit is calculated from the equation for first-order dissipation. Assuming a first-order decrease in concentrations on contaminated vegetation, the concentration on the vegetation at time t after spray, C_t, can be calculated based on the initial concentration, C_0, as:

$$C_t = C_0 \times e^{-kt} \qquad \text{(Equation 1)}$$

where k is the first-order decay coefficient ($k=\ln(2)\div t_{50}$). Time-weighted average concentration (C_{TWA}) over time t can be calculated as the integral of C_t (SERA, 2004)) divided by the duration (t):

$$C_{TWA} = C_0 (1 - e^{-kt}) \div (k\ t). \qquad \text{(Equation 2)}$$

A separate scenario involving the consumption of contaminated vegetation contaminated by drift rather than direct spray is not considered in this risk assessment. As detailed further in Section 3, assessing risk attributable to contamination by drift is not necessary because the direct spray scenario leads to estimates of risk that are below a level of concern. Thus, it is expected that vegetation contamination from drift would result in less residue concentration than that resulting from direct application and would not impact risk characterization.

3.4 DOSE-RESPONSE ASSESSMENT

This section addresses the quantitative relationship between the chemical dose and the incidence of adverse health effects in humans.

3.4.1 Overview

EPA derived a chronic RfD of 2.5 mg/kg/day based on a dog NOAEL of 250 mg/kg/day and an uncertainty factor of 100. The NOAEL selected by EPA appears to be the most appropriate and is supported by additional studies developing NOAELs in rats and mice, as well as a number of studies on potential reproductive and developmental effects in test animals. Consistent with the approach taken by EPA (2003), no acute RfD will be derived in this risk assessment and the chronic RfD of 2.5 mg/kg/day will be used to characterize the risks of both acute and longer term exposures (SERA, 2004).

3.4.2 Existing Guidelines for Chronic Exposure

EPA has not derived an agency-wide RfD for imazapyr, i.e., there is no RfD for imazapyr listed on EPA's Integrated Risk Information System (http://www.epa.gov/NCEA/iris/ help_start.htm). EPA's Office of Pesticide Programs derived an RfD of 2.5 mg/kg/day (EPA, 1997) based on a study of male and female dogs were administered imazapyr in the diet for one year at concentrations of 0, 1,000, 5,000, or 10,000 mg imazapyr/kg diet (ppm) (Shellenberger, 1987). As discussed in Section 3.2.3, no adverse effects attributable to treatment were noted in any treatment group. As reported by EPA (1997), the highest dietary concentration corresponded to reported daily doses of 250 mg/kg/day. In deriving the RfD, EPA (1997) used an uncertainty factor of 100 (10 for species-to-species extrapolation and 10 for sensitive subgroups in the human population) (250 mg/kg/day ÷ 100 = 2.5 mg/kg/day). Because the available data on reproductive toxicity and teratogenicity do not indicate that young animals are more sensitive than adults to imazapyr, no additional uncertainty factor for infants or

children was applied. This approach and the resulting RfD have been maintained in the pesticide tolerances for imazapyr published by Office of Pesticide Programs (EPA, 2003).

No other criteria for imazapyr have been found in a search of other organizations responsible for setting environmental or occupational exposure recommendations, criteria or standards (i.e., World Health Organization [WHO], Occupational Safety and Health Administration [OSHA], National Institute for Occupational Safety and Health [NIOSH], or American Conference of Governmental Industrial Hygienists [ACGIH]). No published recommendations from these agencies or organizations were encountered in the literature search.

3.4.3 Acute RfD

EPA has not derived an acute RfD for imazapyr. In its pesticide tolerances for imazapyr, EPA (2003) states that: *An acute dietary endpoint was not selected based on the absence of an appropriate endpoint attributable to a single dose*. EPA also derived incidental oral risk values that cover a range of 1 to 30 days. For imazapyr, EPA (2003) specifies a NOAEL of 250 mg/kg/day, identical to that used for the chronic RfD, and a margin of exposure of 100, identical to the uncertainty factor used for the chronic RfD. While not explicitly identifying this as an acute RfD, this approach is functionally equivalent to setting the acute RfD for incidental oral exposure to the chronic RfD of 2.5 mg/kg/day (SERA, 2004).

As discussed in Section 3.2.3 and detailed in Table 3, the dog study (Shellenberger, 1987) is supported by chronic oral toxicity studies in both rats (Daly, 1988) and mice (Auletta, 1988) as well as several studies designed to detect adverse effects on reproduction and development (Section 3.2.4). The teratology studies (Salamon et al., 1983a, 1983b, 1983c, 1983d) typically involve gavage doses over a relatively short period of time, in the range of 10 to 14 days and can be considered as a basis for deriving short term RfDs. However, for imazapyr, an acute NOAEL that is substantially above 250 mg/kg/day could be identified. Thus, consistent with the approach taken by EPA (2003), no acute RfD will be derived in this risk assessment and the chronic RfD of 2.5 mg/kg/day will be used to characterize the risks of both acute and longer term exposures (SERA, 2004).

3.5 RISK CHARACTERIZATION

This section of the risk assessment estimates the potential for adverse health effects by integrating the information from the dose-response assessment with the exposure assessment.

3.5.1 Overview

For both workers and members of the general public, risk is characterized quantitatively using a hazard quotient, the ratio of the exposure estimate to the chronic RfD. Because all exposure

assessments are based on the typical application rate of 0.26 lb a.e./acre, the level of concern for the hazard quotient is one (1) at the typical application rate. Because the maximum application rate is 1.5 lb a.e./acre, the level of concern at the maximum application rate is 0.17 (i.e., 0.26 lb a.e./acre ÷ 1.5 lb a.e./acre).

Typical exposures to imazapyr do not lead to estimated doses that exceed a level of concern for either workers or the general public at either the typical or highest application rate. Although there are several uncertainties in the exposure assessments for workers and the general public, the upper limits for hazard quotients associated with chronic exposures are substantially below the level of concern. Based on the available information and under the foreseeable conditions of application, there is no route of exposure or scenario suggesting that the workers or the general public will be at any substantial risk from chronic exposure to imazapyr, even at the upper range of the application rate considered in this risk assessment.

Mild irritation to the eyes can result from exposure to relatively high levels of imazapyr. Exposure to the eye can be minimized or avoided by prudent industrial hygiene practices (e.g., exercising care to reduce splashing and wearing goggles) during the handling of the compound.

3.5.2 Workers

A summary of the risk characterization for workers associated with exposure to imazapyr is presented in Appendix B, Table B-34. Risk is characterized as the hazard quotient, the ratio of the estimated doses to the RfD (Appendix B, Table B-33). For both acute and chronic exposures (i.e., daily exposures that might occur over the course of an application season), the chronic RfD of 2.5 mg/kg/day is used to characterize risk.

As indicated in Section 2, the exposures in Appendix B, Table B-33 and the subsequent hazard quotients in Appendix B, Table B-34 are based on the typical application rate of 0.26 lb a.e./acre and the "level of concern" is one (i.e., if the hazard quotient is below 1.0, the exposure is less than the RfD). For all exposure scenarios, the estimated dose scales linearly with application rate. Thus, at an application rate of 1.5 lb a.e./acre, the highest labeled application rate, the level of concern would be 0.17 (i.e., 0.26 lb/acre ÷ 1.5 lb/acre).

The highest hazard quotient for workers based on chronic exposure is 0.02 – the upper range for broadcast ground spray (Appendix B, Table B-34). Even at the highest application rate modeled, the upper range of hazard quotients is below the level of concern by a factor of 8.5 (0.17 ÷ 0.02).

While the accidental exposure scenarios are not the most severe that could potentially occur (e.g., complete immersion of the worker or contamination of the entire body surface for a prolonged period of time) they are representative of the most plausible scenarios for accidental exposure. The highest hazard quotient for accidental worker exposures given in Appendix B, Table B-34 is 0.003 (i.e., the upper range for a worker wearing contaminated gloves for 1 hour). Because the estimate of the absorbed dose is linearly related to the hazard quotient, a scenario in which the worker wore contaminated gloves for about 166 consecutive hours (1÷0.006 = 166.666) or a about 7 days would be required to reach a level of concern (a hazard quotient of one) at the typical application rate.

Based on the highest application rate, the hazard quotient of 0.003 is below the level of concern (i.e., 0.17) by a factor of 57. Thus, at the highest application rate, a worker would have to wear contaminated gloves for 57 hours or about 2.5 days to reach a level of concern.

Based on conservative exposure assumptions, workers would not likely be exposed to concentrations of imazapyr that are regarded as unacceptable and none of the exposure scenarios modeled result in exposures approach a level of concern.

Confidence in this risk characterization for acute worker exposures is diminished by the lack of experimental data on the dermal absorption kinetics of imazapyr and that for chronic exposures is diminished by the lack investigations examining worker exposure. Uncertainties in the estimated dermal absorption rates and worker exposure rates are incorporated into the exposure assessment and risk characterization.

As discussed in Section 3.2.11, imazapyr is mildly irritating to the skin and eyes. Quantitative risk characterization for eye irritation was not derived; however, from available toxicity data, effects to the skin and eyes are likely to be the only overt effects as a consequence of exposure to imazapyr (SERA, 2004).

3.5.3 General Public

Risk characterization for the general exposed to imazapyr is summarized in Appendix B, Table B-36. Although there is some uncertainty in the chronic exposure assessments for the general public, as discussed in Section 3.3.3, the highest hazard quotients associated with chronic exposures are substantially below a level of concern. Based on the available information and under the conditions of application considered in this risk assessment, there appears to be no route of exposure or scenario suggesting that the general public will be at any substantial risk from chronic exposure to imazapyr even if the level of concern is set to 0.17 (i.e., that associated with the maximum application rate considered in this risk assessment). The highest hazard quotient for the consumption of contaminated vegetation is

0.009, a factor of over 100 below the level of concern at the typical application rate (1÷0.009) and about 19 (0.17÷0.009) below the level of concern at the maximum application rate.

For the acute exposure scenarios, none of the hazard quotients in listed in Appendix B, Table B-36 exceed the level of concern at the typical application rate of 0.26 lb a.e./acre (i.e., a hazard quotient of 1) or the level of concern at the highest application rate of 1.5 lb a.e./acre (i.e., a hazard quotient of 0.17). Thus, even at the highest application rate that might be used, none of the exposure scenarios result in a level of concern based on central estimates of exposure. At the upper range of exposure, the scenario for drinking contaminated water after an accidental spill into a small pond, the hazard quotient (0.2) only slightly exceeds a level of concern at the highest application rate (i.e., a hazard quotient of 0.2 compared to a level of concern of 0.17 at the highest application rate). At the typical application rate of 0.26 lb/acre, this scenario is below the level of concern by a factor of 5 (1÷0.2). All of the assumptions used to develop this scenario have a simple linear relationship to the resulting hazard quotient. If the accidental spill were to involve 20 gallons rather than 200 gallons of a field solution of imazapyr, all of the hazard quotients would be a factor of 10 less.

The direct spray of a small child yields a hazard quotient of 0.03, which is below the level of concern both at the typical application rate and at the highest application rate. Similar to the accidental spill scenario, this is an extreme scenario that is intended to assess a worst-case exposure.

All of the other acute exposure scenarios summarized in Appendix B, Table B-36 result in hazard quotients of 0.1 or less, well below the level of concern at either the typical application rate (level of concern = 1) or the maximum application rate (level of concern = 0.17).

Each of the hazard quotients summarized in Appendix B, Table B-36 is based on a single exposure scenario. It is possible that some individuals could experience more than one exposure route. In such cases risk could be approximated by summing the hazard quotients for each individual exposure scenario. For imazapyr, consideration of multiple exposure scenarios has little impact on the results of the risk assessment. For example, based on the upper ranges for typical levels of acute exposure (i.e., sprayed directly on the lower legs, staying in contact with contaminated vegetation, eating contaminated fruit, drinking contaminated water from a stream, and consuming contaminated fish at rates characteristic of subsistence populations), the combined hazard quotient is 0.035 (0.003 + 0.0007 + 0.02 + 0.0009 + 0.01). This is below the level of concern by a factor of about 29 at the typical application rate (1÷0.035) and about 5 at the highest application rate (0.17÷0.035). Similarly, for all of the chronic exposure scenarios, the addition of all possible pathways leads to hazard

quotient of approximately 0.079004007, with consumption of contaminated vegetation (0.07) accounting for virtually all of the totaled risk.

3.5.4 Sensitive Subgroups

There is no information to suggest that specific groups or individuals may be especially sensitive to imazapyr. As indicated in Section 3.2, the mechanism of action for imazapyr is not well understood. It does not appear to specifically affect the nervous system (Section 3.2.8) or the immune system (Section 3.2.7) but there is suggestive evidence that it may affect endocrine function (Section 3.1.8). Given the very low hazard quotients for imazapyr, there appears to be no basis for concern that certain groups are more sensitive to imazapyr or at greater risk due to imazapyr exposure. EPA (1997, 2003) has indicated that infants and children are not likely to be more sensitive to imazapyr than adults.

3.5.5 Synergistic Effects of Imazapyr in Combination with Other Herbicides and Adjuvants

Imazapyr is often applied in combination with other herbicides, such as glyphosate formulations. In addition, surfactants, anti-foaming agents, and tracer dyes are often included in the final herbicide solution. No studies were located in the literature that investigated the toxicity of herbicides mixtures to mammals. The absence of such information does not allow a characterization of the joint action of imazapyr (i.e., synergism, antagonism, or additivity) with other herbicides and adjuvants. The limited information about the toxicity of a mixture of imazapyr with imazethapyr submitted to EPA by the manufacturer (Lowe, 1988) as part of the registration process, did not indicate that the mixture possessed greater toxicity than imazapyr by itself (SERA, 2004).

3.6 DATA GAPS AND UNCERTAINTY

Uncertainty can be introduced into a health risk assessment at every step of the process and occurs because risk assessment is a complex process, requiring the integration of the following:

- Release of pollutants into the environment
- Fate and transport of pollutants in a variety of different and variable environments, by processes that are often poorly understood or too complex to quantify accurately (EPA, 2005c)

Uncertainty is inherent in the process even when using the most accurate data and the most sophisticated models. There a number of sources of uncertainty in the human health risk assessment for imazapyr:

- Variable uncertainty,
- Model uncertainty, and
- Variability.

Model uncertainty is associated with all models used in all phases of a risk assessment, including:

- Animal models used as surrogates for testing human toxicity,
- Probability of adverse effects in a human population that is highly variable genetically, and in age, activity level, and lifestyle;
- The dose-response models used in extrapolations, and
- The computer models used to predict the fate and transport of chemicals in the environment.

Using laboratory test animals as surrogates for humans introduces uncertainty into the risk factor because of the considerable interspecies variability in sensitivity. Computer models are simplifications of reality, requiring exclusion of some variables that influence predictions but cannot be included in models because of (1) increased complexity or (2) a lack of data for these variables. A specific variable may be important, in terms of its impacts on uncertainty, in some instances and not in others. A similar problem can occur when a model that is applicable under average conditions is used for a case in which conditions differ from the average. Finally, choosing the correct model form is often difficult, because conflicting theories appear to explain a phenomenon equally well (EPA, 2005c).

The use of standard EPA default values in any risk analysis introduces another layer of uncertainty. These include inhalation rates, body weight, and lifespan, which are standard default values used in most risk assessments. Inhalation rate is highly correlated to body weight for adults. Using a single point estimate for these variables instead of a joint probability distribution ignores a variability that may influence the results by a factor of up to two or three (EPA, 2005c).

Imazapyr is generally applied mixed with a number of adjuvants, including surfactants, foam-suppressing agents, and tracer dies. Additionally, imazapyr may also be applied in combination with other herbicides such a glyphosate. As discussed in Section 3.2.13, there a wide variety of surfactants available. Thus, the number of possible mixture combinations is relatively high. No mammalian studies were identified that investigated the toxicity of imazapyr

mixed with adjuvants or other herbicides. This risk assessment only evaluated human exposure to the active ingredient without considering the toxicity of imazapyr in combination with adjuvants or other herbicides. Although the results of the risk assessment indicate that imazapyr is practically non-toxic to humans, the risk to humans exposed to imazapyr mixed with other agents is an unknown.

4.0 ECOLOGICAL RISK ASSESSMENT

4.1 OVERVIEW OF APPROACH

The ecological risk assessment follows the methodology recommended by EPA (1998). This methodology generally includes the following four steps:

- **Hazard Identification.** Identifying the chemicals that will be addressed in the risk assessment and the toxicological hazards posed by these products.
- **Exposure Assessment.** Characterizing the magnitude, frequency, and duration of exposure to a chemical for workers and members of the general public.
- **Dose-Response Assessment.** Identifies the quantitative relationship between the chemical dose and the incidence of adverse health effects in ecological receptors.
- **Risk Characterization.** Estimating the potential for adverse health effects by integrating the information from the dose-response assessment with the exposure assessment.

Each of these steps is discussed in greater detail in subsequent sections.

4.2 HAZARD IDENTIFICATION

4.2.1 Overview

Toxicity studies with imazapyr have failed to demonstrate any significant or substantial toxicity in test animals exposed to imazapyr via multiple routes of exposure. As with virtually all ecological risk assessments, few wildlife species have been assayed relative to the large number of non-target species that might be exposed to a chemical such as imazapyr. Acknowledging this limitation, imazapyr appears to be relatively non-toxic to terrestrial and aquatic animals (SERA, 2004).

The toxicity of imazapyr to terrestrial plants is relatively well characterized. Imazapyr is practically non-toxic to conifers, but is toxic to many other non-target plants. Imazapyr inhibits acetolactate synthase (ALS), an enzyme that catalyzes the biosynthesis of three branched-chain amino acids, all of which are essential for plant growth. Although post-emergence application is more effective than pre-emergence application, toxicity can be induced either through foliar or root absorption. Imazapyr is not metabolized extensively in plants but is transported rapidly from treated leaves to root systems and may be exuded into the soil from the roots of treated plants (SERA, 2004).

The available data indicate that imazapyr is relatively non-toxic to soil microorganisms, aquatic invertebrates, and fish. Imazapyr is not expected to bioaccumulate or bioconcentrate in the food chain. In terrestrial animals and birds, imazapyr is practically non-toxic.

Toxicity studies with aquatic plants indicate that the most sensitive species appear to be aquatic macrophytes, such *Lemna gibba* and *Myrophyllium sibiricum*, with reported EC_{25} values of 0.013 mg a.e./L in both species. Some algae appear to be substantially less sensitive, with EC_{50} values on the order of about 0.2 mg/L. In tolerant plant species, concentrations up to 100 mg /L may cause either no effect or may be associated with a growth stimulation rather than growth inhibition (SERA, 2004).

4.2.2 Toxicity to Terrestrial Organisms

This section reviews available information regarding the toxicity of imazapyr to terrestrial organisms, including mammals, birds, amphibians (terrestrial phase), terrestrial invertebrates, and terrestrial plants.

4.2.2.1 Mammals

The toxicity studies used to assess the potential hazards of imazapyr to humans (Table 3) will also be used in the risk assessment for mammalian wildlife. As discussed in Section 3.2 and further detailed in Table 3, virtually all of the laboratory toxicity studies on imazapyr with test animals have demonstrated no effects clearly attributable to imazapyr exposure. While the mechanism of imazapyr in plants is relatively well understood (Section 4.1.2.4), it is not clear what, if any, toxicity imazapyr may cause in mammalian wildlife. Chronic studies in three mammalian species (dogs, rats, and mice) and reproductive studies in two mammalian species (rats and rabbits) indicate that imazapyr is not likely to be associated with adverse effects at relatively high-dose levels.

4.2.2.2 Birds

Both ducks and quail have been studied in 5-day acute toxicity bioassays and 18-week reproduction studies (Table 5). As with the mammalian studies, no adverse effects have been reported in birds at the concentrations studied. Fletcher (1983a, 1983b) reported no acute toxicity (mortality) at imazapyr concentrations of up to 5,000 ppm in the diet. The acute exposures were equivalent to average daily doses of 674 mg/kg body weight (bw) in quail (Fletcher, 1983b) and 1,149 mg/kg bw in ducks (Fletcher, 1983a).

Similarly, in the 18-week reproductive studies, no effects were reported on reproductive endpoints (i.e., egg production, hatchability, survival of hatchlings) at dietary concentrations of up to 2,000 ppm. The 18-week exposures were equivalent to average daily doses of 200 mg/kg in both quail and ducks (Fletcher et al., 1995a,b). The LD_{50} for bobwhite quail and mallard ducks is >2,150 mg/kg (Fletcher et al., 1984a,b).

4.2.2.3 Adult Amphibians and Reptiles

No studies were found in the open literature that assessed the toxicity of imazapyr to adult amphibians or reptiles. Trumbo (unpublished study), conducted 96-hour acute bioassays with bull frog (*Rana catesbeiana*) tadpoles. The results of this study are summarized in Table 6) and discussed in Section 4.2.3.2.

4.2.2.4 Terrestrial Invertebrates

The only information on the toxicity of imazapyr to a terrestrial invertebrate is provided in studies with the honey bee conducted by Atkins (1984) and Atkins and Kellum (1983) (Table 7). Atkins and Kellum (1983) identified an oral LD_{50} in the honey bee of >0.1 mg/bee. Taking an average weight of 0.093 g/bee or 0.000093 kg/bee (SERA, 2004) and making the very conservative assumption of 100 percent absorption, this would correspond to an LD_{50} greater than 1,000 mg/kg bw [0.1 mg imazapyr/bee ÷ 0.000093 kg bw/bee = 1,075 mg/kg]. The toxicity of imazapyr in honey bees is comparable to the LD_{50} values reported in experimental mammals (Table 3) and birds (Table 5). Because terrestrial insect toxicity data for imazapyr is limited to a single terrestrial insect species, the honey bee, the ability to characterize potential effects in other species is limited.

4.2.2.5 Terrestrial Plants (Macrophytes)

The toxicity of imazapyr to terrestrial plants is relatively well characterized (Table 8). After foliar application, imazapyr is transported throughout the plant via the phloem and is able to control deeply rooted weeds. The efficacy of imazapyr appears to be particularly strongly related to its transport in phloem (SERA, 2004). Rapid transport from treated leaves to root systems has been noted by Nissen et al. (1995) using liquid growth cultures of leafy spurge (*Euphordia esula*) after foliar treatments with ^{14}C-imazapyr. By day 8 after application, 14 percent of the applied imazapyr remained in the leaf tissue, but 17 percent was transported to the root system. In terms of total absorption, 62.5 percent of the applied radioactivity was absorbed by day 2 and 80.0 percent by day 8. Under the assumption of simple first-order absorption, the absorption rate, k_a, should be constant over time and can be calculated as the natural logarithm of the proportion of the unabsorbed dose divided by the duration of exposure:

$$k_a = \ln(1- P_a)/t \qquad \text{(Equation 3)}$$

where P_a is the proportion absorbed over the time interval t. The k_a values calculated for day 2 and day 8 are 0.49 day^{-1} (ln[1-0.625]/2) and 0.20 day^{-1} (ln[1-0.8)/8]), respectively. Thus, at least in this species, the rate of absorption may not be constant with time and first order absorption kinetics may not apply. Alternatively, these differences may simply reflect random variation in the responses of the plants or the measurements taken during the study. The data

reported by Nissen et al. (1995) do not include a sufficient number of time points to evaluate either possibility.

Imazapyr does not appear to be readily or extensively metabolized by plants, although imazapyr metabolites from leafy spurge were detected but not identified after 8 days in the study by Nissen et al. (1995).

Some herbicides may be absorbed by plant foliage, translocated to the roots, and subsequently exuded from the roots to the surrounding soil, posing a risk to neighboring plants. This process, referred to as allelopathy (SERA, 2004). Although reports of allelopathic effects for imazapyr have not been reported in field studies, Nissen et al. (1995) found that about 3 percent of absorbed imazapyr may be exuded from the root system of leafy spurge into a liquid culture medium by day 8 after treatment. This report, combined with the fact that herbicides with similar physical and chemical properties as that of imazapyr, generally translocate similarly in plants (SERA, 2004), suggests that imazapyr has the potential to induce allelopathic effects.

4.2.2.6 Terrestrial Microorganisms

Relatively little information is available concerning the toxicity of imazapyr to terrestrial microorganisms. In pure culture laboratory assays, imazapyr inhibited the growth of two strains of plant-associated bacteria, *Bacillus subtilis* and *Bacillus circulans*, isolated from wheat. LC_{50} values ranged from about 10 to 100 micromoles (µM) (Forlani et al., 1995). Three other species of *Bacillus,* as well as several additional soil bacteria, were not affected at concentrations up to 1,000µM (Forlani et al., 1995). Thus, effects on bacteria appear to be highly species specific with variations in sensitivity of up to a factor of 100. Consequently, imazapyr does appear to have the potential to shift bacterial soil populations that contain sensitive species of bacteria. In addition, imazapyr has been shown to inhibit rates of cellulose decomposition and carboxymethyl cellulase activity in peat soil with 59 percent organic carbon (Ismail and Wong, 1994). These investigators speculate that the reduction in cellulose degradation was likely only a temporary effect and that imazapyr activity on terrestrial microorganisms may decline as the herbicide is adsorbed to soil and thus unavailable to microorganisms. Imazapyr is likely to bind relatively strongly to peat. Alternatively, imazapyr may persist in soil for a prolonged period of time, particularly in relatively arid regions, and will not bind strongly to alkaline soils with low organic matter. Thus, in at least some areas, a potential for longer-term effects on soil microorganisms seems plausible. As with effects on both terrestrial and aquatic plants, the plausibility and magnitude of any such effects are likely to be highly site-specific (SERA, 2004).

Wang et al. (2005), studying biodegradation of imazapyr in four soil types from China, reported that the half-life of imazapyr in non-sterile soils was in the range of 30 to 45 days, while 81 to 133 days in sterile soils. Biodegradation in four non-sterile soils accounted for 62 percent to 78 percent of imazapyr degradation. In contrast, less than 39 percent of imazapyr degradation was associated with chemical mechanisms. The authors reported that the rate constant of imazapyr under non-sterile conditions were 2.3 to 4.4 times faster than that under sterile conditions, concluding that the indigenous soil microorganisms play an important role in imazapyr degradation.

In the same study by Wang et al., (2005), two imazapyr-degrading bacterial strains were isolated in an enrichment culture technique and were identified as *Pseudomonas fluorescenes* and *Bacillus cereus*. When added to test soils, the bacterial strains could degrade 81 percent to 87 percent of the imazapyr after 48 hours of incubation. The treatment soils with the added bacterial strains increased the imazapyr degradation rate by 3 to 4 fold over that for control samples.

4.2.3 Aquatic Organisms

This section summarizes the available information assessing the toxicity of imazapyr to aquatic organisms, including fish, aquatic-phase amphibians, aquatic invertebrates, and aquatic plants.

4.2.3.1 Fish

The results of toxicity studies with a number of fish species are summarized in Table 9. Standard 96-hour acute bioassays indicate that the LC_{50} >100 mg/L. Foreign studies found that the silver barb (*Barbus gonionotus*) and Nile tilapia (*Oreochromis niloticus niloticus*) may be more sensitive to the acute toxic effects of imazapyr with 96-hour LC_{50} values of 2.71 mg/L and 4.36 mg/L, respectively (Supamataya et al., 1981). This study is published in Thai with an English abstract and a full text copy of this study was not obtained and translated for the current risk assessment. As discussed in Section 4.3, the 96-hour LC_{50} concentrations reported in this study are substantially above concentrations that may be encountered in the environment under normal use scenarios for imazapyr. However, the results from these studies are further considered in the dose-response assessment for fish (Section 4.4) and risk characterization (Section 4.5).

The chronic toxicity of imazapyr has also been tested in an early life-stage bioassay using rainbow trout (*Oncorhynchus mykiss*) at concentrations of 0, 6.59, 12.1, 24.0, 43.1, or 92.4 mg/L for 62-day exposures. At the highest concentration, a nearly significant effect on hatching was observed (Manning, 1989b); however, the investigator judged that this effect was not toxicologically significant. Nonetheless, the classification of 92.4 mg/L as a NOAEL is

questionable (SERA, 2004). Consistent with the imazapyr risk assessment conducted by SERA (2004) for the U.S. Forest Service, the next lower dose, 43.1 mg/L, will be used as the NOAEL. As discussed in Section 4.5, any of these concentrations are far in excess of concentrations that are likely to occur in the environment.

4.2.3.2 Amphibians

Only one unpublished study was found that investigated the acute toxicity of several imazapyr formulations to bull frog (*Rana catesbeiana*) tadpoles. Trumbo (unpublished) exposed bull frog tadpoles to imazapyr acid, Stalker®, and Habitat® solutions for 96 hours. The reported 96-hour LC_{50} concentrations for imazapyr acid, Stalker®, and Habitat® were 799.6 mg a.i./L, 14.77 mg a.i./L, and 1,739 mg a.i./L., indicating that imazapyr is not very toxic to bull frog tadpoles.

EPA (Hurley and Shanaman, 2007) conducted a risk assessment to evaluate potential impacts of imazapyr to the federally-listed California red-legged frog (*Rana aurora draytonii*) (CRLF) and its critical habitat. The assessment endpoints for the CRLF included direct toxic effects on survival, reproduction, and growth of individual CRLF's, as well as indirect effects, such as reduction of the food source and/or modification of habitat. Risk quotients (RQs) for direct acute effects to the CRLF were calculated using acute toxicity data from either registrant-submitted studies or acceptable studies available in the open literature for the surrogate species, freshwater fish for the aquatic-phase and birds for the terrestrial-phase, when toxicity data on amphibians were not available. RQs for direct chronic (reproductive, growth) effects were also calculated using either registrant-submitted or acceptable open literature chronic toxicity data for freshwater fish and birds. To assess potential indirect effects to the CRLF via direct effects to potential prey (and consequently a reduction of available prey items), toxicity data for freshwater fish and invertebrates as well as birds (surrogate for terrestrial-phase amphibians), terrestrial invertebrates and mammals were considered. Registrant-submitted and/or acceptable open literature aquatic and terrestrial plant toxicity studies were used to assess risk to primary producers, and in turn, potential indirect effects to the CRLF.

This risk assessment for the CRLF indicates that no direct effects are expected on either the aquatic or terrestrial phase of the CRLF. There are also no indirect effects expected for the CRLF through direct effects to either its terrestrial or aquatic food sources. The effects determination for direct effects on the CRLF and for indirect effects through food sources is no effect. The risk assessment determined that the CRLF may be adversely affected through direct effects on habitat and/or primary productivity (i.e., ecosystem structure and function for both the aquatic plant community and riparian vegetation). Critical habitat may also be adversely modified based on direct effects to aquatic vascular plants and terrestrial plants. The risks exceed the level of concern (LOC) for non-listed, non-target terrestrial plants

(monocots and dicots) for all imazapyr uses. The risks to non-listed non-target aquatic vascular plants exceed the LOC for aquatic, rangeland and forestry uses (aerial application) as well as rights-of-way (assuming 50 percent pervious surfaces). No effects are expected for aquatic non-vascular plants (EPA, 2007).

4.2.3.3 Aquatic Invertebrates

Three aquatic toxicity studies were conducted with the water flea (*Daphnia magna*). In one study, Arsenal® was tested with an unspecified surfactant and yielded a 48-hr LC_{50} of 350 mg-Arsenal®/L (79.1 mg a.e. imazapyr/L) and an NOEC of 180 mg-Arsenal®/L (40.7 mg a.e./L). Other product registrant studies where *Daphnia* was exposed to an imazapyr formulation (~50 percent) lacking the surfactant resulted in a 48-hour EC_{50} concentration of 373 mg a.e./L (Cyanamid, 1997). The results of these two studies highlight the potential effect of surfactant on aquatic toxicity, and the authors concluded that the components of the Arsenal® formulation, other than a surfactant, do not influence the toxicity of imazapyr to aquatic organisms. Kintner and Forbis (1983b) also reported 24 and 48-hour LC_{50} concentrations of greater than 100 mg/L (the highest dose tested [HDT]), in static tests conducted with newly-hatched *Daphnia* (less than 24 hours old).

Manning (1989c) conducted chronic studies with the water flea, reporting no adverse effects on survival, reproduction or growth of 1st generation *Daphia* after 7, 14 and 21 days of exposure at concentrations up to 97.1 mg/L, the HDT. Per FIFRA registration requirements, the NOEC was considered to be the HDT (97.1 mg/L), and the maximum allowable toxicant concentration (MATC) was considered to be > 97.1 mg/L.

Testing with other invertebrate species that exhibit alternative life cycles has been limited to growth studies with the Eastern oyster (*Crassostrea virginica*), and survival of northern pink shrimp (*Penaeus duorarum*). Although these species are not native to Washington, they do provide reasonable surrogates for the Pacific oyster (*Crassostrea gigas*) and burrowing shrimp (*Neotrypaea* spp.) In these product registrant tests, the EC_{50} for growth inhibition was established at a concentration greater than 132 mg-imazapyr/L, with the NOEC set at this concentration – the HDT. The pink shrimp survival LC_{50} was >189 mg imazapyr/ L, and the NOEC was again set at this HDT (Mangels and Ritter, 2000).

Fowlkes et al. (2003) conducted *in situ* microcosm studies with imazapyr in Florida cypress domes, which are isolated, shallow basins that collect surficial waters from adjacent forested areas. This study utilized *in situ* microcosm experiments to assess the effects of a concentration gradient of imazapyr (0.184, 1.84, and 18.4 mg/L (equivalent to 1, 10, and 100 times the expected environmental concentration from a normal application rate) on the macroinvertebrate community of a logged pond cypress dome using changes in

macroinvertebrate composition, chironomid biomass, and chironomid head-capsule deformities. Control microcosms were used that were not significantly different from the surrounding cypress dome for any parameter, suggesting that enclosure effects were likely of minimal importance in the final experimental results. The lack of statistical difference ($r < 0.05$) in macroinvertebrate community composition, chironomid deformity rate, and chironomid biomass between treatments suggested that imazapyr did not affect the macroinvertebrate community at the concentrations tested.

Table 10 summarizes the aquatic toxicity tests conducted with imazapyr in fish and aquatic invertebrates.

4.2.3.4 Aquatic Plants

Bioassays were conducted as part of the product registration process to study the toxicity of imazapyr to aquatic plants. The most sensitive species appear to be the aquatic macrophytes *Lemna gibba*, with a reported EC_{25} of 0.013 mg a.i./L (Hughes, 1987), and *Myrophyllium sibiricum*, with a reported EC_{25} of 0.013 mg a.i./L for shoot growth and 0.0079 mg a.i./L for root growth (Roshon et al., 1999).

As detailed in Table 11, aquatic algae appear to be substantially less sensitive. The most sensitive species of algae appears to be *Chlorella emersonii*, with an EC_{50} of about 0.2 mg/L (Landstein et al., 1993). The growth of other species of algae is stimulated rather than inhibited by imazapyr at concentrations of up to 100 mg/L (Hughes, 1987). As with terrestrial plants, some species of aquatic plants may develop resistance to imazapyr. Bioassays conducted with *Chlorella emersonii* indicate that resistant strains may be less sensitive to imazapyr by a factor of about 10 (Landstein et al., 1993).

4.2.4 Adjuvant and Inert Ingredient Toxicity to Terrestrial and Aquatic Ecological Receptors

Current FIFRA regulations do not require manufacturers to reveal the surfactant formulations, as FIFRA regulates the active ingredients only. Similarly, many of the inert ingredients in the commercial imazapyr formulations are not known. Herbicide toxicity studies conducted under FIFRA are required to evaluate the active ingredient of the product formulation only, and not the toxicity of the inert ingredients or the surfactants that may be used to facilitate plant herbicide efficacy. For some ecological receptors, particularly aquatic receptors, the choice of which surfactant can have substantial ecological relevance, as the few tests conducted with surfactants have shown higher toxicity than the herbicide. Similarly, in environments where a variety of herbicides and/or pesticides may be used, the potential for chemical interactions of inert ingredients should also be understood to minimize risks (Entrix, 2003). This section

summarizes the existing information on the toxicity inherent to the inert ingredients and surfactants that could be used in the application of imazapyr.

4.2.4.1 Inert Ingredients

Two of the inert ingredients in Arsenal® are listed as glacial acetic acid and water (Entrix, 2003). Water is non-toxic and required for life. The toxicity of acetic acid is summarized in Table 12), as summarized in Entrix (2003). Acetic acid is also a component of LI 700®, a common non-ionic surfactant potentially used with imazapyr.

4.2.4.2 Adjuvants

Surfactants are the most commonly used adjuvants added to herbicide spray solutions to promote herbicide adsorption and uptake. Generally two classes of surfactants are used: non-ionic nonylphenol alcohols and/or fatty acids, and crop-oil based concentrates. Their inherent chemical properties can have a range of effects on environmental receptors that are independent of the herbicide formulation. Section 3.2.13 describes some of the more commonly used surfactants. In brief, the acute toxicity of alkylphenol ethoxylate surfactants like R-11® to fish and other aquatic species has been reported in the range of 4 to 12 mg/L. Crop-oil based surfactants such as Agri-Dex® exhibit lower toxicity. On the basis of EPA aquatic toxicity criteria, all the surfactants used would be considered practically non-toxic (Agri-Dex®) to moderately toxic (R-11®). All of the surfactants can cause irritation to skin and ocular tissue at high doses, and receive ratings of moderate (scores of 4 to 6 on an 8-point scale) irritants in mammals. Limited testing by oral administration in mammals indicates that the surfactants are "practically non-toxic" (Entrix, 2003).

Studies with the herbicide glyphosate demonstrate that the toxicity of surfactants is generally greater than the toxicity of the active ingredient in herbicide formulation that they are mixed. Toxicity studies with Rodeo®, a glyphosate formulation, relate how the toxicity of the Rodeo® formulation was 1,100 mg/L without surfactant, and 680 mg/L with the mixture containing 0.4 percent X-77 (Mitchel et al., 1987). A similar relationship has been observed with aquatic invertebrates with Rodeo® (Henry, 1992). Recent studies with both imazapyr (Arsenal®) and glyphosate (Rodeo®) examined the inherent toxicity of the surfactants also, both with and without the herbicides (Smith et al., 2004). As demonstrated in Table 13, the toxicity of the seed and crop-oil based surfactant Agri-Dex® to rainbow trout is three orders of magnitude lower than R-11®. When surfactant was mixed with herbicide, the toxicity of the surfactant was reduced and the toxicity of the herbicide was increased. These studies reveal that the toxicity associated with herbicide/surfactant mixtures is not additive, and is generally associated with the surfactant. Of the surfactants examined in detail, the order of toxicity, from lowest to highest, would appear to be as follows: Agri-Dex®, Class Act® NG, Dyne-Amic®, and R-11®.

The alkylphenols and octyl phenol ethoxylates, the active ingredients in surfactants such as Dyne-Amic® and R-11®, belong to a broader class of chemicals known as nonylphenols. Cox (1996) estimated that approximately 80 percent of the alkyl phenol ethoxylates are nonylphenol ethoxylates and the other 20 percent are octyl phenol ethoxylates. Because these compounds are not components of the herbicide formulation, their exact formulations are patent-protected and are not reportable under FIFRA. However, EPA considers the nonylphenols as an "inert of toxicological concern" (Entrix, 2003).

Nonylphenol ethoxylates degrade to nonylphenol and related compounds that can be relatively persistent in the environment. Sublethal effects at exposure concentrations below acutely toxic levels include impaired swimming activity, altered breathing rate, and reduced heart rate in fish at 0.5 mg/L, and inhibited siphon retraction, byssal thread formation and reduced burrowing activity in sessile shellfish at concentrations greater than 1 mg/L (Entrix, 2003). Lethal effects as reported in the literature are summarized in Table 14. The intermediate breakdown products of these surfactants can include both linear and branched chain alkylphenols, which may also be toxic. Some of these products have been shown to elicit weak estrogenic effects when administered at high doses to laboratory animals (Bakke, 2003). Assessing risk associated with the various surfactants containing alkylphenols is nearly impossible as the precise alkylphenol derivates used in each surfactant and their concentrations is proprietary information and not provided by the manufacturers (Entrix, 2003).

4.3 EXPOSURE ASSESSMENT

The exposure assessment characterizes the magnitude, frequency, and duration of exposure to imazapyr for ecological receptors, including terrestrial receptors (mammals, birds, terrestrial-phase amphibians, terrestrial invertebrates, and terrestrial plants) and aquatic receptors (fish, aquatic invertebrates, and aquatic plants). Figure 2 presents a conceptual model outlining the primary exposure pathways modeled for ecological receptors. The model is not intended to depict all potential exposure routes, but only those with complete exposure pathways that may lead to toxicity and those with complete exposure pathways that are unlikely to result in toxicity. As an example, the available toxicity data indicate that imazapyr does not bioaccumulate, so that consumption of plants or animals from contaminated environments is unlikely to result in toxicity.

The conceptual site model (Figure 2):

- Identifies the primary source of contamination in the environment;
- Shows how imazapyr at the original point of release might move in the environment;

- Identifies the different types of ecological receptor populations (e.g., terrestrial and aquatic animals and plants) who might come into contact with contaminated media;
- Lists the potential exposure pathways (e.g., direct spray, ingestion of contaminated water, dermal contact with contaminated vegetation) that may occur for each population

4.3.1 Overview

Exposure of terrestrial animals to imazapyr may occur via direct spray, ingestion of contaminated media (vegetation, prey species, or water), grooming activities, or indirect contact with contaminated vegetation. In acute exposure scenarios developed for this ecological risk assessment, the highest exposures for small terrestrial vertebrates will occur from a direct spray and could be as high as 6.3 mg a.e./kg at an application rate of 0.26 lb a.e./acre (Appendix B, Table B-60).

There is a wide range of acute exposures associated with the consumption of contaminated vegetation by terrestrial animals: central estimates range from 0.33 mg/kg for a small mammal to 7 mg/kg for a large bird with upper ranges of about 0.7 mg/kg for a small mammal and about 20 mg/kg for a large bird (Appendix B, Table B-60). The consumption of contaminated water results in much lower levels of acute exposure (Appendix B, Table B-60).

A similar pattern is seen for chronic exposures as that for acute exposure. Estimated daily doses for a small mammal consuming contaminated vegetation at the application site are in the range of about 2.53E -5 mg/kg to 0.06 mg/kg. The highest doses resulting from chronic exposure to contaminated vegetation far exceed those that associated the consumption of contaminated water, which range from 4E -7 mg/kg/day to 4E -5 mg/kg/day for a small mammal. The exposure assessment indicates that the toxicity of imazapyr to terrestrial animals is very low and that exposure of terrestrial animals to imazapyr presents very low risk.

Five exposure scenarios were considered for terrestrial plants: direct spray, spray drift, runoff, wind erosion and the use of contaminated irrigation water. Unintended direct spray is expressed simply as the application rate considered in this risk assessment, 0.26 lb a.e./acre and should be regarded as an extreme/accidental form of exposure. All of the exposure scenarios are highly dependent on site-specific conditions. The exposure estimates are intended to represent conservative, but plausible exposure ranges; however these ranges may over-estimate or under-estimate actual exposures in some cases. Spray drift is based on estimates of AgDRIFT modeling conducted by SERA (2004) in their risk assessment of imazapyr for the U.S. Forest Service. The proportion of the applied amount transported off-site from runoff is based on GLEAMS modeling conducted by SERA (2004) for clay, loam, and sand soils. The amount of imazapyr that might be transported off-site from wind erosion is based on estimates of annual soil loss associated with wind erosion and the assumption that

the herbicide is incorporated into the top 1 cm of soil (SERA, 2004). Exposure from the use of contaminated irrigation water is based on the same data used to estimate human exposure from the consumption of contaminated ambient water and involves both monitoring studies as well as GLEAMS modeling.

Exposures of aquatic plants and animals are based on essentially the same information used to assess the exposure of terrestrial species to contaminated water. Based on GLEAMS modeling conducted by SERA (2004), the peak estimated concentration of imazapyr in surface water associated with the normal application of imazapyr is 0.002 (0.0001 to 0.08) mg a.e./L at an application rate of 1 lb a.e./acre. For chronic exposures, the average estimated concentration of imazapyr in surface water associated with the normal application of imazapyr is 0.0001 (0.00001 to 0.001) mg a.e./L at an application rate of 1lb a.e./acre. For the hazard assessment, these contaminant concentrations are adjusted based on the application rate (0.26 lb a.e./acre) considered in this risk assessment.

4.3.2 Terrestrial Animals

Terrestrial animals may be exposed to imazapyr via direct spray, the ingestion of contaminated media (vegetation, prey species, or water), grooming activities, or indirect contact with contaminated vegetation. Table 15 summarizes the exposure pathways for terrestrial mammals addressed in this risk assessment. The exposure assessments for terrestrial animals are summarized in Appendix B, Table B-60. As with the human health exposure assessment, the computational details for each exposure assessment presented in this section are provided Appendix B (Tables B-37 through B-59).

Because of allometric relationships and dietary requirements, small animals will generally receive a higher dose of a chemical, in terms of mg/kg body weight, than will large animals for a given type of exposure (SERA, 2004). Consequently, most general exposure scenarios for mammals and birds are based on small animals. For small mammals such as mice, a body weight of 20 grams is generally assumed. For small mammals and birds, exposure assessments are conducted for direct spray (Appendix B, Tables B-37 and B-38), consumption of contaminated fruit (Appendix B, Tables B-41 through B-43), and contaminated water (Appendix B, Tables B-44 through B-46).

It is assumed that grasses will generally have higher concentrations of herbicides than fruits and other types of vegetation (SERA, 2004). Because small mammals do not generally consume large amounts of grass, the exposure scenario for contaminated grass is based on consumption by a large herbivorous mammal (deer) (Appendix B, Tables B-49 through B-51). Other exposure scenarios for mammals involve the consumption of contaminated insects by a

small mammal (Appendix B, Table B-55) and the consumption of small mammals by a large mammalian carnivore (Appendix B, Table B-58).

Exposure scenarios for birds are summarized in Table 15 and involve the consumption of contaminated insects by a small bird (Appendix B, Table B-56), the consumption of contaminated fish by a predatory bird (Appendix B, Tables B-47 and B-48), the consumption of small mammals by a predatory bird (Appendix B, Table B-59), and the consumption of contaminated grasses by a large bird (Appendix B, Tables B-52 through B-54).

4.3.2.1 Direct Spray

Broadcast application of herbicides may result in direct exposure of wildlife species. The amount of herbicide absorbed depends on the application rate, the surface area of the animal, and the rate of absorption. Four direct spray exposure scenarios are evaluated. The first assumes direct application of imazapyr to one half of the body surface area of a 20-gram (g) mammal (Appendix B, Table B-37). The absorbed dose over the first 24-hour period is estimated using the assumption of first-order dermal absorption. In the absence of data describing dermal absorption in small mammals, the estimated absorption rate for humans is used (Section 3.2.3). An empirical relationship between body weight and surface area (Boxenbaum and D'Souza, 1990) is used to estimate the surface area of the animal (SERA, 2004).

There are substantial uncertainties that affect the estimates for absorbed dose. The estimate based on first-order dermal absorption does not consider fugitive losses from the surface of the animal and may overestimate the absorbed dose. Conversely, some animals, particularly birds and mammals, groom frequently, which may contribute to the total absorbed dose by direct ingestion of the compound residing on fur or feathers. Other vertebrates, particularly amphibians, may have skin that is far more permeable than the skin of most mammals. Quantitative methods for considering the effects of grooming or increased dermal permeability are not available (SERA, 2004).

As a conservative upper limit, the second exposure scenario, detailed in Appendix B, Table B-38, assumes complete absorption over a 24-hour exposure period.

Because of the relationship of body size to surface area, very small organisms, like honey bees and other terrestrial insects, might be exposed to much greater amounts of imazapyr per unit body weight, compared with small mammals. Consequently, a third exposure scenario direct application to the honey bee, using a body weight of 0.093 g (USDA/APHIS, 1993) and the equation proposed by Boxenbaum and D'Souza (1990) for estimating body surface area. Because there is no information regarding the dermal absorption rate of imazapyr in bees or

other invertebrates, this exposure scenario (Appendix B, Table B-39) assumes complete absorption over the first 24 hours of exposure (SERA, 2004).

The final direct spray scenario is for the terrestrial phase of an adult amphibian. No studies were located that assess imazapyr toxicity to adult amphibians or reptiles. As recommended by EPA (2005b), surrogate species are used to predict potential risks for species with no toxicity data (*i.e*. reptiles, amphibians). It is assumed that use of surrogate effects data is sufficiently conservative to apply to the broad range of species within taxonomic groups. EPA (2005b) recommends the use of avian toxicity data as surrogate data for both amphibians and reptiles. Under this scenario, it is assumed that a frog is completely covered (100 percent of body surface area) with a spray of imazapyr solution applied at 0.26 lb a.e./acre. As with the honey bee, this scenario assumes complete absorption. The northern green frog (*Rana clamitans*) was selected as a representative adult amphibian. EPA (1993) lists the mean body weight and surface area for this species as 49.1 g and 17 cm², respectively. This exposure scenario is detailed in Appendix B, Table B-40).

Direct spray scenarios were not considered for large mammals. As noted above, allometric relationships indicate that exposure in large mammals would likely be less than in small mammals in any direct spray scenario. As will be discussed in Section 4.5, the results of the direct spray scenarios for the small mammals, which are considered the most conservative scenario for direct spray to a mammal, indicate that doses are below a level of concern.

4.3.2.2 Indirect Contact

The indirect contact scenario required a number of assumptions for modeling exposure. The only approach for estimating the significance of indirect dermal contact is to assume a relationship between the application rate and the dislodgeable foliar residue. The value reported by Harris and Solomon (1992) (Appendix B, Table B-2) was used to estimate that the dislodgeable residue will be approximately 10 percent of the nominal application rate (SERA, 2004).

No dermal transfer rates are available for wildlife species. Dermal transfer rates in humans are based on brief (e.g., 0.5 to 1-hour) exposures that measure the transfer from contaminated soil to skin (Durkin et al., 995). Wildlife species are likely to spend longer periods of time in contact with contaminated media. It is reasonable to assume that for prolonged exposures a steady state may be reached between chemical concentrations on the skin, the rate of absorption, and concentrations on contaminated vegetation. Unfortunately, there are no studies that address the kinetics of such a scenario. Fish bioaccumulation studies with imazapyr indicate that imazapyr does not accumulate in fish tissue. Thus, a plausible partition

coefficient is unity (i.e., the concentration of the chemical on the surface of the animal will be equal to the dislodgeable residue on the vegetation) (SERA, 2004).

Under these assumptions, the absorbed dose resulting from contact with contaminated vegetation will be one-tenth that associated with comparable direct spray scenarios. As will be discussed in the risk characterization for ecological effects (Section 4.5), the direct spray scenarios results in exposure levels below the estimated NOAEL (i.e., hazard quotients below one). Therefore, details of the indirect exposure scenarios for contaminated vegetation are not further elaborated in this document.

4.3.2.3 Ingestion of Contaminated Vegetation or Prey

A number of exposure scenarios for consumption of contaminated vegetation were used to evaluate acute and chronic exposure for small mammals (Appendix B, Tables B-42 and B-43), large mammals (Appendix B, Table B-49 through B-51) and large birds (Appendix B, Tables B-52 through B-54).

Small Mammal – A small mammal is used because allometric relationships indicate that small mammals will ingest greater amounts of food per unit body weight compared with larger mammals. The amount of food consumed per day by a small mammal (i.e., an animal weighing approximately 20 g) is equal to about 15 percent of the mammal's total body weight (EPA, 1989). This value may overestimate or underestimate exposure depending upon the species. For example, a 20-g herbivore has a caloric requirement of about 13.5 kcal/day. If the diet consists largely of seeds (4.92 kcal/g), the animal's daily food consumption would be approximately 14 percent of its body weight ([13.5 kcal/day ÷ 4.92 kcal/g]÷20g = 0.137). A diet consisting largely of vegetation (2.46 kcal/g) would result in a daily food consumption equivalent to approximately 27 percent of the animal's body weight ([13.5 kcal/day ÷ 2.46 kcal/g]÷20g = 0.274) (EPA, 1993). For this exposure assessment (Appendix B, Table B-41), it is assumed that the daily food consumption rate of a 20-g mammal is 3.6 g/day or about 18 percent of its body weight (EPA, 1993).

Large Herbivorous Mammal – The diets of large herbivorous mammals may consist largely of grasses, which may retain substantially higher pesticide residues than other types of vegetation, such as forage crops or fruits (SERA, 2004). Under the large-mammal exposure scenario, the consumption of contaminated range grass is modeled for a 70-kg herbivore, such as a deer. Caloric requirements for herbivores and the caloric content of vegetation used to estimate food consumption based on information provided in EPA (1993). The details of these exposure scenarios are provided in Appendix B [Table B-49 (acute exposure) and Tables B-51 and B-52(chronic exposure)].

The acute exposure scenario assumes sprayed (contaminated) vegetation makes up 100 percent of the animals diet. Two chronic exposure scenarios are modeled for large mammals consuming contaminated vegetation. The first is an on-site scenario that assumes a 70-kg herbivore consumes short grass for a 90-day period after imazapyr application. Contaminated vegetation is assumed to account for 30 percent of the diet with a range of 10 percent to 100 percent of the diet. These are essentially arbitrary assumptions reflecting grazing time at the application site by the animal. Because the animal is assumed to be feeding at the application site, drift is set to unity (i.e., direct spray). This scenario is detailed in Appendix B, Table B-50.

The second chronic exposure scenario assumes that a large mammal grazes within a radius of 25 to 100 feet of the application site consuming 100 percent of the diet from the contaminated area. For this scenario, detailed in Appendix B, Table B-50 , the model AgDRIFT was used to estimate deposition of imazapyr on off-site vegetation. Drift estimates from AgDRIFT are summarized in Appendix B, Table B-50. A discussion of the model is provided in Section 4.2.3.2. (SERA, 2004)

Large Herbivorous Bird – Acute and chronic exposure scenarios have also been modeled for a large, herbivorous bird (e.g., 4-kg Canada goose) consuming contaminated vegetation. These exposure scenarios are detailed in Appendix B, Table B-52 (acute) and Tables B-53 and B-54 (chronic). As with the large mammal, there are two chronic exposure scenarios for on-site and off-site exposure. The estimated amounts of pesticide residue on vegetation are based on the relationship between application rate and residue rates on different types of vegetation. Residue rates are based on Fletcher et al. (1995,a,b).

Small Insectivorous Mammal and Small Insectivorous Bird – Acute exposure scenarios are modeled for a small insectivorous bird (10 g) and small insectivorous mammal (20 g). No monitoring data are available reporting the concentrations of imazapyr in insects after spray applications. The empirical relationships recommended by Fletcher et al. (1995,a,b) are used as surrogates as detailed in Appendix B, Tables B-55 (mammal) and B-56 (bird). To be conservative, the residue rates for small insects are used (45 to 135 ppm per lb/acre) rather than the residue rates from large insects (7 to 15 ppm per lb/acre) (SERA, 2004).

Carnivorous Mammal and Carnivorous Bird – Acute exposure scenarios are modeled for a small carnivorous mammal (Appendix B, Table B-58) and a small carnivorous bird (Appendix B, Table B-59). The scenarios assume that a small mammal is directly sprayed (see Appendix B, Table B-37) with of 100 percent absorption of the applied imazapyr (Appendix B, Table B-38).

Piscivorous Bird – Acute and chronic exposure scenarios are modeled for a piscivorous bird consuming fish from a contaminated pond. The exposure scenarios are detailed in Appendix B, Table B-47 (acute) and Table B-48 (chronic). Predatory birds generally consume more food per unit body weight than do predatory mammals (EPA, 1993), such that the exposure scenarios modeled for fish consumption by a piscivorous bird represent a worst-case scenario. Therefore, separate exposure scenarios were not modeled for a piscivorous mammal (SERA, 2004).

4.3.2.4 Ingestion of Contaminated Water

Small Mammal – Acute and chronic exposure scenarios are modeled for a small mammal (20 g) consuming contaminated water. Estimated concentrations of imazapyr in water for the acute and chronic exposure scenarios are identical to those used in the human health risk assessment (Appendix B, Table B-25 [acute] and B-26 [chronic]). As with the human health risk assessment the acute scenario assumes a spill of 200 gallons of imazapyr solution into a pond covering 1,000 m² and 1 m deep. Under the chronic scenario, contamination is attributed to runoff and/or percolation. The acute and chronic exposure scenarios for the small mammal are detailed in Appendix B, Tables B-45 and B-46, respectively.

There are well-established relationships between body weight and water consumption across a wide range of mammalian species (EPA, 1989). Mice weighing about 0.02 kg consume approximately 0.005 L of water/day (i.e., 0.25 L/kg body weight/day) (SERA, 2004). This value is used in the exposure assessment for the small (20-g) mammal.

4.3.3 Terrestrial Plants

The primary hazard to non-target terrestrial plants associated with the application of most herbicides is unintended direct deposition or spray drift. Herbicides may be transported off-site by percolation, runoff, or by wind erosion of soil, resulting in risk to non-target plants.

4.3.3.1 Direct Spray

Unintended direct spray can result in an exposure concentration equivalent to the application rate. It is plausible that non-target plants immediately adjacent to the application site could be sprayed directly. This scenario was modeled in the human health risk assessment for the consumption of contaminated vegetation.

4.3.3.2 Off-Site Drift

Because off-site drift is more or less a physical process that depends on droplet size and meteorological conditions rather than the specific properties of the herbicide, estimates of off-site drift can be modeled using AgDRIFT (Teske et al., 2001). AgDRIFT is a model

developed as a joint effort by the EPA Office of Research and Development and the Spray Drift Task Force, a coalition of pesticide registrants.

For aerial applications, AgDRIFT permits very detailed modeling of drift based on the chemical and physical properties of the applied product, the configuration of the aircraft, as well as wind speed and temperature. For ground applications, AgDRIFT provides estimates of drift based solely on distance downwind as well as the types of ground application: low boom spray, high boom spray, and orchard airblast. Representative estimates based on AgDRIFT (Version 1.16) are given in Appendix B, Table B-2. For the current risk assessment, the AgDRIFT estimates are used for consistency with comparable exposure assessments conducted by EPA. In addition, AgDRIFT represents a detailed evaluation of a very large number of field studies and is likely to provide more reliable estimates of drift. Further details of AgDRIFT are available at http://www.AgDRIFT.com/.

Estimates of drift for ground and aerial applications are given in Appendix B, Table B-2. In ground broadcast applications, imazapyr will typically be applied by low boom ground spray and thus these estimates are used in the current risk assessment.

Drift associated with backpack (directed foliar applications) are likely to be much less although studies quantitatively assessing drift after backpack applications have not been encountered. Drift distance can be estimated using Stoke's law, which describes the viscous drag on a moving sphere. According to Stoke's law:

$$v = D^2 \times g \div 18n = 28{,}700\ D^2 \qquad \text{(Equation 4)}$$

where v is the velocity of fall (cm sec^{-1}), D is the diameter of the sphere (cm), g is the force of gravity (ca. 980 cm sec^{-2}), and *n* is the viscosity of air (1.9 @ 10^{-4} g sec^{-1} cm^{-1} at 20°C) (Goldstein et al., 1974).

In typical backpack ground sprays, droplet sizes are greater than 100 µ, and the distance from the spray nozzle to the ground is 3 feet or less. In mechanical sprays, raindrop nozzles might be used. These nozzles generate droplets that are usually greater than 400 µ, and the maximum distance above the ground is about 6 feet. In both cases, the sprays are directed downward. Thus, the amount of time required for a 100 µ droplet to fall 3 feet (91.4 cm) is approximately 3.2 seconds,

$$91.4 \div [2.87 \text{ X } 10^5 (0.01)^2].$$

The comparable time for a 400 µ droplet to fall 6 feet (182.8 cm) is approximately 0.4 seconds.

For most applications, the wind velocity will be no more than 5 miles/hour, which is equivalent to approximately 7.5 feet/second (1 mile/hour = 1.467 feet/second). Assuming a wind direction perpendicular to the line of application, 100 µ particles falling from 3 feet above the surface could drift as far as 23 feet (3 seconds X 7.5 feet/second). A raindrop or 400 µ particle applied at 6 feet above the surface could drift about 3 feet (0.4 seconds X 7.5 feet/second).

For backpack applications, wind speeds of up to 15 miles/hour may be encountered. At this wind speed, a 100 µ droplet can drift as far as 68 feet (3 seconds X 15 X1.5 feet/second). Smaller droplets will drift further and the proportion of these particles in the spray, as well as the wind speed and turbulence, will affect the proportion of the applied herbicide that drifts off site (SERA, 2004).

4.3.3.3 Runoff

Herbicides may be transported to off-site soil via runoff or percolation. Both routes are considered in estimating contamination of surface waters; however, only runoff is consider in assessing contamination of off-site soils. Runoff can contaminate off-site surficial soils and has the potential to impact non-target plants. Percolation, on the other hand, represents the amount of the herbicide that can transported below the ground surface to the root zone and beyond, possibly impacting water quality via groundwater discharge. Although percolation could potentially affect off-site vegetation, this scenario is not modeled.

Based on the GLEAMS modeling scenario conducted by SERA (2004) (Section 3.3.3.4), but using an application rate of 0.26 lb a.e./acre, the proportion of applied imazapyr lost by runoff was estimated for clay, loam, and sand at rainfall rates ranging from 5 inches to 250 inches per year. The results are summarized in Appendix B, Table B-63 and indicate that runoff will be negligible in relatively arid environments as well as in sandy or loam soils. In clay soils, which have the highest runoff potential, off-site loss may be up to about 60 percent of the applied amount at sites with very high runoff potential (i.e., clay soil and high rates of rainfall).

4.3.3.4 Contaminated Irrigation Water

Non-target plant species may be unintentionally exposed via irrigation water contaminated with herbicide. Given the mobility of imazapyr and its persistence in soil, the contamination of irrigation water is a plausible scenario. The exposure concentrations under such a scenario will depend on imazapyr concentrations in irrigation water and the amount of irrigation water applied to a field.

Irrigation rates and frequency depend on climate, soil type, topography, and plant species under cultivation. Typically, plants require 0.1 to 0.3 inch of water per day (Delaware Cooperative Extension Service, 1999); however there is no general approach for determining

irrigation rates (SERA, 2004). In absence of any guidance regarding irrigation rates, an irrigation rate of 1 inch/day is used to model exposure of plants to contaminated irrigation water. This is somewhat higher than the maximum daily irrigation rate reported for sandy soil (0.75 inch/day) and substantially higher than the maximum daily irrigation rate for clay (0.15 inch/day) (Delaware Cooperative Extension Service, 1999).

Based on the estimated concentrations of imazapyr in ambient water and an irrigation rate of 1 inch/day, the estimated application rate of imazapyr to the irrigated area is 2.04×10^{-5} (1.02×10^{-6} to 8.14×10^{-4}) lb a.e./acre (see Appendix B, Table B-57 for details). The estimated exposure concentrations are inconsequential relative to off-site drift and runoff. Specifically, off-site movement from runoff can result in estimated off-site application rates of 0.15 lb a.e./acre (Appendix B, Table B-63) and off-site movement from drift can result in off-site application rates of about 4.9×10^{-3} lb a.e./acre at 25 feet from the application site after ground broadcast applications (Appendix B, Table B-64).

4.3.3.5 Wind Erosion

Wind erosion is a major transport mechanism for soil (Winegardner, 1996). Although no specific incidents of non-target plant damage from imazapyr attributable to wind erosion have been encountered in the literature, this mechanism has been associated with the environmental transport of other herbicides (Buser, 1990). Numerous models have been developed for wind erosion (Strek and Spaan, 1997; Strek and Stein, 1997) and the quantitative aspects of soil erosion by wind are extremely complex and site specific. Field studies conducted on agricultural sites found that wind erosion may account for annual soil losses ranging from 2 to 6.5 metric tons/ha (Allen and Fryrear, 1977). The upper range reported by Allen and Fryrear (1977) is nearly the same as the rate of 2.2 tons/acre (5.4 tons/ha) reported by the USDA (1998).

Potential transport of imazapyr via wind erosion is estimated using average soil losses ranging from 1 to 10 tons/ha year, with a median loss rate of 5 tons/ha year. The value of 5 tons/ha year is equivalent to 500 g/m² (1 ton = 1,000 kg and 1 ha = 10,000 m²) or 0.05 g/cm² (1 m² = 10,000 cm²). Using a soil density of 2 g/cm³, the depth of soil removed from the surface per year would be 0.025 cm ([0.05 g/cm²] ÷ [2 g/cm³]). The average amount per day would be about 0.00007 cm/day (0.025 cm per year ÷ 365 days/year). This central estimate is based on a typical soil loss rate of 5 tons/ha year. For this risk assessment, soil loss per day ranges from 0.00001 cm/day (0.00007 ÷ 5 = 0.000014) to 0.0001 cm/day (0.00007 × 2 = 0.00014) (SERA, 2004).

The amount of imazapyr potentially transported by wind erosion depends on several factors, including application rate, depth of incorporation into the soil, soil persistence, wind speed,

topography and surficial soil conditions. For this risk assessment, it is assumed that imazapyr is incorporated into the top 1 cm of soil.

4.3.4 Soil Organisms

No studies were found that investigated the toxicity of imazapyr to soil invertebrates or microorganisms. Because of insufficient data to develop an exposure model for these organisms, risk to soils organisms is not assessed.

4.3.5 Aquatic Organisms

Potential impacts to aquatic biota are based on estimated water concentrations of imazapyr that were developed for the human health risk assessment (Appendix B, Table B-25). The maximum estimated surface water imazapyr contamination rate associated with its application is 0.002 (0.0001 to 0.08) mg a.e./L at an application rate of 1 lb a.e./acre. For longer-term exposures, average estimated rate of contamination of ambient water associated with the normal application of imazapyr is 0.0001 (0.00001 to 0.001) mg a.e./L at an application rate of 1 lb a.e./acre. Because GLEAMS is a linear model, these contamination rates are adjusted with equations in the spreadsheets (Appendix B tables) based on the application rate of 0.26 lb a.e./acre used in this risk assessment.

4.4 DOSE-RESPONSE ASSESSMENT

This section addresses the quantitative relationship between the chemical dose and the incidence of adverse effects in ecological receptors.

4.4.1 Overview

The dose-response assessment for terrestrial mammals is based on the same environmental and chemical parameters used the human health risk assessment. A chronic NOAEL of 250 mg/kg/day is applied to both acute and chronic exposure scenarios.

A 5-day dietary NOEL of 674 mg/kg/day is used for birds to characterize acute exposures, while an 18-week dietary NOAEL of 200 mg/kg/day (based on reproductive effects) is used to characterize chronic exposure.

As stated above, no imazapyr toxicity data are available for adult amphibians or reptiles. As recommended by EPA (2005b), avian toxicity data may be used as surrogate data for adult amphibians and reptiles. The direct spray scenario assumes an acute exposure, therefore, the avian 5-day dietary NOEL of 674 mg/kg/day is used to assess acute exposure.

The only data available for imazapyr toxicity in terrestrial invertebrates are those from a study conducted with honey bees in which the NOAEL (based on mortality) for imazapyr was 1,000 mg/kg bw. This value is used in the exposure assessment for terrestrial insects.

Toxicity data for imazapyr in terrestrial plants are available for pre-emergent and post-emergent applications. For exposures involving the off-site drift of imazapyr, the range of NOAEL values for post-emergence applications is from 0.00049 lb/acre for sensitive species to 0.018 lb/acre for tolerant species. The range of NOAEL values reported in studies investigating exposure via off-site runoff for pre-emergence applications is from 0.002 lb/acre for sensitive species to 1 lb/acre for tolerant species. These values were used in modeling exposure of terrestrial plants via spray drift and runoff.

Toxicity studies with imazapyr indicate that it is practically non-toxic to fish and aquatic invertebrates. An NOEC of 100 mg/L is used to assess acute exposures in tolerant fish species. For sensitive species, the lowest LC_{50} value encountered in the open literature, 2.71 mg/L, is used. Three chronic studies with fish suggest no substantial differences between the acute and chronic toxicity of imazapyr, with a life-cycle NOEC of about 100 mg/L. A chronic early life stage study conducted on rainbow trout showed a decrease in larval survival at a mean measured concentration of 92.4 mg/L (Manning, 1989). Although the decrease in larval survival at a concentration of 92.4 mg/L was not statistically different from controls, EPA (2005b) judged that a concentration of 43.1 mg/L (the highest test concentration below 92.4 mg/L) should be used as the no-observed-apparent-effect concentration (NOAEC) for this study. Considering that a number of steelhead trout, the anadromous form of rainbow trout, Evolutionarily Significant Units (Seuss) are listed under the Endangered Species Act in Washington State, the NOAEC of 43.1 mg/L is used to assess chronic exposure in sensitive species.

Aquatic invertebrates do not appear to be any more sensitive to imazapyr than fish. Therefore, an NOEC value of 100 mg/L, based on acute study and life cycle studies in water fleas, is used to assess both acute and chronic exposures.

Of the aquatic biota, aquatic macrophytes demonstrate the greatest sensitivity to imazapyr. An EC_{25} of 0.013 mg/L in both *Lemna gibba* and *Myriophyllum sibricium* is used to assess exposure in aquatic macrophytes. Unicellular aquatic algae appear to be more tolerant to imazapyr than aquatic macrophytes. An of EC_{50} of 0.2 mg/L is used to assess exposure in sensitive species of algae, while an NOEC of 100 mg/L is used to assess exposure in more tolerant algae species.

4.4.2 Toxicity to Terrestrial Organisms

4.4.2.1 Mammals

For the mammalian exposure scenarios, a chronic NOAEL of 250 mg/kg/day is used for both acute and chronic exposure, based on a one-year study with dogs (Shellenberger, 1987) that reported an NOAEL of 250 mg/kg/day (NOAEL = 10,000 ppm in diet) (Table 3). The results of exposure modeling (Appendix B, Table B-60) indicate that neither the acute nor the chronic exposure scenarios via any route of exposure for mammals resulted in hazard quotients of one or above. The hazard quotients are substantially below a level of concern.

The use of the NOAEL for dogs to characterize risks for all terrestrial mammals appears to be very conservative. As summarized in Table 3, higher chronic NOAELs were reported in studies with mice (e.g., >1,000 mg/kg/day, equivalent to 10,000 ppm in diet) (Auletta, 1988) and rats (e.g., over 500 mg/kg/day – equivalent to 10,000 ppm in diet) (Daly, 1988).

4.4.2.2 Birds

Imazapyr exhibits very low acute toxicity in birds. After 5-day dietary exposures, no mortality or signs of toxicity were apparent at doses up to 674 mg/kg/day (5,000 ppm dietary concentration) in bobwhite quail (Fletcher, 1983a) and 1,419 mg/kg (5,000 ppm dietary concentration) in mallard ducks (Fletcher, 1983b) (Table 5). Single-dose administration of Arsenal® by gavage in bobwhite quail (Fletcher, 1984a) and mallard ducks (Fletcher, 1984b) indicated an NOAEL of 2,150 mg Arsenal®/kg in both species. As noted in Table 5, this NOAEL for Arsenal® corresponds to a dose of about 600 mg imazapyr/kg.

The somewhat lower NOAELs reported in the 5-day feeding studies compared to that of the gavage studies do not suggest gavage administration is less toxic than dietary administration but simply reflects the lower dose rates used in the dietary studies. Typically, gavage dosing leads to greater toxicity because all of the agent is inserted into the crop of the bird at one time. In dietary studies, the consumption of the compound is spread more evenly over the course the study period as the bird consumes food (SERA, 2004).

For this risk assessment, the 5-day dietary NOEL of 674 mg/kg/day in bobwhite quail (Fletcher, 1983a) is used to characterize risks to birds associated with acute exposures. Given the higher NOAELs via gavage exposure, it is likely that the true NOAEL for dietary exposure is substantially higher than 674 mg/kg/day, the highest dose used in the 5-day feeding study. Because of the very low hazard quotients resulting from the acute exposure scenarios (Appendix B, Table B-61), the use of the lower acute NOAEL of 674 mg/kg/day for birds results in a very conservative approach in assessing risk to birds exposed to imazapyr.

The chronic exposure scenario uses the18-week dietary NOAEL of 200 mg/kg/day based on reproductive endpoints (i.e., egg production, hatchability, survival of hatchlings) in both bobwhite quail (Fletcher et al., 1995a) and mallard ducks (Fletcher et al., 1995b). This NOAEL (200 mg/kg/day) is the highest subchronic (18-week) dose tested in birds.

4.4.2.3 Terrestrial Invertebrates

The only studies investigating imazapyr toxicity to insects are those by Atkins (1984) and Atkins and Kellum (1983) with the honey bee. TheLD_{50} in the honey bee is greater than 1,000 mg/kg bw. The toxicity data for the honey bee are consistent with those for mammals and birds, indicating that imazapyr are not very toxic to the honey bee. Given the large number of terrestrial invertebrate species, there is a great deal of uncertainty in the use of this single species acute toxicity value.

4.4.2.4 Terrestrial Plants (Macrophytes)

Plant toxicity studies were conducted with imazapyr as part of the registration process. Exposures were via direct application (i.e., lbs/acre) or in soil (i.e., concentration in soil). The studies investigated effects on seed germination, seed emergence, and post-emergent plant growth and viability (Table 8). In the study by American Cyanamid (1988b), imazapyr was tested in all three types of assays at application rates ranging from 0.000068 kg/ha to 1.12 kg/ha, corresponding to about 0.00006 to 1.0 lb a.e./acre. The greatest toxicity was observed in post-emergence assays, with reported EC_{50} values of 0.00219 to 0.0175 kg/ha in several species (green peas, soybeans, onions, corn, wheat, oats, sugar beets, sunflowers, tomatoes, and cucumbers). The sugar beet was the most sensitive species with an NOEC (plant growth) of 0.000548 kg/ha (0.00049 lb/acre). A study by Christensen et al. (1995) also identified sugar beet as the most sensitive species with an NOEC (shoot dry weight) of 0.0010 lb/acre.

The sugar beet NOEC of 0.00049 lb/acre from the American Cyanamid (1988b) is used to characterize risks associated with direct spray or spray drift in sensitive plant species. Appendix B, Table B-65 details exposure due to drift from ground application and Table B-66 details exposure attributable to drift from aerial application.

The most tolerant species in the post-emergence assays appears to be the onion, with an NOEC of 0.091 lb/acre based on survival and 0.018 lb/acre based on shoot length and weight Christensen et al. (1995). The NOEC of 0.018 lb/acre is used to characterize risk in tolerant plants exposed via drift from ground application (Appendix B, Table B-66) and drift from aerial application (Appendix B, Table B-66).

Non-target plants exposed via off-site transport through runoff will most likely be exposed through contaminated soil. Therefore, the results of seedling emergence assays (Table 8) are used to characterize risks associated with runoff. The sugar beet was identified as the most sensitive species in the study by American Cyanamid (1988b) in which an EC_{25} of 0.00219 kg/ha (0.002 lb/acre), the lowest application rate, was identified for sugar beet. The most tolerant species, also identified in the study by American Cyanamid (1988b), appears to be wheat, sunflower, tomato, cucumber, oats, soybeans, and green peas, all with no significant effect on seedling emergence at an application rate of 1.12 kg/ha, equivalent to about 1 lb/acre. Thus, for characterizing risks from runoff, the EC_{25} of 0.002 lb/acre in sugar beet is used for the most sensitive species and the NOEC of 1 lb/acre is used for tolerant species (Appendix B, Table B-64).

4.4.2.5 Soil Microorganisms

No studies were found that investigated the toxicity of imazapyr to soil invertebrates or microorganisms. Because of insufficient data to develop an exposure model for these organisms, risk to soils organisms is not assessed.

4.4.3 Aquatic Organisms

4.4.3.1 Fish

Toxicity studies submitted to EPA in support of the registration of imazapyr indicate that it is practically non-toxic to fish, with LC_{50} values >100 mg/L in most studies and >1,000 mg/L in others (Table 9). Supamataya et al. (1981), however, reported much lower LC_{50} values in two freshwater fish species, the silver barb (*Barbus gonionotus*) and the Nile tilapia (*Oreochromis niloticus niloticus* [previously *Sarotherodon niloticus]*) reported LC_{50}s of 2.71 mg/L and 4.36 mg/L, respectively. The species tested by Supamataya et al. (1981) are not native to the United States and may not be relevant to assessing risks associated with applications of imazapyr in Washington. However, the LC_{50} value of 2.71 mg/L reported by Supamataya et al. (1981) is used to characterize acute risk to sensitive fish species, while the NOEC of 100 mg/L is used to characterize acute risk in tolerant fish species (Appendix B, Table B-63).

Chronic exposure to imazapyr in fish was addressed in three studies: a full life-cycle study in fathead minnow reported an NOEC of 118 mg/L (Drotter et al., 1999), an early life-stage study in the fathead minnow reported an NOEC of 120 mg/L, and an early life-stage study in rainbow trout reported an NOEC of 43.1 mg/L. The NOECs reported for the fathead minnow are very similar to the acute NOEC of 100 mg/L. One approach to assessing risks to fish from chronic imazapyr exposure would be to use the NOEC of 120 mg/L derived from the fathead minnow study as the NOEC for tolerant species and NOEC of 43.1 mg/L derived with rainbow trout as the NOEC for chronic exposure in sensitive fish species. This approach, however, ignores the very low LC_{50} values reported by Supamataya et al. (1981). As an alternative, the NOEC of

120 mg/L is used to characterize risk for chronic imazapyr exposure in tolerant species, whereas the LC_{50} value of 2.71 mg/L is retained to also characterize risk of chronic exposure in sensitive species.

4.4.3.2 Aquatic Invertebrates

The toxicity of imazapyr to aquatic invertebrate is very similar its toxicity in fish. Studies by Forbis et al. (1984) and Kintner and Forbis (1983b) with *Daphnia magna* (Table 10) report an acute NOEC of 100 mg/L, which is used to characterize risk via acute exposure in aquatic invertebrates. Unlike the case with fish, there are not data indicating that sensitive and tolerant invertebrate species. The NOEC of 100 mg/L in *Daphnia* is nearly identical to the NOEC of 109 mg/L identified by Ward (1989) in tests with oysters. Thus, the NOEC of 100 mg/L is used to characterize risk to aquatic invertebrates associated with acute exposure to imazapyr. Manning's (1989c) 21-day life-cycle study with *Daphnia magna* demonstrates that the chronic NOEC of 97.1 mg/L is nearly identical to the acute NOEC of 100 mg/Ls for imazapyr. The NOEC of 97.1 mg/L is used to characterize risk to aquatic invertebrates from chronic exposure (Appendix B, Table B-63).

The *in situ* microcosm study conducted by Fowlkes et al. (2003) examined impacts of imazapyr to benthic macroinvertebrate (BMI) communities in logged cypress dome ponds. No impacts were reported to BMI communities after 14 days of exposure to imazapyr concentrations up to 18.4 mg/L., resulting in an NOEC > 18.4 mg/L. This NOEC was not used as the chronic exposure endpoint because the study did not dose the ponds at concentrations above 18.4 mg/L, so that the actual NOEC is unknown. The 21-day daphnid life-cycle study conducted by Manning (1989c) is a very sensitive test as it examines chemical toxicity to adults, embryos, and larvae. The NOEC of 97.1 mg/L for the daphnid 21-day life-cycle test is likely a better estimate of the chronic toxicity of imazapyr to aquatic invertebrates than the NOEC estimated by Fowlkes et al. (2003).

4.4.3.3 Aquatic Plants

Aquatic macrophytes are much more sensitive to imazapyr than aquatic animals. Of the species tested, the most sensitive is duckweed (*Lemna gibba*), with anEC_{25} (growth) of 0.013 mg/L (Hughes, 1987). Unicellular algae appear to be less sensitive, with EC_{50} values ranging from 0.2 mg/L to 2 mg/L for *Chlorella* (Landstein et al., 1993). Freshwater diatoms are relatively tolerant to imazapyr, with NOECs on the order of 10 to 100 mg/L (Hughes, 1987) (Table 11). The EC_{25} of 0.013 mg/L (*Lemna gibba*) is used to characterize risk in aquatic macrophytes, while theEC_{50} of 0.2 mg/L is used to characterize risk in sensitive aquatic algae and the NOEC of 100 mg/L is used to characterize risk in more tolerant species (Appendix B, Table B-63).

4.5 RISK CHARACTERIZATION

This section of the risk assessment estimates the potential for adverse health effects to ecological receptors by integrating the information from the dose-response assessment with the exposure assessment.

4.5.1 Overview

Based on the results of the ecological risk assessment, imazapyr exposure is unlikely adverse affect in terrestrial or aquatic animals. The weight of evidence suggests that imazapyr exposure is unlikely to adversely affect mammals, birds, fish, amphibians (aquatic and terrestrial phases), or terrestrial and aquatic invertebrates at the application rate of 0.26 lb a.e./acre.

Non-target plant species could be affected by off-site drift or by off-site movement via runoff. Imazapyr toxicity attributable to runoff may pose greater risk to non-target plant than drift. Residual soil contamination with imazapyr could be prolonged in some areas, particularly arid regions with predominantly clay soils. In relatively arid regions where microbial degradation may be the primary pathway for reducing imazapyr residues in soil, sensitive plant species may be susceptible to residual toxicity for several months to years. Soil persistence in regions with relatively high annual precipitation would be expected to be much less. The persistence and movement of imazapyr in soil is governed by many factors, is highly complex, and can vary significantly depending on site-specific factors. Thus, the estimates of risk to non-target plant species attributable to residual concentrations of imazapyr in soil should be considered as only very rough estimates of risk.

Aquatic macrophytes appear to be more sensitive to imazapyr than unicellular algae. The maximum concentrations of imazapyr in surface water modeled in this risk assessment demonstrate the potential to adversely affect some aquatic macrophytes. Chronic exposure to the lower concentrations of imazapyr used in this risk assessment, however, are substantially below the level of concern.

4.5.2 Terrestrial Organisms

4.5.2.1 Terrestrial Vertebrates (Mammals, Birds, and Amphibians)

Risk characterization, expressed as hazard quotients for terrestrial vertebrates, is summarized in Appendix B, Table B-62. Hazard quotients are calculated by dividing the estimated environmental exposure concentration (EEC) by the toxicity values derived from laboratory studies used to characterize acute or chronic exposure. The level of concern for the hazard quotient is one at the application rate of 0.26 lb a.e./acre. At the maximum application rate of 1.5 lb a.e./acre specified on the labels for Habitat® and Polaris®, the level of concern is 0.17

(i.e., 0.26 lb a.e./acre ÷ 1.5 lb a.e./acre). Hazard quotients below the level of concern indicate very low risk associated with imazapyr exposure.

The highest hazard quotient for any acute exposure is 0.07 (7E-01), which represents the upper exposure range for a small mammal consuming contaminated insects. The highest chronic hazard quotient of 0.05 (5E-02) occurs under the exposure scenario for a large bird consuming on-site contaminated vegetation. The hazard quotients for all exposure scenarios for terrestrial vertebrates are all well below one and below the level of concern for the maximum application rate (0.17). The highest hazard quotient of 0.07 is below the level of concern by a fact of 2.4 (0.17 ÷ 0.07). Thus, at an application rate of 0.26 lb a.e./acre, which represents the 95 percent UCI of application rates from 817 WSDA application records over a 2-year period, there appears to be no acute or chronic risk to terrestrial vertebrates associated with exposure to imazapyr.

4.5.2.2 Terrestrial Invertebrates

Risk characterization for terrestrial invertebrates exposed to imazapyr is based on a single study conducted with the honey bee. Based on an acute exposure scenario (direct spray), the hazard quotient of 0.04 (4E-02) is below one at an application rate of 0.26 lb a.e./acre and below the level of concern by a factor of 4.25 (0.17 ÷ 0.04) at the maximum application rate. Based on a single-species toxicity data, there appears to be no acute or chronic risk to terrestrial invertebrates associated with exposure to imazapyr.

4.5.2.3 Soil Microorganisms

Insufficient data were available to allow characterization of risk to soil microorganisms exposed to imazapyr. Microbial degradation of imazapyr may be the primary route of removal in soils (Tu et al., 2001). Wang et al. (2005), studying biodegradation of imazapyr in four soil types from China, reported that the half-life of imazapyr in non-sterile soils was in the range of 30 to 45 days, while 81 to 133 days in sterile soils. Biodegradation in four non-sterile soils accounted for 62 percent to 78 percent of imazapyr degradation. In contrast, less than 39 percent of imazapyr degradation was associated with chemical mechanisms. The authors reported that the rate constant of imazapyr under non-sterile conditions were 2.3 to 4.4 times faster than that under sterile conditions, concluding that the indigenous soil microorganisms play an important role in imazapyr degradation.

In the same study by Wang et al. (2005), two imazapyr-degrading bacterial strains were isolated in an enrichment culture technique and were identified as *Pseudomonas fluorescenes* and *Bacillus cereus*. When added to test soils, the bacterial strains could degrade 81 percent to 87 percent of the imazapyr after 48 hours of incubation. The treatment soils with the added

bacterial strains increased the imazapyr degradation rate by 3 to 4 fold over that for control samples.

Based on the studies by Tu et al. (2001) and Want et al. (2005), at least some strains of soil bacteria are able to use imazapyr as an energy source.

4.5.2.4 Terrestrial Plants

The risk characterization for terrestrial plants is summarized in Appendix B, Table B-64 (exposure via runoff) and Tables B-65 and B-66 (spray drift). As summarized in Table B-65, sensitive, non-target plants exposed via runoff could be at risk with hazard quotients as high as 75 under the scenario of clay soils and an annual precipitation of 250 inches. This is an unrealistic scenario for Washington State and over-estimates risk. Reviewing historical precipitation data for Washington State, the highest annual rainfall of 137.21 inches was recorded at the Quinault Ranger station on the Washington coast and is based on 45 years of records (1931 to 1976) (WRCC, 2009). Even this represents an extreme precipitation rate, but at an annual precipitation rate of 137 inches, the hazard quotient for sensitive plants exposed via runoff would be between 43 and 57.

As indicated in Appendix B, Tables B-64 and B-65, sensitive non-target plants may be at risk from off-site drift of imazapyr at distances of up to 300 feet from the application site after ground application and up to 500 feet for aerial applications. The risk to off-site tolerant plant species from herbicide drift from ground broadcast applications (Table B-65) is negligible. Under the aerial application scenario, a hazard quotient of 2 is estimated for tolerant plant species up to 25 feet from the application site.

For both ground and aerial drift, the closer that the non-target species are to the application site the greater the risk. The actual degree of risk is determined by site-specific conditions, especially wind speed, wind direction, and altitude of application in the case of aerial application.

As summarized in Section 4.3.3.5, daily soil losses due to wind erosion, expressed as a proportion of an application rate, could be in the range 0.00001 to 0.0001. This is substantially less than off-site losses associated with runoff from clay soils at annual precipitation rates of 15 inches or more (Appendix B, Table B-64) but more similar to off-site losses associated with drift at a distance of 500 feet or more from the application site (Appendix B, Table B-65). As with the drift scenarios, wind erosion has the potential to carry imazapyr-contaminated soils off site, potentially putting sensitive plant species at risk. This is especially true in arid environments.

Residual soil contamination with imazapyr could pose long-term risks to non-target plants in some regions. The results of GLEAMS modeling, summarized in Appendix A, Table A-3, indicate peak concentrations of imazapyr in clay soils at an annual precipitation rate of 5 inches and at an application rate of 0.26 lb a.e./acre would be about 1.7 mg/kg.

Rahman et al. (1993) studied the toxicity of varying concentrations of imazapyr in soil on the growth of four plant species in sandy loam soil: white mustard, radish, oats, and corn. White mustard was the most sensitive species, with an EC_{50} of about 0.006 mg/kg soil and an NOEC of 0.001 mg/kg soil. Corn was the least sensitive species, with an EC_{50} of about 0.1 mg/kg soil and an NOEC of 0.02 ppm. Comparing the NOECs for even the most tolerant species (corn), modeled concentration of imazapyr in soil could be associated with substantial growth inhibition in some plant species. A central issue for characterizing risk in non-target plant species is determining the duration of exposure to toxic concentrations of imazapyr in soil. As summarized in Table 1, reported field dissipation halftimes in soil range from about 25 days to 180 days, corresponding to dissipation or degradation rate coefficients of 0.0039 to 0.028 $days^{-1}$ [$k = \ln(2) \div t_{1/2}$]. In first order dissipation models, the fraction, f, remaining after time t is:

$$f = e^{-kt} \qquad \text{Equation 5}$$

Rearranging Equation 5 to solve for time, t:

$$t = \ln(f) \div -k. \qquad \text{Equation 6}$$

Taking the range of degradation rate coefficients of 0.0039 to 0.028 $days^{-1}$, the time required to go from a concentration of 1.7 mg/kg (i.e., after the application of 0.26 lb a.e./acre) to 0.001 mg/kg would be:

$$t = \ln(0.001 \text{ mg/kg} \div 1.7 \text{ mg/kg}) \div -0.0039 \text{ to } 0.028 \text{ days}^{-1} = 266 \text{ to } 1{,}907 \text{ days},$$

corresponding to about 9 months to 5.2 years. At an application rate of 0.26 lb a.e./acre, some residual effects to plant species could be expected for up several years under arid conditions and if microbial degradation were the only significant dissipation mechanism. Based on the GLEAMS modeling, microbial degradation will likely be the controlling factor for dissipation only in very arid environments. At annual rainfall rates of 10 inches or more, imazapyr will be removed from soil by runoff and/or percolation. Runoff is likely to be the dominant mechanism in clay soils and percolation the dominant mechanism in sandy soils. Dissipation in Intermediate soil types, such as loam, is controlled by a mix of runoff and percolation.

SERA (2004), using the GLEAMS, modeled the loss of imazapyr (application rate = 1 lb a.e./acre) from clay soil at annual precipitation rates of 5, 25, 50, 100, and 200 inches per year. Figure A-1 in Appendix A summarizes the results. At an annual rate of 5 inches per year, the loss from soil is attributable completely to microbial degradation, which is characterized using a halftime of 25 days for the GLEAMS modeling in clay soil (Table A-3). Under the modeling conditions, the concentration of imazapyr in soil does not reach the NOEC of 0.001 mg/kg until about day 340 after application. At an annual rainfall rate of 200 inches per year, about 50 percent of the applied compound is lost from the application site by runoff and the estimated concentration in soil reaches the NOEC of 0.001 mg/kg in about 60 days.

Characterizing risk to non-target plants from residual soil contamination of imazapyr can only be done qualitatively. The persistence and movement of imazapyr in soil is complex and governed by multiple site-specific conditions. Non-target plants could certainly be at risk from exposure to residual concentrations of imazapyr in soils, but the degree of risk is dependent on soil type, precipitation, application rate of imazapyr, and soil microbial communities. The persistence of imazapyr applied in riparian areas could also be affected by flooding regimes in the watershed. Contaminated soil in riparian areas and floodplains could be removed during high-flow events. Once in suspension, imazapyr could then potentially be degraded by photolysis.

4.5.3 Aquatic Organisms

4.5.3.1 Aquatic Animals

Available acute toxicity data for aquatic species indicate that imazapyr is practically non-toxic to fish and invertebrates (EPA, 2005b). Under the conditions modeled for this risk assessment, and as summarized in Appendix B, Table B-63 , at an application rate of 0.26 lb a.e./acre, all of the hazard quotients for aquatic animals are extremely low and well below the level of concern. The highest hazard quotient of 0.008 is below the level of concern at the 0.26 lb a.e./acre application rate (LOC=1.0) by a factor of 125 and below the level of concern at the highest application rate (LOC=0.17) by a factor of 21. Hazard quotients below the level of concern indicate very low risk associated with imazapyr exposure in aquatic animals.

The risk characterization for the accidental spill scenario indicates that sensitive fish and larval amphibians could be at risk at the highest concentrations modeled under the accidental spill scenario (Appendix B, Table B-62). The accidental spill scenario is an extremely arbitrary scenario and the actual concentrations in the water after a spill would depend on the amount of compound spilled and the size of the water body receiving the spill.

The accidental spill scenario is extremely conservative, baaed on the spill of a large volume of imazapyr solution into a small pond. Additionally, the toxicity value of 2.71 mg/L represents

the lowest concentration (LC_{50}) reported in the literature to result in mortality to fish. An early life-stage study with rainbow trout reported an NOEC of 43.1 mg/L (Manning, 1989b). Cold-water species such as rainbow trout are preferred test animals in toxicity studies because of their sensitivity to chemical stressors (EPA, 2005b). Rainbow trout are in the genus *Oncorhynchus,* which includes many of the ESA-listed species in Washington:

- Steelhead trout (*O. mykiss*) – Puget Sound, Columbia River, Snake River;
- Chinook salmon (*O. tshawytscha*) – Puget Sound and Columbia River; and
- Chum salmon (*O. keta*) – Hood Canal.

Applying the NOEC of 43.1 mg/L instead of the 2.71 mg/L in Appendix B, Table B-62 reduces the hazard quotient for the accidental spill scenario to 0.1, below the level of concern. Thus, the selection of 2.71 mg/L as the reference toxicity value for sensitive fish and amphibian species may overestimate risk to sensitive fish and amphibian species found in Washington.

4.5.3.2 Aquatic Plants

Aquatic plants, particularly macrophytes, are much more sensitive to imazapyr than aquatic animals. The maximum hazard quotient calculated for aquatic macrophytes at an application rate of 0.26 lb a.e./acre at the upper range of exposure is 1.6, which is above the level. Thus, under the modeled worst-case conditions, aquatic macrophytes could be exposed to concentrations of imazapyr that could result in acute effects. The highest hazard quotient for chronic exposure is 0.02, which is below the level of concern (Appendix B, Table B-62),

Hazard quotients for acute and chronic exposures in sensitive unicellular algae species are below levels of concern based on the 0.26 lb a.e./acre application rate (Appendix B, Table B-62). Imazapyr presents very low risk to unicellular algae species based on the conditions modeled in this risk assessment.

Hazard quotients for both aquatic macrophytes and unicellular algae are well above the level of concern for the accidental spill scenario (Appendix B, Table B-62). Accidental spills of large quantities of imazapyr into relatively small bodies of water could lead to very high water concentrations (e.g., 3 mg a.e./L to 4 mg a.e./L). After spills of this magnitude, acute effects to aquatic macrophytes and unicellular algae could be anticipated.

4.5.4 Federally Listed Species and State Species of Concern

The ecological risk assessment for imazapyr is based on very conservative assumptions to account for exposures of sensitive ecological receptors. Of particular concern are species listed under the Endangered Species Act (ESA), which include mammals, birds, reptiles, amphibians, fish, invertebrates, and plants. In addition to the ESA-listed species within

Washington, the Washington Department of Fish and Wildlife (WDFW) has designated a number of animal species as species of concern. Similarly, the Washington Department of Natural Resources' Natural Heritage Programs has compiled a list of rare plants within the state. Appendix C summarizes all of the ESA-listed species within Washington State, as well as state species of concern and rare plants. Distribution maps for ESA-listed species are also included in Appendix C. Maps depicting the locations of Washington's rare plants were downloaded from the Washington Natural Heritage Program's web site (http:// www1.dnr.wa.gov/nhp/refdesk/index.html) and are included in an accompanying CD.

The risk characterization concluded that imazapyr poses almost no risk to terrestrial and aquatic animals. Direct exposure to imazapyr is expected to pose almost no risk to animal species in Washington listed as threatened, endangered, or as species of concern. The only study examining impacts of imazapyr to ESA-listed species was an ecological risk assessment conducted by EPA (Hurley and Shanaman, 2007) (see Section 4.2.3.2) to evaluate potential impacts of imazapyr to the federally-listed California red-legged frog and its critical habitat. The risk assessment for the CRLF concluded that no direct effects are expected on either the aquatic or terrestrial phase of the CRLF. There are also no indirect effects expected for the CRLF through direct effects to either its terrestrial or aquatic food sources.

Conversely, terrestrial and aquatic plants listed as threatened, endangered, as species of concern, or as rare could be at risk when exposed to imazapyr, either directly or indirectly. EPA (2005b), in its ecological risk assessment of imazapyr conducted as part of the registration process, concluded that levels of concern are exceeded for endangered terrestrial monocots and dicots in dry and semi-aquatic areas receiving a combination of runoff and drift and from spray drift alone from low application rate (0.9 lb a.e./acre) via ground and aerial applications. Imazapyr application should be avoided in areas known to host listed or rare plant species.

Ecological risk assessments typically only address risks to receptor species based on exposure to chemical stressors such as herbicides. They cannot quantitatively evaluate indirect effects to receptors attributable to habitat alteration or impacts to prey resources attributable to the chemical of concern. A possible concern related to the application of imazapyr to non-target plant species is the potential for indirect effects to listed and sensitive animal and plant species, particularly in riparian habitats. Riparian vegetation performs important ecological functions, including serving as terrestrial and aquatic habitat, stabilizing stream banks, providing shade to streams, and providing large woody debris to increase complexity of in-stream habitat (Kocher and Harris, 2007). Actions that do not directly affect listed and sensitive animals species, but that affect their habitats, may indirectly affect these species by decreasing habitat function. As an example, EPA's (2007) in its ecological risk

assessment evaluating the potential effects of imazapyr on the California red-legged frog concluded that the use of imazapyr and its isopropylamine salt is likely to adversely affect the CRLF based on indirect effects attributable to habitat modification from impacts to aquatic and terrestrial plants). The case of the CRLF demonstrates that indirect effects to listed and sensitive species may occur as a result of imazapyr application, a factor that must be considered when designing and implementing imazapyr application programs.

4.6 UNCERTAINTIES AND DATA GAPS

The discussion of uncertainties and data gaps in the ecological risk assessment are based on comments in EPA's ecological risk assessment for imazapyr (2005b). The majority of the toxicity information used in the current risk assessment was taken from studies conducted by the manufacturer as part of the product registration process and is the same information used by EPA for their ecological risk assessment. There are a number of areas of uncertainty in the terrestrial and the aquatic organism risk assessments that could potentially cause an underestimation of risk. First, this assessment accounts only for exposure of non-target organisms to imazapyr, but not to its degradation products. The risks presented in this assessment could be underestimated if degradates also exhibit toxicity under the conditions of use as stated on product labels. Data are not available concerning the toxicity of the degradation products of imazapyr. Second, the risk assessment only considers the most sensitive species tested and only considers a subset of possible use scenarios. For the aquatic organism risk assessment, there are uncertainties associated with the GLEAMS model, input values, and the use of surrogate scenarios.

Additional uncertainty results from the lack of information and/or data in several components of this ecological risk assessment, as follows.

Data are limited concerning residue levels in foliage, flowers, and seeds to accurately predict potential risks to terrestrial organisms (birds, mammals, amphibians, and insects) that may contact imazapyr residues after application. Depending upon a specific wildlife species' foraging habits, whole above ground plant samples may either underestimate or overestimate actual exposure.

Based on the soil half-lives, residues of imazapyr in soils would be expected to persist. Consequently, risks from exposure to birds, small mammals, and soil invertebrates through dermal contact or ingestion of soils may occur. The available measured data related to wildlife dermal contact with pesticides are extremely limited. EPA (2005b) assuming ingestion of soil at an incidental rate of 15 percent of the diet, reported that screening level calculations indicate that ingestion of soil would not significantly increase dietary exposure of imazapyr. However, this remains an uncertainty.

Duckweed is the only surrogate plant tested to represent the entire aquatic vascular plant population that includes emerged, floating, or submerged in water bodies including marine/estuarine plants.

The tested terrestrial plants exhibited a wide range of sensitivity to imazapyr. However, this study, conducted as part of the imazapyr registration process, was categorized as supplemental by EPA (2005b)because: (1) the seedlings were subjected to overcrowding and excessive competition because the area of the pot container may have restricted seedling growth (4-inch-diameter Dixie cups were used to plant 10 seeds in each cup); and (2) "fresh weight" was used instead of "dry weight" as the measurement endpoint, possibly causing variability in the toxic effect due to plant moisture content. The value for repeating the seedling emergence and vegetative vigor studies was rated by EPA (2005b) as "high" to better understand the effects of imazapyr to terrestrial plants.

Seedling emergence and vegetative vigor studies were conducted using active ingredient mixed with acetone and/or some oil or surfactant. Commonly, these plant toxicity studies are conducted using the end-use product. This is to ensure that effects data will be applicable to use of the herbicide in the field with the assumption that constituents of the end-use product may have the potential to modify the toxicity of the active ingredient. There is considerable uncertainty as to the chemical similarity between tested mixtures containing the active ingredient and the actual end-use products. The presence of surfactants or oils, in and of themselves, on the Generally Recognized as Safe lists does not address the potential ecological effects of these materials, alone or in combination with the active ingredient, upon terrestrial plants. Information demonstrating the chemical similarity between constituents in end-use products and the tested solvents, oils, and surfactants mixed with the active ingredient in the presently available plant-effects studies would be useful in addressing the aforementioned uncertainty. Alternatively, additional plant effects testing with the end-use product would also reduce uncertainty regarding effects thresholds of actual herbicide products used in the field (EPA, 2005b).

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TABLES

TABLE 1

PHYSICAL AND CHEMICAL PROPERTIES OF IMAZAPYR AND ITS ISOPROPYLAMINE SALT[1]

Imazapyr Risk Assessment
Washington State

Parameter	Value	
CAS Number	81334-34-1 81510-83-0 (isopropylamine salt)	
EPA Registration Number	241-426 (Habitat®) 228-534 (Polaris®)	
Molecular Weight (grams)	261.3 (acid)	
	320.4 (isopropylamine salt)	
Salt-to-Acid Conversion Factor	0.8155 (261.3/320.4)	
pK_a	1.9 and 3.6; 1.81 and 3.64	
Water Solubility (mg/L – ppm)	10,000 to 15,000 (acid @ 25°C)	
pH of Formulation	6.6 – 7.2 (Habitat®) (BASF 2008 – MSDS) 6.6 – 7.2 (Polaris®) (Nufarm 2006 – MSDS)	
K_{ow}	1.3	
K_{oc} (mL/g oc) (EPA, 2005)	15 8.2 31 17 100 100	18 82 110 53 150
Soil $t_{1/2}$	210 days to 5.9 years	
Water/Sediment, Aerobic $t_{1/2}$	17 months to no degradation	
Water/Sediment, Anaerobic $t_{1/2}$	Not metabolized	
Field Dissipation $t_{1/2}$ (days)	25 to 180	
Photolysis $t_{1/2}$ (days)	3.7 @ pH 7 in water to 149 in surface soil	
Hydrolysis $t_{1/2}$ (days)	Stable to 325 at pH 7	
Plant $t_{1/2}$ (days)	15 to 37 (composite of different types of vegetation)	

Note(s)

1. Information about the physical and chemical properties of imazapyr and its isopropylamine salt were taken from SERA (Syracuse Environmental Research Associates, Inc.) (2004), except where otherwise noted.

Abbreviation(s)

CAS = Chemical Abstracts Service
°C = degrees Celsius
EPA = U.S. Environmental Protection Agency
mg/L = milligrams per liter
mL/g oc = milliliters per gram organic carbon
MSDS = material safety data sheet
pK_a = acid dissociation constant
ppm = parts per million

TABLE 2

WATER, SEDIMENT, AND TISSUE CONCENTRATIONS OF IMAZAPYR IN MISSOURI AND FLORIDA TREATMENT PONDS[1]

Imazapyr Risk Assessment
Washington State

	Pond				
Parameter	**Control**	**1**	**2**	**3**	**4**
Concentration					
Water (µg/L)	<0.207	28	75	213	261
Sediment (µg/kg)	<0.475	1.5	2.5	10.2	10.2
$T_{1/2}$ (water – days)	NA	14.1	8.4	14.5	3.9
$T_{1/2}$ (sediment – days)	NA	Not calculated[3]	Insufficient data	Not calculated[2]	9.2
Tissue Residues (ppb)					
Bluegill	<5.35	<50 (MDL)	<50 (MDL)	636 @ 3 hrs post-treatment, <50 (MDL) thereafter	<50 ppb (MDL)
Catfish	One sample 14.1, Remainder <5.35	<50 (MDL)	<50 (MDL)	233 @ 3 hrs post-treatment, <50 thereafter	<50 ppb (MDL)
Tilapia	<5.35	<50 (MDL)	<50 (MDL)	68 @ 3 hrs post-treatment, <50 thereafter	<50 ppb (MDL)
Crayfish	One sample 10.6, remainder <5.35	<50 (MDL)	<50 (MDL)	59 @ 3 hrs post-treatment, <50 thereafter	<50 ppb (MDL)

Note(s)

1. Source: Entrix 2003.
2. Approximate concentrations based on interpretation of graphical data.

Abbreviation(s)

NA = not applicable
MDL = method detection limit
ppb = parts per billion
µg/kg = micrograms per kilogram
µg/L = micrograms per liter

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Oral – Acute			
Albino Rat (M & F)	5,000 mg/kg bw	LD_{50} ≥ 5,000 mg/kg	Fischer, 1983
Albino Rat (M & F)	5,000 mg/kg bw	LD_{50} ≥ 5,000 mg/kg	Fischer, 1986a
Albino Rat (M & F)	5,000 mg/kg bw	LD_{50} ≥ 5,000 mg/kg	Fischer, 1986b
Albino Rat (M & F)	5,000 mg/kg bw	LD_{50} ≥ 5,000 mg/kg	Fischer, 1989a
Albino Rat (M & F)	5,000 mg/kg bw	LD_{50} ≥ 5,000 mg/kg	Lowe, 1988
Albino Rat (M & F)	5,000 mg/kg bw	LD_{50} ≥ 5,000 mg/kg	Lowe, 1999
Oral – Subchronic			
Albino Rat (M & F)	15,000 or 20,000 ppm in diet	Dietary NOAEL 20,000 ppm 1,695 mg/kg/day (M) 1,740 mg/kg/day (F)	Hess, 1992
Holstein Cows	Dosed 28 to 29 days	Milk Residue	Khunachak, 1999
	0 mg a.i./kg bw/day	≤2.10 ppb	
	2 mg a.i./kg bw/day	≤10 ppb	
	6 mg a.i./kg bw/day	24.3-34.9 ppb	
	20 mg a.i./kg bw/day	75.3-108 ppb	
	60 mg a.i./kg bw/day	222-313 ppb	

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Oral – Subchronic			
Holstein Cows		Muscle Residue	
	0 mg a.i./kg bw/day	<4.49 ppb	
	2 mg a.i./kg bw/day	<50.0 ppb	
	6 mg a.i./kg bw/day	<50.0 ppb	
	20 mg a.i./kg bw/day	97.3 ppb	
	60 mg a.i./kg bw/day	234 ppb	
		Fat Residue	
	0 mg a.i./kg bw/day	<4.71 ppb	
	2 mg a.i./kg bw/day	<50.0 ppb	
	6 mg a.i./kg bw/day	<50.0 ppb	
	20 mg a.i./kg bw/day	66.7 ppb	
	60 mg a.i./kg bw/day	92.1	
		Kidney Residue	
	0 mg a.i./kg bw/day	<4.64 ppb	
	2 mg a.i./kg bw/day	246 ppb	
	6 mg a.i./kg bw/day	519 ppb	
	20 mg a.i./kg bw/day	4,360 ppb	
	60 mg a.i./kg bw/day	7,510 ppb	
		Liver Residue	
	0 mg a.i./kg bw/day	<4.58 ppb	
	2 mg a.i./kg bw/day	<50.0 ppb	
	6 mg a.i./kg bw/day	<50.0 ppb	
	20 mg a.i./kg bw/day	300 ppb	
	60 mg a.i./kg bw/day	809 ppb	

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Oral – Chronic			
Mouse (M & F)	0, 1,000, 5,000, and 10,000 ppm in diet for 18 months.	No statistically significant difference between control and treated mice. No evidence of carcinogenicity. NOAEL = 10,000 ppm	Auletta, 1988; Hess, 1992
Albino Rat (M & F)	0, 1,000, 5,000, and 10,000 ppm in diet for 24 months.	No statistically significant difference between control and treated mice. No evidence of carcinogenicity. NOAEL = 10,000 ppm	Daly, 1988; Hess, 1992
Dogs (Beagles) (M & F)	0, 1,000, 5,000, and 10,000 ppm in diet for 12 months.	No clinical signs of toxicity and no mortality. NOAEL = 10,000 ppm	Shellenberber, 1987
Oral – Reproductive/Terratogenic			
Albino Rat (M & F) – F_0 generation in 2-generation reproductive study	0, 1,000, 5,000, and 10,000 ppm in diet. Rats treated for 64 days prior to mating, throughout the two mating periods, and for approximately 3 weeks after the end of the second mating period.	F_0 & F_{1b} adult generation: no treatment-related effects on mortality or pathology, & no clinical signs of toxicity. F_{1a}, F_{1b}, F_{2a}, & F_{2b} pups: no adverse effects on viability, survival, or lactation indices, or on the clinical condition of the pups.	Robinson, 1987
New Zealand Albino Rabbits (F)	0, 250, 1000, or 2,000 mg a.i./kg/bw by gavage on days 6-18 of gestation.	Exposure concentrations of 250 mg a.i./kg/bw did not produce exaggerated pharmacological or embryocidal effects.	Salamon et al., 1983a
	250 mg a.i./kg/bw	Mortality in 2/5	
	1000 mg a.i./kg/bw	Mortality in 4/5	
	2000 mg a.i./kg/bw	Mortality in 5/5	

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Oral – Reproductive/Terratogenic			
New Zealand Albino Rabbits (F)	0, 25, 100, or 400 mg a.i./kg/bw by gavage on days 6-18 of gestation.	No evidence of reproductive effects in dams; no statistically significant differences in fetal body weight & crown-rump length compared to controls.	Salamon et al., 1983b
Albino Rats (F)	0, 100, 300, or 1,000 mg a.i./kg/bw by gavage on days 6-15 of gestation.	No mortality or terratogenicity.	Salomon et al., 1983c
Albino Rats (F)	0, 250, 500, 1,000, or 2,000 mg a.i./kg/bw by gavage on days 6-15 of gestation.	No mortality, pharmacological or embryocidal effects.	Salomon et al., 1983d
Inhalation			
Albino Rat (M & F)	Whole-body exposure of 4.62 ± 1.41 mg a.i./L for 4 hours MMAD = 1.6 µm ± 0.06.	No mortality LC_{50} > 4.62 mg/L	Hershman and Moore, 1986
Inhalation			
Albino Rat (M & F)	Whole-body exposure of 1.3 mg a.i./L (aerosol) for 4 hours. MMAD = 3.3 µm ± 2.5.	No mortality or changes in body weight or absolute organ weights LC_{50} > 1.3 mg/L	Voss et al., 1983
Albino Rat (M & F)	Whole-body exposure of 3.34 ± 0.76 mg a.i./L (aerosol) for 4 hours MMAD = 5.00 ± 2.94 µm, 6.15 ± 2.67 µm.	No mortality or clinical signs of toxicity. No changes in body weight or absolute organ weights. LC_{50} > 3.34 mg/L	Werley, 1987

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Dermal			
Albino Rat (M & F)	Single dose of 5,000 mg a.i./kg bw.	No mortality, signs of toxicity or changes in body weight.	Lowe and Bradley, 1996
Albino Guinea Pig (M)	Dermal sensitization was assessed by 9 induction applications (3/week for 3 weeks) followed by a challenge application 14 days after the last induction. Test material was applied beneath an occlusive covering and left in contact with the skin for 6 hours. 0.4 mL of test material was applied as a minimally irritating 75% dilution in saline for inductions and as a nonirritating 25% dilution for the challenge. (Test material specified as Chopper RTU 6)	No apparent effects or clinical toxicity effects on body weight or survival.	American Cyanamid Co., 1988a
Albino Guinea Pig (M)	Dermal sensitization was assessed by thrice weekly induction applications for 3 weeks (9 total applications) followed by a challenge application 14 days after the last induction. The inductive and challenge applications consisted of 0.4 g of test material applied to intact clipped skin for 6 hours via gauze pad moistened with 0.4 mL of saline and covered with an occlusive wrap. (Test material specified as Arsenal® 5-G)	No apparent effects or clinical toxicity effects on body weight or survival.	Costello, 1986
New Zealand White Rabbits (M & F)	Single dermal dose of 2.0 mL/kg or 2,148 mg/kg applied to shaved skin using an impervious plastic cuff that provided 24-hour contact. (Test material specified as AC 3532-149 or 2-[4 isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl] nicotinic acid; 2 lb/gallon formulation.)	LD_{50} > 2,000 mg/kg	Fischer, 1983

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Dermal			
New Zealand White Rabbits (M)	0.5 mL applied to shaved, abraded or intact skin (intact and abraded sites were on opposite side of the midline of the same animal) for 24 hours. [Test material specified as AC 3532-149 or 2-[4-isopropyl- 4-methyl-5-oxo-2-imidazolin-2-yl] nicotinic acid; 2 lb/gallon formulation.)	Test material considered to be mildly irritating to rabbit skin.	Fischer, 1983
New Zealand White Rabbits (M & F)	Single dermal dose of 2000 mg/kg applied to the shaved intact dorsal skin (area equals approximately 10% of body surface) of non-fasted animals. Test material held under impervious plastic cuff for 24-hour continuous contact. After 24-hour exposure, cuff removed, treated site wiped with moistened gauze pad, and animals fitted with fiber collars to prevent further ingestion of remaining test material. 14-day observation period. (Test material specified as Arsenal® Herbicide 5% granular formulation.)	LD_{50} > 2,000 mg/kg	Fischer, 1986a
New Zealand White Rabbits (M)	0.5 g applied to shaved, abraded or intact skin (intact and abraded sites were on opposite side of the midline of the same animal) for 24 hours. (Test material specified as Arsenal® Herbicide 5% granular formulation.)	Test material considered to mildly irritating to rabbit skin.	Fisher, 1986a

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Dermal			
New Zealand White Rabbits (M & F)	Single dermal dose of 2,000 mg/kg or 1.9 mL/kg applied to shaved intact skin (area equals approximately 10% of body surface) of non-fasted animals. Test material held under impervious plastic cuff for 24-hour continuous contact. After 24-hour exposure, cuff removed, treated site wiped with moistened gauze pad, and animals fitted with fiber collars to prevent further ingestion of remaining test material. 14-day observation period. (Test material specified as Chopper C/S.)	Only sign of toxicity was decreased activity, but no mortality. Necropsies showed no visible lesions. $LD_{50} \geq 2{,}000$ mg/kg	Fischer, 1986b
New Zealand White Rabbits (M)	Test material (0.5 mL) was applied to shaved intact skin (1" square). An untreated site on the opposite side of the midline served as a control. The sites were covered with a gauze pad and occluded with a plastic wrap for a contact time of 4 hours. (Test material specified as Chopper C/S, sample purity 22.6%.)	Test material mildly irritating to rabbit skin.	Fischer, 1986b
New Zealand White Rabbits (M & F)	Single dermal dose of 2,000 mg test formulation/kg applied to clipped intact trunk skin (.10% of total body surface area) using an impervious plastic wrap that provided 24-hour contact. (Test material specified as AC 243,997 6% RTU [6.0% a.i.].)	No signs of toxicity, mortality, changes in body weight gain, or significant gross pathology. $LD_{50} \geq 2{,}000$ mg/kg	Fischer, 1989b

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Dermal			
New Zealand White Rabbits (M & F)	0, 100, 200, or 400 mg/kg/day to close-clipped, intact or abraded, occluded backs, 5 days/week for 3 weeks.	No systemic toxicity (i.e., no adverse effects on body weight, food consumption, hematology, serum chemistry, or organ weights).	Larson and Kelly, 1983
Guinea Pig	Dermal sensitization was assessed by once weekly induction applications for 3 weeks followed by a challenge application 14 days after the last induction. 0.3 g of test material moistened with 0.9% saline was used for the inductive and challenge applications. Test material was left in uncovered contact with clipped skin for 6 hours. (Test material specified as AC 243,997 [93% pure].)	No clinical signs of toxicity or significant changes in body weight.	Ledoux, 1983
New Zealand White Rabbits (M & F)	Single dermal dose of 1.92 mL/kg or 2,000 mg/kg applied by application to dorsal surface (area equals ~10% of body surface) to non-fasted, shaved animals. Test material held under impervious plastic cuff for 24-hour continuous contact. After 24-hour exposure, cuff removed, treated site wiped with moistened gauze pad, and animals fitted with fiber collars to prevent further ingestion of remaining test material. (Test material specified as Imazethapyr/Imazapyr 170/6.5 gallon/L AS formulation.)	No apparent signs of toxicity. $LD_{50} \geq 2{,}000$ mg/kg	Lowe, 1988

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Dermal			
New Zealand White Rabbits (M)	0.5 mL applied to shaved, 1" squares of intact skin on dorsal surface (opposite side of the midline of the same animal served as control). Test material was covered with gauze pad, occluded with plastic wrap, and left in contact with skin for 4 hours. [Test material specified as Imazethapyr/ Imazapyr 170/6.5 gallon/L AS formulation.]	Test material not irritating to rabbit skin	Fischer, 1983
Eye			
New Zealand White Rabbits (M)	0.1 mL instilled into conjunctival sac of right eye (left eye served as control) with or without rinsing after 20 seconds. (Test material specified as 2-(4-isopropyl-4-methyl- 5-oxo-2-imidazolin- 2-yl)nicotinic acid; 2 lb/gallon formulation.)	Test material was irritating to the rabbit eye with complete recovery after 7 days	Fischer, 1983
New Zealand White Rabbits (M)	100 mg instilled into conjunctival sac of the right eye (left eye served as control) without rinsing for 24 hours, after which time, treated eyes were rinsed with tap water. (Test material specified as Arsenal® Herbicide 5% granular formulation.)	Test material was irritating to the rabbit eye with complete recovery after 7 days	Fischer, 1986a
New Zealand White Rabbits (M)	0.1 mL instilled into conjunctival sac of right eye (left eye served as control) without rinsing for 24 hours, after which time, treated eyes were rinsed with tap water. (Test material specified as Chopper C/S Formulation sample purity 22.6%.)	Test material was irritating to the rabbit eye with complete recovery after 72 hours	Fischer, 1986b

TABLE 3

IMAZAPYR TOXICITY TO MAMMALS
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Eye			
New Zealand White Rabbits (M)	0.1 mL of powdered test material was instilled into the conjunctival of the left eye (right eye served as untreated control) without rinsing for 24 hrs., after which time, treated eyes were rinsed with tap water. (Test material specified as AC 243,997 6% RTU [6.0% a.i.].)	Test material was minimally irritating to the rabbit eye. All animals recovered by 24 hours.	Fischer, 1989c
New Zealand White Rabbits (M)	0.1 mL instilled into conjunctival sac of right eye (left eye served as control) without rinsing for 24 hours, after which time, treated eyes were rinsed with tap water. (Test material specified Imazethapyr/ Imazapyr 170/6.5 gallon/L AS formulation.)	Test material was nonirritating to the rabbit eye.	Lowe, 1988

Abbreviation(s)

a.i. =
a.i./kg = active ingredient per kilogram
a.i./L = active ingredient per liter
bw/day = body weight per day
F = females
L = liter
M = males
NOAEL = no-observed-adverse-effect level
mg a.i./L = milligrams active ingredient per liter
mg/kg = milligrams per kilogram
mg/kg bw = milligrams per kilogram body weight
mg/kg/day = milligrams per kilogram per day
mg/L = milligrams per liter
mL = milliliter
mL/kg = milliliters per kilogram
MMAD = mass median aerodynamic diameter
ppb = parts per billion
ppm = parts per million
µm = micrometer

TABLE 4

SUMMARY OF MODELED CONCENTRATIONS OF IMAZAPYR IN A POND AND STREAM[1]

Imazapyr Risk Assessment
Washington State

Results reported in µg/L per 0.26 lb a.e./acre applied

Annual Rainfall	Clay		Loam		Sand	
(inches)	Average	Maximum	Average	Maximum	Average	Maximum
Pond						
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.0138	0.0208	0.0000	0.0000	0.0002	0.0018
20	0.0175	0.0370	0.0000	0.0000	0.0106	0.0252
25	0.2027	0.0552	0.0000	0.0000	0.2456	0.0419
50	0.0267	0.1326	0.0002	0.0005	0.0489	0.0072
100	0.0289	0.2401	0.0032	0.0128	0.0432	0.1033
150	0.0280	0.3358	0.0041	0.0175	0.0358	0.1125
200	0.0265	0.4221	0.0042	0.0176	0.0304	0.1157
250	0.0243	0.4472	0.0041	0.0165	0.0264	0.1164
Stream						
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.0001	0.0141	0.0000	0.0000	0.0000	0.0005
20	0.0003	0.0322	0.0000	0.0000	0.0003	0.0093
25	0.0004	0.0534	0.0000	0.0000	0.0009	0.0018
50	0.0010	0.1634	0.0000	0.0008	0.0027	0.0412
100	0.0015	0.3352	0.0003	0.0212	0.0033	0.0810
150	0.0017	0.4481	0.0004	0.0277	0.0030	0.1005
200	0.0017	0.5267	0.0005	0.0270	0.0027	0.1092
250	0.0016	0.5304	0.0005	0.0242	0.0024	0.1124

Note(s)

1. Source: SERA (Syracuse Environmental Research Associates, Inc.), 2004.

Abbreviation(s)

lb a.e./acre = pounds acid equivalents per acre
µg/L = micrograms per liter

TABLE 5

ORAL TOXICITY OF IMAZAPYR TO BIRDS
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference[1]
Oral Acute			
Bobwhite Quail	0, 312, 625, 1,250, 2,500, or 5,000 ppm in the diet for 5 days. (0, 38, 72, 48, 322, and 674 mg/kg bw based on measured food consumption.)	No mortality	Fletcher, 1983a
Mallard Duck	0, 312, 625, 1,250, 2,500, or 5,000 ppm in the diet for 5 days. (0, 64, 145, 273, 595, or 1,149 mg/kg bw based on measured food consumption.)	No mortality	Fletcher, 1983b
Bobwhite Quail	0, 1,470, or 2,150 mg/kg bw administered via gavage. (Test substance specified as Arsena®l Herbicide. Based on 0.278 ratio of imazapyr in Arsenal® [correspond to imazapyr doses of about 410 and 600 mg/kg].)	No mortality. No abnormal behavioral reactions or systemic signs of toxicity were observed. Gross pathological examination revealed no abnormal tissue alterations. 21-day observation period. $LD_{50} \geq$ 2,150 mg/kg bw	Fletcher et al., 1984a
Mallard Duck	0, 1470, or 2,150 mg/kg bw administered via gavage. (Test substance specified as Arsenal® Herbicide. Based on 0.278 ratio of imazapyr in Arsenal® [correspond to imazapyr doses of about 410 and 600 mg/kg].)	No mortality. No abnormal behavioral reactions or systemic signs of toxicity were observed. Gross pathological examination revealed no abnormal tissue alterations. $LD_{50} \geq$ 2,150 mg/kg bw	Fletcher et al., 1984b
Bobwhite Quail	0, 312, 625, 1,250, 2,500, or 5,000 ppm in the diet for 5 days and then a basal diet for the next 3 days. (Test substance specified as Arsenal®.)	No mortality. No abnormal behavioral reactions or systemic signs of toxicity. Gross pathological examination revealed no abnormal tissue alterations. $LD_{50} \geq$ 5,000 mg/kg bw.	Fletcher et al., 1984c

TABLE 5

ORAL TOXICITY OF IMAZAPYR TO BIRDS
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference[1]
Oral – Acute			
Mallard Ducks	0, 312, 625, 1,250, 2,500, or 5,000 ppm in the diet for 5 days and then a basal diet for the next 3 days. (Test substance specified as Arsenal®.)	No mortality. No abnormal behavioral reactions or systemic signs of toxicity. Gross pathological examination revealed no abnormal tissue alterations. LD_{50} ≥ 5,000 mg/kg bw.	Fletcher et al., 1984d
Bobwhite Quail	0, 500, 1,000, or 2,000 ppm in the diet for 18 weeks. (50, 100, or 200 mg/kg bw based on measured food consumption.) (Test material specified as AC 243,997 Technical.)	No significant reductions for any of the reproductive endpoints examined (i.e., egg production, hatchability, survival of hatchlings). NOEC for reproductive effects = 2,000 ppm.	Fletcher et al., 1995a
Mallard Ducks	0, 500, 1,000, or 2,000 ppm in the diet for 18 weeks. (50, 100, or 200 mg/kg bw based on measured food consumption.) (Test material specified as AC 243,997 Technical.)	No significant reductions for any of the reproductive endpoints examined (i.e., egg production, hatchability, survival of hatchlings). NOEC for reproductive effects = 2,000 ppm.	Fletcher et al., 1995b

Note(s)
1. Source: SERA (Syracuse Environmental Research Associates, Inc.), 2004.

Abbreviation(s)
LD_{50} = lethal dose causing mortality in 50 percent of test animals
mg/kg = milligrams per kilogram
mg/kg bw = milligrams per kilogram body weight
NOEC = no observed effect concentration
ppm = parts per million

TABLE 6

TOXICITY OF IMAZAPYR TO AMPHIBIANS
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Bull Frog (*Rana catesbeiana*) (tadpoles)	96-hr static exposure to imazapyr acid, Stalker® (27.6% imazapyr IPA salt), and Habitat® (28.7% imazapyr IPA salt)	96-hr LC_{50} = 799.6 mg/L (imazapyr acid) 1,739 mg/L (Habitat®) 14.77 mg/L (Stalker®)	Trumbo, unpublished data

Abbreviation(s)
IPA =
mg/L = milligrams per liter

TABLE 7

TOXICITY OF IMAZAPYR TO TERRESTRIAL INVERTEBRATES

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Honey Bee (*Apis mellifera*)	Topical exposure of 100 µg a.i./bee	96-hr LD_{50} > 100 µg a.i./bee (96-hr LD_{50} > 1,000 mg/kg-bw, assuming 100% absorption of the applied dose – see text)	Atkins, 1984; Atkins and Kellum, 1983

Abbreviation(s)

mg/kg-bw = milligram per kilogram body weight
µg a.i./bee = microgram active ingredient per bee

TABLE 8

TOXICITY OF IMAZAPYR TO TERRESTRIAL PLANTS

Imazapyr Risk Assessment
Washington State

Species	Dose	Response	Reference
Cucumber, soybean, wheat, onions, peas, tomato, corn, sugar beets sunflower, and oats (Tier II non-target terrestrial plants.)	***Seed germination*** seeds on filter paper exposed to 0.035 to 1.12 kg a.i./ha ***Seedling emergence*** Application rate: 0.00219 to 1.12 kg a.i./ha ***Post-emergency/foliar application*** Technical grade acid in 1:1 (v/v) solution of acetone and water and sprayed at 400 L/ha with laboratory belt sprayer. Tween 20 surfactant added to spray solution at 0.25% (v/v). ***Study 1*** Seedlings grown 13 days prior to treatment with application rates of 0.00219 to 1.12 kg a.i./ha ***Study 2*** Larger seedlings grown for 28 days with application rates of 0.000068 to 0.01750 kg a.i./ha.	Tomato: EC_{50} = 1.12 kg a.i./ha Sugar beet: EC_{25} = 0.14 kg a.i./ha Sugar beet: EC_{25} = 0.00219 kg a.i./ha Corn and Onion: EC_{25} = 1.12 kg a.i./ha All crops tested EC_{25} = 0.00219 – 0.00875 kg a.i./ha EC_{50} = = 0.00219 – 0.0175 kg a.i./ha ***Study 1*** Based on heights, no significant injury at <0.0085 kg a.i./ha. Based on weights, no significant injury at <0.035 kg a.i./ha. Height is most sensitive objective endpoint. All plants died at 0.28 kg a.i./ha and above. Most Sensitive**:** Sugar beets affected at rates of >0.000548 kg a.i./ha. ***Study 2*** Visual injury (50%) at ~0.001 kg a.i./ha, 50% inhibition based on height at 0.00219 kg a.i./ha, ~50% inhibition based on weight at 0.00219 kg a.i./ha, All plants died at 0.00875 kg a.i./ha and above. Large seedlings tolerated higher levels than smaller seedlings. Monocots could tolerate up to 0.00875 kg/ha without damage. Dicots were more variable.	American Cyanamid, 1988b

TABLE 8

TOXICITY OF IMAZAPYR TO TERRESTRIAL PLANTS

Imazapyr Risk Assessment
Washington State

Species	Dose	Response	Reference
Cucumber, soybean, wheat, onions, peas, tomato, corn, sugar beets sunflower, and oats. (Tier II non-target plants vegetative vigor phytotoxicity.)	A single application to emerged seedlings. 28-day observation period. Nominal concentrations of 0.00025, 0.0005, 0.001, 0.002, 0.004, and 0.008 lb a.i./acre applied to sugar beets. And nominal concentrations of 0.008, 0.018, 0.0036 (soybean only), 0.041, 0.091, 0.21, and 0.46 lb a.i./acre applied to onions and soybeans. (Test material was AC 252.925 in a 2 lb per gallon aquesous salt [2AS] formulation.)	***Plant Survival*** Onion***:*** EC_{25} = 0.095 lb a.i./acre; EC_{50} = 0.16 lb a.i./acre; NOEC = 0.091 lb a.i./acre. Soybean**:** EC_{25} ≥ 0.46 lb a.i./acre; EC_{50} ≥ 0.46 lb a.i./acre; NOEC = 0.46 lb a.i./acre. Sugar beet**:** EC_{25} = 0.0033 lb a.i./acre; EC_{50} = 0.0049 lb a.i./acre; NOEC = 0.002 lb a.i./acre ***Shoot Length*** Onion: EC_{25} = 0.036 lb a.i./acre; EC_{50} = 0.075 lb a.i./acre; NOEC = 0.018 lb a.i./acre Soybean**:** EC_{25} = 0.043 lb a.i./acre; EC_{50} = 0.34 lb a.i./acre; NOEC = 0.002 lb a.i./acre. Sugar beet**:** EC_{25} = 0.0025 lb a.i./acre; EC_{50} = 0.0036 lb a.i./acre; NOEC = 0.002 lb a.i./acre ***Shoot Dry Weight*** Onion: EC_{25} = 0.035 lb a.i./acre; EC_{50} = 0.063 lb a.i./acre; NOEC = 0.018 lb a.i./acre Soybean**:** EC_{25} = 0.083 lb a.i./acre; EC_{50} = 0.26 lb a.i./acre; NOEC = 0.041 lb a.i./acre. Sugar beet**:** EC_{25} = 0.0021 lb a.i./acre; EC_{50} = 0.0027 lb a.i./acre; NOEC = 0.001 lb a.i./acre Sugar beet was most sensitive species tested.	Christensen et al., 1995

TABLE 8

TOXICITY OF IMAZAPYR TO TERRESTRIAL PLANTS

Imazapyr Risk Assessment
Washington State

Species	Dose	Response	Reference
Barley, corn, cotton, sorghum, sugar beet, sunflower, and wheat	Application of 400 L/ha to give rates up to 63 g a.i./ha; 34-day observation period. (Test material was Arsenal® Herbicide (technical grade, purity NOS.)	Little to no effect on seedling emergence. The test substance is a potent inhibitor of plant growth, at 63 g a.i./ha, severe growth inhibition and mortality of all species tested. Sugar beets were most susceptible and soybeans being the most tolerant.	Malefyt, 1986
Corn, cucumber, oats, onion, peas, soybeans, sugar beets, sunflower, tomato, and wheat	Test substance applied to seeds at a concentration of 35, 70, 140, 280, 560, and 1120 g a.i./ha. (Test substance specified as AC 243,997 [99.1% purity].)	No statistically significant effect on the germination of cucumber, soybean, wheat, onion, or peas. Tomatoes and corn showed a significant reduction in germination at the highest rate of 1.12 kg/ha. No significant reduction was observed at lower rates. Sugar beet, sunflower, and oats showed some reduction in germination. A 25% detrimental effect level on seed germination was not obtained at any rate with cucumber, soybean, wheat, onions, peas, corn, or sunflower. A 25% detrimental effect level was observed at rates >0.14 kg/ha in sugar beets, and a 50% effect was observed at 1.12 kg/ha in tomatoes, and at various rates with oats.	Malefyt, 1990a
Corn, cucumber, oats, onions, peas, soybeans, sugar beets, sunflower, tomato, and wheat	Concentrations of 0.068, 0.137, 0.274, 0.548, 1.095, 2.19, 4.38, 8.75, and 17.5 g/ha for sugar beets, corn, and oats. For wheat, sunflower, and cucumbers the lowest three rates were dropped and 35, 70, and 140 g/ha were added. (Test material was AC 243,997 [99.1% purity].)	Green pea was the most tolerant species to post-emergence applications. All other species tested showed higher sensitivity. Sugar beets were the most sensitive, (affected at rates of 0.548 g/ha). Larger seedlings tolerated higher levels than smaller seedlings. The monocot species could withstand up to 8.75 g/ha without noticeableinjury. Tolerance in dicot species was more variable. Larger-seeded species were able to tolerate higher levels than smaller-seeded species.	Malefyt, 1990b

TABLE 8

TOXICITY OF IMAZAPYR TO TERRESTRIAL PLANTS

Imazapyr Risk Assessment
Washington State

Species	Dose	Response	Reference
Onion (*Allium cepa*)	Onions exposed to 6,000 µg a.i./L	No chromosome aberration NOEL = 6,000 µg a.i./L	Grisolia et al., 2004

Abbreviation(s)

a.e./ha = acid equivalent per hectare
a.i./kg = active ingredient per kilogram
a.e./L = acid equivalent per liter
EC = effect concentration
g = grams
kg = kilograms
mg = milligrams
mg/L = milligrams per liter
µg = micrograms
µg/L = micrograms per liter

TABLE 9

TOXICITY OF IMAZAPYR TO FISH
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Bluegill Sunfish (*Lepomis macrochirus*)	Nominal concentrations of the test substance were 0, 56, 100, 180, 320, 560, and 1,000 mg/L. (Test substance specified as AC 252,925 [combination of AC 243,997 with isopropylamine in water].)	No mortality 96-hr LC_{50} ≥ 1,000 mg/L	Cohle and McAllister, 1984a
Bluegill Sunfish	Nominal concentrations of the test substance were 0, 56, 100, 180, 320, 560, and 1,000 mg/L. (Test substance specified as Arsenal® Herbicide [22.6% purity].)	96-hr LC_{50} = 180 mg/L	Cohle and McAllister, 1984b
Rainbow Trout (*Oncorhynchus mykiss*)	Nominal concentrations of the test substance were 0, 32, 56, 100, 180, and 320 mg/L. (Test substance specified as Arsenal® Herbicide [22.6% purity].)	96-hr LC_{50} = 110 mg/L	Cohle and McAllister, 1984c
Rainbow Trout	Mean measured concentrations were 13, 29, 39, 68, and 110 mg a.e./L. (Test material was Arsenal® [21.5% imazapyr].)	96-hr LC_{50} ≥ 110 mg a.e./L	Drotter et al., 1995
Fathead Minnow (*Pimephales promelas*)	Nominal concentrations of 7.5, 15, 30, 60, and 120 mg a.i./L. (Test material was AC 342997 [purity NOS].)	NOEC = 120 mg a.i./L LOEC ≥ 120 mg a.i./L MATC ≥ 120 mg a.i./L	Drotter et al., 1998
Fathead Minnow	Mean measured concentrations of 7.4, 15, 31, 62, and 118 mg a.i./L. (Test material was AC 342997 [99.6% purity].)	NOEC ≥ 118 mg a.i./L LOEC ≥ 118 mg a.i./L MATC ≥ 118 mg a.i./L	Drotter et al., 1999
Bluegill Sunfish	Nominal concentrations were	96-hr LC_{50} ≥ 100 mg /L	Kintner and Forbis, 1983a
Bluegill Sunfish	0, 10, 18 32, 53, and 100 mg/L. (Test material was AC 243,997 [99.5% purity].)		
Atlantic Silversides (*Menidia menidia*)	Mean measured concentrations were 0, 23.2, 39.5, 58.1, 112, and 184 mg/L. (Test material was AC 243,997 [99.5% purity].)	96-hr LC_{50}=184 mg /L	Manning, 1989a

TABLE 9

TOXICITY OF IMAZAPYR TO FISH
Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Rainbow Trout	Measured concentrations of 0, 6.59, 12.1, 24.0, 43.1, or 92.4 mg/L for 62 days. Flow-through test. (Test material was AC 243,997.)	No statistical effects on hatching, survival, or growth.	Manning 1989b
Chinook Salmon (*Oncorhynchus tshawytscha*) Smolts	Static exposure to 0, 50, 100, 200, 400, 800, or 1,600 µg a.i./L for 96 hrs.	The osmoregulatory capacity of Chinook smolts based on plasma sodium level and gill ATPase was not affected by imazapyr at concentrations up to 1,600 µg a.i./L. NOEC > 1,600 µg a.i./L	Patten, 2003
Nile Tilapia (*Oreochromis niloticus niloticus*)	Static acute toxicity testing using 2- to 3-cm fingerlings.	24-hr LC_{50} = 4,670 µg/L 48-hr LC_{50} = 4,630 µg/L 72-hr LC_{50} = 4,610 µg/L 96-hr LC_{50} = 4,360 µg/L	Supamataya et al., 1981
Silver Barb (*Barbonymus gonionotus*)	Static acute toxicity testing using 2- to 3-cm fingerlings.	24-hr LC_{50} = 2,706 µg/L 96-hr LC_{50} = 2,706 µg/	Supamataya et al., 1981

Abbreviation(s)

LOEC = lowest-observed effect concentration
MATC =
mg a.e./L = milligrams acid equivalents per liter
mg a.i./L = milligrams active ingredient per liter
mg/L = milligrams per liter
NOEC = no-observed-effect concentration
µg/L = micrograms per liter
µg a.e./L = micrograms acid equivalents per liter

TABLE 10

TOXICITY OF IMAZAPYR TO AQUATIC INVERTEBRATES

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Water Flea (*Daphnia magna*)	Nominal concentrations were 0, 32, 56, 100, 180, 320, 560, and 1,000 mg/L. (Test material was Arsenal® [22.6% purity].)	48-hr LC_{50} = 350 mg/L	Forbis et al., 1984
Water Flea	0, 10, 18, 32, 56, or 100 mg/L. (Test material was AC 243,997 Technical.)	48-hr $LC_{50} \geq$ 100 mg/L	Kintner and Forbis, 1983b
Water Flea	Measured concentrations of <2.63 (control) 5.73, 11.7, 23.8, 45.6, or 97.1 mg/L in a 21-day flow-through test. (Test material was AC 243,997 [99.5% a.i.].)	No adverse effects on survival, reproduction, or growth of 1st generation. 7-, 14- and 21-day $LC_{50} \geq$ 97.1 mg/L NOEC = 97.1 mg/L MATC ≥ 97.1 mg/L	Manning, 1989c
Freshwater Clam (*Corbicula fluminea*)	Single application of a nominal concentrations 0.091 lb a.e./acre to a model freshwater pool system. 28-day observation period. (Test material was Arsenal® Herbicide [purity NOS].)	Imazapyr was not detected in clam tissues above the method detection limit of 50 ppb.	Christensen et al., 1999
Eastern Oyster (*Crassostrea virginica*) and Grass Shrimp (*Paleomonetes pugio*)	28-day bioconcentration test followed by 14-day depuration phase. During the uptake phase, concentrations consisted of a mixture of radiolabelled or non-radiolabelled test substance at a nominal concentration of 0.25 mg a.i./L. (Test material was AC 243,997 [purity NOS].)	The test substance was not found to bioconcentrate in tissues. Tissue concentrations of the test substance did not exceed the exposure concentration.	Drotter et al., 1996
Eastern Oyster	Mean measure concentrations of 16, 27, 46, 80, and 132 mg a.i./L. 96-hour flow-through test. (Test material was AC 243,997 [99.6% purity].)	Oyster shell growth was not significantly reduced in any treatment group.	Drotter et al., 1997
Eastern Oyster	Measured concentrations were <10.5, 21.5, 42.4, 65.5, 109, and 173 mg/L. (Test material was AC 243,997 [99.5%].)	Shell Growth NOEC = 109 mg/L 96-hr $EC_{50} \geq$ 173 mg/L	Ward, 1989

TABLE 10

TOXICITY OF IMAZAPYR TO AQUATIC INVERTEBRATES

Imazapyr Risk Assessment
Washington State

Animal	Dose	Response	Reference
Freshwater Macrobenthic Invertebrate Communities	48 *in situ* microcosms were treated with single doses of imazapyr at concentrations of 0, 0.184, 1.84, and 18.4 mg a.i./L. Test durations was 14 days.	The lack of statistical difference ($r < 0.05$) in macroinvertcbrate community composition, chironomid deformity rate, and chironomid biomass between treatments suggests that imazapyr did not affect the macroinvertebrate community at the concentrations tested. NOEC > 18.4 mg a.i./L	Fowlkes et al., 2003

Abbreviation(s)

a.i. = active ingredients
lb a.e./acre =
MATC = maximum allowable toxic concentration
mg a.e./L = milligrams acid equivalents per liter
mg a.i./L = milligrams active ingredients per liter
mg/L = milligrams per liter
NOEC = no-observed effect concentration

TABLE 11

TOXICITY OF IMAZAPYR TO AQUATIC PLANTS

Imazapyr Risk Assessment
Washington State

Species	Dose	Response	Reference
Macrophytes			
Duckweek (*Lemna gibba*)	Nominal concentrations of 0, 0.01, 0.018, 0.032, 0.056, and 0.100 mg a.e./L for 14 days. Static.	Frond counts EC_{25} = 0.013 mg a.e./L EC_{50} = 0.024 mg a.e./L	Hughes, 1987
Duckweed	Nominal concentrations of 0, 6.3, 12.6, 25.2, 50.4, and 100 µg a.i./L. (Test material was AC 252,925 2 AS [purity NOS].)	No visual phytotoxicity at concentrations >13.0 µg a.i./L. NOEC = 13.0 µg a.i./L. EC_{25} = 14.1 µg a.i./L EC_{50} = 22.8 µg a.i./L	Hughes et al., 1995
False Eurasian water-milfoil (*Myriophyllum sibricium*)	14-day static exposure to nominal concentrations of imazapyr (Arsenal®. Concentration range used not specified). (Test substance specified as Arsenal®.)	Shoot growth: EC_{25} = 13 µg a.i./L; EC_{50} = 32 µg a.i./L. Root number: EC_{25} = 22 µg a.i./L; EC_{50} = 29 µg a.i./L. Root growth (dry mass): EC_{25} = 7.9 µg a.i./L; EC_{50} = 9.9 µg a.i./L.	Roshon et al., 1999
Unicellular Algae			
Green algae (*Selenastrum capricornutum*)	Nominal concentrations of 10-100 mg a.e./L. Mean measured concentrations of 9.4-101.2 mg/L. 7-day exposure.	Based on cell density, EC_{25} = 48 mg a.e./L EC_{50} = 71 mg a.e./L.	Hughes, 1987
Blue-green Algae (*Anabaena flos-aquae*)	Nominal concentrations of 0, 5.6, 10, 18, 32, 52, and 100 mg a.e./L for 7 days.	Cell count: EC_{25} = 7.3 mg a.e./L EC_{50} = 11.7 mg a.e./L	Hughes, 1987
Freshwater Diatom (*Naviculla pelliculosa*)	Concentrations of 10 to 100 mg a.e./L for 7 days. Static.	All concentrations caused stimulation rather than inhibition of cell number. Extent of stimulation was 1.6 to 17% with no apparent dose/response relationship. EC_{50} >41,000 µg a.i./L	Hughes, 1987

TABLE 11

TOXICITY OF IMAZAPYR TO AQUATIC PLANTS
Imazapyr Risk Assessment
Washington State

Species	Dose	Response	Reference
Unicellular Algae			
Marine Diatom (*Skeletonema costatum*)	Nominal concentrations of 10-100 mg a.e./L. Mean measured concentrations of 8.9–90.5 mg/L 7-day exposure.	Cell density EC_{25} = 42.2 mg a.e./L EC_{50} = 85.5 mg a.e./L	Hughes, 1987
Green Algae (*Chlorella emersonii*)	Concentrations ranging from 261 µg/L to about 26,100 µg/L.	Growth IC_{50} = 200 µg/L. Resistant strains of Chlorella had about 10-fold higher IC_{50}s.	Landstein et al., 1993
Dwarf Eelgrass (Zostera japonica)	1 m² plots of eelgrass were treated with 0.84 or 1.68 kg a.e./ha imazapyr or 480 g a.e./L Isopropylamine salt. Plots were evaluated based on a visual rating of percent ground covered by eelgrass canopy compared to the control 9 to 14 months after treatment	NOEL = 1.68 kg. a.i./kg	Patten, 2003

Abbreviation(s)

a.e./ha = acid equivalent per hectare
a.i./kg = active ingredient per kilogram
a.e./L = acid equivalent per liter
EC = effect concentration
g = grams
kg = kilograms
mg = milligrams
m² = square meters
mg/L = milligrams per liter
µg = micrograms
µg/L = micrograms per liter

TABLE 12

SUMMARY OF ACETIC ACID TOXICITY TESTS[1]
Imazapyr Risk Assessment
Washington State

Test Species	Type of Organism	Toxicity Test	Toxicity End Point	Value	Concentration Unit
Wheat	Plant	EC 50	Visible injury	23.3	mg/m^3
Alfalfa	Plant	EC 50	Visible injury	7.8	mg/m^3
Corn	Plant	EC 50	Visible injury	50.1	mg/m^3
Pseudomonas putida	Bacteria	Toxicity threshold	Multiplication inhibition	2,850	mg/L
Microcystis aeruginosa	Algae	Toxicity threshold	Multiplication inhibition	90	mg/L
Scenedesmus quadricauda	Green algae	Toxicity threshold	Multiplication inhibition	4,000	mg/L
Entosiphon sulcatum	Protozoa	Toxicity threshold	Multiplication inhibition	78	mg/L
Uronema parduczi	Protozoa	Toxicity threshold	Multiplication inhibition	1,350	mg/L
Vorticella campanula	Protozoa	Toxicity threshold	Perturbation level	12	mg/L
Brine shrimp	Arthropod	TLm	—	32-47	mg/L
Grammarus pulex	Arthropod	TLm	—	6	mg/L
Limnea ovata	Mollusc	Perturbation level	—	15	mg/L
Bluegill	Fish	TLm	(24 & 96 hr, respectively)	100-1,000, 75	mg/L
Mosquito fish (*Gambusia affinis*	Fish	TLm (24-96 hr)*	—	251	mg/L
Fathead minnow (*Pimephales promelas*)	Fish	LC_{50} (1, 24, 48, 72, 96 hr	Death	175, 106, 106, 79, & 79	mg/L
Culex sp. larvae	Insects	TLm (24-48 hr)*	—	1,500	mg/L
Mice	Mammals	LC_{50} (1 hr)	Inhalation	5,000	ppm

Note(s)
1. Source: Entrix, 2003.

Abbreviation(s)
LC =
mg/L = milligrams per liter
mg/m^3 = milligrams per cubic meters
ppm = parts per million
TLm = median tolerance limit

TABLE 13

SURFACTANT TOXICITY SUMMARY[1]

Imazapyr Risk Assessment
Washington State

Product	Principal Components	Acute Mammalian Toxicity (LD_{50} – ppm)	Rainbow Trout Acute Toxicity (96-hr LC_{50} – mg/L)	Daphnid (Water Flea) Acute Toxicity (48-hr LC_{50} – mg/L)
Agri-Dex®	Petroleum oil, polyoxyethylene sorbitan fatty acid ester, sorbitan fatty acid ester	>5,010 oral (rat) >2,020 dermal (rabbit)	>1,000 (practically non-toxic)	>1,000 (practically non-toxic)
Class Act® NG	Ammonium sulfate, saccharides, alkyl polyglycoside	No Data	447 (practically non-toxic)	377 (practically non-toxic)
Dyne-Amic®	Modified vegetable (seed) oil, pollysiloxane polyether copolymer, alkyl phenol ethoxylate	>5,050 oral (rat) >2,020 dermal (rabbit)	23.2 (slightly toxic)	60 (slightly toxic)
R-11®	Nonylphenol polyethoxylate (90%) 1-Butanol (10%) Dimethylpolysiloxane (<1%)	790 oral (rat) 4,200 dermal (rabbit) 100 inhalatio (PEL/TLV)	3.8 – 6 NOEC =1 mg/L	5.7 – 19 NOEC = 0.25 mg/L (population size)

Note(s)

1. Sources: WSDA, 2009; Wilbur-Ellis, 2006; Bakke, 2007.

Abbreviation(s)

mg/L = milligrams per liter
NOEC =
PEL/TLV – Permissible Exposure Limit/Threshold Limit Value
ppm = parts per million

TABLE 14

ACUTE TOXICITY OF NONYLPHENOL TO AQUATIC BIOTA[1]
Imazapyr Risk Assessment
Washington State

Test Species	Type of Organism	Toxicity Test	End Point	Value	Units
Mytilus edulis	Mussel	Bioconcentration Factor	Bioconcentration Factor	10	Wet weight
Caenorhabditis elegons	Nematode	24-hr LC_{50}	Death	7.2	mg/L
Mysidopsis bahia	Mysid	96-hr LC_{50}	Death	43	mg/L
Fathead minnow	Fish	96-hr LC_{50}	Death	135	mg/L
Gadus morhua	Fish	96-hr LC_{50}	Death	3,000	mg/L

Note(s)
1. Source: Entirix, 2003.

Abbreviation(s)
LC_{50} = lethal concentration resulting in mortality to 50 percent of test population
mg/L = milligrams per liter

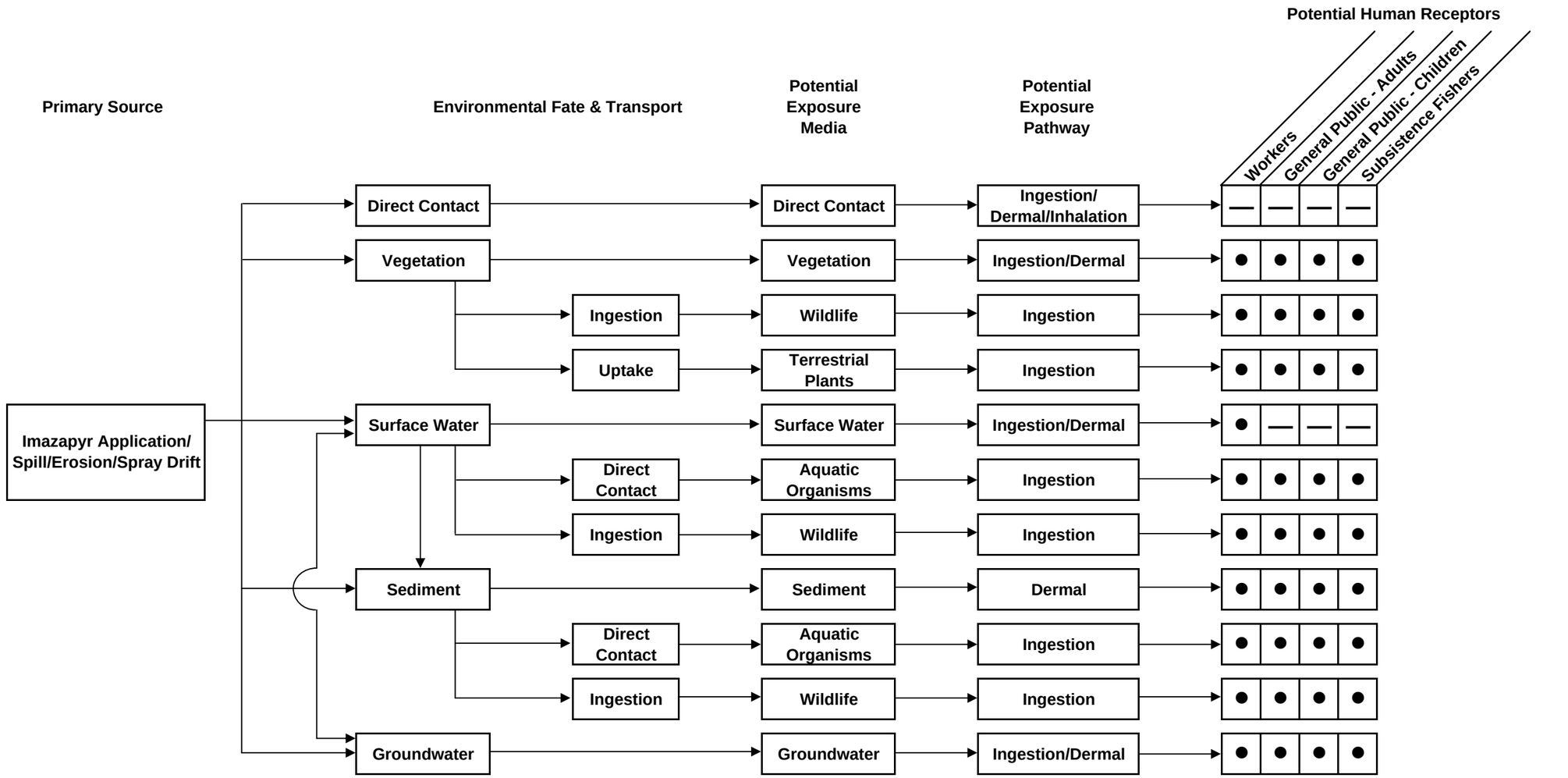
TABLE 15

IMAZAPYR EXPOSURE SCENARIOS FOR MAMMALS AND BIRDS
Imazapyr Risk Assessment
Washington State

	Mammals				Birds			
Exposure	**Small Herbivore**	**Carnivore**	**Insectivore**	**Large Herbivore**	**Piscivore**	**Herbivore**	**Insectivore**	**Carnivore**
Direct Spray								
1st order absorption kinetics over 50% of body surface	A	—	—	—	—	—	—	—
100% absorption over 50% of body surface	A	—	—	—	—	—	—	—
Fruit Consumption	—	—	—	—	—	—	---	---
On site	A/C	—	—	—	—	—	---	---
Off site	C	—	—	—	—	—	---	---
Water Consumption	—	—	—	—	—	—	---	---
Spill	A	—	—	—	---	—	---	---
Drift/Runoff	A/C	—	—	—	—	—	---	---
Grass Consumption	—	—	—		—	—	—	—
On site	—	—	—	A/C	—	A/C	—	—
Off site	—	—	—	C	—	C	—	—
Insect Consumption	—	—	**A**	—	—	—	**A**	—
Mammal Consumption	—	**A**	—	—	—	—	---	**A**
Fish Consumption	—	—	—	—	—	—	---	—
After spill	—	—	—	—	A	—	---	—
Runoff	—	—	—	—	C	—	---	—

Abbreviation(s)
A = Acute exposure
C = Chronic exposure

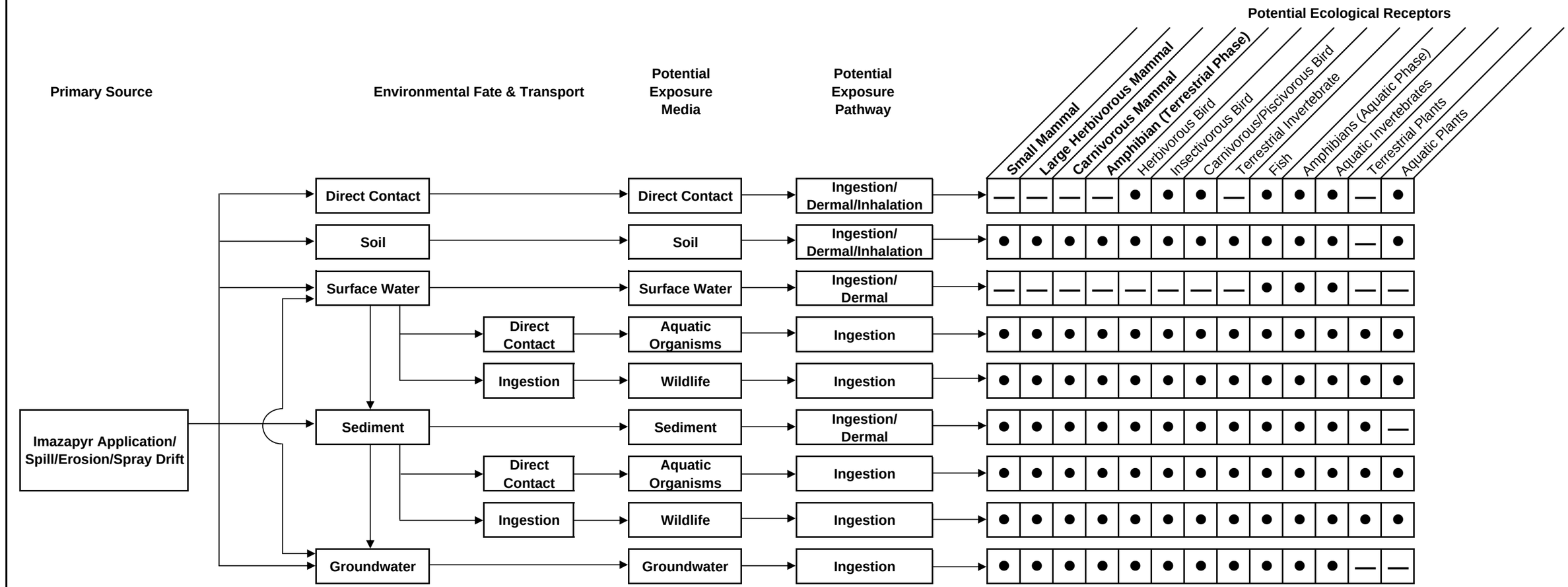
FIGURES



IMAZAPYR HUMAN HEALTH
RISK ASSESSMENT CONCEPTUAL MODEL
Imazapyr Risk Assessment
Project Location

By: RES	Date: 06/28/09	Project No. 14858.000
AMEC Geomatrix		Figure 1

14858-000\reports\figures_conceptual model.xls



EXPLANATION

— **Complete exposure pathway potentially resulting in toxicity**

● **Insignificant exposure pathway**

IMAZAPYR ECOLOGICAL
RISK ASSESSMENT CONCEPTUAL MODEL
Imazapyr Risk Assessment
Project Location

By: RES	Date: 06/28/09	Project No. 14858.000
AMEC Geomatrix		Figure 2

14858-000\reports\figures_conceptual model.xls

APPENDIX A

Imazapyr Activity in Soil

IMAZAPYR ACTIVITY IN SOIL

Imazapyr Risk Assessment
Washington State

Submitted to:
Washington State Department of Agriculture
Olympia, WA

Submitted by:
AMEC Geomatrix, Inc.
Lynnwood, WA

June 2009

Project 14858.000

AMEC Geomatrix

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IMAZAPYR ACTIVITY IN SOIL

Imazapyr Risk Assessment
Washington State

1.0 INTRODUCTION

This section summarizes information about the activity of imazapyr in soils and, using this summary information, attempts to make broad-scale estimates of potential imazapyr persistence in soils of Washington State. An extensive literature search was conducted to identify more recent studies investigating imazapyr soil persistence, but few additional studies were found. The majority of these studies have already been cited and summarized in previous risk assessment documents and imazapyr fact sheets, including the U.S. Environmental Protection Agency's (EPA) *Screening Level Ecological Risk Assessment for the Reregistration of Imazapyr* (2005).

1.1 DISSIPATION MECHANISMS

Imazapyr is an anionic, organic acid that is non-volatile and degrades in clear shallow waters. Imazapyr is both persistent and mobile in soil. Imazapyr is a water soluble, weak acid with an acid dissociation constant (pK_a) of about 3.8. Based on this pK_a, imazapyr is mainly in anionic form at pH levels typically found in the environment. An estimated 61 percent is ionized at pH 4, 94 percent is ionized at pH 5, and greater than 99 percent is ionized at pH 6 and higher. Commercial formulations contain imazapyr acid or the imazapyr isopropylamine salt, both of which are generally dissolved in a water solution. Most environmental fate data were available for imazapyr and based on dissociation of the isopropylamine salt in water. The behavior of the two compounds in the environment should be similar. This fate summary does not address inert ingredients or other herbicides present in end use product mixtures with imazapyr (EPA, 2005).

Imazapyr is degraded in soils primarily by microbial metabolism. It will quickly undergo photodegradation in aqueous solutions (photohydrolysis), but there is little to no photodegradation of imazapyr in soil, and it is not readily degraded by other chemical processes. Imazapyr does not bind strongly with soil particles and, depending on soil pH, can be neutral or negatively charged. When negatively charged, imazapyr remains available in the environment (Tu et al., 2001).

1.2 VOLATILIZATION

Imazapyr does not volatilize readily when applied in the field. The potential to volatilize, however, increases with increasing temperature, increasing soil moisture, and decreasing clay and organic matter content (Tu et al., 2001).

1.3 PHOTODEGRADATION

Imazapyr is rapidly degraded by sunlight in aquatic solutions. In soils, however, there is little or no photodegradation of imazapyr (WSSA, 1994).

1.4 MICROBIAL DEGRADATION

Microbial degradation is the primary mechanism of imazapyr degradation in soils (Tu et al., 2001). Tu et al. (2001) reported that the half-life of imazapyr in soils typically ranged from one to seven months, depending on soil type, temperature, and soil moisture.

The half-life of imazapyr is shorter at cooler soil temperatures (25°C versus 35°C) and in sandier soils (sandy loam versus clay loam) (American Cyanamid, 1986). Degradation rates are decreased in anaerobic soil conditions (WSSA, 1994). In studies of the related compound imazaquin, microbial degradation rates increased with increasing soil moisture content (between 5 to 75 percent of field capacity) and increasing soil temperatures (from 15°C to 30°C). Microbial degradation, additionally, was more rapid in soils that did not bind the herbicide strongly. Imazapyr that is bound strongly to soil particles may be unavailable for microbial degradation (Tu et al., 2001).

EPA (2005) reported that imazapyr was essentially stable to aerobic and anaerobic soil metabolism, with no major transformation products identified during the course of laboratory studies. The persistence of imazapyr in soil was demonstrated by extrapolation of laboratory half-lives in three aerobic soils to approximately 1.2 years, 1.4 years, and 5.9 years (EPA, 2005). Studies by American Cyanamid (1983) and Ta (1999) reported soil half-lives of 210 days and 330 days, respectively.

Wang et al. (2005), studying biodegradation of imazapyr in four soil types from China, reported that the half-life of imazapyr in non-sterile soils was in the range of 30 to 45 days, while in sterile soils was in the range of 81 to 133 days. Biodegradation in four non-sterile soils accounted for 62 percent to 78 percent of imazapyr degradation. In contrast, less than 39 percent of imazapyr degradation was associated with chemical mechanisms. The authors reported that the rate constant of imazapyr under non-sterile conditions were 2.3 to 4.4 times faster than that under sterile conditions, concluding that the indigenous soil microorganisms play an important role in imazapyr degradation.

In the same study by Wang et al. (2005), two imazapyr-degrading bacterial strains were isolated in an enrichment culture technique and were identified as *Pseudomonas fluorescenes* and *Bacillus cereus*. When added to test soils, the bacterial strains could degrade 81 percent to 87 percent of the imazapyr after 48 hours of incubation. The treatment soils with the added bacterial strains increased the imazapyr degradation rate by 3 to 4 fold over that for control samples.

1.5 CHEMICAL DECOMPOSITION

Imazapyr changes form readily with changes in pH, but is not necessarily degraded in this process. It does not readily undergo hydrolysis (Mangels, 1990a), and no other chemical degradation mechanisms have been reported.

Minor concentrations of identified and unidentified transformation products were detected in aerobic studies (EPA, 2005). In these studies, 2-[4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl]-3-hydroxy pyridine reached a maximum of approximately 7 percent of parent radioactivity and, based on simple kinetics, would not be expected to significantly exceed this maximum. It was estimated that 2-[4-isopropyl-4- methyl-5-oxo-2-imidazolin-2-yl]-3-hydroxy pyridine had a relatively short half-life of around one month. Based on structural similarity, the mobility in soil of 2-[4-isopropyl-4-methyl-5-oxo- 2-imidazolin-2-yl]-3-hydroxy pyridine would be expected to be approximately the same as parent imazapyr. 2-[4-Isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl]-3-carboxymethyl pyridine was detected at $\leq$3 percent of the applied parent radioactivity, but may have been an artifact produced during sample extraction and preparation. 2-[(1-Carbamoyl-1,2-dimethylpropyl) carbamoyl]nicotinic acid reached approximately 7 percent of applied parent radioactivity at the end of a 30-day hydrolysis study at pH 9 (EPA, 2005).

1.6 ADSORPTION

The adsorption of imazapyr to soil particles is generally weak, but can vary depending on soil properties (Tu et al., 2001). Adsorption is reversible, and desorption occurs readily (WSSA, 1994). Because the exact chemical form of the herbicide is determined by environmental pH, the adsorption capacity of imazapyr changes with soil pH. A decline in pH below 5 increases adsorption of imazapyr to soil particles. Above pH 5, imazapyr becomes ionized, increasing its negative charge, and limiting its ability to bind with soils (Mangels, 1990b). Vizantinopoulos and Lolos (1994) found that adsorption decreased with increasing soil temperature, and Dickens and Wehtje (1986) found that adsorption increased with time and decreased soil moisture. In general, imidazolinone herbicides show an increase in soil adsorption capacity with an increase in soil clay content and organic matter, but studies of imazapyr have been conflicting (Dickens and Wehtje, 1986; Wehtje et al., 1987; Mangels, 1990b; McDowell et al., 1997; Pusino et al., 1997; El Azzouzi et al., 1998).

Present as an anion at typical environmental pH values, imazapyr tends to be weakly sorbed, and therefore mobile in soils. Above pH 5, the herbicide will take on an ionized form, increasing the risk of herbicide runoff. McDowell et al. (1997) found that heavy rainfall caused significant movement of the herbicide (or more likely, moved the soil particles that the imazapyr was adsorbed to), and leaching up to 50 centimeters (cm) deep in soils have been reported (WSSA, 1994). Imazapyr is prone to leach into groundwater and to runoff into surface water. Sorption coefficients reported in the literature vary, but this is likely due to the range of soils and experimental conditions used in different studies. For anionic compounds in general, sorption would tend to diminish with increasing environmental pH. Consistent with this expectation, in several studies involving a total of 11 different soils and sediments, adsorption coefficients were low, as demonstrated by batch/bulk equilibrium sorption coefficients that range from 0.04 to 3.4 milliliters per gram (mL/g), with a median of 0.6 mL/g. There was no apparent correlation between sorption and soil organic matter (Table A-1) (EPA, 2005).

Börjesson et al. (2004) studied the fate of imazapyr (as imazapyr isopropylammonium: Arsenal® 250) applied to a Swedish railway embankment for a period of 8 years. The average annual precipitation of the study area was 600 millimeters (mm) (~24 inches). Imazapyr was applied at two study sites: one site received 750 grams (g) of imazapyr/hectare (ha), while the other received 1,500 g imazapyr/ha. Soil and groundwater samples were collected biannually for 8 years after application to study imazapyr dissipation. The authors also measured sorption, desorption, organic carbon content, and microbial amount and activity at each of the study sites. The results of the study indicated that organic carbon content correlated positively and pH correlated negatively to the adsorption of imazapyr in soil, and increasing organic carbon content decreased desorption from soil. Microbial content and activity were low and did not correlate significantly to organic carbon content. The authors reported that the majority of imazapyr was found in the upper 30 cm of soil. The dissipation half-lives calculated during the first sampling season (0 to 168 days) for the two application rates of 750 g imazapyr/ha and 1,500 g imazapyr/ha were 67 and 144 days, respectively.

1.7 PERSISTENCE OF IMAZAPYR IN SOIL

The persistence of imazapyr in soil is governed by a multitude of factors including climate (temperature, precipitation, and wind), hydrology, soil characteristics, microbial activity, and chemical degradation. Tu et al. (2001) summarized the results of a number of studies investigating the soil persistence of imazapyr. Depending on environmental conditions, imazapyr was reported to have an average half-life in soils of several months (Vizantinopoulos and Lolos, 1994; El Azzouzi et al., 1998). El Azzouzi et al. (1998) reported half-lives between >58 to 25 days in two Moroccan soils. In a laboratory study, the half-life of imazapyr ranged from 69 to155 days, but factors affecting degradation rates were difficult to identify because

the pH varied with temperature and organic content (McDowell et al., 1997). Vizantinopoulos and Lolos (1994) reported that in loam and clay loam soils with pH 7 to 8, half-lives ranged up to 50 months. The manufacturer reports that persistence in soils is influenced by soil moisture, and that in drought conditions imazapyr could persist for more than one year (Peoples, 1984). Lee et al. (1991) reported that imazapyr residues in soil following post-emergent application increased eight days after initial application and continued to increase until a peak of 0.23 ppm at day 231 post-treatment. The authors attributed these increases to runoff of residues from plant surfaces following rainfall and to the release of residues from decaying plant matter.

Syracuse Environmental Research Associates, Inc. (SERA), in the imazapyr ecological and human health risk assessment prepared for the U.S. Forest Service (SERA, 2004), modeled the environmental fate of imazapyr using the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model. GLEAMS is a root zone model that can be used to examine the fate of chemicals in various types of soils under different meteorological and hydrogeological conditions (Knisel and Davis, 2000). As with many environmental fate and transport models, the input and output files for GLEAMS can be complex.

In SERA's modeling scenario, the application site was assumed to consist of a 10-acre-square area that drained directly into a small pond or stream. The chemical-specific values as well as the details of the pond and stream scenarios used in the GLEAMS modeling are summarized in Table A-2. The GLEAMS modeling, based on a number of precipitation scenarios, yielded estimates of runoff, sedimentation, and percolation that were in turn used to estimate concentrations in the stream adjacent to a treated plot as well as concentrations in three soil types: clay, loam, and sand. The GLEAMS results for concentrations of imazapyr in soil are summarized in Table A-3.

A critical question regarding residual soil concentrations of imazapyr is how long herbicidal activity may persist. Reported field dissipation halftimes in soil range from about 25 days to 180 days, corresponding to dissipation or degradation rate coefficients of 0.0039 to 0.028 $days^{-1}$ [$k = \ln(2) \div t_{1/2}$]. In any first order dissipation model, the fraction, *f*, remaining after time *t* is:

$$f = e^{-kt}.$$

By rearrangement, the time required to reach a certain fraction is:

$$t = \ln(f) \div -k.$$

The approximate concentration of imazapyr in soil associated with a No Observed Effects Concentration (NOEC) for the most sensitive plant species is about 0.001 milligrams per kilogram (mg/kg) and the NOEC for the most tolerant plant species is about 0.02 mg/kg. Thus, taking the range of degradation rate coefficients of 0.0039 to 0.028 $days^{-1}$, the time required to go from a concentration of 1.7 ppm (i.e., after the application of 0.26 pounds acid equivalent per acre [lbs a.e./acre]) to 0.001 parts per million (ppm) would be:

$$t = \ln(0.001 \text{ mg/kg} \div 1.7 \text{ mg/kg}) \div - (0.0039 \text{ to } 0.028 \text{ days}) = 266 \text{ to } 1{,}905 \text{ days, } -1$$

corresponding to about 9 months to 5.2 years. Thus, at an application rate of 0.26 lbs a.e./acre, some residual effects on plant species could be expected for several years if microbial degradation was the only significant mechanism in the reduction of imazapyr in soil.

Based on the GLEAMS modeling, microbial degradation will be the controlling factor only in very arid environments. At annual rainfall rates of 10 inches/year or more, imazapyr will be removed from the soil by runoff, percolation, or a combination of these. Runoff is likely to be the dominant mechanism in clay soils and percolation the dominant mechanism in sandy soils. Intermediate soil types, such as loam, evidence a mix of runoff and percolation depending on specific soil and site characteristics. The quantitative impact of losses from runoff and percolation are illustrated in Figure A-1, which gives the concentration of imazapyr in clay soil at annual rainfall rates of 5, 25, 50, 100, and 200 inches at an application rate of 1 lb a.e./acre, based on GLEAMS modeling conducted by SERA (2004). At an annual rainfall rate of 5 inches per year, the loss from soil is attributable completely to microbial degradation, which is characterized using a halftime of 25 days for the GLEAMS modeling in clay soil. Under these conditions, the concentration of imazapyr in soil does not reach the NOEC of 0.001 mg/kg until about day 340 after application. At an annual rainfall rate of 200 inches per year, about 50 percent of the applied compound is lost from the application site by runoff and the estimated concentration in soil reaches the NOEC of 0.001 mg/kg in about 60 days.

The results of the GLEAMS modeling conducted by SERA (2004) demonstrate that climate and soil type can substantially affect the persistence of imazapyr in soil. Low permeability clay soils likely lose much of the applied imazapyr via surface runoff and wind erosion, so that soil concentrations would be expected to be higher in arid regions than in areas with more precipitation. Imazapyr loss from loam soils occurs through a combination of surface runoff, wind erosion, and percolation, while the predominant route of loss in sand is likely via percolation.

2.0 IMAZAPYR PERSISTENCE IN WASHINGTON STATE SOILS

Based on the above discussion, predicting concentrations of imazapyr in soils at some point after application cannot be done with any degree of precision. The many environmental variables affecting imazapyr degradation and dissipation in soils preclude definitive statements about imazapyr persistence in soils across Washington State, even when restricting predictions to soils in riparian areas. Annual precipitation, wind speed and direction, topography, soil type, vegetative cover, herbicide application rate, and application method are but a few of the variables that must be considered on a site-specific and situation specific basis to make informed estimated of imazapyr soil persistence. Even with this information, the available laboratory studies that have investigated imazapyr soil persistence are few and the ranges of environmental variables that were addressed in those studies were limited. Another factor that must be considered when applying imazapyr along riparian corridors is the river/stream hydrograph. Residual imazapyr in surficial soils along rivers and streams will likely be removed during high-flow and flood events.

Predictive models, such as the GLEAMS model, are able to provide broad-scale predictions regarding herbicide soil persistence based on algorithms that incorporate a limited set of environmental and chemical parameters. The reliability of the model predictions is improved by inputting site-specific data; however, the uncertainty associated with such predictions may be relatively great, depending on the algorithms used by the model.

Generalizations may be made about the relative persistence of imazapyr in soil based on soil type and annual precipitation. Based on GLEAMS modeling of soil concentrations of imazapyr in clay, loam, and sand soils and annual rainfall (Table A-3), rainfall is a major factor in removing imazapyr from soil via runoff (clay) and percolation (sand). Generally, imazapyr will be less persistent in sandy soils, slightly ore persistent in clay soils, and most persistent in loamy soils. As annual rainfall increases from 10 to 100 inches, the predicted soil concentrations of imazapyr decrease exponentially. Regionally, imazapyr soil persistence will be governed, largely, by annual precipitation. In arid regions with rainfall ≤10 inches/year, imazapyr is expected to be more persistent than in areas with higher annual precipitation. Table A-4 provides average annual rainfall for Washington counties. Annual precipitation is typically the least in regions east of the Cascades, greatest along the Washington coast, and intermediate in the Puget Sound Basin. Based on average annual rainfall by county, generally, imazapyr would be expected to have the longest soil persistence when applied in areas east of the Cascades and the least persistence when applied in coastal areas, with intermediate soil persistence within the Puget Sound Basin. Soil persistence, however, will be governed by site-specific conditions.

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TABLES

TABLE A-1

SORPTION COEFFICIENTS FOR IMAZAPYR IN 11 SOIL/SEDIMENTS[1]

Imazapyr Risk Assessment
Washington State

Soil/Sediment Type	Kd (mL/g)	Koc (mL/g oc)
Loamy sand soil	0.04	15
Sandy loam soil	0.07	8.2
Sand sediment (Florida)	0.11	31
Loam soil	0.23	17
Loamy sand soil (Delaware)	0.52	100
Silt loam sediment (Missouri)	0.64	100
Clay loam soil (North Dakota)	0.84	18
Silt loam soil	0.86	82
Sandy loam soil (Princeton)	1.9	110
Silt loam soil (Wisconsin)	2.4	53
Pond sediment	3.4	150

Note(s)

1. Source: EPA (U.S. Environmental Protection Agency), 2005.

Abbreviation(s)

Kd = soil adsorption coefficient
Koc = organic carbon partition coefficient
mL/g = milliliters per gram
mL/g oc = milliliters per gram organic carbon

TABLE A-2

CHEMICAL AND SITE PARAMETERS USED IN GLEAMS MODELING FOR IMAZAPYR[1]

Imazapyr Risk Assessment
Washington State

Parameter[2]	Clay	Loam	Sand	Comment/Reference
Halftimes (days)				
Aquatic Sediment	NA			Note 3
Foliar	26			Note 4
Soil	25	67	180	Note 5
Water	325			Note 6
K_{oc} (mL/g)	99.8			Note 7
K_d (mL/g)	4.55	4.55	4.55	Note 8
Water Solubility (mg/L)	13,100			Cortes, 1990
Foliar wash-off fraction	0.9			Knisel and Davis, 2000

Note(s)

1. Source: SERA (Syracuse Environmental Research Associates, Inc.), 2004.
2. Site Parameters:
   Pond – 1-acre pond, 2-meters deep, with a 0.01 sediment fraction. 10-acre-square field (660 feet by 660 feet) with a root zone of 60 inches and four soil layers.
   Stream base flow rate of 4,420,000 liters/day with a flow velocity of 0.08 meters/second or 6,912 meters/day.
   Stream width of 2 meters (about 6.6 feet) and depth of about 1 foot. 10-acre-square field (660 feet by 660 feet) with a root zone of 60 inches and four soil layers.
3. Imazapyr is not degraded under anaerobic conditions (SERA, 2004).The sediment degradation rate is set to zero in the model runs.
4. Central estimate from Michael and Neary (1993) and close to the reference value of 30 days given by Knisel and Davis (2000).
5. The degradation halftime in soil is highly dependent on microbial population. The range of 25 to 180 days is based on a large number of soil degradation studies. The central estimate of 67 days is taken as the geometric mean of the range.
6. Based on hydrolysis halftime at pH 7 from American Cyanamid (1986). More rapid degradation is plausible under conditions where photolysis may be the predominant mechanism of degradation.
7. Value for silt loam from Holman (2000).
8. Kd values vary substantially among soil types. The value of 4.55 is taken from Mangels (1994) and is the only Kd reported specifically for pond sediment.

Abbreviation(s)

Kd = soil adsorption coefficient
Koc = organic carbon partition coefficient
mL/g = milliliters per gram
mL/g oc = milliliters per gram organic carbon

TABLE A-3

SUMMARY OF MODELED CONCENTRATIONS OF IMAZAPYR IN SOIL (ALL UNITS ARE MG/KG SOIL OR PPM PER LB/ACRE APPLIED) APPLIED AT 0.26 LBS A.E./ACRE[1]

Imazapyr Risk Assessment
Washington State

	Clay		Loam		Sand	
Annual Rainfall (inches)	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
5	0.1978	1.7212	0.2899	1.5568	0.3450	1.3440
10	0.1642	1.5998	0.1917	1.3672	0.1131	0.9552
15	0.1364	1.5149	0.1226	1.1950	0.0466	0.9195
20	0.1157	1.4319	0.0869	1.0467	0.0266	0.9170
25	0.1014	1.3616	0.0655	0.9172	0.0176	0.9165
50	0.0651	1.1096	0.0257	0.9165	0.0061	0.9165
100	0.0347	1.0376	0.0090	0.9165	0.0039	0.9165
150	0.0180	1.0376	0.0052	0.9165	0.0035	0.9165
200	0.0067	1.0376	0.0038	0.9165	0.0033	0.9165
250	0.0033	1.0376	0.0034	0.9165	0.0032	0.9165

Note(s)

1. Source: SERA (Syracuse Environmental Research Associates, Inc.), 2004.

Abbreviation(s)

lbs a.e./acre = pounds acid equivalents per acre
lb/acre = pound per acre
mg/kg = milligrams per kilogram
ppm = parts per million

TABLE A-4

AVERAGE ANNUAL RAINFALL BY COUNTY[1]

Imazapyr Risk Assessment
Washington State

Results reported in inches

County	Annual Rainfall
Adams	11.28
Asotin	15.42
Benton	7.89
Chelan	8.83
Clallam	24.99
Clark	39.48
Columbia	19.29
Cowlitz[2]	45.52
Douglas	11.30
Ferry	15.49
Franklin[3]	9.80
Garfield	16.80
Grant	7.88
Grays Harbor[4]	83.07
Island	20.08
Jefferson	18.69
King	38.10
Kitsap[5]	45.06
Kittitas[6]	8.87
Klickitat	17.15
Lewis[7]	46.06
Lincoln	14.51
Mason	65.17
Okanogan[8]	11.62
Pacific[9]	112.83
Pend Oreille	25.92
Pierce	38.81
San Juan[10]	28.93
Skagit	32.37
Skamania[11]	85.71
Snohomish	35.48
Spokane	16.09
Stevens	17.42
Thurston	50.75

TABLE A-4

AVERAGE ANNUAL RAINFALL BY COUNTY[1]

Imazapyr Risk Assessment
Washington State

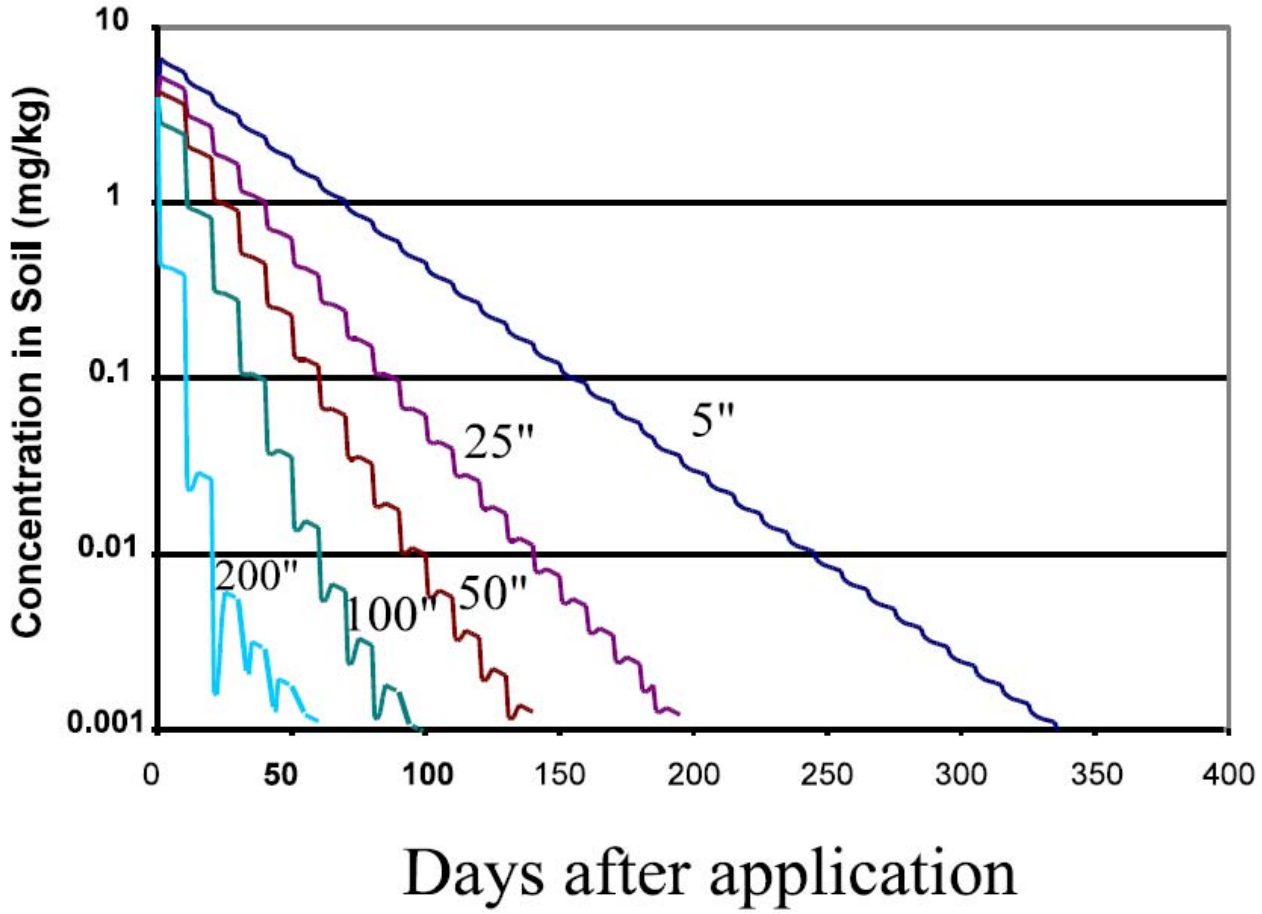
Results reported in inches

County	Annual Rainfall
Wahkiakum	79.45
Walla Walla	19.34
Whatcom	34.64
Whitman	20.17
Yakima	8.10

Note(s)

1. Based on rainfall records of the county seat, except where otherwise noted (WRCC, 2009).
2. Rainfall records from Longview.
3. Rainfall records from Connell.
4. Rainfall records from Aberdeen.
5. Rainfall records from Bremerton.
6. Rainfall records from Ellensburg.
7. Rainfall records from Centralia.
8. Rainfall records from Omak.
9. Rainfall records from Naselle.
10. Rainfall records from Olga.
11. Rainfall records from Carson.

FIGURE



CONCENTRATION OF IMAZAPYR IN CLAY SOILS
AS MODELED BY GLEAMS[1]
Imazapyr Risk Assessment
Washington State

By: RES	Date: 06/29/09	Project No. 14858
AMEC Geomatrix		Figure A-1

1. Source: SERA (Syracuse Environmental Research Associates, Inc.), 2004.

APPENDIX B

Risk Assessment Worksheets

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Imazapyr Risk Assessment

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TABLE B-1

PROGRAM DATA: APPLICATION RATES, APPLICATION VOLUMES, AND CONCENTRATIONS IN FIELD SOLUTIONS

Imazapyr Risk Assessment
Washington State

Parameter/ Assumption	Code/ Range	Equation/ Value	Units	Reference/ Equation
Application Rate	**ApRt**			
	Central	0.26	lb/acre	Prog!ApRt_C
	Lower	0.26		Prog!ApRt_L
	Upper	0.26		Prog!ApRt_U
Application Volume	**ApVol**			
	Central	10	gal/acre	Prog!ApVol_C
	Lower	5		Prog!ApVol_L
	Upper	20		Prog!ApVol_U
Concentration in field solution (lb/gal)	**$Conc_{ppg}$**	***ApRt (lb/acre) / ApVol (gal/acre)***		Note 1
	Central	0.026	lb/gal	Eq
	Lower	0.013		Eq
	Upper	0.052		Eq
Conversion Factor for lbs/gal to mg/mL	**CnvF**	119.8	mg/mL/lb/gal	
Concentration in field solution (mg/mL)	**FldConc**	***$Conc_{ppg}$ * CnvF***		Note 2
	Central	3.1	mg/mL	Eq
	Lower	1.6		Eq
	Upper	6.2		Eq
Number of significant figures in mg/L concentration.	**NSig**	2		Prog!Nsig
		2		
		2		

Notes

1. The lower range of the application volume is used to calculate the upper range of the concentration in field solution and the upper range of the application volume is used to calculate the lower range of the concentration in field solution.
2. Typically, rounding the concentration in field solutions to two significant digits will be reasonable. The pink shaded cell may be changed by the user. If the contents of the cells are deleted, the values are rounded to one significant place.

TABLE B-2

GENERAL REFERENCE VALUES AND EXPOSURE FACTORS USED IN WORKSHEETS

Imazapyr Risk Assessment

Washington State

Receptor	Factor	Value	Units	Reference	Reference Note
Adult Female	Body weight	64	kg	EPA/ORD, 1985	page 5, Table 2-2
Adult Female	Surface area, feet and lower Legs	2,915	cm^2	EPA/ORD, 1992	p. 8-11, Table 8-3, total for feet and lower legs.
Adult Female	Surface area, wearing shorts and T-shirt	5,300	cm^2	EPA/ORD, 1992	p. 8-11, Table 8-3, total for arms, hands, lower legs, and feet.
Adult Male	Body weight	70	kg	ICRP, 1975	p. 13
Subsistence Populations	Body weight	70	kg	ICRP, 1975	p. 13
Aerial Spray Worker	Absorbed dose rate, central estimate	0.00003	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Aerial Spray Worker	Absorbed dose rate, lower range	0.000001	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Aerial Spray Worker	Absorbed dose rate, upper range	0.0001	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Aerial Spray Worker	Hours of application per day, central estimate	7	hours per day	USDA, 1989a	N/A
Aerial Spray Worker	Hours of application per day, lower range	6	hours per day	USDA, 1989a	N/A
Aerial Spray Worker	Hours of application per day, upper range	8	hours per day	USDA, 1989a	N/A
Aerial Spray Worker	Acres treated per hour, central estimate	70	acres/hour	USDA, 1989a	Acres treated per hour.
Aerial Spray Worker	Acres treated per hour, lower range	40	acres/hour	USDA, 1989a	Acres treated per hour.
Aerial Spray Worker	Acres treated per hour, upper range	100	acres/hour	USDA, 1989a	Acres treated per hour.
Backpack Worker	Absorbed dose rate, central estimate	0.003	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Backpack Worker	Absorbed dose rate, lower range	0.0003	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Backpack Worker	Absorbed dose rate, upper range	0.01	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Backpack Worker	Hours of application per day, central estimate	7	hours per day	USDA, 1989a	N/A
Backpack Worker	Hours of application per day, lower range	6	hours per day	USDA, 1989a	N/A
Backpack Worker	Hours of application per day, upper range	8	hours per day	USDA, 1989a	N/A
Backpack Worker	Acres treated per hour, central estimate	0.625	acres/hour	USDA, 1989a	Acres treated per hour.
Backpack Worker	Acres treated per hour, lower range	0.25	acres/hour	USDA, 1989a	Acres treated per hour.

TABLE B-2

GENERAL REFERENCE VALUES AND EXPOSURE FACTORS USED IN WORKSHEETS

Imazapyr Risk Assessment

Washington State

Receptor	Factor	Value	Units	Reference	Reference Note
Backpack Worker	Acres treated per hour, upper range	1	acres/hour	USDA, 1989a	Acres treated per hour.
Carnivorous bird	Body weight	0.637	kg	Dunning 1993	p. 97. Female spotted owl (*Strix occidentalis*). Range of 548 to 760 g.
Carnivorous bird	Kilocalories, alpha parameter for allometric equation	1.146	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	Eq. 3-35, p. 3-22
Carnivorous bird	Kilocalories, beta parameter for allometric equation	0.749	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	Eq. 3-35, p. 3-22
Large Bird	Body weight	4	kg	Default	Canada goose
Large Bird	Kilocalories, alpha parameter for allometric equation	3.12	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	Eq. 3-35, p. 3-22
Large Bird	Kilocalories, beta parameter for allometric equation	0.604	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	Eq. 3-35, p. 3-22
Small Bird	Body weight	0.01	kg	Default	N/A
Small Bird	Kilocalories, alpha parameter for allometric equation	3.12	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	Eq. 3-35, p. 3-22
Small Bird	Kilocalories, beta parameter for allometric equation	0.604	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	Eq. 3-35, p. 3-22
Child	Body weight	13.3	kg	EPA/ORD, 1996	p. 7-1, Table 7-2
Child	Surface area, Whole body	6,030	cm^2	EPA/ORD, 1996	p. 6-15, Table 6-6, 50th percentile
Conversion Factors	Liters per gal	3.785	L/gal	N/A	N/A
Conversion Factors	Pound per milligram	453600	mg/lb	N/A	N/A
Conversion Factors	lbac2mgcm2	0.01121	mg/cm^2 per lb/acre	N/A	N/A
Conversion Factors	lbac2ugcm2	11.21	ug/cm^2 per lb/acre	N/A	N/A
Conversion Factors	Conversion for milligrams to pounds	2.204E-06	lb/mg	N/A	N/A
Conversion Factors	Conversion for milligrams to pounds	3,785	ml/gal	N/A	N/A
Small insects	Caloric content (wet weight)	1.5	kcal/g	EPA/ORD, 1993	Table 4-1, p. 4-13, Value for beetles, Wet weight.
Vegetation	Caloric content (dry weight)	2.46	kcal/g	EPA/ORD, 1993	p. 3-5
Vegetation	Water content (proportion)	0.85	unitless	EPA/ORD, 1993	p. 4-14

TABLE B-2

GENERAL REFERENCE VALUES AND EXPOSURE FACTORS USED IN WORKSHEETS

Imazapyr Risk Assessment

Washington State

Receptor	Factor	Value	Units	Reference	Reference Note
Ground Spray Worker	Absorbed dose rate, central estimate	0.0002	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Ground Spray Worker	Absorbed dose rate, lower range	0.00001	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Ground Spray Worker	Absorbed dose rate, upper range	0.0009	(mg/kg bw)/ (lbs handled per day)	SERA, 2001	Acres treated per hour.
Ground Spray Worker	Hours of application per day, central estimate	7	Hours per day	USDA, 1989a	N/A
Ground Spray Worker	Hours of application per day, lower range	6	Hours per day	USDA, 1989a	N/A
Ground Spray Worker	Hours of application per day, upper range	8	Hours per day	USDA, 1989a	N/A
Ground Spray Worker	Acres treated per hour, central estimate	16	acres/hour	USDA, 1989a	Acres treated per hour.
Ground Spray Worker	Acres treated per hour, lower range	11	acres/hour	USDA, 1989a	Acres treated per hour.
Ground Spray Worker	Acres treated per hour, upper range	21	acres/hour	USDA, 1989a	Acres treated per hour.
Honey bee	Body weight	0.000093	kg	Default	N/A
Honey bee	Surface area, alpha parameter for allometric equation	0.111	BW(kg),SA(m^2)	Boxenbaum and D'Souza, 1990	Note that Boxenbaum and D'Souza 1990 give 1110 which give WA in cm2. Value is converted to be consistent with mammalian values.
Honey bee	Surface area, beta parameter for allometric equation	0.65	BW(kg)	Boxenbaum and D'Souza, 1990	N/A
Carnivorous mammal	Body weight	5	kg	EPA/ORD, 1993	p. 2-221. Central value for red fox with a range of 3 to 7 kg.
Carnivorous mammal	Kilocalories, alpha parameter for allometric equation	1.894	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	p. 3-6, equation 3-11, carnivores
Carnivorous mammal	Kilocalories, beta parameter for allometric equation	0.7	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	p. 3-6, equation 3-11, carnivores
Large Mammal	Body weight	70	kg	Default	N/A
Large Mammal	Kilocalories, alpha parameter for allometric equation	1.518	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	p. 3-6, Eq. 3-10, herbivores
Large Mammal	Kilocalories, beta parameter for allometric equation	0.73	BW(g),Kcal kcal/day)	EPA/ORD, 1993	p. 3-6, Eq. 3-10, herbivores

TABLE B-2

GENERAL REFERENCE VALUES AND EXPOSURE FACTORS USED IN WORKSHEETS

Imazapyr Risk Assessment

Washington State

Receptor	Factor	Value	Units	Reference	Reference Note
Rabbit	Body weight	1.3	kg	Default	N/A
Rabbit	Surface area, alpha parameter for allometric equation	0.11	BW(g), Kcal (kcal/day)	EPA/ORD, 1993	N/A
Rabbit	Surface area, beta parameter for allometric equation	0.65	BW(g), Kcal (kcal/day)	EPA/ORD, 1993	N/A
Small Mammal	Body weight	0.02	kg	Default	N/A
Small Mammal	Caloric content (wet weight)	1.7	kcal/g	EPA/ORD, 1993	Table 4-1, p. 4-13
Small Mammal	Food consumption, alpha parameter for allometric equation	0.621	BW(g),FC(g)	EPA/ORD, 1993	p. 3-6, equation for rodents
Small Mammal	Food consumption, beta parameter for allometric equation	0.584	BW(g),FC(g)	EPA/ORD, 1993	p. 3-6, equation for rodents
Small Mammal	Kilocalories, alpha parameter for allometric equation	1.894	BW(g),KCal(kcal/day)	EPA/ORD, 1993	p. 3-6, equation 3-11, carnivores
Small Mammal	Kilocalories, beta parameter for allometric equation	0.7	BW(g),Kcal (kcal/day)	EPA/ORD, 1993	p. 3-6, equation 3-11, carnivores
Small Mammal	Surface area, alpha parameter for allometric equation	0.11	BW(kg),SA(m^2)	EPA/ORD, 1993	eq. 3-22, p. 3-14
Small Mammal	Surface area, beta parameter for allometric equation	0.65	BW(kg),SA(m^2)	EPA/ORD, 1993	eq. 3-22, p. 3-14
Small Mammal	Water consumption, alpha parameter for allometric equation	0.099	BW(kg),WC(L)	EPA/ORD, 1993	Eq. 3-17, p. 3-10, all mammals
Small Mammal	Water consumption, beta parameter for allometric equation	0.9	BW(g),FC(g)	EPA/ORD, 1993	Eq. 3-17, p. 3-10, all mammals
Misc	Liquid adhering to skin	0.008	mL/cm^2	Mason and Johnson, 1987	Weight of liquid adhering to surface of skin after a spill.
Misc	Dislodgeable residue as proportion	0.1	none	Harris and Solomon, 1992	Estimate of dislodgeable residue as a proportion of application rate shortly after application based on 2,4-D.
Standard Pond	Depth	1	m	Default	Depth of pond
Standard Pond	Surface area	1,000	m^2	Default	Surface Area
Standard Pond	Volume of spill	200	gallons	Default	Volume of spill

TABLE B-2

GENERAL REFERENCE VALUES AND EXPOSURE FACTORS USED IN WORKSHEETS

Imazapyr Risk Assessment

Washington State

Receptor	Factor	Value	Units	Reference	Reference Note
VegRR	Broadleaf/forage plants and small insects, central estimate	45	mg chem/ kg veg	Fletcher et al., 1994	Broadleaf/forage plants and small insects.
VegRR	Broadleaf/forage plants and small insects, upper range	135	mg chem/ kg veg	Fletcher et al., 1994	Broadleaf/forage plants and small insects.
VegRR	Fruits, pods, seeds, and large insects, central estimate	7	mg chem/ kg veg	Fletcher et al., 1994	Fruits, pods, seeds, and large insects.
VegRR	Fruits, pods, seeds, and large insects, upper range	15	mg chem/ kg veg	Fletcher et al., 1994	Fruits, pods, seeds, and large insects.
VegRR	Short grass, central estimate	85	mg chem/ kg veg	Fletcher et al., 1994	Short grass
VegRR	Short grass, upper range	240	mg chem/ kg veg	Fletcher et al., 1994	Short grass
VegRR	Tall grass, central estimate	36	mg chem/ kg veg	Fletcher et al., 1994	Tall grass
VegRR	Tall grass, upper range	110	mg chem/ kg veg	Fletcher et al., 1994	Tall grass
Worker	Body weight	70	kg	ICRP, 1975	p. 13
Worker	Surface area, hands	840	cm^2	EPA/ORD, 1992	p. 8-11
Worker	Surface area, lower legs	2,070	cm^2	EPA/ORD, 1992	p. 8-11
Green Frog	Body weight	0.0491	kg	EPA/ORD, 1993	p. 2-446
Green Frog	Surface area	17	cm^2	EPA/ORD, 1993	p. 2-446

TABLE B-3

CONSUMPTION VALUES USED IN WORKSHEETS

Imazapyr Risk Assessment
Washington State

Receptor	Item	Qualifier	Modifier	Value	Units	Reference	Reference Note
Adult Female	Fish	Amount	central estimate	0.01	kg/day	EPA/ORD, 1996	p. 10-51. Average of means from four studies rounded to one significant place.
Adult Female	Fish	Amount	upper range	0.158	kg/day	Ruffle et al., 1994	N/A
Adult Female	Fruit	Proportion of body weight	central estimate	0.00168	kg fruit/kg bw/day	EPA/ORD, 1996	Table 9-3, p. 9-11, mean value.
Adult Female	Fruit	Proportion of body weight	lower range	0.00168	kg fruit/kg bw/day	EPA/ORD, 1996	Table 9-3, p. 9-11, the 5th percentile is given as zero. For these worksheets, the central estimate is used for the lower bound.
Adult Female	Fruit	Proportion of body weight	upper range	0.01244	kg fruit/kg bw/day	EPA/ORD, 1996	Table 9-3, p. 9-11, 95th percentile value.
Adult Female	Vegetation, home grown	Proportion of body weight	central estimate	0.00076	kg veg/kg bw/day	EPA/ORD, 1996	Table 12-15, p. 9-14, mean for individuals between 20 and 39 years old.
Adult Female	Vegetation, home grown	Proportion of body weight	lower range	0.00008	kg veg/kg bw/day	EPA/ORD, 1996	Table 12-15, p. 9-14, 5th percentile for individuals between 20 and 39 years old.
Adult Female	Vegetation, home grown	Proportion of body weight	upper range	0.00492	kg veg/kg bw/day	EPA/ORD, 1996	Table 12-15, p. 9-14, 95th percentile for individuals between 20 and 39 years old.
Adult Female	Vegetation	Amount	Extreme	0.454	kg food	EPA/ORD, 1996	1 lb. The approximate mid range of the above typical and upper limits based on the 64 kg body weight.
Adult Female	Vegetation	Proportion of body weight	central estimate	0.0036	kg veg/kg bw/day	EPA/ORD, 1996	Table 9-12, p. 9-12, mean.
Adult Female	Vegetation	Proportion of body weight	lower range	0.00075	kg veg/kg bw/day	EPA/ORD, 1996	Table 9-12, p. 9-12, 5th percentile.
Adult Female	Vegetation	Proportion of body weight	upper range	0.01	kg veg/kg bw/day	EPA/ORD, 1996	Table 9-12, p. 9-12, 95th percentile.
Adult Female	Water	Amount	central estimate	2	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, midpoint of mean (1.4 L/day) and 90th percentile (2.4 L/day) rounded to one significant place.
Adult Female	Water	Amount	lower range	1.4	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, mean.
Adult Female	Water	Amount	upper range	2.4	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, 90th percentile.
Adult Male	Fish	Amount	central estimate	0.01	kg/day	EPA/ORD, 1996	p. 10-51, average of means from four studies rounded to one significant place.
Adult Male	Fish	Amount	upper range	0.158	kg/day	Ruffle et al., 1994	N/A

TABLE B-3

CONSUMPTION VALUES USED IN WORKSHEETS

Imazapyr Risk Assessment
Washington State

Receptor	Item	Qualifier	Modifier	Value	Units	Reference	Reference Note
Adult Male	Fruit	Proportion of body weight	central estimate	0.00168	unitless	EPA/ORD, 1996	Table 9-3, p. 9-11, mean value.
Adult Male	Fruit	Proportion of body weight	lower range	0.00168	unitless	EPA/ORD, 1996	Table 9-3, p. 9-11. The 5th percentile is given as zero. For these worksheets, the central estimate is used for the lower bound.
Adult Male	Fruit	Proportion of body weight	upper range	0.01244	unitless	EPA/ORD, 1996	Table 9-3, p. 9-11, 95th percentile value.
Adult Male	Vegetation, home grown	Proportion of body weight	central estimate	0.00076	unitless	EPA/ORD, 1996	Table 12-15, p. 9-14, mean for individuals between 20 and 39 years old.
Adult Male	Vegetation, home grown	Proportion of body weight	lower range	0.00008	unitless	EPA/ORD, 1996	Table 12-15, p. 9-14, 5th percentile for individuals between 20 and 39 years old.
Adult Male	Vegetation, home grown	Proportion of body weight	upper range	0.00492	unitless	EPA/ORD, 1996	Table 12-15, p. 9-14, 95th percentile for individuals between 20 and 39 years old.
Adult Male	Vegetation	Amount	Extreme	0.454	kg/day	EPA/ORD, 1996	1 lb. The approximate mid range of the above typical and upper limits based on the 64 kg body weight.
Adult Male	Vegetation	Proportion of body weight	central estimate	0.0036	unitless	EPA/ORD, 1996	Table 9-12, p. 9-12, mean.
Adult Male	Vegetation	Proportion of body weight	lower range	0.00075	unitless	EPA/ORD, 1996	Table 9-12, p. 9-12, 5th percentile.
Adult Male	Vegetation	Proportion of body weight	upper range	0.01	unitless	EPA/ORD, 1996	Table 9-12, p. 9-12, 95th percentile.
Adult Male	Water	Amount	central estimate	2	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, midpoint of mean (1.4 L/day) and 90th percentile (2.4 L/day) rounded to one significant place.
Adult Male	Water	Amount	lower range	1.4	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, mean.
Adult Male	Water	Amount	upper range	2.4	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, 90th percentile.
Subsistence Populations	Fish	Amount	central estimate	0.081	kg/day	EPA/ORD, 1996	p. 10-51, median value of 94 individuals.
Subsistence Populations	Fish	Amount	upper range	0.77	kg/day	EPA/ORD, 1996	p. 10-51, highest value of 94 individuals.
Fish-eating Bird	Fish	Proportion of body weight	central estimate	0.1	unitless	EPA/ORD, 1993	various species.
Fish-eating Bird	Fish	Proportion of body weight	lower range	0.05	unitless	EPA/ORD, 1993	various species.
Fish-eating Bird	Fish	Proportion of body weight	upper range	0.15	unitless	EPA/ORD, 1993	various species.

TABLE B-3

CONSUMPTION VALUES USED IN WORKSHEETS

Imazapyr Risk Assessment
Washington State

Receptor	Item	Qualifier	Modifier	Value	Units	Reference	Reference Note
Child	Water	Amount	central estimate	1	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, midpoint of mean (0.61L/day) and 90th percentile (1.5 L/day) rounded to one significant place.
Child	Water	Amount	lower range	0.61	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, mean.
Child	Water	Amount	upper range	1.5	L/day	EPA/ORD, 1996	p. 3-28, Table 3-30, 90th percentile.

TABLE B-4

CHEMICAL AND PHYSICAL PROPERTIES FOR IMAZAPYR

Imazapyr Risk Assessment
Washington State

Property	Receptor	Value	Units	Document Reference
Bioconcentration Factor (BCF), edible, acute	N/A	0.5	L/kg fish	Section 3.3.3.5
Bioconcentration Factor (BCF), edible, chronic	N/A	0.5	L/kg fish	Section 3.3.3.5
Bioconcentration Factor (BCF), whole fish, acute	N/A	0.5	L/kg fish	Section 3.3.3.5
Bioconcentration Factor (BCF), whole fish, chronic	N/A	0.5	L/kg fish	Section 3.3.3.5
Kow (Octanol-water partition coefficient)	N/A	1.3	unitless	Table 1
Molecular weight	N/A	261.3	grams/mole	Table 1
Water Solubility	N/A	13100	mg/L	Table 1
First order dermal absorption rate (ka), central estimate	N/A	0.0011	per hour	Section 3.3.2.2
First order dermal absorption rate (ka), lower range	N/A	0.00044	per hour	Section 3.3.2.2
First order dermal absorption rate (ka), upper range	N/A	0.0029	per hour	Section 3.3.2.2
Dermal permeability (Kp), central estimate	N/A	0.000056	cm/hour	Section 3.3.2.2
Dermal permeability (Kp), lower range	N/A	0.000028	cm/hour	Section 3.3.2.2
Dermal permeability (Kp), upper range	N/A	0.00011	cm/hour	Section 3.3.2.2
Halftime, central estimate	Fruit	26	days	Section 3.3.3.6
Halftime, lower range	Fruit	15	days	Section 3.3.3.6
Halftime, upper range	Fruit	37	days	Section 3.3.3.6
Halftime, central estimate	Vegetation	26	days	Section 3.3.3.6
Halftime, lower range	Vegetation	15	days	Section 3.3.3.6
Halftime, upper range	Vegetation	37	days	Section 3.3.3.6

TABLE B-5

TOXICITY VALUES FOR IMAZAPYR
Imazapyr Risk Assessment
Washington State

Receptor	Receptor	Qualifier	Endpoint	Value	Units	Document Reference
Human	acute	N/A	Reference Dose (RfD)	2.5	mg/kg bw	Section 3.4.2
Human	chronic	N/A	Reference Dose (RfD)	2.5	mg/kg bw/day	Section 3.4.3
Mammals	acute	N/A	NOAEL	250	mg/kg bw	Section 4.4.2.1
Mammals	chronic	N/A	NOAEL	250	mg/kg bw/day	Section 4.4.2.1
Birds	acute	N/A	NOAEL	674	mg/kg bw	Section 4.4.2.2
Birds	chronic	N/A	NOAEL	200	mg/kg bw/day	Section 4.4.2.2
Honey bee	acute	N/A	NOAEL	1000	mg/kg bw	Section 4.4.2.3
Fish	acute	sensitive species	LC50	2.7	mg/L	Section 4.4.3.1
Fish	acute	tolerant species	NOEC	100	mg/L	Section 4.4.3.1
Fish	chronic	sensitive species	LC50	2.7	mg/L	Section 4.4.3.1
Fish	chronic	tolerant species	NOEC	120	mg/L	Section 4.4.3.1
Aquatic invertebrate	acute	N/A	NOEC	100	mg/L	Section 4.4.3.3
Aquatic invertebrate	chronic	N/A	NOEC	97.1	mg/L	Section 4.4.3.3
Algae	acute	sensitive species	EC50	0.2	mg/L	Section 4.4.3.4
Algae	acute	tolerant species	NOEC	100	mg/L	Section 4.4.3.4
Algae	chronic	sensitive species	EC50	0.2	mg/L	Section 4.4.3.4
Algae	chronic	tolerant species	NOEC	100	mg/L	Section 4.4.3.4
Macrophyte, aquatic	acute	N/A	EC25	0.013	mg/L	Section 4.4.3.4
Macrophyte, aquatic	chronic	N/A	EC25	0.013	mg/L	Section 4.4.3.4
Terrestrial plant	Seedling Emergence	sensitive species	EC25	0.002	lb/acre	Section 4.4.2.4
Terrestrial plant	Seedling Emergence	tolerant species	NOEC	1	lb/acre	Section 4.4.2.4
Terrestrial plant	Vegetative vigor	sensitive species	NOEC	0.00049	lb/acre	Section 4.4.2.4
Terrestrial plant	Vegetative vigor	tolerant species	NOEC	0.018	lb/acre	Section 4.4.2.4

TABLE B-6

SUMMARY OF CHEMICAL SPECIFIC DERMAL ABSORPTION VALUES

Imazapyr Risk Assessment

Washington State

Parameter/Assumption	Code / Range	Equation/ Value	Units	DermSum
Zero-Order absorption rate	**Kp**			
	Central	0.000056	cm/hour	Section 3.3.2.2
	Lower	0.000028		Section 3.3.2.2
	Upper	0.00011		Section 3.3.2.2
First-Order absorption rate	**ka**			
	Central	0.0011	$hour^{-1}$	Section 3.3.2.2
	Lower	0.00044		Section 3.3.2.2
	Upper	0.0029		Section 3.3.2.2

TABLE B-7

ESTIMATES OF WATER CONTAMINATION RATES--I.E., THE CONCENTRATION IN AMBIENT WATER PER POUND APPLIED PER ACRE

Imazapyr Risk Assessment
Washington State

Parameter/ Assumption	Code/ Range	Equation/ Value	Units	WaterSum
Short-term peak concentrations	**Peak**			
	Central	0.002	mg/L	Section 3.3.3.4
	Lower	0.0001		Section 3.3.3.4
	Upper	0.08		Section 3.3.3.4
Longer-term average concentrations	**Average**			
	Central	0.0001	mg/L	Section 3.3.3.4
	Lower	0.00001		Section 3.3.3.4
	Upper	0.001		Section 3.3.3.4

TABLE B-8

CALCULATION OF ZERO-ORDER DERMAL PERMEABILITY RATE (KP) IN CM/HOUR

Imazapyr Risk Assessment
Washington State

Short Title	Calculation of Kp			ChemDrmKp
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Molecular weight	**MW**	261.3	g/mole	Table 1
Ko/w	**Kow**	1.3	unitless	Table 1
Vector a[]	**a[1]**	1		
	a[2]	261.3		
	a[3]	0.113943352		
Transpose of a[] (***a'***)	1	261.3	0.113943352	
X'X Cross Product Matrix	**X'X**			
	0.055931	-9.41546E-05	-0.0103443	
	-9.4155E-05	5.978E-07	-2.22508E-05	
	-0.0103443	-2.22508E-05	0.00740677	
a'X'X a	**a'X'X a**	0.04395608		
Coefficients for model				
Intercept	K_0	-2.72576		
Coeff for Log_{10}(Kow)	K_1	0.706648		
Coeff for MW	K_2	-0.006151		
Standard deviation of model	**s**	0.727129		
Critical value at 0.025 with 87 d.f.	$t_{0.025}$	1.96		
Log_{10} of Estimated dermal permeability rate (Kp)	**Log(Kp) =**	***× K2 Log10(Kow) + K0***		
	Central	-4.252498458		Eq
	Lower 95% CI	-4.551295995		Eq
	Upper 95% CI	-3.953700921		Eq
Estimated dermal permeability rate (Kp)	***Kp =***	$10^{Log(Kp)}$		
	Central	5.59116E-05	cm/hour	Eq
	Lower 95% CI	2.80999E-05		Eq
	Upper 95% CI	0.00011125		Eq

TABLE B-9

CALCULATION OF FIRST-ORDER DERMAL ABSORPTION RATE

Imazapyr Risk Assessment

Washington State

Short Title	**Calculation of ka**			**ChemDrmKa**
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Molecular weight	**MW**	261.3	g/mole	Table 1
Ko/w	**Kow**	1.3	unitless	Table 1
Vector a[]	**a[1]**	1		
	a[2]	261.3		
	a[3]	0.113943352		
Transpose of a[] (***a'***)	1	261.3	0.113943352	
X'X Cross Product Matrix	**X'X**			
	0.307537	-0.00103089	0.00822769	
	-0.00103089	0.000004377	-9.44359E-05	
	0.00822769	-9.44359E-05	0.0085286	
a'X'X a	**a'X'X a**	0.064007689		
Coefficients for model				
Intercept	$\mathbf{K_0}$	-1.49615		
Coeff for Log_{10}(Kow)	$\mathbf{K_1}$	0.233255		
Coeff for MW	$\mathbf{K_2}$	-0.005657		
Standard deviation of model	**s**	0.787218		
Critical value at 0.025 with 26 d.f.	$\mathbf{t_{0.025}}$	2.056		
Log_{10} of Estimated first-order absorption rate	**Log(ka) =**	***× K2 Log10(Kow) + K0***		
	Central	-2.947746243		Eq
	Lower 95% CI	-3.357227661		Eq
	Upper 95% CI	-2.538264826		Eq
Estimated first-order absorption rate	***ka =***	$\boldsymbol{10^{Log(ka)}}$		
	Central	0.001127856	hour-1	Eq
	Lower 95% CI	0.000439311		Eq
	Upper 95% CI	0.002895577		Eq

TABLE B-10

WORKER EXPOSURE ESTIMATES FOR BACKPACK WORKER
BASED ON THE AMOUNT OF MATERIAL HANDLED PER DAY
Imazapyr Risk Assessment
Washington State

Short Title	**General Exposure**			**WkGenExp**
Receptor	**Backpack Worker**			
Duration	**Chronic**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Equation**
Application rates	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Hours of application per day	**Hrs**			
	Central	7	hours	USDA, 1989a
	Lower	6		USDA, 1989a
	Upper	8		USDA, 1989a
Acres treated per hour	**APH**			
	Central	0.625	acres/hour	USDA, 1989a
	Lower	0.25		USDA, 1989a
	Upper	1		USDA, 1989a
Acres treated per day:	**ATD**	**Hrs × APH**		
	Central	4.375	acres/day	Eq
	Lower	1.5		Eq
	Upper	8		Eq
Amount handled per day:	**Amnt**	**ApR × ATD**		
	Central	1.1375	lb/day	Eq
	Lower	0.39		Eq
	Upper	2.08		Eq
Absorbed dose rate:	**ADR**			
	Central	0.003	(mg agent/kg bw) ÷ (lbs agent handled per day)	SERA, 2001
	Lower	0.0003		SERA, 2001
	Upper	0.01		SERA, 2001
Absorbed dose	**Dose**	**Amnt × ADR**		
	Central	3.41E-03	mg/kg bw/day	Eq
	Lower	1.17E-04		Eq
	Upper	2.08E-02		Eq

TABLE B-11

WORKER EXPOSURE ESTIMATES FOR GROUND SPRAY WORKER BASED ON THE AMOUNT OF MATERIAL HANDLED PER DAY

Imazapyr Risk Assessment
Washington State

Short Title	**General Exposure**			**WkGenExp**
Receptor	**Ground Spray Worker**			
Duration	**Chronic**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Equation**
Application rates	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Hours of application per day	**Hrs**			
	Central	7	hours	USDA, 1989a
	Lower	6		USDA, 1989a
	Upper	8		USDA, 1989a
Acres treated per hour	**APH**			
	Central	16	acres/hour	USDA, 1989a
	Lower	11		USDA, 1989a
	Upper	21		USDA, 1989a
Acres treated per day:	**ATD**	**Hrs × APH**		
	Central	112	acres/day	Eq
	Lower	66		Eq
	Upper	168		Eq
Amount handled per day:	**Amnt**	**ApR × ATD**		
	Central	29.12	lb/day	Eq
	Lower	17.16		Eq
	Upper	43.68		Eq
Absorbed dose rate:	**ADR**			
	Central	0.0002	(mg agent/kg bw) ÷ (lbs agent handled per day)	SERA, 2001
	Lower	0.00001		SERA, 2001
	Upper	0.0009		SERA, 2001
Absorbed dose	**Dose**	**Amnt × ADR**		
	Central	5.82E-03	mg/kg bw/day	Eq
	Lower	1.72E-04		Eq
	Upper	3.93E-02		Eq

TABLE B-12

WORKER EXPOSURE ESTIMATES FOR AERIAL SPRAY WORKER BASED ON THE AMOUNT OF MATERIAL HANDLED PER DAY

Imazapyr Risk Assessment
Washington State

Short Title	**General Exposure**			**WkGenExp**
Receptor	**Aerial Spray Worker**			
Duration	**Chronic**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Equation**
Application rates	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Hours of application per day	**Hrs**			
	Central	7	hours	USDA, 1989a
	Lower	6		USDA, 1989a
	Upper	8		USDA, 1989a
Acres treated per hour	**APH**			
	Central	70	acres/hour	USDA, 1989a
	Lower	40		USDA, 1989a
	Upper	100		USDA, 1989a
Acres treated per day:	**ATD**	**Hrs × APH**		
	Central	490	acres/day	Eq
	Lower	240		Eq
	Upper	800		Eq
Amount handled per day:	**Amnt**	**ApR × ATD**		
	Central	127.4	lb/day	Eq
	Lower	62.4		Eq
	Upper	208		Eq
Absorbed dose rate:	**ADR**			
	Central	0.00003	(mg agent/kg bw) ÷ (lbs agent handled per day)	SERA, 2001
	Lower	0.000001		SERA, 2001
	Upper	0.0001		SERA, 2001
Absorbed dose	**Dose**	**Amnt × ADR**		
	Central	3.82E-03	mg/kg bw/day	Eq
	Lower	6.24E-05		Eq
	Upper	2.08E-02		Eq

TABLE B-13

ACCIDENTAL DERMAL EXPOSURE ASSESSMENT USING ZERO-ORDER ABSORPTION, WORKER, SURFACE AREA, HANDS, FOR 1 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Contaminated Gloves, 1 Minute**			**DrmZr**
Receptor	**Worker**			
Duration	**Acute**			
Surface Contaminated	**Surface Area, Hands**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area	**SA**	840	cm²	EPA/ORD, 1992
Duration of Exposure	T_min	1	minutes	Scenario parameter
	T_hr	0.0167	hours	Eq
Body weight	**BW**	70	kg	ICRP, 1975
Concentration in solution (mg/mL)	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
Dermal permeability	**Kp**			
	Central	0.000056	cm/hour	Section 3.3.2.2
	Lower	0.000028		Section 3.3.2.2
	Upper	0.00011		Section 3.3.2.2
Absorbed Dose	**Dose**	***Kp × Conc × T_hr × SA ÷ BW***		
	Central	3.47E-05	mg/kg	Eq
	Lower	8.96E-06	mg/kg	Eq
	Upper	1.36E-04	mg/kg	Eq

TABLE B-14

ACCIDENTAL DERMAL EXPOSURE ASSESSMENT USING ZERO-ORDER ABSORPTION, WORKER, SURFACE AREA, HANDS, FOR 60 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Contaminated Gloves, 1 Hour**			**DrmZr**
Receptor	**Worker**			
Duration	**Acute**			
Surface Contaminated	**Surface Area, Hands**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area	**SA**	840	cm^2	EPA/ORD, 1992
Duration of Exposure	T_min	60	minutes	***Scenario parameter***
	T_hr	1.0000	hours	Eq
Body weight	**BW**	70	kg	ICRP, 1975
Concentration in solution (mg/mL)	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
Dermal permeability	**Kp**			
	Central	0.000056	cm/hour	Section 3.3.2.2
	Lower	0.000028		Section 3.3.2.2
	Upper	0.00011		Section 3.3.2.2
Absorbed Dose	**Dose**	***Kp × Conc × T_hr × SA ÷ BW***		
	Central	2.08E-03	mg/kg	Eq
	Lower	5.38E-04	mg/kg	Eq
	Upper	8.18E-03	mg/kg	Eq

TABLE B-15

ACCIDENTAL DERMAL EXPOSURE ASSESSMENT USING FIRST-ORDER ABSORPTION, WORKER, SURFACE AREA, HANDS, FOR 60 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Spill on Hands, 1 hour**			**DrmFOA**
Receptor	**Worker**			
Duration	**Acute**			
Surface Contaminated	**Surface Area, Hands**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area	**SA**	840	cm^2	EPA/ORD, 1992
Duration of Exposure		60	minutes	Scenario parameter
	T	1	hours	Eq
Body weight	**BW**	70	kg	ICRP, 1975
Liquid adhering to skin	**L**	0.008	mL/cm^2	Mason and Johnson, 1987
Concentration in solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
First-order dermal absorption rates	**ka**			
	Central	0.0011	$hour^{-1}$	Section 3.3.2.2
	Lower	0.00044		Section 3.3.2.2
	Upper	0.0029		Section 3.3.2.2
Amount Deposited on Skin	**Amnt**	***L × SA × Conc***		
	Central	20.832	mg	Eq
	Lower	10.752		Eq
	Upper	41.664		Eq
Proportion absorbed over period T	**Prop**	***1-exp(-ka T)***		
	Central	0.001099395	$hour^{-1}$	Eq
	Lower	0.000439903		Eq
	Upper	0.002895799		Eq
Absorbed Dose	**Dose**	***Amnt × Prop ÷ BW***		
	Central	3.27E-04	mg/kg bw	Eq
	Lower	6.76E-05		Eq
	Upper	1.72E-03		Eq

TABLE B-16

ACCIDENTAL DERMAL EXPOSURE ASSESSMENT USING FIRST-ORDER ABSORPTION, WORKER, SURFACE AREA, LOWER LEGS, FOR 60 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Spill on Lower Legs, 1 hour**			**DrmFOA**
Receptor	**Worker**			
Duration	**Acute**			
Surface Contaminated	**Surface Area, Lower legs**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area	**SA**	2,070	cm^2	EPA/ORD, 1992
Duration of Exposure		60	minutes	***Scenario parameter***
	T	1	hours	Eq
Body weight	**BW**	70	kg	ICRP, 1975
Liquid adhering to skin	**L**	0.008	mL/cm^2	Mason and Johnson, 1987
Concentration in solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
First-order dermal absorption rates	**ka**			
	Central	0.0011	$hour^{-1}$	Section 3.3.2.2
	Lower	0.00044		Section 3.3.2.2
	Upper	0.0029		Section 3.3.2.2
Amount Deposited on Skin	**Amnt**	***L × SA × Conc***		
	Central	51.336	mg	Eq
	Lower	26.496		Eq
	Upper	102.672		Eq
Proportion absorbed over period T	**Prop**	***1-exp(-ka T)***		
	Central	0.001099395	$hour^{-1}$	Eq
	Lower	0.000439903		Eq
	Upper	0.002895799		Eq
Absorbed Dose	**Dose**	***Amnt × Prop ÷ BW***		
	Central	8.06E-04	mg/kg bw	Eq
	Lower	1.67E-04		Eq
	Upper	4.25E-03		Eq

TABLE B-17

ACCIDENTAL DERMAL EXPOSURE ASSESSMENT USING FIRST-ORDER ABSORPTION, CHILD, SURFACE AREA, WHOLE BODY, FOR 60 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Child Direct Spray, 1 Hour**			**DrmFOA**
Receptor	**Child**			
Duration	**Acute**			
Surface Contaminated	**Surface Area, Whole body**			
Parameter/Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface area	**SA**	6,030	cm^2	EPA/ORD, 1996
Duration of exposure		60	minutes	***Scenario parameter***
	T	1	hours	Eq
Body weight	**BW**	13.3	kg	EPA/ORD, 1996
Liquid adhering to skin	**L**	0.008	mL/cm^2	Mason and Johnson, 1987
Concentration in solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
First-order dermal absorption rates	**ka**			
	Central	0.0011	$hour^{-1}$	Section 3.3.2.2
	Lower	0.00044		Section 3.3.2.2
	Upper	0.0029		Section 3.3.2.2
Amount deposited on skin	**Amnt**	***L × SA × Conc***		
	Central	149.544	mg	Eq
	Lower	77.184		Eq
	Upper	299.088		Eq
Proportion absorbed over period T	**Prop**	***1-exp(-ka T)***		
	Central	0.001099395	$hour^{-1}$	Eq
	Lower	0.000439903		Eq
	Upper	0.002895799		Eq
Absorbed dose	**Dose**	***Amnt × Prop ÷ BW***		
	Central	1.24E-02	mg/kg bw	Eq
	Lower	2.55E-03		Eq
	Upper	6.51E-02		Eq

TABLE B-18

ACCIDENTAL DERMAL EXPOSURE ASSESSMENT USING FIRST-ORDER ABSORPTION, ADULT FEMALE, SURFACE AREA, FEET AND LOWER LEGS, FOR 60 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Adult Female, Lower Legs, 1 Hour**			**DrmFOA**
Receptor	**Adult Female**			
Duration	**Acute**			
Surface Contaminated	**Surface Area, Feet and Lower Legs**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface area	**SA**	2915	cm^2	EPA/ORD, 1992
Duration of exposure		60	minutes	***Scenario parameter***
	T	1	hours	Eq
Body weight	**BW**	64	kg	EPA/ORD, 1985
Liquid adhering to skin	**L**	0.008	mL/cm^2	Mason and Johnson, 1987
Concentration in solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
First-order dermal absorption rates	**ka**			
	Central	0.0011	$hour^{-1}$	Section 3.3.2.2
	Lower	0.00044		Section 3.3.2.2
	Upper	0.0029		Section 3.3.2.2
Amount Deposited on Skin	**Amnt**	***L × SA × Conc***		
	Central	72.292	mg	Eq
	Lower	37.312		Eq
	Upper	144.584		Eq
Proportion absorbed over period T	**Prop**	***1-exp(-ka T)***		
	Central	0.001099395	$hour^{-1}$	Eq
	Lower	0.000439903		Eq
	Upper	0.002895799		Eq
Absorbed Dose	**Dose**	***Amnt × Prop ÷ BW***		
	Central	1.24E-03	mg/kg bw	Eq
	Lower	2.56E-04		Eq
	Upper	6.54E-03		Eq

TABLE B-19

DERMAL CONTACT WITH CONTAMINATED VEGETATION, ADULT FEMALE, SURFACE AREA, WEARING SHORTS AND T-SHIRT, FOR 1 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Vegetation Contact, Shorts and T-shirt**			**DrmVegC**
Receptor	**Adult Female**			
Surface Contaminated	**Surface Area, Wearing Shorts and T-shirt**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area	**SA**	5300	cm^2	EPA/ORD, 1992
Contact Time	**Tc**	1	hours	***Scenario parameter***
Exposure Time	**Te**	24	hours	***Scenario parameter***
Body weight (W)	**BW**	64	kg	EPA/ORD, 1985
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Conversion Factor	**CnvF**	11.21	µg/cm^2/lb/acre	
Metric Application Rate (µg/cm^2)	**ApR_m**	***ApR × CnvF***		
	Central	2.9146	µg/cm^2/lb/acre	Eq
	Lower	2.9146		Eq
	Upper	2.9146		Eq
Proportion Dislodgeable	**PropDr**	0.1	proportion	Harris and Solomon, 1992
Dislodgeable Residue	**Dr**	***ApR_m × PropDr***		
	Central	0.29146	µg/cm^2/lb/acre	Eq
	Lower	0.29146		Eq
	Upper	0.29146		Eq
Transfer Rate	**Tr**	$10^{(1.09 \times Log10(Dr)+0.05)} / 1{,}000\ \mu g/mg$		
	Central	2.93E-04	mg/(cm^2 hr)	Eq
	Lower	2.93E-04		Eq
	Upper	2.93E-04		Eq
Amount Transferred to Skin Surface	**Amnt**	***SA × Tr × Tc***		
	Central	1.5512	mg	Eq
	Lower	1.5512		Eq
	Upper	1.5512		Eq
First-order dermal absorption rates	**ka**			
	Central	0.0011	$hour^{-1}$	Section 3.3.2.2
	Lower	0.00044		Section 3.3.2.2
	Upper	0.0029		Section 3.3.2.2
Proportion absorbed over period T	**Prop**	**1-exp(-ka Te)**		
	Central	0.0261	$hour^{-1}$	Eq
	Lower	0.0105		Eq
	Upper	0.0672		Eq

TABLE B-19

DERMAL CONTACT WITH CONTAMINATED VEGETATION, ADULT FEMALE, SURFACE AREA, WEARING SHORTS AND T-SHIRT, FOR 1 MINUTE(S)

Imazapyr Risk Assessment
Washington State

Short Title	**Vegetation Contact, Shorts and T-shirt**			**DrmVegC**
Receptor	**Adult Female**			
Surface Contaminated	**Surface Area, Wearing Shorts and T-shirt**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Absorbed Dose	**Amnt**	**Amnt × Prop ÷ BW**		
	Central	6.31E-04	mg/kg bw	Eq
	Lower	2.55E-04		Eq
	Upper	1.63E-03		Eq

Notes

1. The method of Durkin et al. (1995, p. 68, equation 4) is used to calculate the transfer rate (Tr) in units of µg/(cm² hr) based on the dislodgeable residue (Dr) in units of µg/cm². This is converted to units of mg/(cm² hr) by dividing by 1,000 µg/mg.

TABLE B-20

CONSUMPTION OF CONTAMINATED FRUIT BY A ADULT FEMALE
(ACUTE EXPOSURE AFTER A SINGLE APPLICATION)

Imazapyr Risk Assessment
Washington State

Short Title	**Contaminated Fruit**			**FdPropBW_Ac**
Receptor	**Adult Female**			
Duration	**Acute**			
Material Consumed	**Fruit**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Amount consumed per day per unit body weight	**Amnt**			
	Central	0.00168	kg food/kg BW per day	EPA/ORD, 1996
	Lower	0.00168		EPA/ORD, 1996
	Upper	0.01244		EPA/ORD, 1996
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	7	mg/kg food per lb/acre	Fletcher et al., 1994
	Lower	7		Fletcher et al., 1994
	Upper	15		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Proportion remaining after washing	**PropR**	1	proportion	***Scenario parameter***
Concentration on vegetation	**Conc**	***ApR × rr × Drift × PropR***		
	Central	1.82	mg/kg food item	Eq
	Lower	1.82		Eq
	Upper	3.9		Eq
Dose	**Dose**	***Conc × Amnt***		
	Central	3.06E-03	mg/kg bw	Eq
	Lower	3.06E-03		Eq
	Upper	4.85E-02		Eq

TABLE B-21

CONSUMPTION OF CONTAMINATED VEGETATION BY A ADULT FEMALE, ACUTE EXPOSURE AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Vegetation**			**FdPropBW_Ac**
Receptor	**Adult Female**			
Duration	**Acute**			
Material Consumed	**Vegetation**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Amount consumed per day per unit body weight	**Amnt**			
	Central	0.0036	kg food/kg BW per day	EPA/ORD, 1996
	Lower	0.00075		EPA/ORD, 1996
	Upper	0.01		EPA/ORD, 1996
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	45	mg/kg food per lb/acre	Fletcher et al., 1994
	Lower	45		Fletcher et al., 1994
	Upper	135		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Proportion remaining after washing	**PropR**	1	proportion	***Scenario parameter***
Concentration on vegetation	**Conc**	***ApR × rr × Drift × PropR***		
	Central	11.7	mg/kg food item	Eq
	Lower	11.7		Eq
	Upper	35.1		Eq
Dose	**Dose**	***Conc × Amnt***		
	Central	4.21E-02	mg/kg bw	Eq
	Lower	8.78E-03		Eq
	Upper	3.51E-01		Eq

TABLE B-22

CONSUMPTION OF CONTAMINATED FRUIT, ADULT FEMALE,
CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**Fruit Chronic**			**FdPropBW_Ch**
Receptor	**Adult Female**			
Duration	**Chronic**			
Material Consumed	**Fruit**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Amount consumed per day per unit body weigh	**Amnt**			
	Central	0.00168	kg food/kg BW per day	EPA/ORD, 1996
	Lower	0.00168		EPA/ORD, 1996
	Upper	0.01244		EPA/ORD, 1996
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	7	mg/kg food per lb/acre	Fletcher et al., 1994
	Lower	7		Fletcher et al., 1994
	Upper	15		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Initial Concentration on Vegetation	C_0	$A \times Drift \times rr$		
	Central	1.82	mg/kg veg.	Eq
	Lower	1.82		Eq
	Upper	3.9		Eq
Halftime on food	t_{50}			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6
Decay Coefficient	**k**	$Ln(2)/t_{50}$		Note1
	Central	0.0267	$Days^{-1}$	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on food at time, t_1.	$Conc_T$	$C_0 \times e^{-kT}$		
	Central	0.1652	mg/kg veg.	Eq
	Lower	0.0284		Eq
	Upper	0.7225		Eq
Time-weighted average concentration on food over time, T.	$Conc_{TWA}$	$C_0 \times (1-e^{-kT}) \div (k\ T)$		
	Central	0.6897	mg/kg veg.	Eq
	Lower	0.4308		Eq
	Upper	1.8846		Eq

TABLE B-22

CONSUMPTION OF CONTAMINATED FRUIT, ADULT FEMALE,
CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**Fruit Chronic**			**FdPropBW_Ch**
Receptor	**Adult Female**			
Duration	**Chronic**			
Material Consumed	**Fruit**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Proportion remaining after washing	**Prop**	1	proportion	***Scenario parameter***
Time-weighted average concentration on consumed vegetation over time, ***T***.	**C_{TWA_Con}**	***$Conc_{TWA}$ × Prop***		
	Central	0.6897		Eq
	Lower	0.4308		Eq
	Upper	1.8846		Eq
Dose	**Dose**	***C_{TWA_Con} × Amnt***		
	Central	1.16E-03	mg/kg bw	Eq
	Lower	7.24E-04		Eq
	Upper	2.34E-02		Eq

TABLE B-23

CONSUMPTION OF CONTAMINATED VEGETATION, ADULT FEMALE, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Vegetation**			**FdPropBW_Ch**
Receptor	**Adult Female**			
Duration	**Chronic**			
Material Consumed	**Vegetation**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Amount consumed per day per unit body weigh	**Amnt**			
	Central	0.0036	kg food/kg BW per day	EPA/ORD, 1996
	Lower	0.00075		EPA/ORD, 1996
	Upper	0.01		EPA/ORD, 1996
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	45	mg/kg food per lb/acre	Fletcher et al., 1994
	Lower	45		Fletcher et al., 1994
	Upper	135		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Initial Concentration on Vegetation	**C_0**	***A × Drift × rr***		
	Central	11.7	mg/kg veg.	Eq
	Lower	11.7		Eq
	Upper	35.1		Eq
Halftime on food	**t_{50}**			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6
Decay Coefficient	**k**	***$Ln(2)/t_{50}$***		
	Central	0.0267	$Days^{-1}$	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on food at time, ***t_1***.	**$Conc_T$**	***$C_0 \times e^{-kT}$***		
	Central	1.0621	mg/kg veg.	Eq
	Lower	0.1828		Eq
	Upper	6.5024		Eq
Time-weighted average concentration on food over time, ***T***.	**$Conc_{TWA}$**	***$C_0 \times (1-e^{-kT}) \div (k\ T)$***		
	Central	4.4337	mg/kg veg.	Eq
	Lower	2.7693		Eq
	Upper	16.9615		Eq

TABLE B-23

CONSUMPTION OF CONTAMINATED VEGETATION, ADULT FEMALE, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Vegetation**			**FdPropBW_Ch**
Receptor	**Adult Female**			
Duration	**Chronic**			
Material Consumed	**Vegetation**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Proportion remaining after washing	**Prop**	1	proportion	***Scenario parameter***
Time-weighted average concentration on consumed vegetation over time, ***T***.	C_{TWA_Con}	***Conc*** $_{TWA}$ ***× Prop***		
	Central	4.4337		Eq
	Lower	2.7693		Eq
	Upper	16.9615		Eq
Dose	**Dose**	C_{TWA_Con} ***× Amnt***		
	Central	1.60E-02	mg/kg bw	Eq
	Lower	2.08E-03		Eq
	Upper	1.70E-01		Eq

TABLE B-24

ACUTE EXPOSURE OF CHILD AFTER AN ACCIDENTAL SPILL OF THE PESTICIDE INTO A POND

Imazapyr Risk Assessment
Washington State

Short Title	**Water Consumption, Accidental Spill**			**WatSpillAmnt**
Receptor	**Child**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area of Pond	**SA**	1000	m^2	Default
Depth of Pond	**Depth**	1	meter	Default
Volume of Pond	**VP_M**	1000	m^3	Eq
	VP_L	1000000	liters	Eq
Concentration in field solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
Volume of Spill	**VS_{Gal}**	200	gallons	Default
	VS_{Lit}	757	liters	Eq
Concentration in pond water	**$Conc_{Wat}$**	***$Conc \times 1000\ mL/L \times VS_L \div VP_L$***		
	Central	2.3467	mg/L	Eq
	Lower	1.2112		Eq
	Upper	4.6934		Eq
Amount of water consumed in one day	**Amnt**			
	Central	1	liters/day	EPA/ORD, 1996
	Lower	0.61		EPA/ORD, 1996
	Upper	1.5		EPA/ORD, 1996
Body weight	**BW**	13.3	kg	EPA/ORD, 1996
Dose	**Dose**	***$Conc_{Wat} \times Amnt \div BW$***		
	Central	1.76E-01	mg/kg	Eq
	Lower	5.56E-02	mg/kg	Eq
	Upper	5.29E-01	mg/kg	Eq

TABLE B-25

CONSUMPTION OF CONTAMINATED WATER, CHILD, ACUTE EXPOSURE

Imazapyr Risk Assessment

Washington State

Short Title	**Water Consumption, Ambient**			**WatAmbAmnt**
Receptor	**Child**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.002	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.0001		Section 3.3.3.4
	Upper	0.08		Section 3.3.3.4
Concentration in water	**$Conc_{Wat}$**	***ApR × WCR***		
	Central	0.00052	mg/L	Eq
	Lower	0.000026		Eq
	Upper	0.0208		Eq
Amount of water consumed in one day	**Amnt**			
	Central	1	L/day	EPA/ORD, 1996
	Lower	0.61		EPA/ORD, 1996
	Upper	1.5		EPA/ORD, 1996
Body weight	**BW**	13.3	kg	EPA/ORD, 1996
Dose	**Dose**	***$Conc_{Wat}$ × Amnt ÷ BW***		
	Central	3.91E-05	mg/kg	Eq
	Lower	1.19E-06	mg/kg	Eq
	Upper	2.35E-03	mg/kg	Eq

TABLE B-26

CONSUMPTION OF CONTAMINATED WATER, ADULT MALE, CHRONIC EXPOSURE

Imazapyr Risk Assessment
Washington State

Short Title	**Water Consumption, Ambient**			**WatAmbAmnt**
Receptor	**Adult Male**			
Duration	**Chronic**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.0001	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.00001		Section 3.3.3.4
	Upper	0.001		Section 3.3.3.4
Concentration in water	**$Conc_{Wat}$**	***ApR × WCR***		
	Central	0.000026	mg/L	Eq
	Lower	0.0000026		Eq
	Upper	0.00026		Eq
Amount of water consumed in one day	**Amnt**			
	Central	2	L/day	EPA/ORD, 1996
	Lower	1.4		EPA/ORD, 1996
	Upper	2.4		EPA/ORD, 1996
Body weight	**BW**	70	kg	ICRP, 1975
Dose	**Dose**	***$Conc_{Wat}$ × Amnt ÷ BW***		
	Central	7.43E-07	mg/kg	Eq
	Lower	5.20E-08	mg/kg	Eq
	Upper	8.91E-06	mg/kg	Eq

TABLE B-27

ACUTE SCENARIO FOR THE CONSUMPTION OF CONTAMINATED FISH BY ADULT MALE AFTER AN ACCIDENTAL SPILL OF THE PESTICIDE INTO A POND

Imazapyr Risk Assessment
Washington State

Short Title	**Fish Consumption, Accidental Spill**			**FishAmntSpill**
Receptor	**Adult Male**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area of Pond	**SA**	1000	m^2	Default
Depth of Pond	**Depth**	1	meter	Default
Volume of Pond	**VP_M**	1000	m^3	Eq
Body weight	**VP_L**	1000000	liters	Eq
Concentration in solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
Volume of Spill	**VS_{Gal}**	200	gallons	Default
	VS_{Lit}	757	liters	Eq
Concentration in pond water	**$Conc_{Wat}$**	***Conc × 1000 mL/L × VS_L ÷ VP_L***		
	Central	2.3467	mg/L	Eq
	Lower	1.2112		Eq
	Upper	4.6934		Eq
Bioconcentration factor	**BCF**			
	Central	0.5	L/kg	Section 3.3.3.5
	Lower	0.5		Section 3.3.3.5
	Upper	0.5		Section 3.3.3.5
Concentration in fish	**$Conc_{Fish}$**	**$Conc_{Wat}$ × BCF**		
	Central	1.17335	mg/kg	Eq
	Lower	0.6056		Eq
	Upper	2.3467		Eq
Amount of fish consumed	**Amnt**			
	Central	0.158	kg/day	Ruffle et al., 1994
	Lower	0.158		Ruffle et al., 1994
	Upper	0.158		Ruffle et al., 1994
Body weight	**BW**	70	kg	ICRP, 1975
Dose	**Dose**	***$Conc_{Fish}$ × Amnt ÷ BW***		
	Central	2.65E-03	mg/kg	Eq
	Lower	1.37E-03	mg/kg	Eq
	Upper	5.30E-03	mg/kg	Eq

TABLE B-28

ACUTE SCENARIO FOR THE CONSUMPTION OF CONTAMINATED FISH BY SUBSISTENCE POPULATIONS AFTER AN ACCIDENTAL SPILL OF THE PESTICIDE INTO A POND

Imazapyr Risk Assessment
Washington State

Short Title	**Fish Consumption, Accidental Spill**			**FishAmntSpill**
Receptor	**Subsistence Populations**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area of Pond	**SA**	1000	m^2	Default
Depth of Pond	**Depth**	1	meter	Default
Volume of Pond	**VP_M**	1000	m^3	Eq
Body weight	**VP_L**	1000000	liters	Eq
Concentration in solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
Volume of Spill	**VS_{Gal}**	200	gallons	Default
	VS_{Lit}	757	liters	Eq
Concentration in pond water	**$Conc_{Wat}$**	***Conc × 1000 mL/L × VS_L ÷ VP_L***		
	Central	2.3467	mg/L	Eq
	Lower	1.2112		Eq
	Upper	4.6934		Eq
Bioconcentration factor	**BCF**			
	Central	0.5	L/kg	Section 3.3.3.5
	Lower	0.5		Section 3.3.3.5
	Upper	0.5		Section 3.3.3.5
Concentration in fish	**$Conc_{Fish}$**	**$Conc_{Wat}$ × BCF**		
	Central	1.17335	mg/kg	Eq
	Lower	0.6056		Eq
	Upper	2.3467		Eq
Amount of fish consumed	**Amnt**			
	Central	0.77	kg/day	EPA/ORD, 1996
	Lower	0.77		EPA/ORD, 1996
	Upper	0.77		EPA/ORD, 1996
Body weight	**BW**	70	kg	ICRP, 1975
Dose	**Dose**	***$Conc_{Fish}$ × Amnt ÷ BW***		
	Central	1.29E-02	mg/kg	Eq
	Lower	6.66E-03	mg/kg	Eq
	Upper	2.58E-02	mg/kg	Eq

TABLE B-29

CONSUMPTION OF CONTAMINATED FISH, ADULT MALE, CHRONIC EXPOSURE

Imazapyr Risk Assessment
Washington State

Short Title	**Fish Consumption, Chronic**			**FishAmntAmb**
Receptor	**Adult Male**			
Duration	**Chronic**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.0001	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.00001		Section 3.3.3.4
	Upper	0.001		Section 3.3.3.4
Concentration in water	**$Conc_{Wat}$**	***ApR × WCR***		
	Central	0.000026	mg/L	Eq
	Lower	0.0000026		Eq
	Upper	0.00026		Eq
Bioconcentration factor	**BCF**			
	Central	0.5	L/kg	Section 3.3.3.5
	Lower	0.5		Section 3.3.3.5
	Upper	0.5		Section 3.3.3.5
Concentration in fish	**$Conc_{Fish}$**	**$Conc_{Wat}$ × BCF**		
	Central	0.000013	mg/kg	Eq
	Lower	0.0000013		Eq
	Upper	0.00013		Eq
Amount of fish consumed	**Amnt**			
	Central	0.01	kg/day	EPA/ORD, 1996
	Lower	0.01		EPA/ORD, 1996
	Upper	0.01		EPA/ORD, 1996
Body weight	**BW**	70	kg	ICRP, 1975
Dose	**Dose**	***$Conc_{Fish}$ × Amnt ÷ BW***		
	Central	1.86E-09	mg/kg	Eq
	Lower	1.86E-10	mg/kg	Eq
	Upper	1.86E-08	mg/kg	Eq

TABLE B-30

CONSUMPTION OF CONTAMINATED FISH, SUBSISTENCE POPULATIONS, CHRONIC EXPOSURE

Imazapyr Risk Assessment
Washington State

Short Title	**Fish consumption, chronic**			**FishAmntAmb**
Receptor	**Subsistence Populations**			
Duration	**chronic**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.0001	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.00001		Section 3.3.3.4
	Upper	0.001		Section 3.3.3.4
Concentration in water	**$Conc_{Wat}$**	***ApR × WCR***		
	Central	0.000026	mg/L	Eq
	Lower	0.0000026		Eq
	Upper	0.00026		Eq
Bioconcentration factor	**BCF**			
	Central	0.5	L/kg	Section 3.3.3.5
	Lower	0.5		Section 3.3.3.5
	Upper	0.5		Section 3.3.3.5
Concentration in fish	**$Conc_{Fish}$**	**$Conc_{Wat}$ × BCF**		
	Central	0.000013	mg/kg	Eq
	Lower	0.0000013		Eq
	Upper	0.00013		Eq
Amount of fish consumed	**Amnt**			
	Central	0.081	kg/day	EPA/ORD, 1996
	Lower	0.081		EPA/ORD, 1996
	Upper	0.081		EPA/ORD, 1996
Body weight	**BW**	70	kg	ICRP, 1975
Dose	**Dose**	***$Conc_{Fish}$ × Amnt ÷ BW***		
	Central	1.50E-08	mg/kg	Eq
	Lower	1.50E-09	mg/kg	Eq
	Upper	1.50E-07	mg/kg	Eq

TABLE B-31

CONCENTRATION IN POND WATER AFTER DIRECT SPRAY OR AFTER DRIFT FROM AERIAL APPLICATION AT DISTANCES DOWNWIND IN FEET FROM THE APPLICATION SITE

Imazapyr Risk Assessment
Washington State

Short Title	**Pond, Drift**			**PondDrift**
Receptor	**Pond**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area of Water Column	**SA**	1	m^2	
Depth of Pond	**Depth**	2	meter	Scenario parameter
Volume of Water Column	***V***	***= SA × Depth***		
	VP_M	2	m^3	Eq
	VP_L	2000	liters	Eq
Proportion of Drift at distances down wind in feet [0 feet = direct spray]	**Prop**			
0		1	unitless	Note 1
25		0.1434		
50		0.0518		
100		0.0195		
300		0.0042		
500		0.0022		
900		0.0009		
Application rate	**ApR**	0.26	lb/acre	Program parameter
Converstion Factor	**Conv**	112.1	mg/m^2 per lb/acre	
Concentration in water at distances downwind in feet	**Conc**	**Prop × ApR × Conv / VPt**		
0		0.0146	mg/L	Eq
25		0.0021		Eq
50		0.0008		Eq
100		0.0003		Eq
300		0.0001		Eq
500		0.0000		Eq
900		0.0000		Eq

Notes

1. Estimated based on AgDrift Version 1.16 defaults (Teske et al., 2001) using an Air Tractor AT-401 aircraft, water, 8-ft boom height, 4-mph wind speed. A large number of options are available in AgDrift for different weather conditions, pesticide mixtures, and aircraft.

TABLE B-32

CONCENTRATION IN STREAM WATER AFTER DIRECT SPRAY OR AFTER DRIFT FROM AERIAL APPLICATION AT DISTANCES DOWNWIND IN FEET FROM THE APPLICATION SITE

Imazapyr Risk Assessment
Washington State

Short Title	**Stream, Drift**			**StreamDrift**
Receptor	**Stream**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Flow rate of stream	**Flow**	710000	L/day	Scenario parameter
Application rate, lbs/acre	**ApR**	0.26	lb/acre	Program parameter
Converstion Factor, lb/acre to mg/m²	**Conv1**	112.1	mg/m² per lb/acre	
Deposition rate, nominal	***Dep***	***= ApR × Conv1***		
	Dep	29.146	mg/m² per lb/acre	Eq
Length of steam segment	**L**	1038	feet	Scenario parameter
Width of steam segment	**W**	6	feet	Scenario parameter
Surface Area of Stream Sprayed, square feet	**SA_ft**	6228	ft²	Eq
Converstion Factor, square feet to square meters	**Conv2**	0.0929	m²/ft²	
Surface Area of Stream Sprayed, square meters	**SA_msq**	578.5812		Eq
Amount deposited on stream surface on spray day	**Amnt**	16863.32766	mg/day	Eq
Proportion of Drift at distances down wind in feet [0 feet = direct spray]	**Prop**			
0		1	unitless	Note 1
25		0.1434		
50		0.0518		
100		0.0195		
300		0.0042		
500		0.0022		
900		0.0009		

TABLE B-32

CONCENTRATION IN STREAM WATER AFTER DIRECT SPRAY OR AFTER DRIFT FROM AERIAL APPLICATION AT DISTANCES DOWNWIND IN FEET FROM THE APPLICATION SITE

Imazapyr Risk Assessment
Washington State

Short Title	**Stream, Drift**			**StreamDrift**
Receptor	**Stream**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Concentration in water at distances downwind in feet	**Conc**	**Amnt × Prop / Flow**		
0		0.023751	mg/L	Eq
25		0.003406		Eq
50		0.001230		Eq
100		0.000463		Eq
300		0.000100		Eq
500		0.000052		Eq
900		0.000021		Eq

Notes

1. Estimated based on AgDrift Version 1.16 defaults (Teske et al., 2001) using an Air Tractor AT-401 aircraft, water, 8-ft boom height, 4-mph wind speed. A large number of options are available in AgDrift for different weather conditions, pesticide mixtures, and aircraft.

TABLE B-33

WORKSHEET E01: SUMMARY OF WORKER EXPOSURE ASSESSMENTS

Imazapyr Risk Assessment

Washington State

Scenario	Receptor	mg/kg/day or mg/kg/event			Detail Worksheet
		Central	Lower	Upper	
Accidental/Incidental Exposures (dose in mg/kg/event)					B-33 - Std
Contaminated Gloves, 1 min.	Worker	3.47E-05	8.96E-06	1.36E-04	B-13
Contaminated Gloves, 1 hour	Worker	2.08E-03	5.38E-04	8.18E-03	B-14
Spill on Hands, 1 hour	Worker	3.27E-04	6.76E-05	1.72E-03	B-15
Spill on lower legs, 1 hour	Worker	8.06E-04	1.67E-04	4.25E-03	B-16
General Exposures (mg/kg/day)					
General exposure	Backpack	3.41E-03	1.17E-04	2.08E-02	B-10
General exposure	Ground Spray	5.82E-03	1.72E-04	3.93E-02	B-11
General exposure	Areal Spray	3.82E-03	6.24E-05	2.08E-02	B-12

TABLE B-34

RISK CHARACTERIZATION FOR WORKERS AT CENTRAL APPLICATION RATE

Imazapyr Risk Assessment
Washington State

Application Rate:		**0.26**	**lbs/acre**		
Application Rate Factor:		**1**	**unitless**		
Exposure Worksheet:		**Table B-33**			**TrToxSum**
Scenario	**Receptor**	**Hazard Quotient**			**Toxicity Value**
		Central	**Lower**	**Upper**	
Accidental/Incidental Exposures (dose in mg/kg/event)					B-33 -Std
Contaminated Gloves, 1 min.	Worker	1E-05	4E-06	5E-05	2.5
Contaminated Gloves, 1 hour	Worker	8E-04	2E-04	3E-03	2.5
Spill on Hands, 1 hour	Worker	1E-04	3E-05	7E-04	2.5
Spill on lower legs, 1 hour	Worker	3E-04	7E-05	2E-03	2.5
General Exposures (mg/kg/day)					
General exposure	Backpack	1E-03	5E-05	8E-03	2.5
General exposure	Ground Spray	2E-03	7E-05	2E-02	2.5
General exposure	Areal Spray	2E-03	2E-05	8E-03	2.5

TABLE B-35

WORKSHEET EO3: SUMMARY OF EXPOSURE ASSESSMENTS FOR THE GENERAL PUBLIC

Imazapyr Risk Assessment
Washington State

Scenario	Receptor	mg/kg/day or mg/kg/event			Detail Worksheet
		Central	Lower	Upper	
Acute Exposures (dose in mg/kg/event)					B-35 -1App
Direct Spray of Child, whole body	Child	1.24E-02	2.55E-03	6.51E-02	B-17
Direct Spray of Woman, feet and lower legs	Adult Female	1.24E-03	2.56E-04	6.54E-03	B-18
Vegetation Contact, shorts and T-shirt	Adult Female	6.31E-04	2.55E-04	1.63E-03	B-19
Contaminated Fruit	Adult Female	3.06E-03	3.06E-03	4.85E-02	B-20
Contaminated Vegetation	Adult Female	4.21E-02	8.78E-03	3.51E-01	B-21
Water consumption, accidental spill	Child	1.76E-01	5.56E-02	5.29E-01	B-24
Water consumption, ambient	Child	3.91E-05	1.19E-06	2.35E-03	B-25
Fish consumption, accidental spill	Adult Male	2.65E-03	1.37E-03	5.30E-03	B-27
Fish consumption, accidental spill	Subsistence Populations	1.29E-02	6.66E-03	2.58E-02	B-28
Chronic/Longer Term Exposures (dose in mg/kg/day)					
Contaminate Fruit	Adult Female	1.16E-03	7.24E-04	2.34E-02	B-22
Contaminate Vegetation	Adult Female	1.60E-02	2.08E-03	1.70E-01	B-23
Water consumption	Adult Male	7.43E-07	5.20E-08	8.91E-06	B-26
Fish consumption	Adult Male	1.86E-09	1.86E-10	1.86E-08	B-29
Fish consumption	Subsistence Populations	1.50E-08	1.50E-09	1.50E-07	B-30

TABLE B-36

RISK CHARACTERIZATION FOR GENERAL PUBLIC
AT CENTRAL APPLICATION RATE
Imazapyr Risk Assessment
Washington State

Application Rate:		**0.26**	**lbs/acre**		
Application Rate Factor:		**1**	**unitless**		
Exposure Worksheet:		**Table B-35**			**TrToxSum**
		Hazard Quotient			**Toxicity Value**
Scenario	**Receptor**	**Central**	**Lower**	**Upper**	
Acute Exposures (dose in mg/kg/event)					B-36 - 1App
Direct Spray of Child, whole body	Child	5E-03	1E-03	3E-02	2.5
Direct Spray of Woman, feet and lower legs	Adult Female	5E-04	1E-04	3E-03	2.5
Vegetation Contact, shorts and T-shirt	Adult Female	3E-04	1E-04	7E-04	2.5
Contaminated Fruit	Adult Female	1E-03	1E-03	2E-02	2.5
Contaminated Vegetation	Adult Female	2E-02	4E-03	0.1	2.5
Water consumption, accidental spill	Child	7E-02	2E-02	0.2	2.5
Water consumption, ambient	Child	2E-05	5E-07	9E-04	2.5
Fish consumption, accidental spill	Adult Male	1E-03	5E-04	2E-03	2.5
Fish consumption, accidental spill	Subsistence Populations	5E-03	3E-03	1E-02	2.5
Chronic/Longer Term Exposures (dose in mg/kg/day)					
Contaminate Fruit	Adult Female	5E-04	3E-04	9E-03	2.5
Contaminate Vegetation	Adult Female	6E-03	8E-04	7E-02	2.5
Water consumption	Adult Male	3E-07	2E-08	4E-06	2.5
Fish consumption	Adult Male	7E-10	7E-11	7E-09	2.5
Fish consumption	Subsistence Populations	6E-09	6E-10	6E-08	2.5

TABLE B-37

DIRECT SPRAY OF SMALL MAMMAL ASSUMING FIRST-ORDER ABSORPTION KINETICS WITH SPRAY OF 0.5 OF THE BODY SURFACE

Imazapyr Risk Assessment
Washington State

Short Title	**Direct Spray, first-order absorption**			**DrmFOA_Allo**
Receptor	**Small Mammal**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of Exposure	**T**	24	hours	***Scenario parameter***
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for surface area				
	alpha	0.11		EPA/ORD, 1993
	beta	0.65		EPA/ORD, 1993
Surface Area		0.0087	meters	
	SA	86.5092	cm^2	10,000 cm^2/m^2
Application rate, lb/acre	**$ApR_{lb/ac}$**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Conversion Factor for lbs/acre to mg/cm^2	**CnvF**	0.01121	mg/cm^2/lb/acre	
Application rate, mg/cm^2	**ApR_{mgcm}**	**$ApR_{lb/a}$ × CnvF**		
	Central	0.0029	lb/acre	Eq
	Lower	0.0029		Eq
	Upper	0.0029		Eq
First-order dermal absorption rates	**ka**			
	Central	0.0011	hour-1	Section 3.3.2.2
	Lower	0.00044		Section 3.3.2.2
	Upper	0.0029		Section 3.3.2.2
Proportion of body surface sprayed	**Prp_{SA}**	0.5	unitless	***Scenario parameter***
Amount Deposited on Skin	**Amnt**	***ApR_{mgcm} × SA × Prp_{SA}***		
	Central	0.1261	mg	Eq
	Lower	0.1261		Eq
	Upper	0.1261		Eq
Proportion absorbed over period T	**Prop**	***1-exp(-ka T)***		
	Central	0.0261	$hour^{-1}$	Eq
	Lower	0.0105		Eq
	Upper	0.0672		Eq
Absorbed Dose	**Dose**	***Amnt × Prop ÷ BW***		
	Central	1.64E-01	mg/kg bw	Eq
	Lower	6.62E-02		Eq
	Upper	4.24E-01		Eq

TABLE B-38

DIRECT SPRAY OF SMALL MAMMAL ASSUMING 100% ABSORPTION WITH SPRAY OF 0.5 OF THE BODY SURFACE

Imazapyr Risk Assessment
Washington State

Short Title	**Direct Spray, 100% absorption**			**Drm100_Allo**
Receptor	**Small Mammal**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of Exposure	**T**	24	hours	***Scenario parameter***
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for surface area				
	alpha	0.11		EPA/ORD, 1993
	beta	0.65		EPA/ORD, 1993
Surface Area		0.0087	meters	
	SA	86.5092	cm^2[10,000 cm^2/m^2]	Eq
Application rate, lb/acre	**$ApR_{lb/ac}$**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Conversion Factor for lbs/acre to mg/cm^2	**CnvF**	0.01121	mg/cm^2/lb/acre	
Application rate, mg/cm^2	**ApR_{mgcm}**	**$ApR_{lb/a}$ × CnvF**		
	Central	0.0029	lb/acre	Eq
	Lower	0.0029		Eq
	Upper	0.0029		Eq
Proportion of body surface sprayed	**Prp_{SA}**	0.5	unitless	***Scenario parameter***
Amount Deposited on Skin	**Amnt**	***ApR_{mgcm} × SA × Prp_{SA}***		
	Central	0.1261	mg	Eq
	Lower	0.1261		Eq
	Upper	0.1261		Eq
Absorbed Dose	**Dose**	***Amnt ÷ BW***		
	Central	6.30E+00	mg/kg bw	Eq
	Lower	6.30E+00		Eq
	Upper	6.30E+00		Eq

TABLE B-39

DIRECT SPRAY OF HONEY BEE ASSUMING 100% ABSORPTION WITH SPRAY OF 0.5 OF THE BODY SURFACE

Imazapyr Risk Assessment
Washington State

Short Title	**Direct Spray, 100% absorption**			**Drm100_Allo**
Receptor	**Honey Bee**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of Exposure	**T**	24	hours	***Scenario parameter***
Body weight	**BW**	0.000093	kg	Default
Allometric coefficients for surface area				
	alpha	0.111		Boxenbaum and D'Souza, 1990
	beta	0.65		Boxenbaum and D'Souza, 1990
Surface Area		0.0003	meters	
	SA	2.6597	cm^2[10,000 cm^2/m^2]	Eq
Application rate, lb/acre	**$ApR_{lb/ac}$**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Conversion Factor for lbs/acre to mg/cm^2	**CnvF**	0.01121	mg/cm^2/lb/acre	
Application rate, mg/cm^2	**ApR_{mgcm}**	**$ApR_{lb/a}$ × CnvF**		
	Central	0.0029	lb/acre	Eq
	Lower	0.0029		Eq
	Upper	0.0029		Eq
Proportion of body surface sprayed	**Prp_{SA}**	0.5	unitless	***Scenario parameter***
Amount Deposited on Skin	**Amnt**	***ApR_{mgcm} × SA × Prp_{SA}***		
	Central	0.0039	mg	Eq
	Lower	0.0039		Eq
	Upper	0.0039		Eq
Absorbed Dose	**Dose**	***Amnt ÷ BW***		
	Central	4.17E+01	mg/kg bw	Eq
	Lower	4.17E+01		Eq
	Upper	4.17E+01		Eq

TABLE B-40

DIRECT SPRAY OF AMPHIBIAN ASSUMING 100% ABSORPTION WITH SPRAY OF 100% OF THE BODY SURFACE

Imazapyr Risk Assessment
Washington State

Short Title	**Direct Spray, 100% absorption**			**Drm100_Allo**
Receptor	**Amphibian**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of Exposure	**T**	24	hours	***Scenario parameter***
Body weight	**BW**	0.0491	kg	EPA/ORD, 1993
Surface area	**SA**	17	cm^2	EPA/ORD, 1993
Application rate, lb/acre	**$ApR_{lb/ac}$**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Conversion Factor for lbs/acre to mg/cm^2	**CnvF**	0.01121	mg/cm^2/lb/acre	
Application rate, mg/cm^2	**ApR_{mgcm}**	**$ApR_{lb/a}$ × CnvF**		
	Central	0.0029	lb/acre	Eq
	Lower	0.0029		Eq
	Upper	0.0029		Eq
Proportion of body surface sprayed	**Prp_{SA}**	1	unitless	***Scenario parameter***
Amount Deposited on Skin	**Amnt**	***ApR_{mgcm} × SA × Prp_{SA}***		
	Central	0.0495	mg	Eq
	Lower	0.0495		Eq
	Upper	0.0495		Eq
Absorbed Dose	**Dose**	***Amnt ÷ BW***		
	Central	2.91E-03	mg/kg bw	Eq
	Lower	2.91E-03		Eq
	Upper	2.91E-03		Eq

TABLE B-41

CONSUMPTION OF CONTAMINATED FRUIT, SMALL MAMMAL,
ACUTE EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**Fruit**			**FdAlloBW_Ac**
Receptor	**Small Mammal**			
Duration	**Acute**			
Material consumed	**Fruit**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for food consumption per day in grams and BW in grams				
	alpha	0.621		EPA/ORD, 1993
	beta	0.584		EPA/ORD, 1993
Amount of food consumed per day	**Amnt**	0.0036	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	7	mg/kg fruit per lb/acre	Fletcher et al., 1994
	Lower	7		Fletcher et al., 1994
	Upper	15		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Proportion of diet contaminated	**PropC**	1	proportion	***Scenario parameter***
Average concentration on consumed vegetation	**Conc**	***ApR × rr × PropC***		
	Central	1.82	mg/kg	Eq
	Lower	1.82		Eq
	Upper	3.9		Eq
Dose	**Dose**	***Amnt × Conc / BW***		
	Central	3.25E-01	mg/kg bw	Eq
	Lower	3.25E-01		Eq
	Upper	6.97E-01		Eq

TABLE B-42

CONSUMPTION OF CONTAMINATED FRUIT, SMALL MAMMAL,
CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**On Site**			**FdAlloBW_Ch**
Receptor	**Small Mammal**			
Duration	**Chronic**			
Material consumed	**Fruit**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for food consumption per day in grams and BW in grams				
	alpha	0.621		EPA/ORD, 1993
	beta	0.584		EPA/ORD, 1993
Amount of food consumed per day	***Amnt =***	***alpha BW ^{beta}***		
	Amnt	0.003571849	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	7	mg/kg fruit per lb/acre	Fletcher et al., 1994
	Lower	7		Fletcher et al., 1994
	Upper	15		Fletcher et al., 1994
Drift	**Drift**			***Note 1***
	Central	1		
	Lower	1		
	Upper	1		
Initial concentration on fruit	**C_0**	***ApR × Drift × rr***		
	Central	1.82	mg/kg fruit	Eq
	Lower	1.82		Eq
	Upper	3.9		Eq
Halftime on fruit	**t_{50}**			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6
Decay Coefficient	**k**	***$Ln(2)/t_{50}$***	See Note 2	
	Central	0.0267	Days-1	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on fruit at time, ***T***.	**$Conc_T$**	***$C_0 \times e^{-kT}$***		
	Central	0.1652	mg/kg fruit	Eq
	Lower	0.0284		Eq
	Upper	0.7225		Eq

TABLE B-42

CONSUMPTION OF CONTAMINATED FRUIT, SMALL MAMMAL,
CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**On Site**			**FdAlloBW_Ch**
Receptor	**Small Mammal**			
Duration	**Chronic**			
Material consumed	**Fruit**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Time-weighted average concentration on fruit over time, ***T***.	**$Conc_{TWA}$**	***$C_0 \times (1\text{-}e^{-kT}) \div (k\ T)$***		
	Central	0.6897	mg/kg fruit	Eq
	Lower	0.4308		Eq
	Upper	1.8846		Eq
Proportion of diet contaminated	**Prop**			***Note 2***
	Central	0.1	proportion	Scenario parameter
	Lower	0.05		Scenario parameter
	Upper	0.2		Scenario parameter
Time-weighted average concentration over time, ***T***, adjusted for the proportion contaminated.	**C_{TWA_Con}**	***$Conc_{TWA} \times Prop$***		
	Central	0.0690		Eq
	Lower	0.0215		Eq
	Upper	0.3769		Eq
Dose	**Dose**	***$C_{TWA\_Con} \times Amnt / BW$***		
	Central	1.23E-02	mg/kg bw	Eq
	Lower	3.85E-03		Eq
	Upper	6.73E-02		Eq

Notes
1. Deposition taken as nominal application rate (i.e., direct spray).
2. Based on data on the shrew (EPA/ORD, 1996, p. 2-214) vegetation may account for about 5% of the diet. This is used as the lower limit. The typical and upper values are judgmentally set to account for incidental contamination of other food items such as insects as well as different feeding preferences among other small mammals.

TABLE B-43

CONSUMPTION OF CONTAMINATED FRUIT, SMALL MAMMAL,
CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**Off Site**			**FdAlloBW_Ch**
Receptor	**Small Mammal**			
Duration	**Chronic**			
Material consumed	**Fruit**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for food consumption per day in grams and BW in grams				
	alpha	0.621		EPA/ORD, 1993
	beta	0.584		EPA/ORD, 1993
Amount of food consumed per day	***Amnt =***	***alpha BW ^{beta}***		
	Amnt	0.003571849	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	7	mg/kg fruit per lb/acre	Fletcher et al., 1994
	Lower	7		Fletcher et al., 1994
	Upper	15		Fletcher et al., 1994
Drift	**Drift**			***Note 1***
	Central	0.0101		
	Lower	0.0058		
	Upper	0.0187		
Initial concentration on fruit	**C_0**	***ApR × Drift × rr***		
	Central	0.0184	mg/kg fruit	Eq
	Lower	0.0106		Eq
	Upper	0.0729		Eq
Halftime on fruit	**t_{50}**			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6
Decay Coefficient	**k**	***$Ln(2)/t_{50}$***	See Note 2	
	Central	0.0267	$Days^{-1}$	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on fruit at time, ***T***.	**$Conc_T$**	***$C_0 \times e^{-kT}$***		
	Central	0.0017	mg/kg fruit	Eq
	Lower	0.0002		Eq
	Upper	0.0135		Eq

TABLE B-43

CONSUMPTION OF CONTAMINATED FRUIT, SMALL MAMMAL, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Off Site**			**FdAlloBW_Ch**
Receptor	**Small Mammal**			
Duration	**Chronic**			
Material consumed	**Fruit**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Time-weighted average concentration on fruit over time, ***T***.	**$Conc_{TWA}$**	***$C_0 \times (1\text{-}e^{-kT}) \div (k\ T)$***		
	Central	0.0070	mg/kg fruit	Eq
	Lower	0.0025		Eq
	Upper	0.0352		Eq
Proportion of diet contaminated	**Prop**			***Note 2***
	Central	0.1	proportion	Scenario parameter
	Lower	0.05		Scenario parameter
	Upper	0.2		Scenario parameter
Time-weighted average concentration over time, ***T***, adjusted for the proportion contaminated.	**C_{TWA_Con}**	***$Conc_{TWA} \times Prop$***		
	Central	0.0007		Eq
	Lower	0.0001		Eq
	Upper	0.0070		Eq
Dose	**Dose**	***$C_{TWA\_Con} \times Amnt / BW$***		
	Central	1.24E-04	mg/kg bw	Eq
	Lower	2.23E-05		Eq
	Upper	1.26E-03		Eq

Notes

1. Deposition taken as nominal application rate with offsite drift after low-boom application at 50 feet for the central estimate,100 feet for the lower estimate, and 25 feet for the upper estimate.
2. Based on data on the shrew (EPA/ORD, 1996, p. 2-214) vegetation may account for about 5% of the diet. This is used as the lower limit. The typical and upper values are judgmentally set to account for incidental contamination of other food items such as insects as well as different feeding preferences among other small mammals.

TABLE B-44

ACUTE EXPOSURE OF SMALL MAMMAL AFTER AN ACCIDENTAL SPILL OF THE PESTICIDE INTO A POND

Imazapyr Risk Assessment
Washington State

Short Title	**Water Consumption, Accidental Spill**			**WatSpillAllo**
Receptor	**Small Mammal**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	0.02	kg	Default
Allometric coefficients forwater consumption per day in liters and BW in				
	alpha	0.099		EPA/ORD, 1993
	beta	0.9		EPA/ORD, 1993
Amount of water consumed per day	***Amnt =***	***alpha BW ^{beta}***		
	Amnt	0.003	liters	Eq
Surface Area of Pond	**SA**	1000	m^2	Default
Depth of Pond	**Depth**	1	meter	Default
Volume of Pond	**VP_M**	1000	m^3	Eq
	VP_L	1000000	liters	Eq
Concentration in field solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
Volume of Spill	**VS_{Gal}**	200	gallons	Default
	VS_{Lit}	757	liters	Eq
Concentration in pond water	**$Conc_{Wat}$**	***Conc × 1,000 mL/L × VS_L ÷ VP_L***		
	Central	2.3467	mg/L	Eq
	Lower	1.2112		Eq
	Upper	4.6934		Eq
Absorbed Dose	**Dose**	***$Conc_{Wat}$ × Amnt ÷ BW***		
	Central	3.44E-01	mg/kg	Eq
	Lower	1.77E-01	mg/kg	Eq
	Upper	6.87E-01	mg/kg	Eq

TABLE B-45

CONSUMPTION OF CONTAMINATED WATER, SMALL MAMMAL, ACUTE EXPOSURE

Imazapyr Risk Assessment

Washington State

Short Title	**Water Consumption**			**WatAmbAllo**
Receptor	**Small Mammal**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for water consumption per day in liters and BW in				
	alpha	0.099		EPA/ORD, 1993
	beta	0.9		EPA/ORD, 1993
Amount of water consumed per day	***Amnt =***	$alpha\ BW^{beta}$		
	Amnt	0.00292794	liters	Eq
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.002	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.0001		Section 3.3.3.4
	Upper	0.08		Section 3.3.3.4
Concentration in water	$Conc_{Wat}$	***ApR × WCR***		
	Central	0.00052	mg/L	Eq
	Lower	0.000026		Eq
	Upper	0.0208		Eq
Dose	**Dose**	$Conc_{Wat} \times Amnt \div BW$		
	Central	7.61E-05	mg/kg	Eq
	Lower	3.81E-06	mg/kg	Eq
	Upper	3.05E-03	mg/kg	Eq

TABLE B-46

CONSUMPTION OF CONTAMINATED WATER,
SMALL MAMMAL, CHRONIC EXPOSURE
Imazapyr Risk Assessment
Washington State

Short Title	**Water Consumption**			**WatAmbAllo**
Receptor	**Small Mammal**			
Duration	**Chronic**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for water consumption per day in liters and BW in				
	alpha	0.099		EPA/ORD, 1993
	beta	0.9		EPA/ORD, 1993
Amount of water consumed per day	***Amnt =***	***alpha BW ^{beta}***		
	Amnt	0.00292794	liters	Eq
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.0001	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.00001		Section 3.3.3.4
	Upper	0.001		Section 3.3.3.4
Concentration in water	**$Conc_{Wat}$**	***ApR × WCR***		
	Central	0.000026	mg/L	Eq
	Lower	0.0000026		Eq
	Upper	0.00026		Eq
Dose	**Dose**	***$Conc_{Wat}$ × Amnt ÷ BW***		
	Central	3.81E-06	mg/kg	Eq
	Lower	3.81E-07	mg/kg	Eq
	Upper	3.81E-05	mg/kg	Eq

TABLE B-47

ACUTE SCENARIO FOR THE CONSUMPTION OF CONTAMINATED FISH BY FISH-EATING BIRD AFTER AN ACCIDENTAL SPILL OF THE PESTICIDE INTO A POND

Imazapyr Risk Assessment
Washington State

Short Title	**Fish Consumption, Accidental Spill**			**FishPropSpill**
Receptor	**Fish-Eating Bird**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Surface Area of Pond	**SA**	1000	m^2	Scenario parameter
Depth of Pond	**Depth**	1	meter	Scenario parameter
Volume of Pond	**VP_M**	1000	m^3	Eq
Body weight	**VP_L**	1000000	liters	Eq
Concentration in solution	**Conc**			
	Central	3.1	mg/mL	Program parameter
	Lower	1.6		Program parameter
	Upper	6.2		Program parameter
Volume of Spill	**VS_{Gal}**	200	gallons	Default
	VS_{Lit}	757	liters	Eq
Concentration in pond water	**$Conc_{Wat}$**	***Conc × 1,000 mL/L × VS_L ÷ VP_L***		
	Central	2.3467	mg/L	Eq
	Lower	1.2112		Eq
	Upper	4.6934		Eq
Bioconcentration factor	**BCF**			
	Central	0.5	L/kg	Section 3.3.3.5
	Lower	0.5		Section 3.3.3.5
	Upper	0.5		Section 3.3.3.5
Concentration in fish	**$Conc_{Fish}$**	**$Conc_{Wat}$ × BCF**		
	Central	1.17335	mg/kg	Eq
	Lower	0.6056		Eq
	Upper	2.3467		Eq
Amount of fish consumed as proportion of body weight	**Prop**			
	Central	0.1	unitless	EPA/ORD, 1993
	Lower	0.05		EPA/ORD, 1993
	Upper	0.15		EPA/ORD, 1993
Dose	**Dose**	***$Conc_{Fish}$ × Prop***		
	Central	1.17E-01	mg/kg	Eq
	Lower	3.03E-02	mg/kg	Eq
	Upper	3.52E-01	mg/kg	Eq

TABLE B-48

CONSUMPTION OF CONTAMINATED FISH,
FISH-EATING BIRD, CHRONIC EXPOSURE
Imazapyr Risk Assessment
Washington State

Short Title	**Fish Donsumption, Chronic**			**FishPropAmb**
Receptor	**Fish-Eating Bird**			
Duration	**Dhronic**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.0001	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.00001		Section 3.3.3.4
	Upper	0.001		Section 3.3.3.4
Concentration in water	**$Conc_{Wat}$**	***ApR × WCR***		
	Central	0.000026	mg/L	Eq
	Lower	0.0000026		Eq
	Upper	0.00026		Eq
Bioconcentration factor	**BCF**			
	Central	0.5	L/kg	Section 3.3.3.5
	Lower	0.5		Section 3.3.3.5
	Upper	0.5		Section 3.3.3.5
Concentration in fish	**$Conc_{Fish}$**	**$Conc_{Wat}$ × BCF**		
	Central	0.000013	mg/kg	Eq
	Lower	0.0000013		Eq
	Upper	0.00013		Eq
Amount of fish consumed as proportion of body weight	**Amnt**			
	Central	0.1	unitless	EPA/ORD, 1993
	Lower	0.05		EPA/ORD, 1993
	Upper	0.15		EPA/ORD, 1993
Dose	**Dose**	***$Conc_{Fish}$ × Prop***		
	Central	1.30E-06	mg/kg	Eq
	Lower	6.50E-08	mg/kg	Eq
	Upper	1.95E-05	mg/kg	Eq

TABLE B-49

CONSUMPTION OF CONTAMINATED VEGETATION, LARGE MAMMAL, ACUTE EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Short grass**			**FdKcal_Ac**
Receptor	**Large Mammal**			
Duration	**Acute**			
Material consumed	**Vegetation**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	70	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories				
	alpha	1.518		EPA/ORD, 1993
	beta	0.73		EPA/ORD, 1993
Caloric requirement per day	**KR**	5226.28803	kcal/day	Eq
Caloric content of vegetation (dry weight)	**KCD**	2.46	kcal/g	EPA/ORD, 1993
Water content of vegetation as a proportion	**PW**	0.85	unitless	EPA/ORD, 1993
Caloric content of vegetation (wet weight)	**KCW**	***KCD × (1-PW)***		
		0.369	kcal/g	Eq
Amount of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		14.16338219	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	85	mg/kg veg per lb/acre	Fletcher et al., 1994
	Lower	85		Fletcher et al., 1994
	Upper	240		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Proportion of diet contaminated	**PropC**	1	proportion	***Scenario parameter***
Average concentration on consumed vegetation	**Conc**	***ApR × rr × Drift × PropC***		
	Central	22.1	µg/cm²	Eq
	Lower	22.1		Eq
	Upper	62.4		Eq
Dose	**Dose**	***Amnt × Conc / BW***		
	Central	4.47E+00	mg/kg bw	Eq
	Lower	4.47E+00		Eq
	Upper	1.26E+01		Eq

TABLE B-50

CONSUMPTION OF CONTAMINATED VEGETATION, LARGE MAMMAL
CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**On site**			**FdKcal_Ch**
Receptor	**Large Mammal**			
Duration	**Chronic**			
Material consumed	**Vegetation**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Body weight	**BW**	70	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	1.518		EPA/ORD, 1993
	beta	0.73		EPA/ORD, 1993
Caloric requirement per day	**KR**	5226.28803	kcal/day	Eq
Caloric content of vegetation (dry weight)	**KCD**	2.46	kcal/g	EPA/ORD, 1993
Water content of vegetation as a proportion	**PW**	0.85	unitless	EPA/ORD, 1993
Caloric content of vegetation (wet weight)	**KCW**	***KCD × (1-PW)***		
		0.369	kcal/g	Eq
Amnt of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		14.16338219	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	85	mg/kg veg per lb/acre	Fletcher et al., 1994
	Lower	85		Fletcher et al., 1994
	Upper	240		Fletcher et al., 1994
Drift	**Drift**		See Note 1	***Note 1***
	Central	1		
	Lower	1		
	Upper	1		
Initial Concentration on Vegetation	**C_0**	***A × Drift × rr***		
	Central	22.1	mg/kg veg.	Eq
	Lower	22.1		Eq
	Upper	62.4		Eq

TABLE B-50

CONSUMPTION OF CONTAMINATED VEGETATION, LARGE MAMMAL
CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION
Imazapyr Risk Assessment
Washington State

Short Title	**On site**			**FdKcal_Ch**
Receptor	**Large Mammal**			
Duration	**Chronic**			
Material consumed	**Vegetation**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Halftime on vegetation	**t_{50}**			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6
Decay Coefficient	**k**	***Ln(2)/t 50***		
	Central	0.0267	$Days^{-1}$	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on vegetation at time, ***T***.	**$Conc_T$**	***$C_0 \times e^{-kT}$***		
	Central	2.0062	mg/kg veg.	Eq
	Lower	0.3453		Eq
	Upper	11.5598		Eq
Time-weighted average concentration on raw vegetation over time, ***T***.	**$Conc_{TWA}$**	***$C_0 \times (1-e^{-kT}) \div (k\ T)$***		
	Central	8.3747	mg/kg veg.	Eq
	Lower	5.2309		Eq
	Upper	30.1537		Eq
Proportion of diet contaminated	**Prop**			***Note 2***
	Central	0.3	proportion	Scenario parameter
	Lower	0.1		Scenario parameter
	Upper	1		Scenario parameter
Time-weighted average concentration on consumed vegetation over time, ***T***.	**C_{TWA_Con}**	***$Conc_{TWA} \times Prop$***		
	Central	2.5124		Eq
	Lower	0.5231		Eq
	Upper	30.1537		Eq
Dose	**Dose**	***$C_{TWA\_Con} \times Amnt / BW$***		
	Central	5.08E-01	mg/kg bw	Eq
	Lower	1.06E-01		Eq
	Upper	6.10E+00		Eq

Notes
1. For this on-site scenario, deposition taken as nominal application rate (i.e., direct spray).
2. Note 2: The contaminated vegetation is assumed to account for 30% of the diet with a range of 10% to 100% of the diet. These are essentially arbitrary assumptions reflecting grazing time by the animal in the treated area.

TABLE B-51

CONSUMPTION OF CONTAMINATED VEGETATION, LARGE MAMMAL, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Off Site**			**FdKcal_Ch**
Receptor	**Large Mammal**			
Duration	**Chronic**			
Material consumed	**Vegetation**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Body weight	**BW**	70	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	1.518		EPA/ORD, 1993
	beta	0.73		EPA/ORD, 1993
Caloric requirement per day	**KR**	5226.28803	kcal/day	Eq
Caloric content of vegetation (dry weight)	**KCD**	2.46	kcal/g	EPA/ORD, 1993
Water content of vegetation as a proportion	**PW**	0.85	unitless	EPA/ORD, 1993
Caloric content of vegetation (wet weight)	**KCW**	***KCD × (1-PW)***		
		0.369	kcal/g	Eq
Amnt of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		14.16338219	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	85	mg/kg veg per lb/acre	Fletcher et al., 1994
	Lower	85		Fletcher et al., 1994
	Upper	240		Fletcher et al., 1994
Drift	**Drift**		See Note 1	***Note 1***
	Central	0.0101		
	Lower	0.0058		
	Upper	0.0187		
Initial Concentration on Vegetation	C_0	***A × Drift × rr***		
	Central	0.22321	mg/kg veg.	Eq
	Lower	0.12818		Eq
	Upper	1.16688		Eq
Halftime on vegetation	t_{50}			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6

TABLE B-51

CONSUMPTION OF CONTAMINATED VEGETATION, LARGE MAMMAL, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Off Site**			**FdKcal_Ch**
Receptor	**Large Mammal**			
Duration	**Chronic**			
Material consumed	**Vegetation**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Decay Coefficient	**k**	$Ln(2)/t_{50}$		
	Central	0.0267	$Days^{-1}$	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on vegetation at time, ***T***.	**$Conc_T$**	$C_0 \times e^{-kT}$		
	Central	0.0203	mg/kg veg.	Eq
	Lower	0.0020		Eq
	Upper	0.2162		Eq
Time-weighted average concentration on raw vegetation over time, ***T***.	**$Conc_{TWA}$**	$C_0 \times (1-e^{-kT}) \div (k\ T)$		
	Central	0.0846	mg/kg veg.	Eq
	Lower	0.0303		Eq
	Upper	0.5639		Eq
Proportion of diet contaminated	**Prop**			***Note 2***
	Central	1	proportion	Scenario parameter
	Lower	1		Scenario parameter
	Upper	1		Scenario parameter
Time-weighted average concentration on consumed vegetation over time, ***T***.	**C_{TWA_Con}**	$Conc_{TWA} \times Prop$		
	Central	0.0846		Eq
	Lower	0.0303		Eq
	Upper	0.5639		Eq
Dose	**Dose**	$C_{TWA\_Con} \times Amnt / BW$		
	Central	1.71E-02	mg/kg bw	Eq
	Lower	6.14E-03		Eq
	Upper	1.14E-01		Eq

Notes

1. Drift estimates are taken from AgDRIFT for low-boom applications: central (50 feet down-wind), lower bound (100 feet down-wind), and upper bound (25 feet down-wind).
2. The assumption for off-site grazing is that 100% of the diet is contaminated.

TABLE B-52

CONSUMPTION OF CONTAMINATED SHORT GRASS, LARGE BIRD, ACUTE EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Short Grass**			**FdKcal_Ac**
Receptor	**Large Bird**			
Duration	**Acute**			
Material consumed	**Short Grass**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	4	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	3.12		EPA/ORD, 1993
	beta	0.604		EPA/ORD, 1993
Caloric requirement per day	**KR**	467.5185301	kcal/day	Eq
Caloric content of vegetation (dry weight)	**KCD**	2.46	kcal/g	EPA/ORD, 1993
Water content of vegetation as a proportion	**PW**	0.85	unitless	EPA/ORD, 1993
Caloric content of vegetation (wet weight)	**KCW**	***KCD × (1-PW)***		
		0.369	kcal/g	Eq
Amount of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		1.266987886	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	85	mg/kg veg per lb/acre	Fletcher et al., 1994
	Lower	85		Fletcher et al., 1994
	Upper	240		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Proportion of diet contaminated	**PropC**	1	proportion	***Scenario parameter***
Average concentration on consumed vegetation	**Conc**	***ApR × rr × Drift × PropC***		
	Central	22.1	µg/cm²	Eq
	Lower	22.1		Eq
	Upper	62.4		Eq
Dose	**Dose**	***Amnt × Conc / BW***		
	Central	7.00E+00	mg/kg bw	Eq
	Lower	7.00E+00		Eq
	Upper	1.98E+01		Eq

TABLE B-53

CONSUMPTION OF CONTAMINATED SHORT GRASS, LARGE BIRD, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**On Site, 1 app.**			**FdKcal_Ch**
Receptor	**Large Bird**			
Duration	**Chronic**			
Material consumed	**Short Grass**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Body weight	**BW**	4	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	3.12		EPA/ORD, 1993
	beta	0.604		EPA/ORD, 1993
Caloric requirement per day	**KR**	467.5185301	kcal/day	Eq
Caloric content of vegetation (dry weight)	**KCD**	2.46	kcal/g	EPA/ORD, 1993
Water content of vegetation as a proportion	**PW**	0.85	unitless	EPA/ORD, 1993
Caloric content of vegetation (wet weight)	**KCW**	***KCD × (1-PW)***		
		0.369	kcal/g	Eq
Amnt of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		1.266987886	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	85	mg/kg veg per lb/acre	Fletcher et al., 1994
	Lower	85		Fletcher et al., 1994
	Upper	240		Fletcher et al., 1994
Drift	**Drift**		See Note 1	***Note 1***
	Central	1		
	Lower	1		
	Upper	1		
Initial Concentration on Vegetation	**C_0**	***A × Drift × rr***		
	Central	22.1	mg/kg veg.	Eq
	Lower	22.1		Eq
	Upper	62.4		Eq

TABLE B-53

CONSUMPTION OF CONTAMINATED SHORT GRASS, LARGE BIRD, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**On Site, 1 app.**			**FdKcal_Ch**
Receptor	**Large Bird**			
Duration	**Chronic**			
Material consumed	**Short Grass**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Halftime on vegetation	**t_{50}**			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6
Decay Coefficient	**k**	***Ln(2)/t_{50}***		
	Central	0.0267	$Days^{-1}$	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on vegetation at time, ***T***.	**$Conc_T$**	***$C_0 \times e^{-kT}$***		
	Central	2.0062	mg/kg veg.	Eq
	Lower	0.3453		Eq
	Upper	11.5598		Eq
Time-weighted average concentration on raw vegetation over time, ***T***.	**$Conc_{TWA}$**	***$C_0 \times (1-e^{-kT}) \div (k\ T)$***		
	Central	8.3747	mg/kg veg.	Eq
	Lower	5.2309		Eq
	Upper	30.1537		Eq
Proportion of diet contaminated	**Prop**			***Note 2***
	Central	0.3	proportion	Scenario parameter
	Lower	0.1		Scenario parameter
	Upper	1		Scenario parameter
Time-weighted average concentration on consumed vegetation over time, ***T***.	**C_{TWA_Con}**	***$Conc_{TWA} \times Prop$***		
	Central	2.5124		Eq
	Lower	0.5231		Eq
	Upper	30.1537		Eq
Dose	**Dose**	***$C_{TWA\_Con} \times Amnt / BW$***		
	Central	7.96E-01	mg/kg bw	Eq
	Lower	1.66E-01		Eq
	Upper	9.55E+00		Eq

Notes

1. For this on-site scenario, deposition taken as nominal application rate (i.e., direct spray).
2. The contaminated vegetation is assumed to account for 30% of the diet with a range of 10% to 100% of the diet. These are essentially arbitrary assumptions reflecting grazing time by the animal in the treated area.

TABLE B-54

CONSUMPTION OF CONTAMINATED SHORT GRASS, LARGE BIRD, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Off Site**			**FdKcal_Ch**
Receptor	**Large Bird**			
Duration	**Chronic**			
Material consumed	**Short Grass**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Duration of exposure	**T**	90	days	***Scenario parameter***
Body weight	**BW**	4	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	3.12		EPA/ORD, 1993
	beta	0.604		EPA/ORD, 1993
Caloric requirement per day	**KR**	467.5185301	kcal/day	Eq
Caloric content of vegetation (dry weight)	**KCD**	2.46	kcal/g	EPA/ORD, 1993
Water content of vegetation as a proportion	**PW**	0.85	unitless	EPA/ORD, 1993
Caloric content of vegetation (wet weight)	**KCW**	***KCD × (1-PW)***		
		0.369	kcal/g	Eq
Amnt of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		1.266987886	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	85	mg/kg veg per lb/acre	Fletcher et al. 1994
	Lower	85		Fletcher et al. 1994
	Upper	240		Fletcher et al. 1994
Drift	**Drift**		See Note 1	***Note 1***
	Central	0.0101		
	Lower	0.0058		
	Upper	0.0187		
Initial Concentration on Vegetation	C_0	***A × Drift × rr***		
	Central	0.22321	mg/kg veg.	Eq
	Lower	0.12818		Eq
	Upper	1.16688		Eq
Halftime on vegetation	t_{50}			
	Central	26	Days	Section 3.3.3.6
	Lower	15		Section 3.3.3.6
	Upper	37		Section 3.3.3.6

TABLE B-54

CONSUMPTION OF CONTAMINATED SHORT GRASS, LARGE BIRD, CHRONIC EXPOSURE SCENARIO AFTER A SINGLE APPLICATION

Imazapyr Risk Assessment
Washington State

Short Title	**Off Site**			**FdKcal_Ch**
Receptor	**Large Bird**			
Duration	**Chronic**			
Material consumed	**Short Grass**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Decay Coefficient	**k**	$Ln(2)/t_{50}$		
	Central	0.0267	$Days^{-1}$	Eq
	Upper	0.0462		Eq
	Lower	0.0187		Eq
Concentration on vegetation at time, ***T***.	**$Conc_T$**	$C_0 \times e^{-kT}$		
	Central	0.0203	mg/kg veg.	Eq
	Lower	0.0020		Eq
	Upper	0.2162		Eq
Time-weighted average concentration on raw vegetation over time, ***T***.	**$Conc_{TWA}$**	$C_0 \times (1-e^{-kT}) \div (k\ T)$		
	Central	0.0846	mg/kg veg.	Eq
	Lower	0.0303		Eq
	Upper	0.5639		Eq
Proportion of diet contaminated	**Prop**			***Note 2***
	Central	1	proportion	Scenario parameter
	Lower	1		Scenario parameter
	Upper	1		Scenario parameter
Time-weighted average concentration on consumed vegetation over time, ***T***.	**C_{TWA_Con}**	$Conc_{TWA} \times Prop$		
	Central	0.0846		Eq
	Lower	0.0303		Eq
	Upper	0.5639		Eq
Dose	**Dose**	$C_{TWA\_Con} \times Amnt / BW$		
	Central	2.68E-02	mg/kg bw	Eq
	Lower	9.61E-03		Eq
	Upper	1.79E-01		Eq

Notes

1. Drift estimates are taken from AgDRIFT for low-boom applications: central (50 feet down-wind), lower bound (100 feet down-wind), and upper bound (25 feet down-wind).
2. For the off-site scenario, it is assumed that 100% of the diet is contaminated.

TABLE B-55

CONSUMPTION OF CONTAMINATED INSECTS, SMALL MAMMAL
ACUTE EXPOSURE SCENARIO
Imazapyr Risk Assessment
Washington State

Short Title	**Small Insects**			**InsCkcal_Ac**
Receptor	**Small Mammal**			
Duration	**Acute**			
Material consumed	**Small insects**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	0.02	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	1.894		EPA/ORD, 1993
	beta	0.7		EPA/ORD, 1993
Caloric requirement per day	**KR**	15.42058933	kcal/day	Eq
Caloric content of prey (wet weight)	**KCW**	1.5	kcal/g	EPA/ORD, 1993
Amount of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		0.010280393	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	45	mg/kg veg per lb/acre	Fletcher et al., 1994
	Lower	45		Fletcher et al., 1994
	Upper	135		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Proportion of diet contaminated	**PropC**	1	proportion	***Scenario parameter***
Average concentration on consumed vegetation	**Conc**	***ApR × rr × Drift × PropC***		
	Central	11.7	µg/cm²	Eq
	Lower	11.7		Eq
	Upper	35.1		Eq
Dose	**Dose**	***Amnt × Conc / BW***		
	Central	6.01E+00	mg/kg bw	Eq
	Lower	6.01E+00		Eq
	Upper	1.80E+01		Eq

TABLE B-56

CONSUMPTION OF CONTAMINATED INSECTS, SMALL BIRD
ACUTE EXPOSURE SCENARIO
Imazapyr Risk Assessment
Washington State

Short Title	**Small Insects**			**InsCkcal_Ac**
Receptor	**Small Bird**			
Duration	**Acute**			
Material consumed	**Small insects**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	0.01	kg	Default
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	3.12		EPA/ORD, 1993
	beta	0.604		EPA/ORD, 1993
Caloric requirement per day	**KR**	12.5358733	kcal/day	Eq
Caloric content of prey (wet weight)	**KCW**	1.5	kcal/g	EPA/ORD, 1993
Amount of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		0.008357249	kg	Eq
Application Rate (lbs/acre)	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Residue Rates	**rr**			
	Central	45	mg/kg veg per lb/acre	Fletcher et al., 1994
	Lower	45		Fletcher et al., 1994
	Upper	135		Fletcher et al., 1994
Drift	**Drift**	1	proportion	***Scenario parameter***
Proportion of diet contaminated	**PropC**	1	proportion	***Scenario parameter***
Average concentration on consumed vegetation	**Conc**	***ApR × rr × Drift × PropC***		
	Central	11.7	µg/cm²	Eq
	Lower	11.7		Eq
	Upper	35.1		Eq
Dose	**Dose**	***Amnt × Conc / BW***		
	Central	9.78E+00	mg/kg bw	Eq
	Lower	9.78E+00		Eq
	Upper	2.93E+01		Eq

TABLE B-57

POTENTIAL EXPOSURE OF NON-TARGET PLANTS THROUGH THE USE OF CONTAMINATED IRRIGATION WATER BASED ON ESTIMATES CONCENTRATIONS IN AMBIENT WATER

Imazapyr Risk Assessment
Washington State

Short Title	**Irrigation Water**			**WatIrrg**
Receptor	**Non-target Plants**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApR**			
	Central	0.26	lb/acre	Program parameter
	Lower	0.26		Program parameter
	Upper	0.26		Program parameter
Water contamination rate	**WCR**			
	Central	0.002	mg/L per lb/acre	Section 3.3.3.4
	Lower	0.0001		Section 3.3.3.4
	Upper	0.08		Section 3.3.3.4
Concentration in irrigation water	**$Conc_{Wat}$**	***ApR × WCR***		
	Central	0.00052	mg/L	Eq
	Lower	0.000026		Eq
	Upper	0.0208		Eq
Amount of irrigation water applied	**Inches**	see Note 1		
	Central	1	inches	**Scenario parameter**
	Lower	0.25		**Scenario parameter**
	Upper	2		**Scenario parameter**
Liters of water applied per acre per inch of irrigation water [See Note 2]	**LpApI**	10,279	liters/inch	
Liters of water applied per acre	**LPA**	***Inches × LpApI***		
	Central	10279	liters	Eq
	Lower	2569.75		Eq
	Upper	20558		Eq
Application Rate (mg/acre)	**$ApR_{mg/a}$**	***$Conc_{Wat}$ × LPA***		
	Central	5.34508	mg/acre	Eq
	Lower	0.0668135		Eq
	Upper	427.6064		Eq
Conversion factor for mg to lb	**Conv**	0.000002204		N/A

TABLE B-57

POTENTIAL EXPOSURE OF NON-TARGET PLANTS THROUGH THE USE OF CONTAMINATED IRRIGATION WATER BASED ON ESTIMATES CONCENTRATIONS IN AMBIENT WATER

Imazapyr Risk Assessment
Washington State

Short Title	**Irrigation Water**			**WatIrrg**
Receptor	**Non-target Plants**			
Duration	**Acute**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Functional application rate (lb/acre)	**ApR**	**$ApR_{mg/a}$ × Conv**		
	Central	1.18E-05	lb/acre	Eq
	Lower	1.47E-07		Eq
	Upper	9.42E-04		Eq

Notes

1. Irrigation rates are higher variable. See discussion in Section 4.3.3.4.
2. Litters of water applied per acre per inch irrigation water:
   1 m^2 = 100 cm × 100 cm = 10,000 cm^2. 1 acre = 4,047 m^2 = 4,047 m^2 ×10,000 cm^2/m^2 = 4,047,000 cm^2. 1 inch = 2.54 cm. 2.54 cm × 4,047,000 cm^2 = 10,279,380 cm^3 = 10,279,380 mL = 10,279 L.

TABLE B-58

CONSUMPTION OF SMALL MAMMAL BY CARNIVOROUS MAMMAL, ACUTE EXPOSURE SCENARIO

Imazapyr Risk Assessment
Washington State

Short Title	**Consumption of Abrev(Prey)**			**SmMKcal_Ac**
Receptor	**Carnivorous Mammal**			
Duration	**Acute**			
Material consumed	**Small Mammal**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	5	kg	EPA/ORD, 1993
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	1.894		EPA/ORD, 1993
	beta	0.7		EPA/ORD, 1993
Caloric requirement per day	**KR**	735.6292	kcal/day	Eq
Caloric content of prey (wet weight)	**KCW**	1.7	kcal/g	EPA/ORD, 1993
Amount of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		0.4327	kg	Eq
Concentration on small mammal after direct spray	**Conc**	***ApR × rr × Drift × PropC***		
	Central	6.3035	mg/kg bw	Eq
	Lower	6.3035		Eq
	Upper	6.3035		Eq
Dose	**Dose**	***Amnt × Conc / BW***		
	Central	5.46E-01	mg/kg bw	Eq
	Lower	5.46E-01		Eq
	Upper	5.46E-01		Eq

TABLE B-59

CONSUMPTION OF SMALL MAMMAL BY CARNIVOROUS BIRD,
ACUTE EXPOSURE SCENARIO
Imazapyr Risk Assessment
Washington State

Short Title	**Consumption of Abrev(Prey)**			**SmMKcal_Ac**
Receptor	**Carnivorous Bird**			
Duration	**Acute**			
Material consumed	**Small Mammal**			
Parameter/ Assumption	**Code / Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Body weight	**BW**	0.637	kg	Dunning, 1993
Allometric coefficients for caloric requirement per day in kilocalories and BW in				
	alpha	1.146		EPA/ORD, 1993
	beta	0.749		EPA/ORD, 1993
Caloric requirement per day	**KR**	144.3727	kcal/day	Eq
Caloric content of prey (wet weight)	**KCW**	1.7	kcal/g	EPA/ORD, 1993
Amount of food consumed per day, wet weight	**Amnt**	***(KR ÷ KCW)*** */1,000 g/kg*		
		0.0849	kg	Eq
Concentration on small mammal after direct spray	**Conc**	***ApR × rr × Drift × PropC***		
	Central	6.3035	mg/kg bw	Eq
	Lower	6.3035		Eq
	Upper	6.3035		Eq
Dose	**Dose**	***Amnt × Conc / BW***		
	Central	8.40E-01	mg/kg bw	Eq
	Lower	8.40E-01		Eq
	Upper	8.40E-01		Eq

TABLE B-60

WORKSHEET G01: SUMMARY OF EXPOSURE ASSESSMENTS FOR THE TERRESTRIAL ANIMALS

Imazapyr Risk Assessment
Washington State

Scenario	Receptor	mg/kg/day or mg/kg/event			Detail Worksheet
		Central	Lower	Upper	
Acute/Accidental Exposures (mg/kg/event)					B-60 -1App
Direct Spray					
first-order absorption	Small Mammal	1.64E-01	6.62E-02	4.24E-01	B-37
100% absorption	Small Mammal	6.30E+00	6.30E+00	6.30E+00	B-38
100% absorption	Honey Bee	4.17E+01	4.17E+01	4.17E+01	B-39
100% absorption	Adult Frog	2.91E-03	2.91E-03	2.91E-03	B-40
Contaminated Vegetation					
Fruit	Small Mammal	3.25E-01	3.25E-01	6.97E-01	B-41
Grass	Large Mammal	4.47E+00	4.47E+00	1.26E+01	B-49
Grass	Large Bird	7.00E+00	7.00E+00	1.98E+01	B-52
Contaminated Water					
Accidental spill	Small Mammal	3.44E-01	1.77E-01	6.87E-01	B-44
Expected Peak Conc.		7.61E-05	3.81E-06	3.05E-03	B-45
Contaminated Insects					
	Small Mammal	6.01E+00	6.01E+00	1.80E+01	B-55
	Small Bird	9.78E+00	9.78E+00	2.93E+01	B-56
Consumption of contaminated Fish					
Accidental spill	Fish-Eating Bird	1.17E-01	3.03E-02	3.52E-01	B-47
Consumption of contaminated small mammal					
	Carnivorous Mammal	5.46E-01	5.46E-01	5.46E-01	B-58
	Carnivorous bird	8.40E-01	8.40E-01	8.40E-01	B-59
Chronic/Longer Term Exposures (dose in mg/kg/day)					
Contaminated Vegetation					
On-site	Small Mammal	1.23E-02	3.85E-03	6.73E-02	B-42
Off-Site		1.24E-04	2.23E-05	1.26E-03	B-43
On-Site	Large Mammal	5.08E-01	1.06E-01	6.10E+00	B-50
Off-Site		1.71E-02	6.14E-03	1.14E-01	B-51
On-Site	Large Bird	7.96E-01	1.66E-01	9.55E+00	B-53
Off-Site		2.68E-02	9.61E-03	1.79E-01	B-54
Contaminated Water					
Water consumption	Small Mammal	3.81E-06	3.81E-07	3.81E-05	B-46
Consumption of contaminated Fish					
Chronic	Fish-Eating Bird	1.30E-06	6.50E-08	1.95E-05	B-48

TABLE B-61

RISK CHARACTERIZATION FOR TERRESTRIAL ANIMALS AT CENTRAL APPLICATION RATE

Imazapyr Risk Assessment
Washington State

Application Rate:		**0.26**	**lbs/acre**		
Application Rate Factor:		**1**	**unitless**		
Exposure Worksheet:		**B-60**			**TrToxSum**
		Hazard Quotient			**Toxicity Value**
Scenario	**Receptor**	**Central**	**Lower**	**Upper**	
Acute/Accidental Exposures (mg/kg/event)					B-61-1App
Direct Spray					
first-order absorption	Small Mammal	7E-04	3E-04	2E-03	250
100% absorption	Small Mammal	3E-02	3E-02	3E-02	250
100% absorption	Honey Bee	4E-02	4E-02	4E-02	1000
100% absorption	Adult Frog	4E-06	4E-06	4E-06	674
Contaminated Vegetation					
Fruit	Small Mammal	1E-03	1E-03	3E-03	250
Grass	Large Mammal	2E-02	2E-02	5E-02	250
Grass	Large Bird	1E-02	1E-02	3E-02	674
Contaminated Water					
Accidental spill	Small Mammal	1E-03	7E-04	3E-03	250
Expected Peak Conc.		3E-07	2E-08	1E-05	250
Contaminated Insects					
	Small Mammal	2E-02	2E-02	7E-02	250
	Small Bird	1E-02	1E-02	4E-02	674
Consumption of Contaminated Fish					
Accidental spill	Fish-Eating Bird	2E-04	4E-05	5E-04	674
Consumption of Contaminated Small Mammal					
Carnivorous Mammal		2E-03	2E-03	2E-03	250
	Carnivorous Bird	1E-03	1E-03	1E-03	674
Chronic/Longer Term Exposures (dose in mg/kg/day)					
Contaminated Vegetation					
On-site	Small Mammal	5E-05	2E-05	3E-04	250
Off-Site		5E-07	9E-08	5E-06	250
On-Site	Large Mammal	2E-03	4E-04	2E-02	250
Off-Site		7E-05	2E-05	5E-04	250
On-Site	Large Bird	4E-03	8E-04	5E-02	200
Off-Site		1E-04	5E-05	9E-04	200
Contaminated Water					
Water consumption	Small Mammal	2E-08	2E-09	2E-07	250
Consumption of contaminated Fish					
chronic	Fish-Eating Bird	7E-09	3E-10	1E-07	200

TABLE B-62

SUMMARY OF AQUATIC RISK QUOTIENTS
AN APPLICATION RATE OF 0.26 LBS/ACRE
Imazapyr Risk Assessment
Washington State

Application Rate:		**0.26**	**lbs/acre**		
Application Rate Factor:		**1**	**unitless**		
Summary of Concentration in Water					
		Concentrations (mg/L)			
	Scenario	**Central**	**Lower**	**Upper**	**Worksheet**
	Accidental Spill	**2**	**1.2**	**5**	B-24
	Peak EEC	5E-04	3E-05	2E-02	B-25
	Longer-term EEC	3E-05	3E-06	3E-04	B-26
Summary of Risk Characterizations					
		Hazard Quotients			**Toxicity Values**
Receptor	**Scenario**	**Central**	**Lower**	**Upper**	**(mg/L)**
Fish					
Sensitive Species					
	Accidental Spill	5E-02	3E-02	0.1	43.1
	Peak EEC	1E-05	6E-07	5E-04	43.1
	Longer-term EEC	6E-07	6E-08	6E-06	43.1
Tolerant Species					
	Accidental Spill	2E-02	1E-02	5E-02	100
	Peak EEC	5E-06	3E-07	2E-04	100
	Longer-term EEC	2E-07	2E-08	2E-06	120
Aquatic invertebrate					
	Accidental Spill	2E-02	1E-02	5E-02	100
	Peak EEC	5E-06	3E-07	2E-04	100
	Longer-term EEC	3E-07	3E-08	3E-06	97.1
Macrophyte, aquatic					
	Accidental Spill	**181**	**93**	**361**	0.013
	Peak EEC	4E-02	2E-03	**1.6**	0.013
	Longer-term EEC	2E-03	2E-04	2E-02	0.013
Algae					
Sensitive Species					
	Accidental Spill	**12**	**6**	**23**	0.2
	Peak EEC	3E-03	1E-04	0.1	0.2
	Longer-term EEC	1E-04	1E-05	1E-03	0.2
Tolerant Species					
	Accidental Spill	2E-02	1E-02	5E-02	100
	Peak EEC	5E-06	3E-07	2E-04	100
	Longer-term EEC	3E-07	3E-08	3E-06	100

TABLE B-63

SUMMARY OF EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION
FOR SENSITIVE AND TOLERANT TERRESTRIAL PLANTS
FROM RUNOFF
Imazapyr Risk Assessment
Washington State

Short Title	**Runoff to Terrestrial Plants**			**PlntRuno2**
Receptor	**Terrestrial Vegetation**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Value**	**Units**	**Reference/ Designation**
Application Rate	**ApRt**	0.26	lb/acre	Program parameter
Toxicity Values (seedling emergence)	**ToxVal**			
Sensitive species	EC25	0.002	lb/acre	Section 4.4.2.4
Tolerant species	NOEC	1	lb/acre	Section 4.4.2.4
Proportion Lost	**Prop**			
Annual Rainfall	Clay	Loam	Sand	
5	0.00E+00	0.00E+00	0.00E+00	
10	0.00E+00	0.00E+00	0.00E+00	
15	1.94E-02	0.00E+00	0.00E+00	
20	4.04E-02	0.00E+00	0.00E+00	
25	6.27E-02	0.00E+00	0.00E+00	
50	1.67E-01	2.89E-04	0.00E+00	
100	3.28E-01	1.53E-02	0.00E+00	
150	4.42E-01	2.20E-02	0.00E+00	
200	5.25E-01	2.40E-02	0.00E+00	
250	5.79E-01	2.43E-02	0.00E+00	
Functional Off-Site Application Rate				
Annual Rainfall				
5	0.00E+00	0.00E+00	0.00E+00	
10	0.00E+00	0.00E+00	0.00E+00	
15	5.04E-03	0.00E+00	0.00E+00	
20	1.05E-02	0.00E+00	0.00E+00	
25	1.63E-02	0.00E+00	0.00E+00	
50	4.34E-02	7.51E-05	0.00E+00	
100	8.53E-02	3.98E-03	0.00E+00	
150	1.15E-01	5.72E-03	0.00E+00	
200	1.37E-01	6.24E-03	0.00E+00	
250	1.51E-01	6.32E-03	0.00E+00	
Hazard Quotients	**Sensitive Species**			
Annual Rainfall	Clay	Loam	Sand	
5	0	0	0	
10	0	0	0	
15	**3**	0	0	
20	**5**	0	0	
25	**8**	0	0	
50	**22**	3.76E-02	0	
100	**43**	**2.0**	0	
150	**57**	**3**	0	

TABLE B-63

SUMMARY OF EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION FOR SENSITIVE AND TOLERANT TERRESTRIAL PLANTS FROM RUNOFF

Imazapyr Risk Assessment
Washington State

Short Title	**Runoff to Terrestrial Plants**			**PlntRuno2**
Receptor	**Terrestrial Vegetation**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Value**	**Units**	**Reference/ Designation**
200	**68**	**3**	0	
250	**75**	**3**	0	
Hazard Quotients	**Tolerant Species**			
Annual Rainfall	Clay	Loam	Sand	
5	0	0	0	
10	0	0	0	
15	5.04E-03	0	0	
20	1.05E-02	0	0	
25	1.63E-02	0	0	
50	4.34E-02	7.51E-05	0	
100	8.53E-02	3.98E-03	0	
150	0.1	5.72E-03	0	
200	0.1	6.24E-03	0	
250	0.2	6.32E-03	0	

TABLE B-64

SUMMARY OF EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION FOR SENSITIVE AND TOLERANT PLANTS FROM DRIFT AFTER LOWBOOM APPLICATION

Imazapyr Risk Assessment
Washington State

Receptor	**Terrestrial Vegetation**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApRt**	0.26	lb/acre	Program parameter
Toxicity Values (Post-emergence)	**ToxVal**			
Sensitive species	NOEC	0.00049	lb/acre	Section 4.4.2.4
Tolerant species	NOEC	0.018	lb/acre	Section 4.4.2.4
Proportion of Drift at distances down wind in feet [0 feet = direct spray]	**Prop**			
0		1	unitless	
25		0.0187		
50		0.0101		
100		0.0058		
300		0.0024		
500		0.0015		
900		0.0008		
Estimates of functional offsite application rate	**OfApRt**	***=ApRt x Prop***		
0		0.26		Eq
25		0.004862		Eq
50		0.002626		Eq
100		0.001508		Eq
300		0.000624		Eq
500		0.00039		Eq
900		0.000208		Eq
Hazard Quotients (Sensitive Species)	**HI**	***= OfApRt / ToxVal***		
0		**531**		Eq
25		**10**		
50		**5**		Eq
100		**3**		Eq
300		**1.3**		Eq
500		0.8		Eq
900		0.4		Eq

TABLE B-64

SUMMARY OF EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION
FOR SENSITIVE AND TOLERANT PLANTS
FROM DRIFT AFTER LOWBOOM APPLICATION
Imazapyr Risk Assessment
Washington State

Receptor	**Terrestrial Vegetation**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Hazard Quotients (Tolerant Species)	**HI**	***= OfApRt / ToxVal***		
0		**14**		Eq
25		0.3		Eq
50		0.1		Eq
100		8E-02		Eq
300		3E-02		Eq
500		2E-02		Eq
900		1E-02		Eq

TABLE B-65

SUMMARY OF EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION FOR SENSITIVE AND TOLERANT TERRESTRIAL PLANTS FROM DRIFT AFTER AERIAL APPLICATION

Imazapyr Risk Assessment
Washington State

Receptor	**Terrestrial Vegetation**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Application Rate	**ApRt**	0.26	lb/acre	Program parameter
Toxicity Values (Post-emergence)	**ToxVal**			
Sensitive species	NOEC	0.00049	lb/acre	Section 4.4.2.4
Tolerant species	NOEC	0.018	lb/acre	Section 4.4.2.4
Proportion of Drift at distances down wind in feet [0 feet = direct spray]	**Prop**			
0		1	unitless	
25		0.1434		
50		0.0518		
100		0.0195		
300		0.0042		
500		0.0022		
900		0.0009		
Estimates of functional off-site application rate	**OfApRt**	***=ApRt x Prop***		
0		0.26		Eq
25		0.037284		Eq
50		0.013468		Eq
100		0.00507		Eq
300		0.001092		Eq
500		0.000572		Eq
900		0.000234		Eq
Hazard Quotients (Sensitive Species)	**HI**	***= OfApRt / ToxVal***		
0		**531**		Eq
25		**76**		
50		**27**		Eq
100		**10**		Eq
300		**2**		Eq
500		**1.2**		Eq
900		0.5		Eq

TABLE B-65

SUMMARY OF EXPOSURE ASSESSMENT AND RISK CHARACTERIZATION FOR SENSITIVE AND TOLERANT TERRESTRIAL PLANTS FROM DRIFT AFTER AERIAL APPLICATION

Imazapyr Risk Assessment
Washington State

Receptor	**Terrestrial Vegetation**			
Duration	**Acute**			
Parameter/ Assumption	**Code/ Range**	**Equation/ Value**	**Units**	**Reference/ Designation**
Hazard Quotients (Tolerant Species)	**HI**	***= OfApRt / ToxVal***		
0		**14**		Eq
25		**2**		Eq
50		0.7		Eq
100		0.3		Eq
300		6E-02		Eq
500		3E-02		Eq
900		1E-02		Eq

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Washington State

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APPENDIX C

Threatened, Endangered, and Sensitive Species
in Washington State

APPENDIX C

Threatened, Endangered, and Sensitive Species
in Washington State

TABLE C-1

SPECIES LISTED AS THREATENED OR ENDANGERED UNDER THE FEDERAL ENDANGERED SPECIES ACT THAT OCCUR IN WASHINGTON STATE[1]

Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	Status	Critical Habitat	Range Map (Figure No.)
Mammals				
Columbian white-tailed deer (Columbia River DPS)	*Odocoileus virginianus leucurus*	E	No	C-1
Gray wolf	*Canis lupus*	E	Yes	C-2
Grizzly bear	*Ursus arctos horribilis*	T	No	C-3
Humpback whale	*Megaptera novaeangliae*	E	No	NA
Killer whale (Southern resident DPS)	*Orcinus orca*	E	Yes	NA
Canada lynx	*Lynx canadensis*	T	Yes	C-4
Pygmy rabbit (Columbian basin DPS)	*Brachylagus idahoensis*	E	No	C-5
Sea otter	*Enhydra lutris nereis*	T	No	C-6
Steller sea lion	*Eumetopias jubatus*	T	Yes	NA
Woodland caribou (Selkirk Mountain DPS)	*Rangifer tarandus caribou*	E	No	C-7
Birds				
Brown pelican	*Pelecanus occidentalis*	E	No	NA
Eskimo curlew	*Numenius borealis*	E	No	NA
Marbled murrelet	*Brachyramphus marmoratus*	T	Yes	NA
Northern spotted owl	*Strix occidentalis caurina*	T	Yes	C-8
Short-tailed albatross	*Phoebastria albatrus*	E	No	C-9
Western snowy plover	*Charadrius alexandrinus nivosus*	T	Yes	C10
Reptiles				
Green sea turtle	*Chelonia mydas*	T	Yes	C-11
Leatherback sea turtle	*Dermochelys coriacea*	E	Yes	C-12

TABLE C-1

SPECIES LISTED AS THREATENED OR ENDANGERED UNDER THE FEDERAL ENDANGERED SPECIES ACT THAT OCCUR IN WASHINGTON STATE[1]

Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	Status	Critical Habitat	Range Map (Figure No.)
Fishes				
Bull trout	*Salvelinus confluentus*	T	Yes	C-13
Chinook salmon (Snake River Fall-Run ESU)	*Oncorhynchus tshawytscha*	T	Yes	C-14
Chinook salmon (Lower Columbia River ESU)	*Oncorhynchus tshawytscha*	T	Yes	C-15
Chinook salmon (Puget Sound ESU)	*Oncorhynchus tshawytscha*	T	Yes	C-16
Chinook salmon Upper Columbia Spring-Run ESU)	*Oncorhynchus tshawytscha*	E	Yes	C-17
Chinook salmon (Snake River Spring/ Summer-Run ESU)	*Oncorhynchus tshawytscha*	T	Yes	C-18
Chum salmon (Columbia River ESU)	*Oncorhynchus keta*	T	Yes	C-19
Chum salmon (Hood Canal Summer-Run ESU)	*Oncorhynchus keta*	T	Yes	C-20
Coho salmon (Lower Columbia River ESU)	*Oncorhynchus kisutch*	T	Yes	NA
Sockeye salmon (Lake Ozette ESU)	*Oncorhynchus nerka*	T	Yes	C-21
Steelhead (Lower Columbia River DPS)	*Oncorhynchus mykiss*	T	Yes	C-22
Steelhead (Middle Columbia River DPS)	*Oncorhynchus mykiss*	T	Yes	C-23
Steelhead (Puget Sound DPS)	*Oncorhynchus mykiss*	T	Yes	C-24
Steelhead (Snake River Basin DPS)	*Oncorhynchus mykiss*	T	Yes	C-25
Steelhead (Upper Columbia River DPS)	*Oncorhynchus mykiss*	T	Yes	C-26

TABLE C-1

SPECIES LISTED AS THREATENED OR ENDANGERED UNDER THE FEDERAL ENDANGERED SPECIES ACT THAT OCCUR IN WASHINGTON STATE[1]

Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	Status	Critical Habitat	Range Map (Figure No.)
Invertebrates				
Oregon silver-spot butterfly	*Speyeria zerene hippolyta*	T	Yes	C-27
Plants				
Bradshaw's desert-parsley	*Lomatium bradshawii*	E	No	C-28
Golden paintbrush	*Castilleja levisecta*	T	No	C-29
Kincaid's lupine	*Lupinus sulphureus* ssp. *kincaidii*	T	Yes	C-30
Nelson's checker-mallow	*Sidalcea nelsoniana*	T	No	C-31
Showy stickseed	*Hackelia venusta*	E	No	C-32
Spalding's catchfly	*Silene spaldingii*	T	No	C-33
Ute Ladies' tresses	*Spiranthes diluvialis*	T	No	C-34
Water howellia	*Howellia aquatilis*	T	No	C-35
Wenatchee Mountains checker-mallow	*Sidalcea oregana* var. *calva*	E	Yes	C-36

Notes
1. Source: NOAA-Fisheries 2009 & USFWS 2009.

Abbreviation(s)
DPS = distinct population segment
E = endangered
ESU = Evolutionarily Significant Unit
NA = not applicable
T = threatened

TABLE C-2

WDFW-LISTED ANIMAL SPECIES[1]

Imazapyr Risk Assessment

Washington State

Common Name	Scientific Name	Status
Mammals		
Black right whale	*Balaena glacialis*	E
Black-tailed jackrabbit	*Lepus californicus*	C
Blue whale	*Baleonoptera musculus*	E
Fin whale	*Baleonoptera physalus*	E
Fisher	*Martes pennanti*	E
Gray whale	*Eschrichtius robustus*	S
Gray-tailed vole	*Microtus canicaudus*	C
Keen's myotis	*Myotis keenii*	C
Mazama (Western) pocket gopher	*Thomomys mazama*	T
Merriam's shrew	*Sorex merriami*	C
Olympic marmot	*Marmota olympus*	C
Pacific harbor porpoise	*Phocoena phocoena*	C
Preble's shrew	*Sorex preblei*	C
Sei whale	*Baleonoptera borealis*	E
Sperm whale	*Physeter macrocephalus*	E
Townsend's ground squirrel	*Spermophilus townsendii*	C
Townsend's big-eared bat	*Corynorhinus townsendii*	C
Washington ground squirrel	*Spermophilus washingtoni*	C
Western gray squirrel	*Sciurus griseus*	T
White-tailed jackrabbit	*Lepus townsendii*	C
Wolverine	*Gulo gulo*	C
Birds		
American white pelican	*Pelecanus erythrorhynchos*	E
Bald eagle	*Haliaeetus leucocephalus*	S
Black-backed woodpecker	*Picoides arcticus*	C
Brandt's cormorant	*Phalacrocorax penicillatus*	C
Burrowing owl	*Athene cunicularia*	C
Cassin's auklet	*Ptychoramphus aleuticus*	C
Common murre	*Uria aalge*	C
Common loon	*Gavia immer*	S
Ferruginous hawk	*Buteo regalis*	T
Flammulated owl	*Otus flammeolus*	C
Golden eagle	*Aquila chrysaetos*	C
Lewis' woodpecker	*Melanerpes lewis*	C
Loggerhead shrike	*Lanius ludovicianus*	C

TABLE C-2

WDFW-LISTED ANIMAL SPECIES[1]

Imazapyr Risk Assessment

Washington State

Common Name	Scientific Name	Status
Birds (continued)		
Merlin	*Falco columbarius*	C
Northern goshawk	*Accipiter gentilis*	C
Oregon vesper sparrow	*Pooecetes gramineus affinis*	C
Peregrine falcon	*Falco peregrinus*	S
Pileated woodpecker	*Dryocopus pileatus*	C
Purple martin	*Progne subis*	C
Sage thrasher	*Oreoscoptes montanus*	C
Sage grouse	*Centrocercus urophasianus*	T
Sage sparrow	*Amphispiza belli*	C
Sandhill crane	*Grus canadensis*	E
Sharp-tailed grouse	*Tympanuchus phasianellus*	T
Slender-billed white-breasted nuthatch	*Sitta carolinensis aculeata*	C
Streaked horned lark	*Eremophila alpestris strigata*	E
Tufted puffin	*Fratercula cirrhata*	C
Upland sandpiper	*Bartramia longicauda*	E
Vaux's swift	*Chaetura vauxi*	C
Western grebe	*Aechmophorus occidentalis*	C
White-headed woodpecker	*Picoides albolarvatus*	C
Yellow-billed cuckoo	*Coccyzus americanus*	C
Reptiles		
California mountain kingsnake	*Lampropeltis zonata*	C
Loggerhead sea turtle	*Caretta caretta*	T
Sagebrush lizard	*Sceloporus graciosus*	C
Sharptail snake	*Contia tenuis*	C
Striped whipsnake	*Masticophis taeniatus*	C
Western pond turtle	*Actinemys marmorata*	E
Amphibians		
Cascade torrent salamander	Rhyacotriton cascadae	C
Columbia spotted frog	Rana luteiventris	C
Dunn's salamander	Plethodon dunni	C
Larch Mountain salamander	Plethodon larselli	S
Northern leopard frog	Rana pipiens	E
Oregon spotted frog	Rana pretiosa	E
Rocky Mountain tailed frog	Ascaphus montanus	C
Van Dyke's salamander	Plethodon vandykei	C
Western toad	Bufo boreas	C

TABLE C-2

WDFW-LISTED ANIMAL SPECIES[1]

Imazapyr Risk Assessment

Washington State

Common Name	Scientific Name	Status
Fish		
Black rockfish	*Sebastes melanops*	C
Bocaccio rockfish	*Sebastes paucispinis*	C
Brown rockfish	*Sebastes auriculatus*	C
Canary rockfish	*Sebastes pinniger*	C
China rockfish	*Sebastes nebulosus*	C
Copper rockfish	*Sebastes caurinus*	C
Eulachon	*Thaleichthys pacificus*	C
Greenstriped rockfish	*Sebastes elongatus*	C
Lake chub	*Couesius plumbeus*	C
Leopard dace	*Rhinichthys falcatus*	C
Margined sculpin	*Cottus marginatus*	S
Mountain sucker	*Catostomus platyrhynchus*	C
Olympic mudminnow	*Novumbra hubbsi*	S
Pacific cod	*Gadus macrocephalus*	C
Pacific hake	*Merluccius productus*	C
Pacific herring	*Clupea pallasi*	C
Pygmy whitefish	*Prosopium coulteri*	S
Quillback rockfish	*Sebastes maliger*	C
Redstripe rockfish	*Sebastes proriger*	C
River lamprey	*Lampetra ayresi*	C
Sockeye salmon (Snake R.)	*Oncorhynchus nerka*	C
Tiger rockfish	*Sebastes nigrocinctus*	C
Umatilla dace	*Rhinichthys umatilla*	C
Walleye pollock	*Theragra chalcogramma*	C
Widow rockfish	*Sebastes entomelas*	C
Yellowtail rockfish	*Sebastes flavidus*	C
Yelloweye rockfish	*Sebastes ruberrimus*	C
Invertebrates		
Giant Palouse earthworm	*Driloleirus americanus*	C
Leschi's millipede	*Leschius mcallisteri*	C
Chinquapin hairstreak	*Habrodais grunus herri*	C
Great arctic	*Oeneis nevadensis gigas*	C
Island marble	*Euchloe ausonides insulanus*	C
Johnson's hairstreak	*Mitoura johnsoni*	C
Juniper hairstreak	*Mitoura grynea barryi*	C

TABLE C-2

WDFW-LISTED ANIMAL SPECIES[1]
Imazapyr Risk Assessment

Washington State

Common Name	Scientific Name	Status
Invertebrates (continued)		
Makah (Queen Charlotte) copper	*Lycaena mariposa charlottensis*	C
Mardon skipper	*Polites mardon*	E
Puget blue	*Plebejus icarioides blackmorei*	C
Sand-verbena moth	*Copablepharon fuscum*	C
Shepard's parnassian	*Parnassius clodius shepardi*	C
Silver-bordered fritillary	*Boloria selene atrocostalis*	C
Taylor's checkerspot	*Euphydryas editha taylori*	E
Valley silverspot	*Speyeria zerene bremnerii*	C
Yuma skipper	*Ochlodes yuma*	C
Blue-gray taildropper	*Prophysaon coeruleum*	C
California floater	*Anodonta californiensis*	C
Columbia oregonian	*Cryptomastix hendersoni*	C
Columbia pebblesnail	*Fluminicola columbiana*	C
Dalles sideband (snail)	*Monadenia fidelis*	C
Giant Columbia River limpet	*Fisherola nuttalli*	C
Newcomb's littorine snail	*Algamorda subrotundata*	C
Northern abalone	*Haliotis kamtschatkana*	C
Olympia oyster	*Ostrea conchaphila*	C
Poplar oregonian	*Cryptomastix populi*	C
Beller's ground beetle	*Agonum belleri*	C
Columbia clubtail (dragonfly)	*Gomphus lynnae*	C
Columbia River tiger beetle	*Cicindela columbica*	C
Hatch's click beetle	*Eanus hatchi*	C
Long-horned leaf beetle	*Donacia idola*	C
Mann's mollusk-eating ground beetle	*Scaphinotus manni*	C
Pacific clubtail	*Gomphus kurilis*	C

Notes
1. Source: WDFW 2009

Abbreviation(s)
E = endangered
T = threatened
C = candidate
S = sensitive
WDFW = Washington State Department of Fish & Wildlife

TABLE C-3

WASHINGTON STATE RARE PLANTS[1,2]

Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	State Rank	State Status
Alismataceae			
Fringed waterplantain	*Damasonium californicum*	S1	T
Apiaceae			
Bulb-bearing water-hemlock	*Cicuta bulbifera*	S2	S
Jointed coyote-thistle	*Eryngium articulatum*	SH	X
Oregon coyote-thistle	*Eryngium petiolatum*	S1	T
Bradshaw's lomatium	*Lomatium bradshawii*	S1	E
Smooth desert-parsley	*Lomatium laevigatum*	S2	T
Rollins' desert-parsley	*Lomatium rollinsii*	S2	T
Sandberg's desert-parsley	*Lomatium sandbergii*	S1	T
Snake Canyon desert-parsley	*Lomatium serpentinum*	S2	S
New lomatium 1	*Lomatium species novum 1 (Kittitas Co.)*	SU	R2
Rib-seed desert-parsley	*Lomatium species novum 2 (Klickitat Co.)*	SU	R2
Suksdorf's desert-parsley	*Lomatium suksdorfii*	S3	S
Hoover's desert-parsley	*Lomatium tuberosum*	S2, S3	S
Oregon yampah	*Perideridia oregana*	S1	R1
Bear's-foot sanicle	*Sanicula arctopoides*	S1	E
Black snake-root	*Sanicula marilandica*	S2	S
Hoover's tauschia	*Tauschia hooveri*	S2	T
Leiberg's tauschia	*Tauschia tenuissima*	SX	X
Asclepiadaceae			
Davis' milkweed	*Asclepias cryptoceras* ssp. *davisii*	S1	T
Asteraceae			
Tall agoseris	*Agoseris elata*	S3	S
Pink agoseris	*Agoseris lackschewitzii*	SU	S
Meadow pussy-toes	*Antennaria corymbosa*	S1	T
Nuttall's pussy-toes	*Antennaria parvifolia*	S2	S
Wormskiold's northern wormwood	*Artemisia borealis* var. *wormskioldii*	S1	E
Forked wormwood	*Artemisia furcata*	SNR	R1
Coyotebush	*Baccharis pilularis* ssp. *consanguinea*	S1	T
Puget balsamroot	*Balsamorhiza deltoidea*	S2?	R2
Vancouver Island beggar-ticks	*Bidens amplissima*	SNR	R1
Thompson's chaenactis	*Chaenactis thompsonii*	S2, S3	S
Sticky-leaf rabbitbrush	*Chrysothamnus viscidiflorus* ssp. *axillaris*	SU	R1

TABLE C-3

WASHINGTON STATE RARE PLANTS[1,2]

Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	State Rank	State Status
Asteraceae (continued)			
Flodman's thistle	*Cirsium flodmanii*	SNR	R1
Idaho hawksbeard	*Crepis bakeri* ssp. *idahoensis*	S1	R1
Hawksbeard	*Crepis modocensis* ssp. *glareosa*	SNR	R1
White eatonella	*Eatonella nivea*	S1	T
Alice's fleabane	*Erigeron aliceae*	S2	S
Basalt daisy	*Erigeron basalticus*	S2	T
Snake River daisy	*Erigeron disparipilus*	SNR	R1
Tall bitter fleabane	*Erigeron elatus*	S1	E
Davis' Fleabane	*Erigeron engelmannii* var. *davisii*	SNR	R1
Howell's daisy	*Erigeron howellii*	S2	T
Gorge daisy	*Erigeron oreganus*	S2	T
Thompson's wandering daisy	*Erigeron peregrinus* var. *thompsonii*	S2	S
Piper's daisy	*Erigeron piperianus*	S3	S
Hairy-seeded daisy	*Erigeron poliospermus* var. *cereus*	SNR	R1
Salish fleabane	*Erigeron salishii*	S2	S
Arctic aster	*Eurybia merita*	S1, S2	S
Spotted Joe-Pye weed	*Eutrochium maculatum* var. *bruneri*	SH	X
Oregon goldenaster	*Heterotheca oregona* var. *oregona*	S1	T
Dwarf alpinegold	*Hulsea nana*	SNR	R1
Smooth goldfields	*Lasthenia glaberrima*	S1	E
Seaside goldfields	*Lasthenia maritima*	SNR	R1
Coastal goldfields	*Lasthenia minor*	SNR	R1
Coast microseris	*Microseris bigelovii*	SX	X
Northern microseris	*Microseris borealis*	S2	S
Cutleaf silverpuffs	*Microseris laciniata* ssp. *leptosepala*	SNR	R1
Harford's ragwort	*Packera bolanderi* var. *harfordii*	SNR	R1
Siskiyou Mountain ragwort	*Packera macounii*	SNR	R1
Porter's butterweed	*Packera porteri*	S1, S2	R1
Slender woolly marbles	*Psilocarphus tenellus* var. *tenellus*	SNR	R1
Sticky goldenweed	*Pyrrocoma hirta var. sonchifolia*	S1	S
Palouse goldenweed	*Pyrrocoma liatriformis*	S2	T
Palouse goldenweed	*Pyrrocoma scaberula*	SU	R2
Oregon white-top aster	*Sericocarpus oregonensis* ssp. *oregonensis*	S1	T
White-top aster	*Sericocarpus rigidus*	S3	S

TABLE C-3

WASHINGTON STATE RARE PLANTS[1,2]
Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	State Rank	State Status
Asteraceae (continued)			
Tolmie's goldenrod	*Solidago missouriensis* var. *tolmieana*	S1, S3	R2
Rush aster	*Symphyotrichum boreale*	S1	T
Hall's aster	*Symphyotrichum hallii*	S1	T
Jessica's aster	*Symphyotrichum jessicae*	S1, S2	E
Camphor daisy	*Tanacetum bipinnatum*	SNR	R1
Lindley's microseris	*Uropappus lindleyi*	SNR	R1
California compassplant	*Wyethia angustifolia*	SU	S
Balsaminaceae			
Western jewel-weed	*Impatiens noli-tangere*	S1	T
Blechnaceae			
Chain-fern	*Woodwardia fimbriata*	S2	S
Boraginaceae			
Narrow-stem cryptantha	*Cryptantha gracilis*	S2	S
Gray cryptantha	*Cryptantha leucophaea*	S2, S3	S
Beaked cryptantha	*Cryptantha rostellata*	S2	T
Miner's candle	*Cryptantha scoparia*	S1	S
Snake River cryptantha	*Cryptantha spiculifera*	S2?	S
Pale alpine-forget-me-not	*Eritrichium nanum var. elongatum*	S1	S
Okanogan stickseed	*Hackelia ciliata*	SNR	R1
Gray stickseed	*Hackelia cinerea*	S1	S
Diffuse stickseed	*Hackelia diffusa var. diffusa*	S2	T
Sagebrush stickseed	*Hackelia hispida var. disjuncta*	S2, S3	S
Rough stickseed	*Hackelia hispida var. hispida*	S1	T
Taylor's Stickseed	*Hackelia sp. 2*	S2	T
Showy stickseed	*Hackelia venusta*	S1	E
Brassicaceae			
Cross-haired rockcress	*Arabis crucisetosa*	S1	T
Olympic Nuttall's rockcress	*Arabis furcata var. olympica*	S2	R2
Scurvygrass	*Cochlearia groenlandica*	S1, S2	S
Douglas' draba	*Cusickiella douglasii*	S1	T
Golden draba	*Draba aurea*	S1 ,S2	S
Lance-leaved draba	*Draba cana*	S1 ,S2	S
Lance-fruited draba	*Draba lonchocarpa* var. *vestita*	SNR	R1
Long-stalked draba	*Draba longipes*	S1	T
Puzzling rockcress	*Halimolobos perplexa* var. *perplexa*	S1	T

TABLE C-3

WASHINGTON STATE RARE PLANTS[1,2]
Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	State Rank	State Status
Brassicaceae (continued)			
Sharpfruited peppergrass	*Lepidium oxycarpum*	S1	T
Common twinpod	*Physaria didymocarpa* var. *didymocarpa*	S1	S
White Bluffs bladderpod	*Physaria douglasii* ssp. *tuplashensis*	S2	T
Fremont's combleaf	*Polyctenium fremontii* var. *fremontii*	S1	T
Persistentsepal yellowcress	*Rorippa columbiae*	S1S2	E
Alpine yellowcress	*Rorippa obtusa* var. *alpina*	SNR	R1
Water awlwort	*Subularia aquatica* var. *americana*	SNR	R1
Howell's thelypody	*Thelypodium howellii* ssp. *howellii*	SNR	R1
Arrow thelypody	*Thelypodium sagittatum* ssp. *sagittatum*	S1	S
Cactaceae			
Snowball cactus	*Pediocactus nigrispinus*	S2	R1
Campanulaceae			
Alaska harebell	*Campanula lasiocarpa*	S2	S
Common blue-cup	*Githopsis specularioides*	S3	S
Howellia	*Howellia aquatilis*	S2 ,S3	T
Water lobelia	*Lobelia dortmanna*	S2	T
Kalm's lobelia	*Lobelia kalmii*	S1	E
Caryophyllaceae			
Swamp sandwort	*Arenaria paludicola*	SX	X
Thompson's Sandwort	*Eremogone franklinii* var. *thompsonii*	SU	R1
loeflingia	*Loeflingia squarrosa* var. *squarrosa*	S1	T
Nuttall's sandwort	*Minuartia nuttallii* ssp. *fragilis*	S1	T
Annual sandwort	*Minuartia pusilla* var. *pusilla*	SNR	R1
Douglas' catchfly	*Silene douglasii* var. *rupinae*	SNR	R1
Sargent's catchfly	*Silene sargentii*	S1	R1
Scouler's catchfly	*Silene scouleri* var. *pacifica*	SU	R1
Seely's silene	*Silene seelyi*	S2 ,S3	S
Spalding's silene	*Silene spaldingii*	S2	T
Celastraceae			
Western wahoo	*Euonymus occidentalis* var. *occidentalis*	S1	T
Ceratophyllaceae			
Smooth hornwort	*Ceratophyllum echinatum*	SNR	R1

TABLE C-3

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Common Name	Scientific Name	State Rank	State Status
Chenopodiaceae			
American bugseed	*Corispermum americanum* var. *americanum*	SU	R2
Common bugseed	*Corispermum pacificum*	SU	R2
Pale bugseed	*Corispermum pallidum*	SH	X
Hairy bugseed	*Corispermum villosum*	SU	R2
Red poverty-weed	*Micromonolepis pusilla*	S1	T
Prostrate poverty-weed	*Monolepis spathulata*	SU	R1
Clusiaceae			
Canadian St. John's-wort	*Hypericum majus*	S2	S
Crassulaceae			
Erect pygmy-weed	*Crassula connata*	S1 ,S2	T
Cuscutaceae			
Desert dodder	*Cuscuta denticulata*	S1	T
Cyperaceae			
Yellow-flowered sedge	*Carex anthoxanthea*	S1	S
Blackened sedge	*Carex atrosquama*	S1	R1
Hair-like sedge	*Carex capillaris*	S1	T
Capitate sedge	*Carex capitata*	S1	R1
Cordroot sedge	*Carex chordorrhiza*	S1	S
Coiled sedge	*Carex circinata*	S1	S
Bristly sedge	*Carex comosa*	S2	S
Constance's sedge	*Carex constanceana*	SH	R1
Back's sedge	*Carex cordillerana*	SNR	R1
Dense sedge	*Carex densa*	S1	T
Yellow sedge	*Carex flava*	S3	S
Yellow bog sedge	*Carex gynocrates*	S1	S
Smooth-fruit sedge	*Carex heteroneura* var. *epapillosa*	S2	S
Krause's sedge	*Carex krausei* ssp. *porsildiana*	SNR	R1
Large-awn sedge	*Carex macrochaeta*	S1	T
Poor sedge	*Carex magellanica* ssp. *irrigua*	S2 ,S3	S
Intermediate sedge	*Carex media*	S2	S
Blunt sedge	*Carex obtusata*	S2	S
Pale sedge	*Carex pallescens*	SNR	R1
Few-flowered sedge	*Carex pauciflora*	S2	S
Several-flowered sedge	*Carex pluriflora*	S1S2	S
Teacher's sedge	*Carex praeceptorum*	S2	R1

TABLE C-3

WASHINGTON STATE RARE PLANTS[1,2]

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Common Name	Scientific Name	State Rank	State Status
Cyperaceae (continued)			
Smoky Mountain sedge	*Carex proposita*	S2	T
Beaked sedge	*Carex rostrata*	S1	S
Canadian single-spike sedge	*Carex scirpoidea* ssp. *scirpoidea*	S2	S
Long-styled sedge	*Carex stylosa*	S1 ,S2	S
Many-headed sedge	*Carex sychnocephala*	S2	S
Lake Tahoe sedge	*Carex tahoensis*	SU	R1
Quill sedge	*Carex tenera* var. *tenera*	S1	T
Sparse-flowered sedge	*Carex tenuiflora*	S1	T
Valley sedge	*Carex vallicola*	S2	S
Purple spike-rush	*Eleocharis atropurpurea*	SX	X
Dwarf spike-rush	*Eleocharis coloradoensis*	SNR	R1
Beaked spike-rush	*Eleocharis rostellata*	S2	S
Green keeled cotton-grass	*Eriophorum viridicarinatum*	S2	S
Awned halfchaff sedge	*Lipocarpha aristulata*	S1	T
Rocky Mountain bulrush	*Schoenoplectus saximontanus*	S1	T
Alpine bulrush	*Trichophorum alpinum*	SNR	R1
Dryopteridaceae			
Toothed wood fern	*Dryopteris carthusiana*	S2?	R1
Crested shield-fern	*Dryopteris cristata*	S2	S
California sword-fern	*Polystichum californicum*	S1, S2	T
Elatinaceae			
Texas bergia	*Bergia texana*	SNR	R1
Ericaceae			
Clubmoss cassiope	*Cassiope lycopodioides*	S1	T
Creeping snowberry	*Gaultheria hispidula*	S2	S
Alpine azalea	*Loiseleuria procumbens*	S1	T
Menziesia	*Menziesia ferruginea* ssp. *glabella*	SNR	R1
Velvet-leaf blueberry	*Vaccinium myrtilloides*	S1	S
Fabaceae			
Palouse milk-vetch	*Astragalus arrectus*	S2	T
Arthur's milk-vetch	*Astragalus arthurii*	S2	S
Asotin milk-vetch	*Astragalus asotinensis*	S2	T
Cotton's milk-vetch	*Astragalus australis* var. *olympicus*	S2	T
Columbia milk-vetch	*Astragalus columbianus*	S3	S
Cusick's milk-vetch	*Astragalus cusickii* var. *cusickii*	S1?	S

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Common Name	Scientific Name	State Rank	State Status
Fabaceae (continued)			
Transparent milk-vetch	*Astragalus diaphanus*	SX	X
Geyer's milk-vetch	*Astragalus geyeri*	S1	T
Thistle milk-vetch	*Astragalus kentrophyta* var. *douglasii*	SX	X
Least bladdery milk-vetch	*Astragalus microcystis*	S2	S
Pauper milk-vetch	*Astragalus misellus* var. *pauper*	S3	S
Loose-flower milk-vetch	*Astragalus multiflorus*	S1	T
Ames' milk-vetch	*Astragalus pulsiferae* var. *suksdorfii*	S1	E
Piper's milk-vetch	*Astragalus riparius*	S1S2	E
Robbins' milk-vetch	*Astragalus robbinsii* var. *minor*	SNR	R1
Whited's milk-vetch	*Astragalus sinuatus*	S1	E
Western hedysarum	*Hedysarum occidentale* var. *occidentale*	S1	S
Thin-leaved peavine	*Lathyrus holochlorus*	S1	E
Torrey's peavine	*Lathyrus torreyi*	S1	T
Pacific pea	*Lathyrus vestitus* ssp. *bolanderi*	S1	E
Prairie lupine	*Lupinus lepidus* var. *cusickii*	SU	R2
Sabin's lupine	*Lupinus sabinianus*	S1	E
Asotin silky lupine	*Lupinus sericeus* var. *asotinensis*	S3	R1
Kincaid's sulfur lupine	*Lupinus sulphureus* ssp. *kincaidii*	S1	E
Sticky crazyweed	*Oxytropis borealis* var. *viscida*	S1, S2	S
Columbia crazyweed	*Oxytropis campestris* var. *columbiana*	S1	E
Slender crazyweed	*Oxytropis campestris* var. *gracilis*	S2	S
Wanapum crazyweed	*Oxytropis campestris* var. *wanapum*	S1	E
Douglas' clover	*Trifolium douglasii*	S1	E
Plumed clover	*Trifolium plumosum* var. *amplifolium*	SNR	R1
Plumed clover	*Trifolium plumosum* var. *plumosum*	S1	T
Thompson's clover	*Trifolium thompsonii*	S2	T
Fagaceae			
Golden chinquapin	*Chrysolepis chrysophylla* var. *chrysophylla*	S2	S
Fumariaceae			
Clackamas corydalis	*Corydalis aquae-gelidae*	S2, S3	S
Gentianaceae			
Swamp gentian	*Gentiana douglasiana*	S2	S
glaucous gentian	*Gentiana glauca*	S2	S
Slender gentian	*Gentianella tenella* ssp. *tenella*	S1	S
swertia	*Swertia perennis*	S1?	R1
Monterey centaury	*Zeltnera muhlenbergii*	SH	R1

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Common Name	Scientific Name	State Rank	State Status
Geraniaceae			
Oregon crane's-bill	*Geranium oreganum*	SX	X
Grossulariaceae			
squaw currant	*Ribes cereum* var. *colubrinum*	S1	E
Idaho gooseberry	*Ribes oxyacanthoides* ssp. *irriguum*	S2	T
Haloragaceae			
Ussurian water-milfoil	*Myriophyllum ussuriense*	SNR	R1
Hydrangeaceae			
Yerba de Selva	*Whipplea modesta*	SNR	R1
Hydrophyllaceae			
Sticky phacelia	*Phacelia lenta*	S2	T
Least phacelia	*Phacelia minutissima*	S1	E
Dwarf phacelia	*Phacelia tetramera*	S1	S
Iridaceae			
Strict blue-eyed-grass	*Sisyrinchium montanum*	S1	T
Pale blue-eyed grass	*Sisyrinchium sarmentosum*	S1S2	T
Blue-eyed grass	*Sisyrinchium septentrionale*	S3	S
Isoetaceae			
Midget quillwort	*Isoetes minima*	S1	R1
Nuttall's quillwort	*Isoetes nuttallii*	S1	S
Juncaceae			
Dwarf rush	*Juncus hemiendytus* var. *hemiendytus*	S1	T
Howell's rush	*Juncus howellii*	S1	T
Kellogg's rush	*Juncus kelloggii*	S1	E
Spreading rush	*Juncus patens*	SNR	R1
Tiehm's rush	*Juncus tiehmii*	S1	T
Inch-high rush	*Juncus uncialis*	S2	S
Curved woodrush	*Luzula arcuata* ssp. *unalaschkensis*	S1	S
Lamiaceae			
Western false dragonhead	*Physostegia parviflora*	SNR	R1
Narrowleaf skullcap	*Scutellaria angustifolia* ssp. *micrantha*	S2 ,S3	R1
Oblong bluecurls	*Trichostema oblongum*	SNR	R1
Lemnaceae			
Columbia water-meal	*Wolffia columbiana*	SNR	R1

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Common Name	Scientific Name	State Rank	State Status
Lentibulariaceae			
Humped bladderwort	*Utricularia gibba*	SNR	R1
Flat-leaved bladderwort	*Utricularia intermedia*	S2	S
Lesser bladderwort	*Utricularia minor*	S2?	R1
Liliaceae			
Twincrest onion	*Allium bisceptrum*	S1	R1
Sierra onion	*Allium campanulatum*	S1	T
Columbian onion	*Allium columbianum*	SNR	R1
Constricted Douglas' onion	*Allium constrictum*	S2, S3	S
Blue Mountain onion	*Allium dictuon*	S2	T
Long-bearded sego lily	*Calochortus longebarbatus* var. *longebarbatus*	S2, S3	S
Sagebrush mariposa-lily	*Calochortus macrocarpus* var. *maculosus*	S1	E
Broad-fruit mariposa	*Calochortus nitidus*	S1	E
Quinault fawnlily	*Erythronium quinaultense*	S1, S2	T
Pink fawn-lily	*Erythronium revolutum*	S3	S
Black lily	*Fritillaria camschatcensis*	S2	S
Small-flowered trillium	*Trillium parviflorum*	S2, S3	S
Siskiyou false-hellebore	*Veratrum insolitum*	S1	T
Linaceae			
Northwestern yellowflax	*Sclerolinon digynum*	S1, S2	T
Lycopodiaceae			
Bog clubmoss	*Lycopodiella inundata*	S2	S
Treelike clubmoss	*Lycopodium dendroideum*	S2	S
Lythraceae			
Grand redstem	*Ammannia robusta*	S1	T
Lowland toothcup	*Rotala ramosior*	S1	T
Malvaceae			
Longsepal globemallow	*Iliamna longisepala*	S3	S
Hairy-stemmed checker-mallow	*Sidalcea hirtipes*	S1	E
Rose checker-mallow	*Sidalcea malviflora* ssp. *virgata*	S1	E
Nelson's checker-mallow	*Sidalcea nelsoniana*	S1	E
Wenatchee Mountain checker-mallow	*Sidalcea oregana* var. *calva*	S1	E

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Common Name	Scientific Name	State Rank	State Status
Marsileaceae			
American pillwort	*Pilularia americana*	S1, S2	T
Monotropaceae			
Pine-foot	*Pityopus californica*	S1	T
Nyctaginaceae			
Pink sand-verbena	*Abronia umbellata* var. *breviflora*	S1	E
Nymphaeaceae			
Pygmy water-lily	*Nymphaea tetragona*	SH	X
Onagraceae			
Small-flower evening-primrose	*Camissonia minor*	S2	S
Dwarf evening-primrose	*Camissonia pygmaea*	S3	S
Naked-stemmed evening-primrose	*Camissonia scapoidea* ssp. *scapoidea*	S1	S
Cespitose evening-primrose	*Oenothera caespitosa* ssp. *caespitosa*	S2	S
Tufted evening-primrose	*Oenothera caespitosa* ssp. *marginata*	S1	T
Long-tubed evening-primrose	*Oenothera flava* ssp. *flava*	SH	X
Ophioglossaceae			
Triangular-lobed moonwort	*Botrychium ascendens*	S2	S
Crenulate moonwort	*Botrychium crenulatum*	S3	S
Western moonwort	*Botrychium hesperium*	S1	T
Skinny moonwort	*Botrychium lineare*	S1	T
Two-spiked moonwort	*Botrychium paradoxum*	S2	T
Stalked moonwort	*Botrychium pedunculosum*	S2	S
Adder's-tongue	*Ophioglossum pusillum*	S1, S2	T
Orchidaceae			
Long-bract frog orchid	*Coeloglossum viride*	S1	T
Clustered lady's-slipper	*Cypripedium fasciculatum*	S3	S
Yellow lady's-slipper	*Cypripedium parviflorum*	S2	T
Twayblade	*Liparis loeselii*	S1	E
White adder's-mouth orchid	*Malaxis monophyllos* var. *brachypoda*	SNR	R1
Sheviak's bog orchid	*Platanthera aquilonis*	SNR	R1
Choris' bog-orchid	*Platanthera chorisiana*	S2	T
Small northern bog-orchid	*Platanthera obtusata*	S2	S
Canyon bog-orchid	*Platanthera sparsiflora*	S1	T
Ute ladies' tresses	*Spiranthes diluvialis*	S1	E
Western ladies-tresses	*Spiranthes porrifolia*	S2	S

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WASHINGTON STATE RARE PLANTS[1,2]

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Common Name	Scientific Name	State Rank	State Status
Orobanchaceae			
Vancouver ground-cone	*Boschniakia hookeri*	S3?	R1
California broomrape	*Orobanche californica* ssp. *grayana*	SX	X
Oxalidaceae			
Western yellow oxalis	*Oxalis suksdorfii*	S1	T
Papaveraceae			
White meconella	*Meconella oregana*	S1	T
Plantaginaceae			
Alaska plantain	*Plantago macrocarpa*	S2	S
Poaceae			
Northern bentgrass	*Agrostis mertensii*	S1, S2	T
Common northern sweet grass	*Anthoxanthum hirtum*	SNR	R1
Blue joint reedgrass	*Calamagrostis canadensis* var. *imberbis*	S2?	R2
Yellow wildrye	*Leymus flavescens*	SNR	R1
Beardless wildrye	*Leymus triticoides*	SNR	R1
Marsh muhly	*Muhlenbergia glomerata*	S1, S2	S
Mexican muhly	*Muhlenbergia mexicana* var. *mexicana*	SNR	R1
Loose-flowered bluegrass	*Poa laxiflora*	S2S3	S
Wheeler's bluegrass	*Poa nervosa*	S2	S
Ocean-bluff bluegrass	*Poa unilateralis* ssp. *pachypholis*	S2	T
Little bluestem	*Schizachyrium scoparium* var. *scoparium*	S1, S2	T
Scribner-grass	*Scribneria bolanderi*	S1	S
Prairie cordgrass	*Spartina pectinata*	S2	S
Polemoniaceae			
Great Basin gilia	*Aliciella leptomeria*	S1	T
Bristle-flowered collomia	*Collomia macrocalyx*	S1	S
Delicate gilia	*Lathrocasis tenerrima*	SU	R1
Baker's linanthus	*Leptosiphon bolanderi*	S2	S
True babystars	*Leptosiphon minimus*	SU	R1
Marigold navarretia	*Navarretia tagetina*	S1	T
Great polemonium	*Polemonium carneum*	S1, S2	T
Washington polemonium	*Polemonium pectinatum*	S2	T
Skunk polemonium	*Polemonium viscosum*	S1, S2	S

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Common Name	Scientific Name	State Rank	State Status
Polygonaceae			
Umtanum desert buckwheat	*Eriogonum codium*	S1	E
Spotted buckwheat	*Eriogonum maculatum*	SX	X
Mountain buckwheat	*Eriogonum marifolium*	SNR	R1
Austin's knotweed	*Polygonum austiniae*	S1	T
Parry's knotweed	*Polygonum parryi*	S1?	T
Portulacaceae			
Rosy pussypaws	*Cistanthe rosea*	S1	T
Pacific lanceleaved springbeauty	*Claytonia multiscapa* ssp. *pacifica*	S1	T
Branching montia	*Montia diffusa*	S2, S3	S
Potamogetonaceae			
Leafy pondweed	*Potamogeton foliosus* ssp. *fibrillosus*	SNR	R1
Blunt-leaved pondweed	*Potamogeton obtusifolius*	S2	S
Western fineleaf pondweed	*Stuckenia filiformis* ssp. *occidentalis*	S1, S2	R1
Primulaceae			
Chaffweed	*Anagallis minima*	S2	T
Frigid shootingstar	*Dodecatheon austrofrigidum*	S1	E
Water-pimpernel	*Samolus parviflorus*	S1	S
Pteridaceae			
Aleutian maidenhair	*Adiantum aleuticum* ssp. *subpumilum*	SU	R2
Fee's lip-fern	*Cheilanthes feei*	S1	T
Steller's rockbrake	*Cryptogramma stelleri*	S1, S2	S
Sierra cliff-brake	*Pellaea brachyptera*	S2	S
Brewer's cliff-brake	*Pellaea breweri*	S2	S
Smooth cliff-brake	*Pellaea glabella* ssp. *simplex*	SU	R2
Ranunculaceae			
Pasqueflower	*Anemone patens* var. *multifida*	S1	T
Tall bugbane	*Cimicifuga elata* var. *elata*	S3	S
Spleenwort-leaved goldthread	*Coptis aspleniifolia*	S2	S
Goldthread	*Coptis trifolia*	S1	T
Pale larkspur	*Delphinium leucophaeum*	S1	E
Wenatchee larkspur	*Delphinium viridescens*	S2	T
Mousetail	*Myosurus clavicaulis*	S2	S
California buttercup	*Ranunculus californicus*	S1	T
Cooley's buttercup	*Ranunculus cooleyae*	S1, S2	S

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Common Name	Scientific Name	State Rank	State Status
Ranunculaceae (continued)			
Gorman's buttercup	*Ranunculus gormanii*	SNR	R1
Downy butter-cup	*Ranunculus hebecarpus*	SNR	R1
Mountain buttercup	*Ranunculus populago*	S2	S
Dwarf buttercup	*Ranunculus pygmaeus*	SU	R1
Obscure buttercup	*Ranunculus triternatus*	S1	E
Rosaceae			
Phipps' hawthorn	*Crataegus phippsii*	S1	R1
Yellow mountain-avens	*Dryas drummondii* var. *drummondii*	S2	S
Queen-of-the-forest	*Filipendula occidentalis*	S2, S3	T
Water avens	*Geum rivale*	S2, S3	S
Ross' avens	*Geum rossii* var. *depressum*	S1	E
Rocky Mountain rockmat	*Petrophyton caespitosum* var. *caespitosum*	S1	T
Chelan rockmat	*Petrophyton cinerascens*	S1	E
Brewer's cinquefoil	*Potentilla breweri*	S1	T
Diverse-leaved cinquefoil	*Potentilla glaucophylla* var. *perdissecta*	S1	S
Newberry cinquefoil	*Potentilla newberryi*	SH	X
Snow cinquefoil	*Potentilla nivea*	S2	S
Five-leaved cinquefoil	*Potentilla rubricaulis*	S1	T
Nagoonberry	*Rubus arcticus* ssp. *acaulis*	S1	T
Northwest raspberry	*Rubus nigerrimus*	S1	E
Menzies' burnet	*Sanguisorba menziesii*	S1	T
Salicaceae			
Hoary willow	*Salix candida*	S1	T
Glaucous willow	*Salix glauca* var. *villosa*	S1, S2	S
Maccall's willow	*Salix maccalliana*	S1	S
False mountain willow	*Salix pseudomonticola*	S1	S
Soft-leaved willow	*Salix sessilifolia*	S2	S
Tweedy's willow	*Salix tweedyi*	S3	S
Rock willow	*Salix vestita* var. *erecta*	SH	X
Saxifragaceae			
Bolandra	*Bolandra oregana*	S2	S
Northern golden-carpet	*Chrysosplenium tetrandrum*	S2	S
Gooseberry-leaved alumroot	*Heuchera grossulariifolia* var. *grossulariifolia*	SNR	R1
Gooseberry-leaved alumroot	*Heuchera grossulariifolia* var. *tenuifolia*	S3	S

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Common Name	Scientific Name	State Rank	State Status
Saxifragaceae (continued)			
Fringed grass-of-parnassus	*Parnassia fimbriata* var. *hoodiana*	S1	T
Kotzebue's grass-of-parnassus	*Parnassia kotzebuei*	S1	T
Northern grass-of-parnassus	*Parnassia palustris* var. *neogaea*	S2	S
Nodding saxifrage	*Saxifraga cernua*	S1, S2	S
Pygmy saxifrage	*Saxifraga rivularis*	S3	S
Tisch's saxifrage	*Saxifraga tischii*	S1?	R1
Strawberry saxifrage	*Saxifragopsis fragarioides*	S1	T
Oregon sullivantia	*Sullivantia oregana*	S1	E
Scrophulariaceae			
Obscure Indian-paintbrush	*Castilleja cryptantha*	S2, S3	S
Golden paintbrush	*Castilleja levisecta*	S1	E
Victoria's paintbrush	*Castilleja victoriae*	S1	E
Few-flowered collinsia	*Collinsia sparsiflora* var. *bruceae*	S1, S2	S
False monkeyflower	*Mimetanthe pilosa*	SNR	R1
Bank monkey-flower	*Mimulus clivicola*	SNR	R1
Cusick monkeyflower	*Mimulus cusickii*	S1	T
Liverwort monkey-flower	*Mimulus jungermannioides*	SH	X
Stalk-leaved monkeyflower	*Mimulus patulus*	S1	T
Pulsifer's monkey-flower	*Mimulus pulsiferae*	S2	S
Suksdorf's monkey-flower	*Mimulus suksdorfii*	S2	S
Washington monkey-flower	*Mimulus washingtonensis*	SX	X
Texas toadflax	*Nuttallanthus texanus*	S1	S
Rosy owl-clover	*Orthocarpus bracteosus*	S1	E
Parry's lousewort	*Pedicularis parryi*	SNR	R1
Mt. Rainier lousewort	*Pedicularis rainierensis*	S2, S3	S
Barrett's beardtongue	*Penstemon barrettiae*	S2	T
Hot-rock penstemon	*Penstemon deustus* var. *variabilis*	S1, S2	T
Fuzzytongue penstemon	*Penstemon eriantherus* var. *whitedii*	S2	S
Wilcox's penstemon	*Penstemon wilcoxii*	S1	S
Cut-leaf synthyris	*Synthyris pinnatifida* var. *lanuginosa*	S2	T
Fringed synthyris	*Synthyris schizantha*	SNR	R1
Solanaceae			
Coyote tobacco	*Nicotiana attenuata*	S2	S
Sparganiaceae			
Water bur-reed	*Sparganium fluctuans*	S1	T

TABLE C-3

WASHINGTON STATE RARE PLANTS[1,2]

Imazapyr Risk Assessment
Washington State

Common Name	Scientific Name	State Rank	State Status
Verbenaceae			
Hoary verbena	*Verbena stricta*	SNR	R1
Violaceae			
Kidney-leaved violet	*Viola renifolia*	S2	S

Notes:

1. Source: WNHP, 2009.
2. Distribution maps for listed plant species are provided on the compact disc (CD) included with this appendix.

Abbreviation(s)

S1 = Critically imperiled (5 or fewer occurrences).
S2 = Imperiled (6 to 20 occurrences), very vulnerable to extirpation.
S3 = Rare or uncommon (21 to 100 occurrences).
S4 = Apparently secure, with many occurrences.
S5 = Demonstrably secure in state.
SA = Accidental in state.
SE = An exotic established in state.
SH = Historical occurrences only but still expected to occur.
SN = Regularly occurring, usually migratory, nonbreeding animals.
SU = Unrankable; need more information.
SX = Apparently extirpated from the state.
SP = Likely to occur or to have occurred but without documentation.
SZ = Not of conservation concern (not SE or SA).
SNR = Not yet ranked.
E = Endangered. In danger of becoming extinct or extirpated from Washington.
T = Threatened. Likely to become Endangered in Washington.
S = Sensitive. Vulnerable or declining and could become Endangered or Threatened in the state.
X = Possibly extinct or Extirpated from Washington.
P1 = Priority 1. Rare nonvascular plant but with insufficient information to assign another rank.
P2 = Priority 2. Nonvascular plant of concern but with insufficient information to assign another rank.
R1 = Review group 1. Of potential concern but needs more field work to assign another rank.
R2 = Review group 2. Of potential concern but with unresolved taxonomic questions.
W = Watch. More abundant and/or less threatened than previously thought.

DISTRIBUTION MAPS OF FEDERALLY LISTED ANIMALS AND PLANTS OCCURRING IN WASHINGTON

Imazapyr Risk Assessment
Washington State

Figure C-1 Distribution of Columbian white-tailed deer (Columbia River DPS) *Odocoileus virginianus leucurus* in Washington.

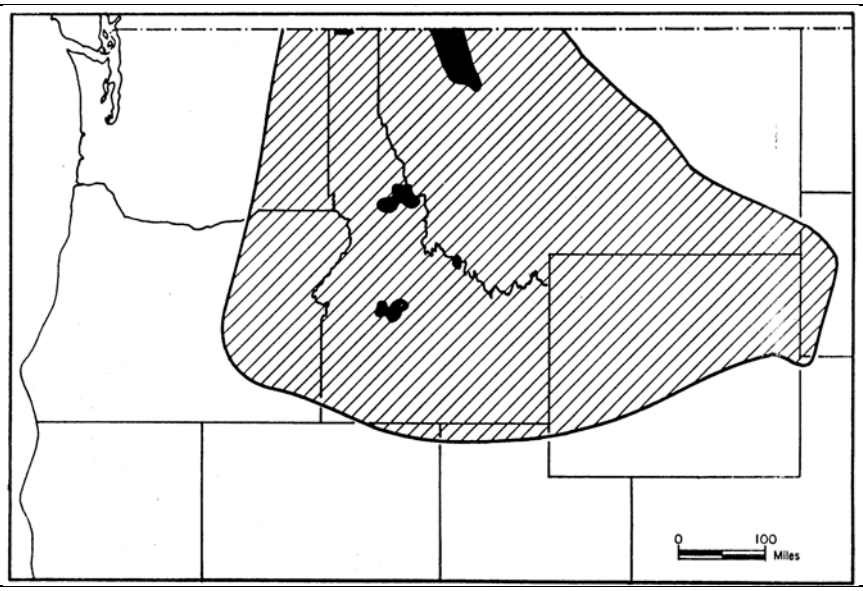

Figure C-2 Distribution of Gray wolf *Canis lupus* in Washington.

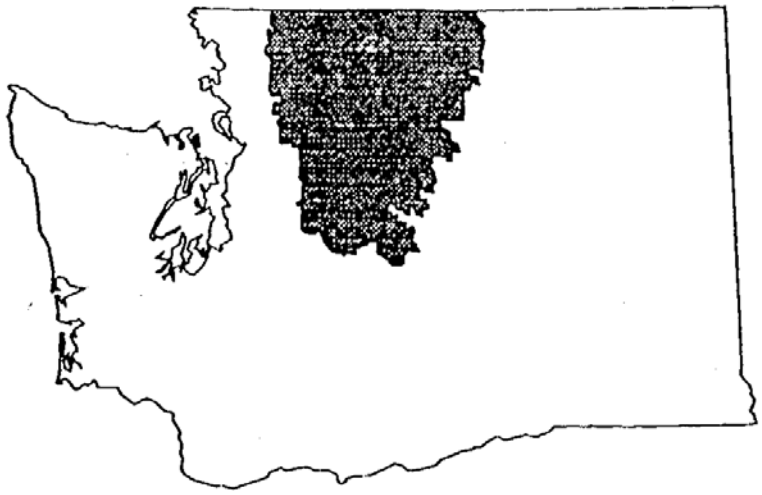

Figure C-3 Distribution of Grizzly bear *Ursus arctos horribilis* in Washington.

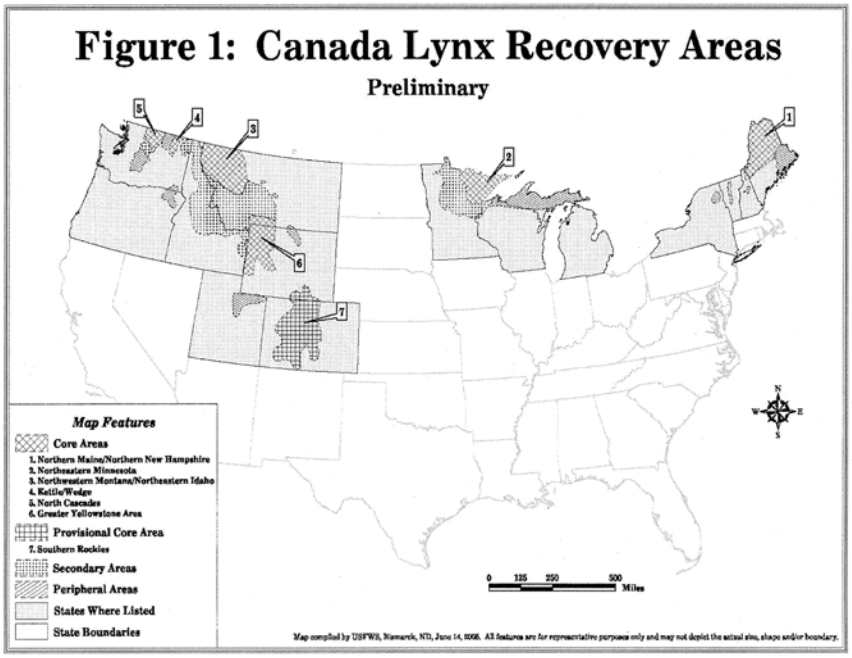

Figure C-4 Distribution of Canada lynx *Lynx canadensis* in Washington.

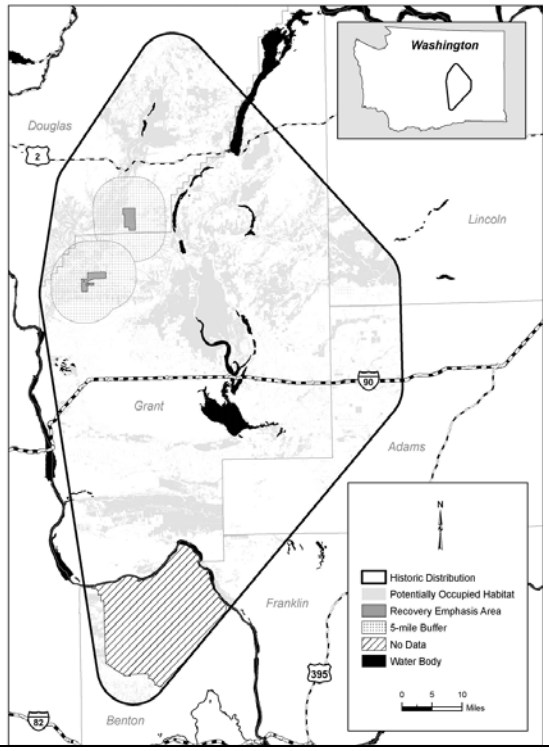

Figure C-5 Distribution of Pygmy rabbit (Columbian basin DPS) *Brachylagus idahoensis* in Washington.

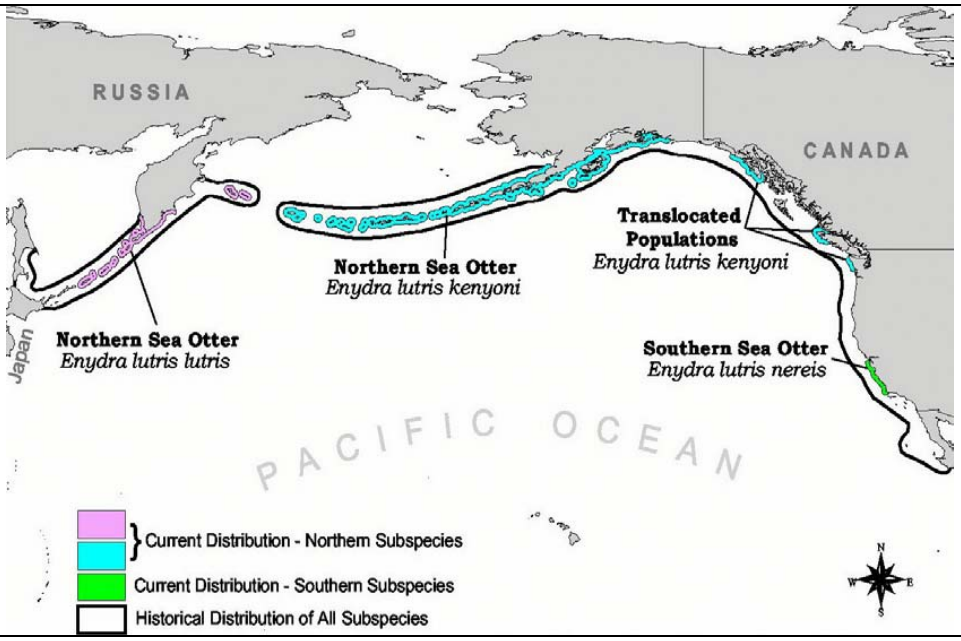

Figure C-6 Distribution of Sea otter *Enhydra lutris nereis* in Washington.

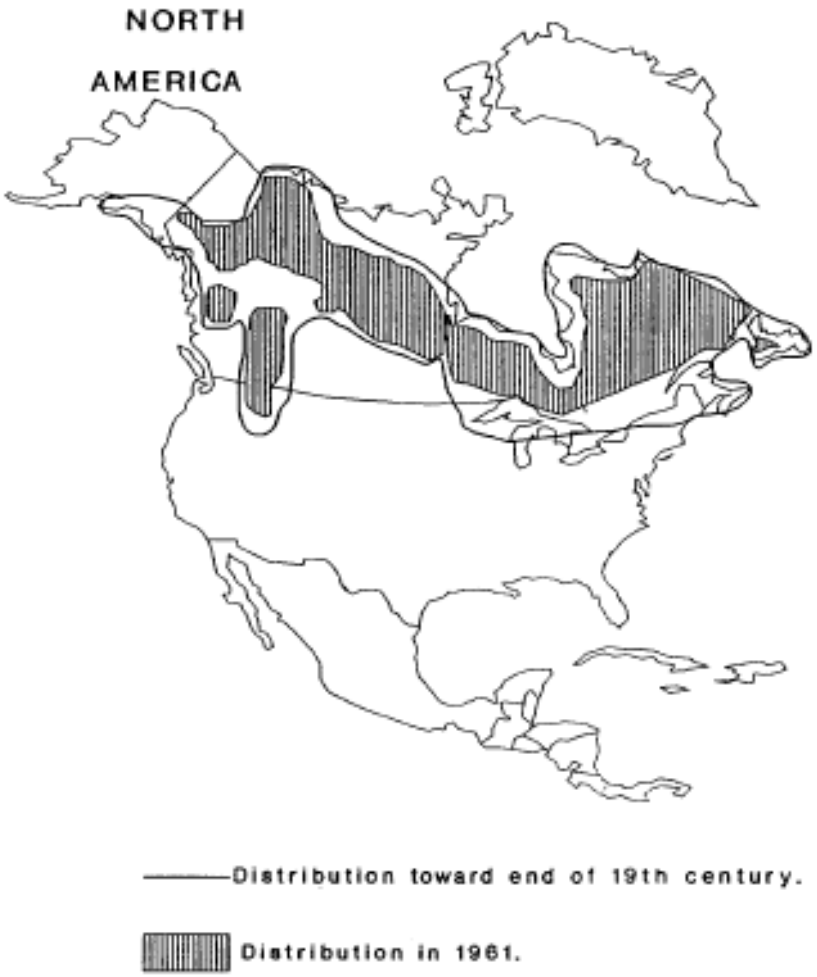

Figure C-7 Distribution of Woodland caribou (Selkirk Mountain DPS) *Rangifer tarandus caribou* in Washington.

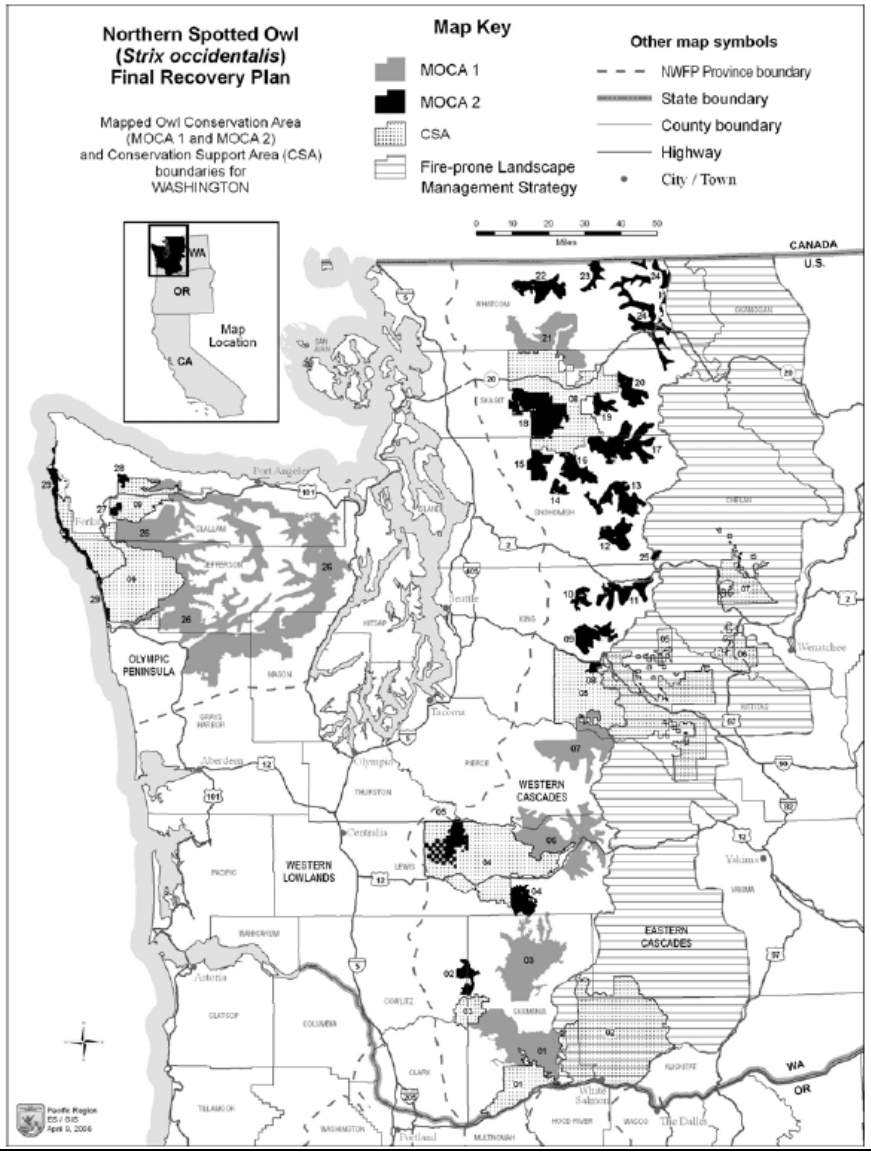

Figure C-8 Distribution of Northern spotted owl *Strix occidentalis caurina* in Washington.

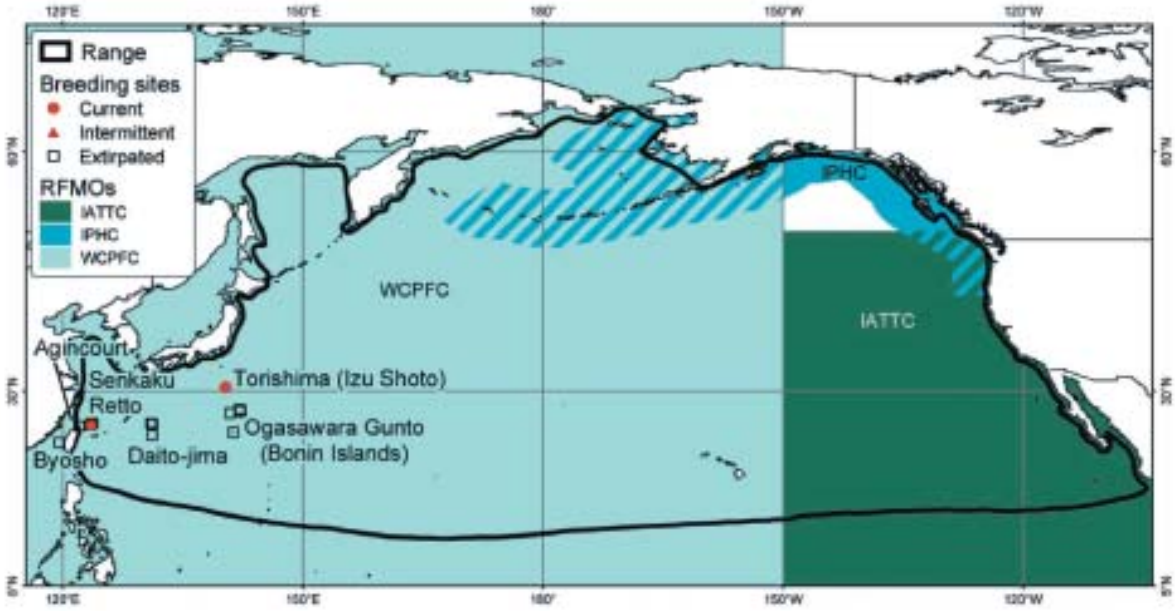

Figure C-9 Distribution of Short-tailed albatross *Phoebastria (=Diomedea) albatrus* in Washington.

Figure C-10 Distribution of Western snowy plover *Charadrius alexandrinus nivosus* in Washington.

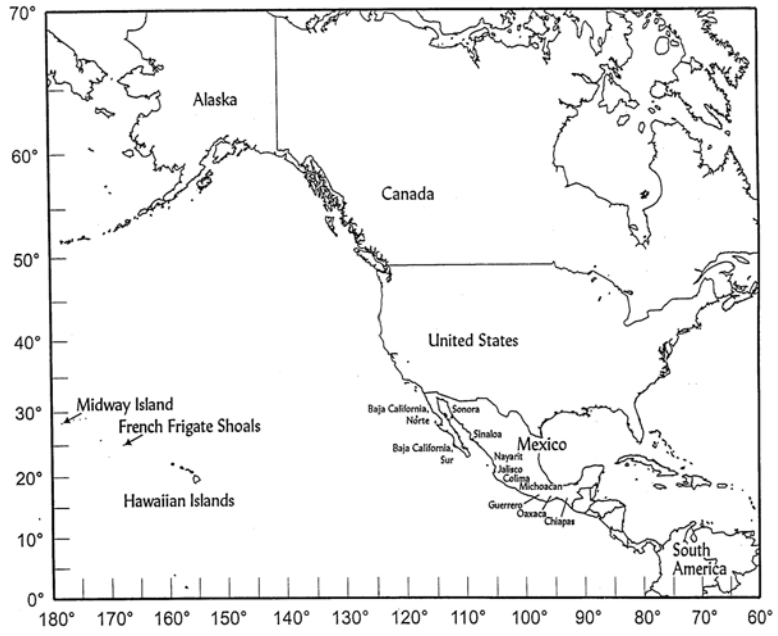

Figure C-11 Distribution of Green sea turtle *Chelonia mydas* in Washington.

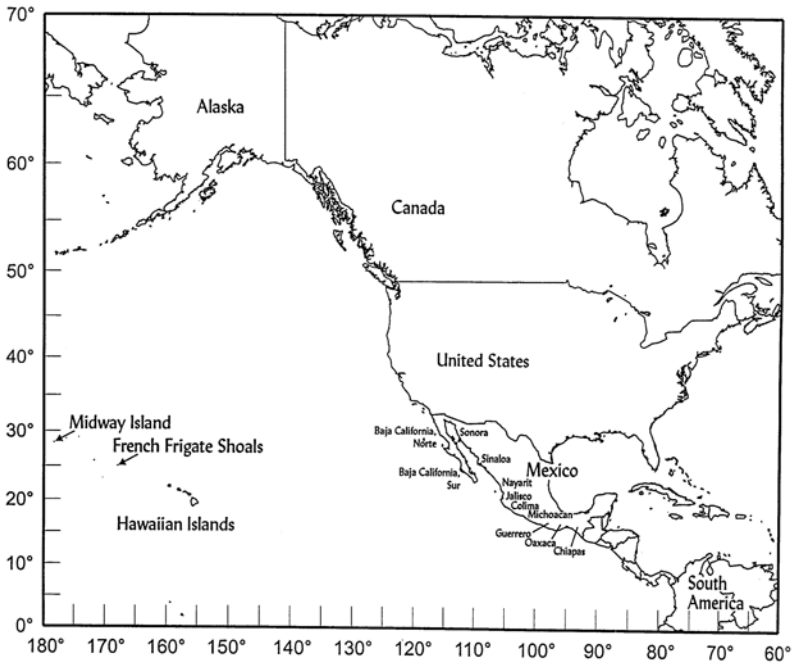

Figure C-12 Distribution of Leatherback sea turtle *Dermochelys coriacea* in Washington.

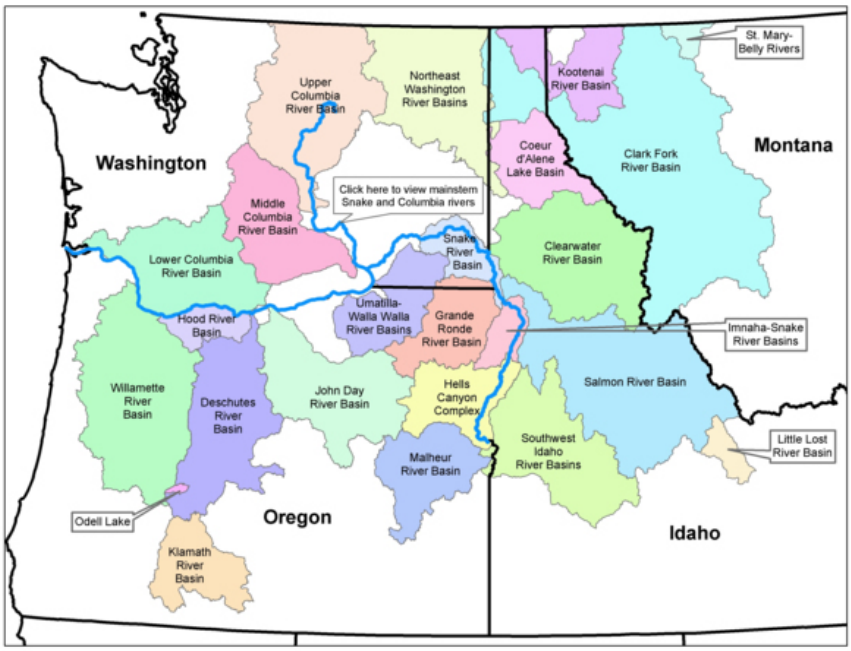

Figure C-13 Distribution of Bull trout *Salvelinus confluentus* in Washington.

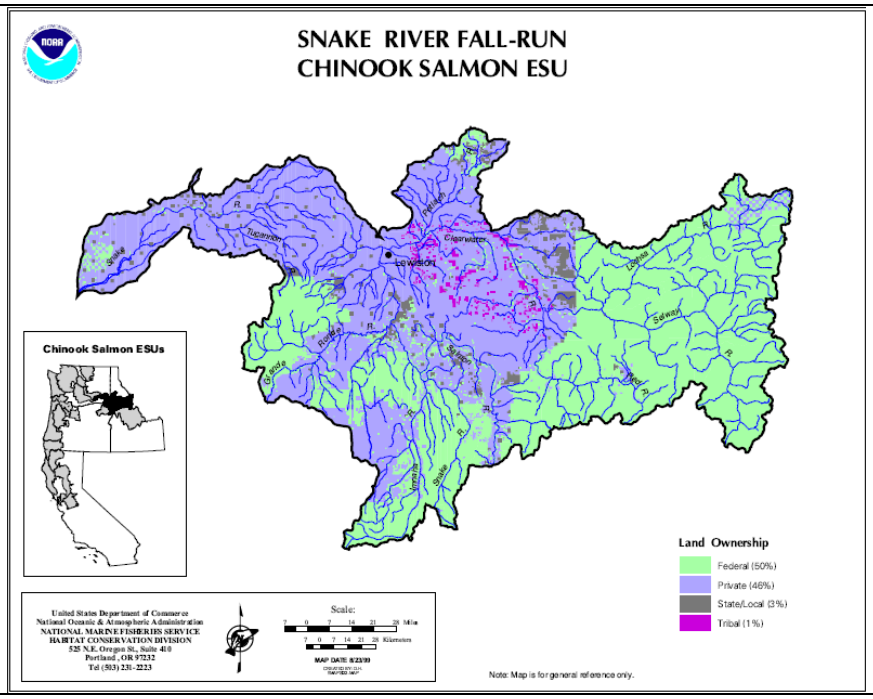

Figure C-14 Distribution of Chinook salmon (Snake River Fall-Run ESU) *Oncorhynchus tshawytscha* in Washington.

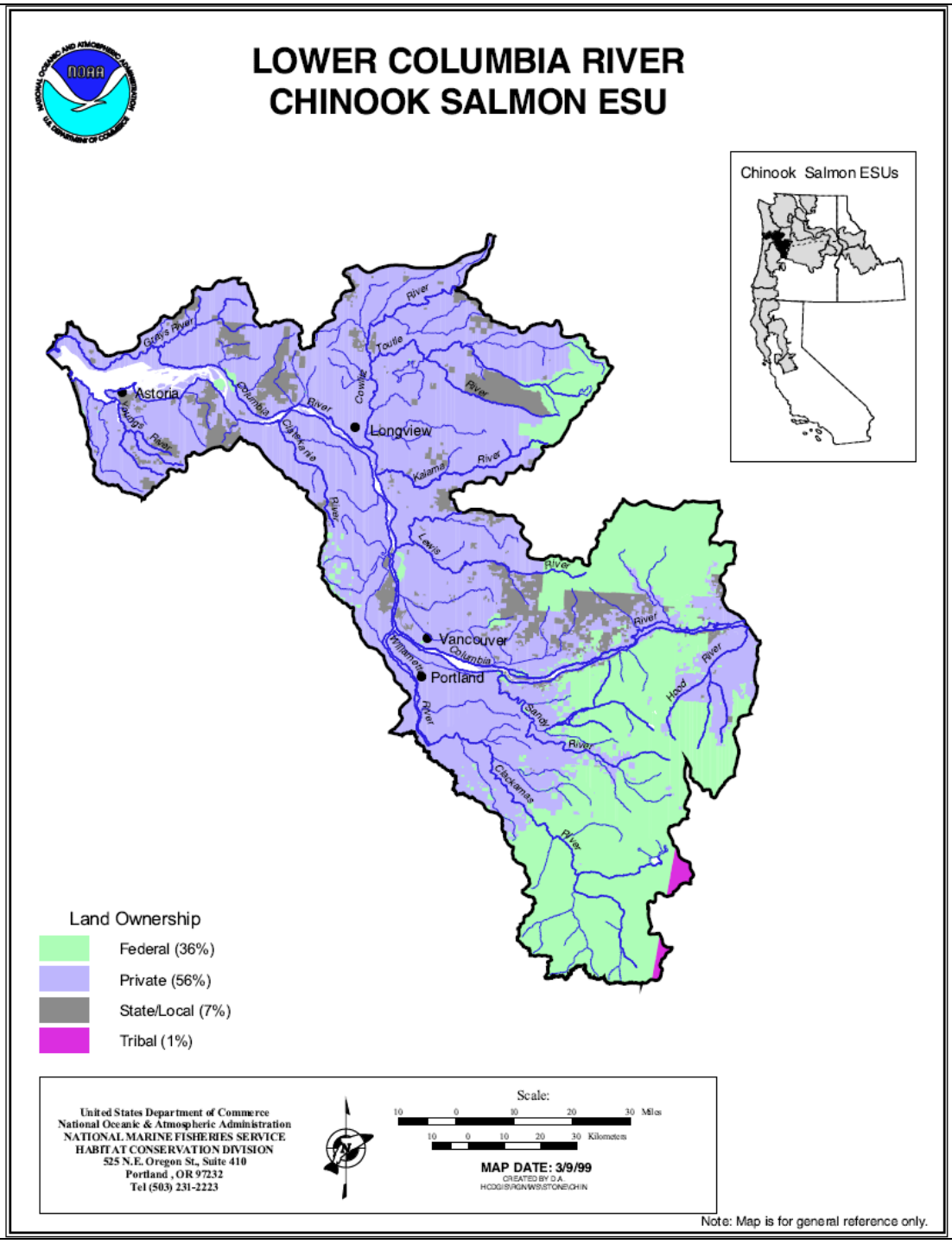

Figure C-15 Distribution of Chinook salmon (Lower Columbia River ESU) *Oncorhynchus tshawytscha* in Washington.

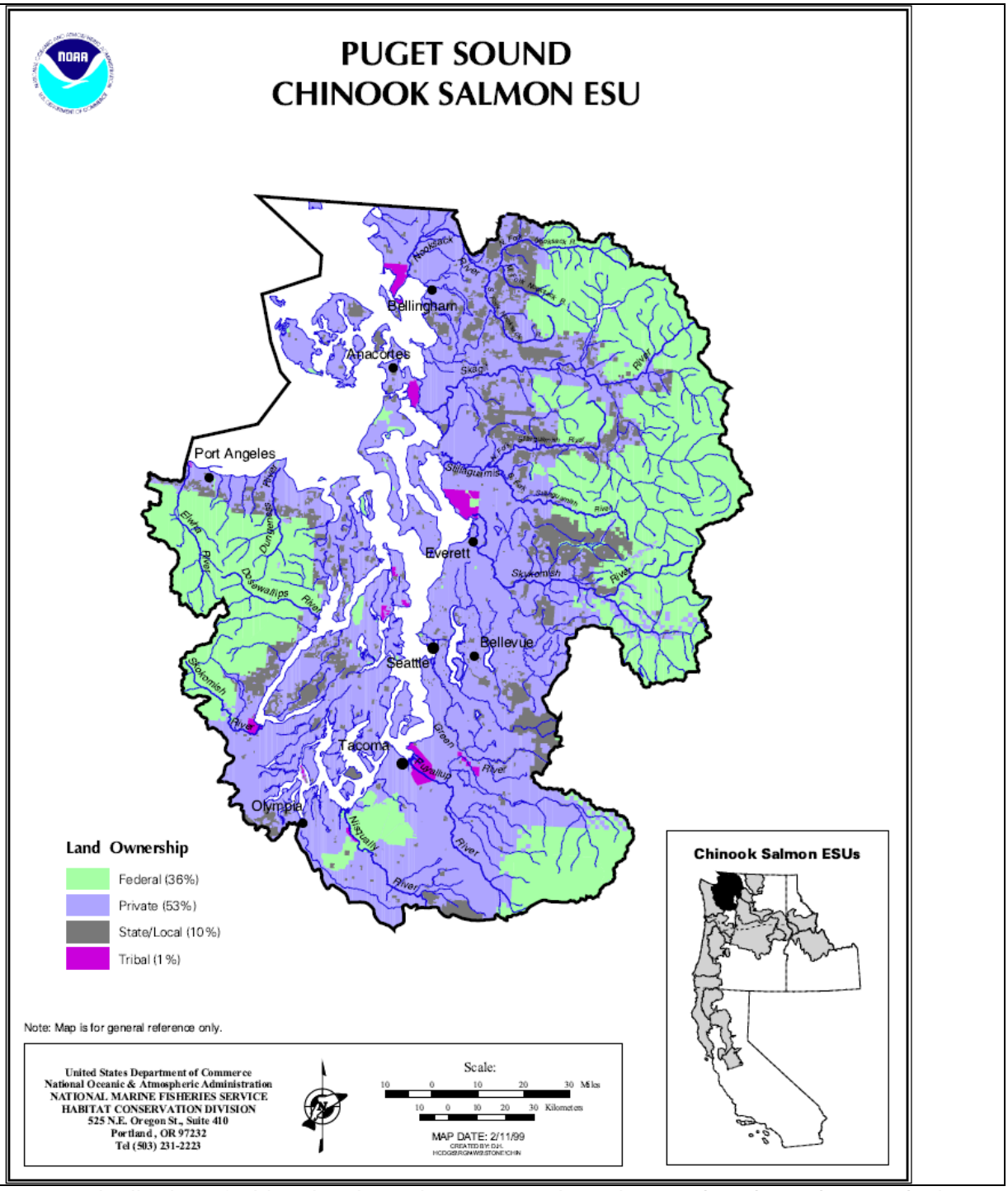

Figure C-16 Distribution of Chinook salmon (Puget Sound ESU) *Oncorhynchus tshawytscha* in Washington.

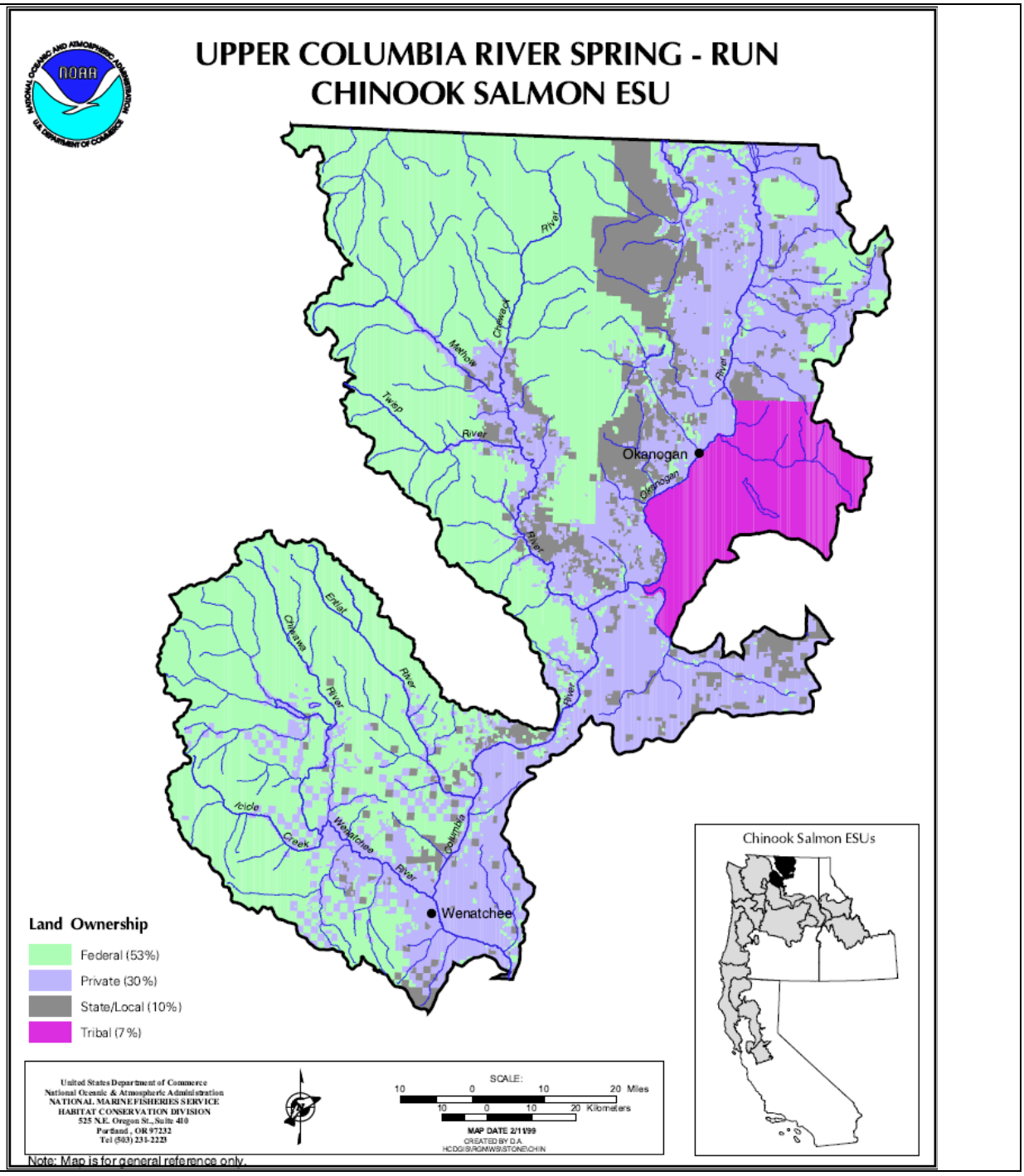

Figure C-17 Distribution of Chinook salmon (Upper Columbia Spring-Run ESU) *Oncorhynchus tshawytscha* in Washington.

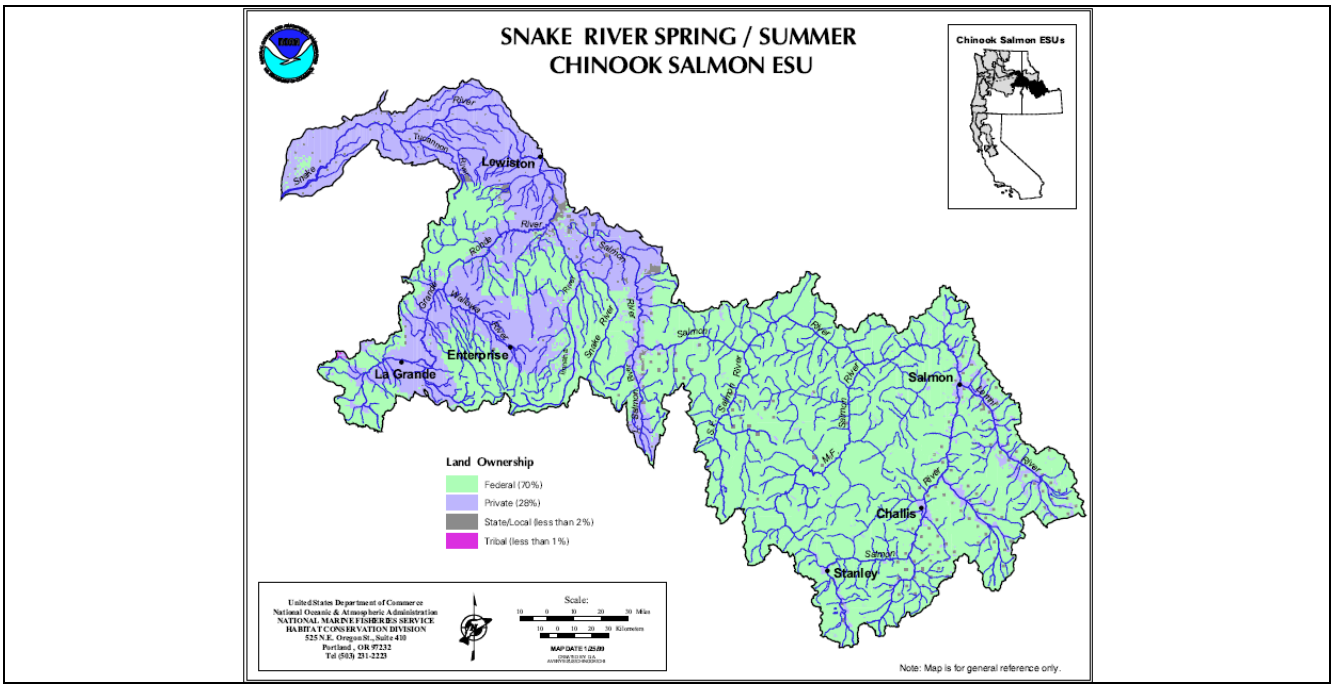

Figure C-18 Distribution of Chinook salmon (Snake River Spring/Summer-Run ESU) *Oncorhynchus tshawytscha* in Washington.

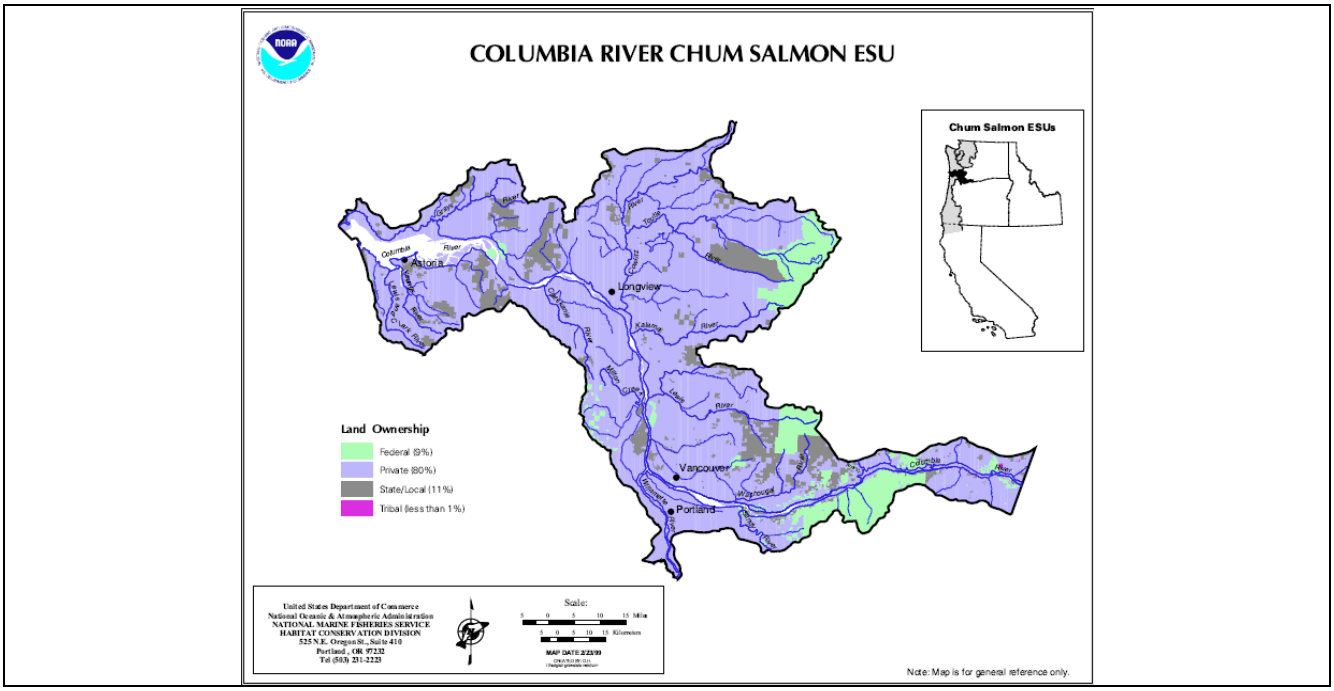

Figure C-19 Distribution of Chum salmon (Columbia River ESU) *Oncorhynchus keta* in Washington.

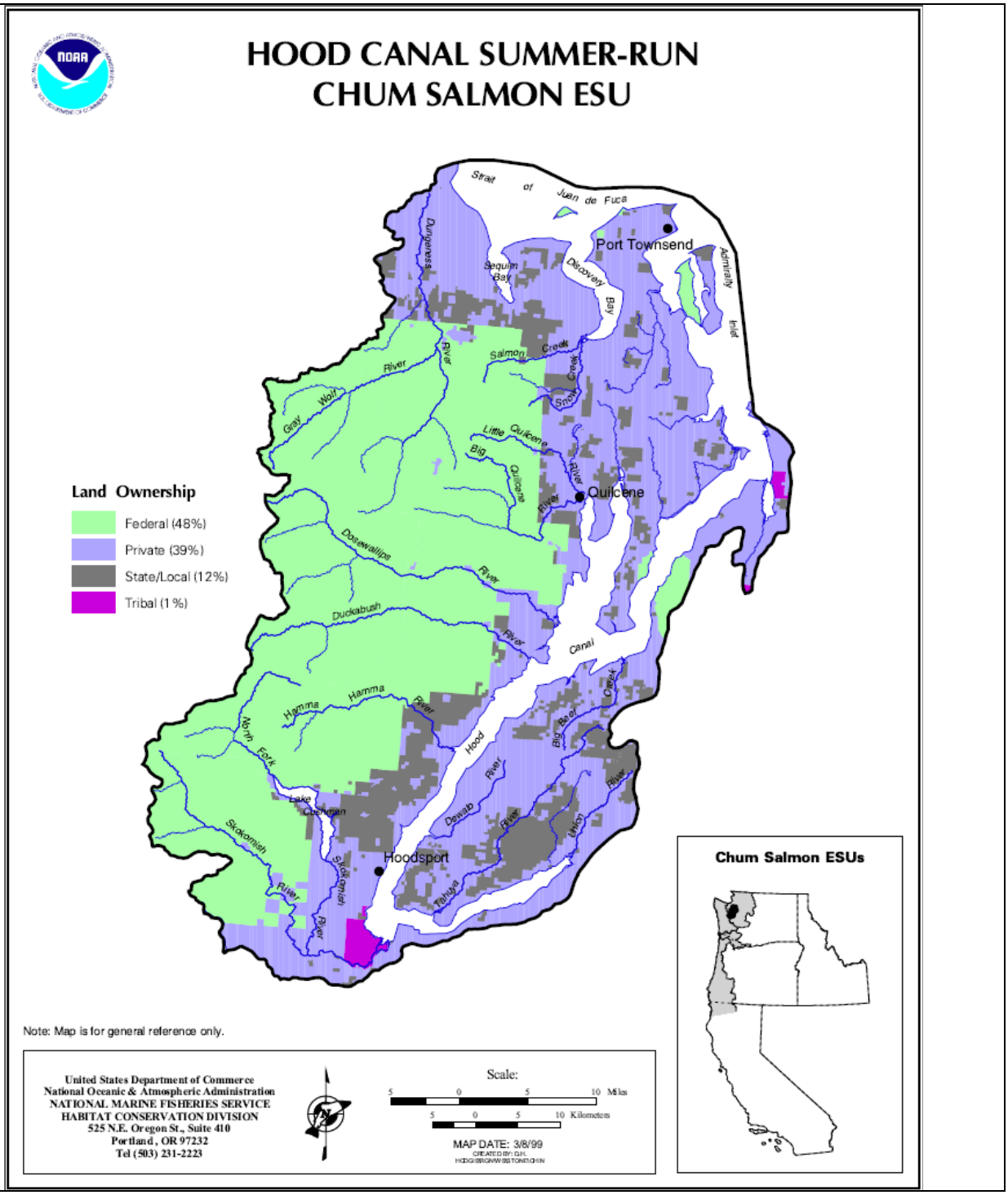

Figure C-20 Distribution of Chum salmon (Hood Canal Summer-Run ESU) *Oncorhynchus keta* in Washington.

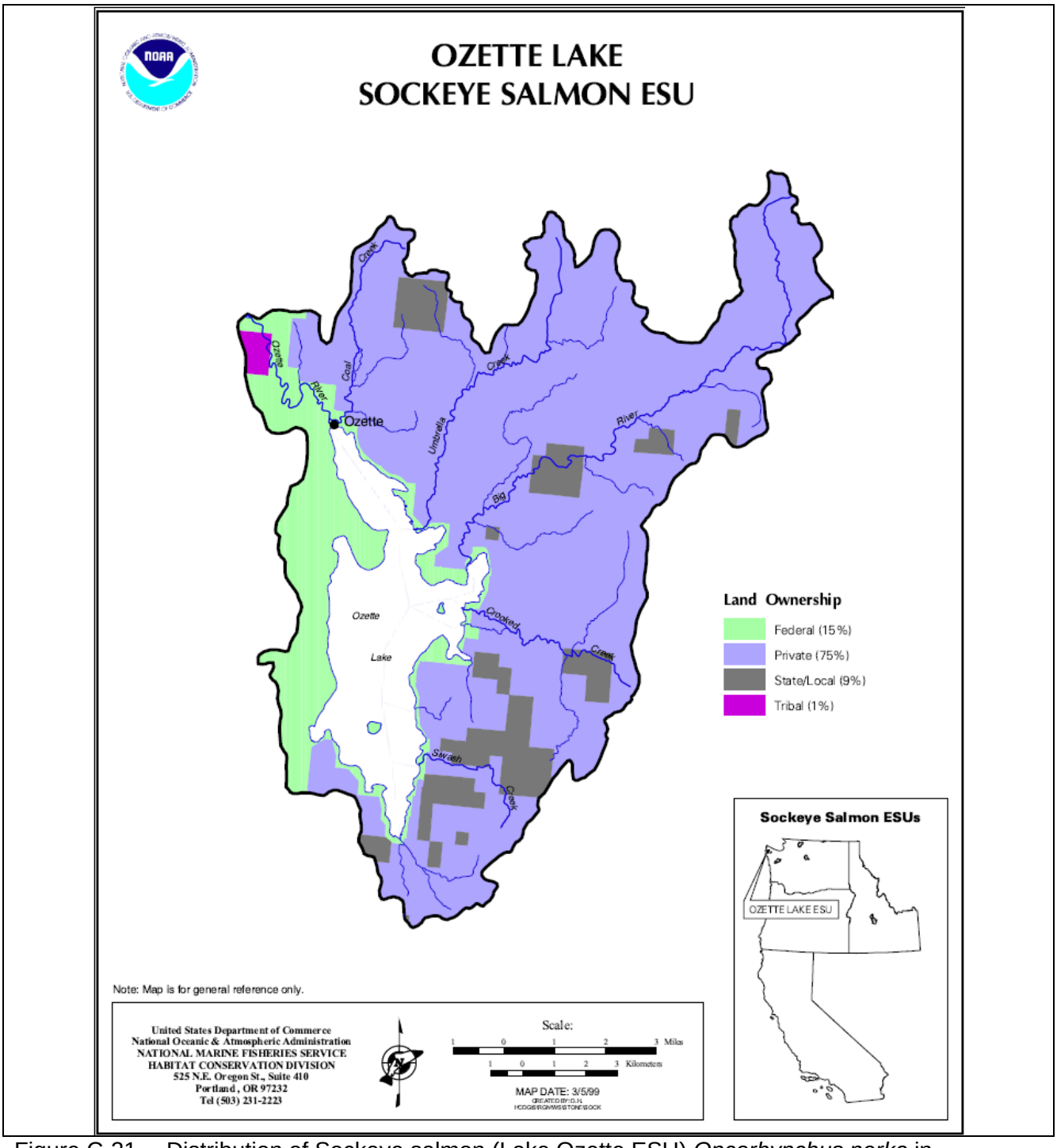

Figure C-21 Distribution of Sockeye salmon (Lake Ozette ESU) *Oncorhynchus nerka* in Washington.

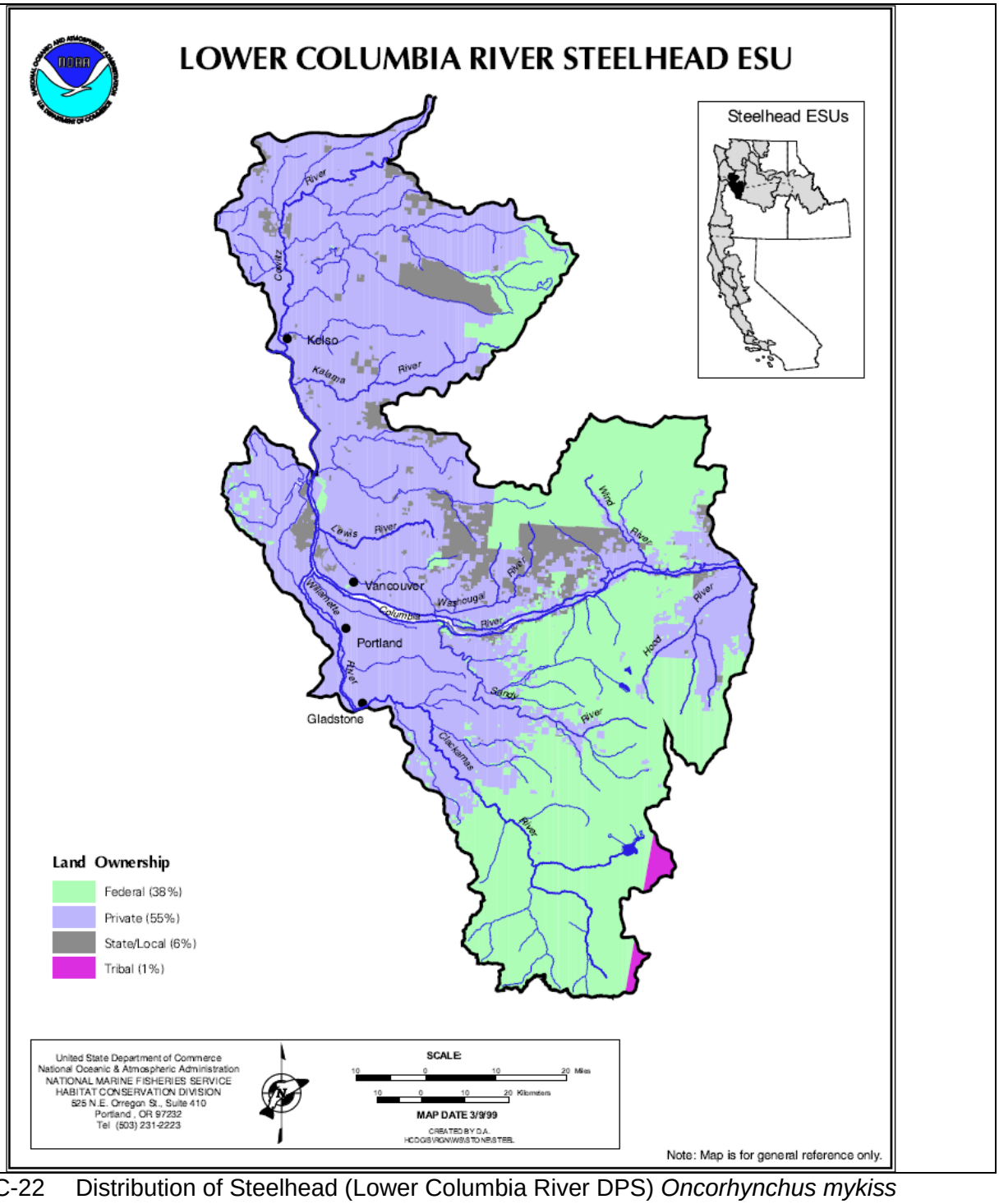

Figure C-22 Distribution of Steelhead (Lower Columbia River DPS) *Oncorhynchus mykiss* in Washington.

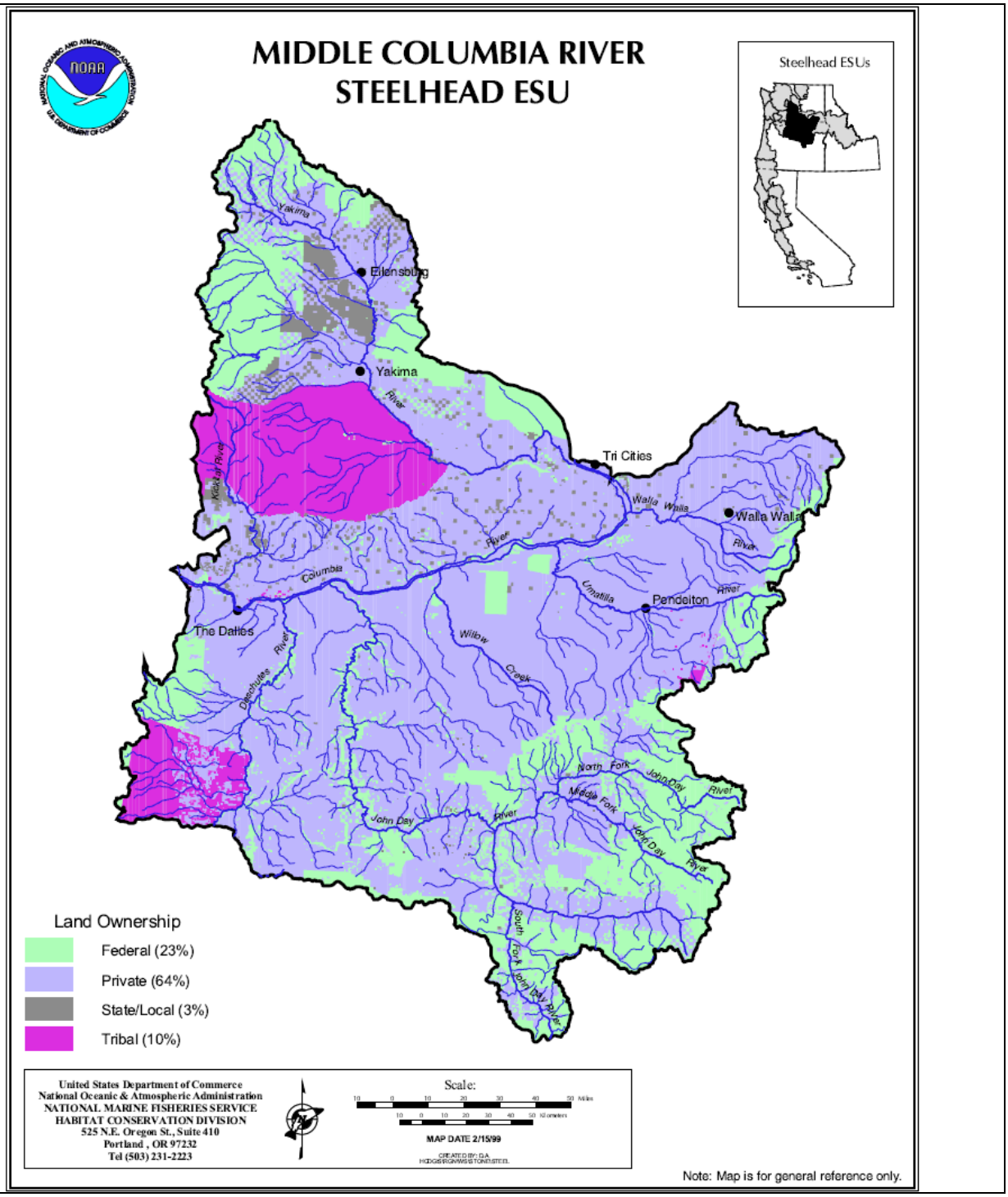

Figure C-23 Distribution of Steelhead (Middle Columbia River DPS) *Oncorhynchus mykiss* in Washington.

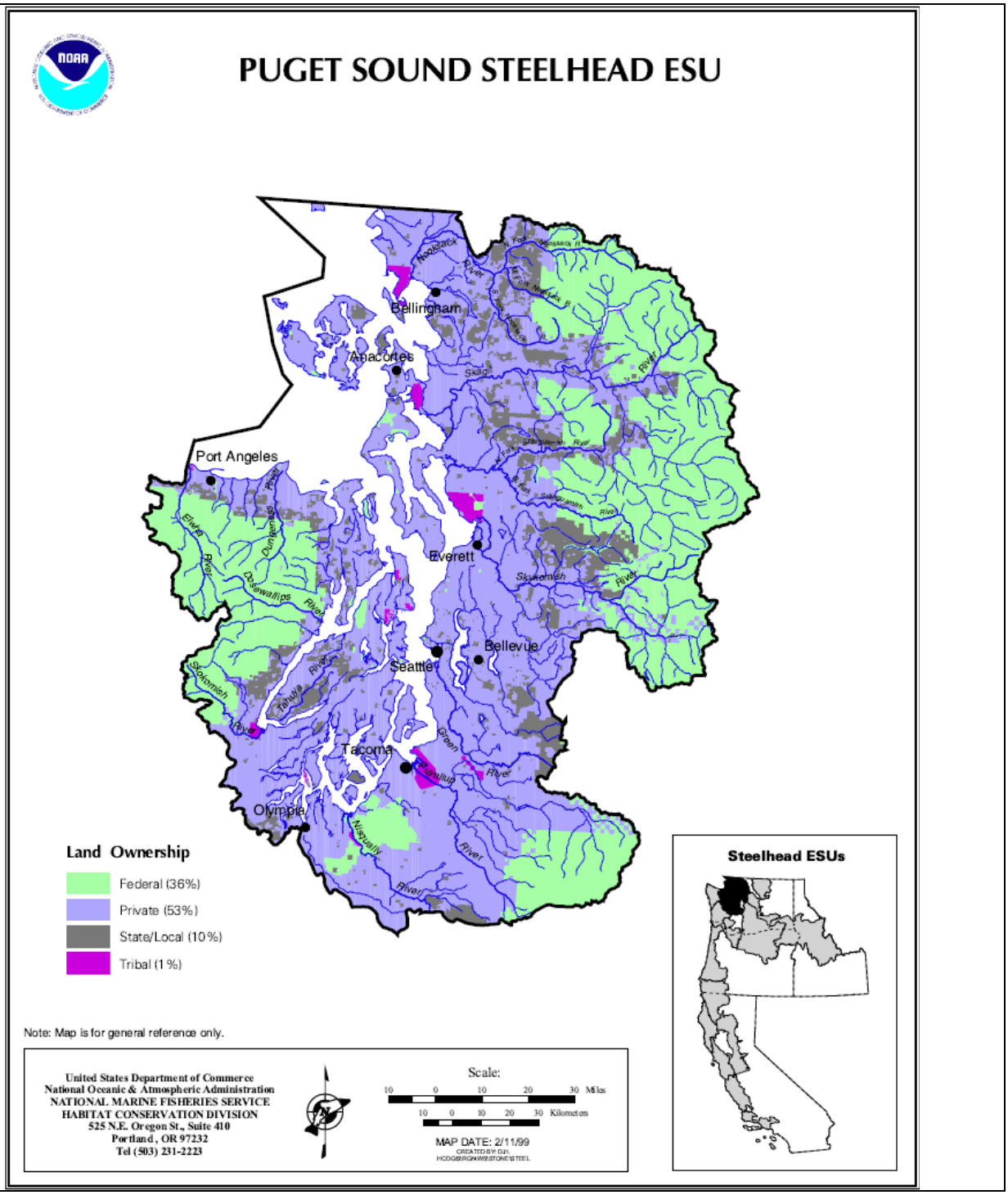

Figure C-24 Distribution of Steelhead (Puget Sound DPS) *Oncorhynchus mykiss* in Washington.

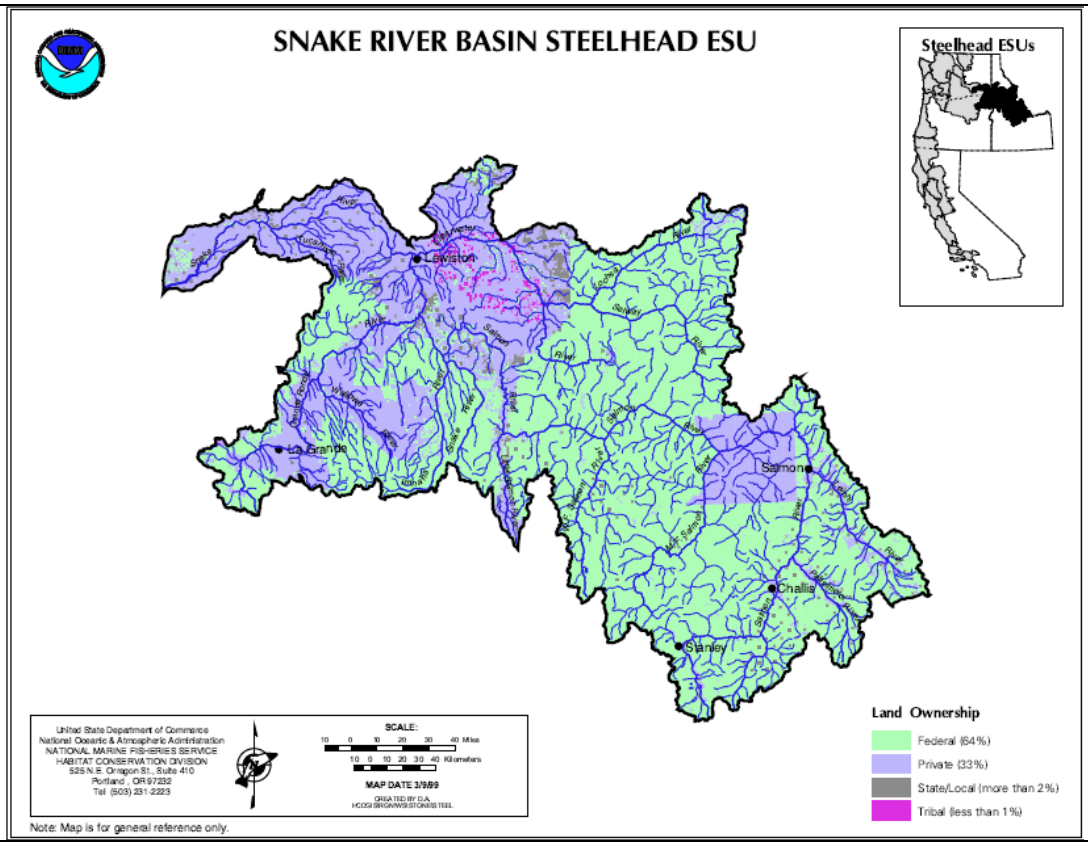

Figure C-25 Distribution of Steelhead (Snake River Basin DPS) *Oncorhynchus mykiss* in Washington.

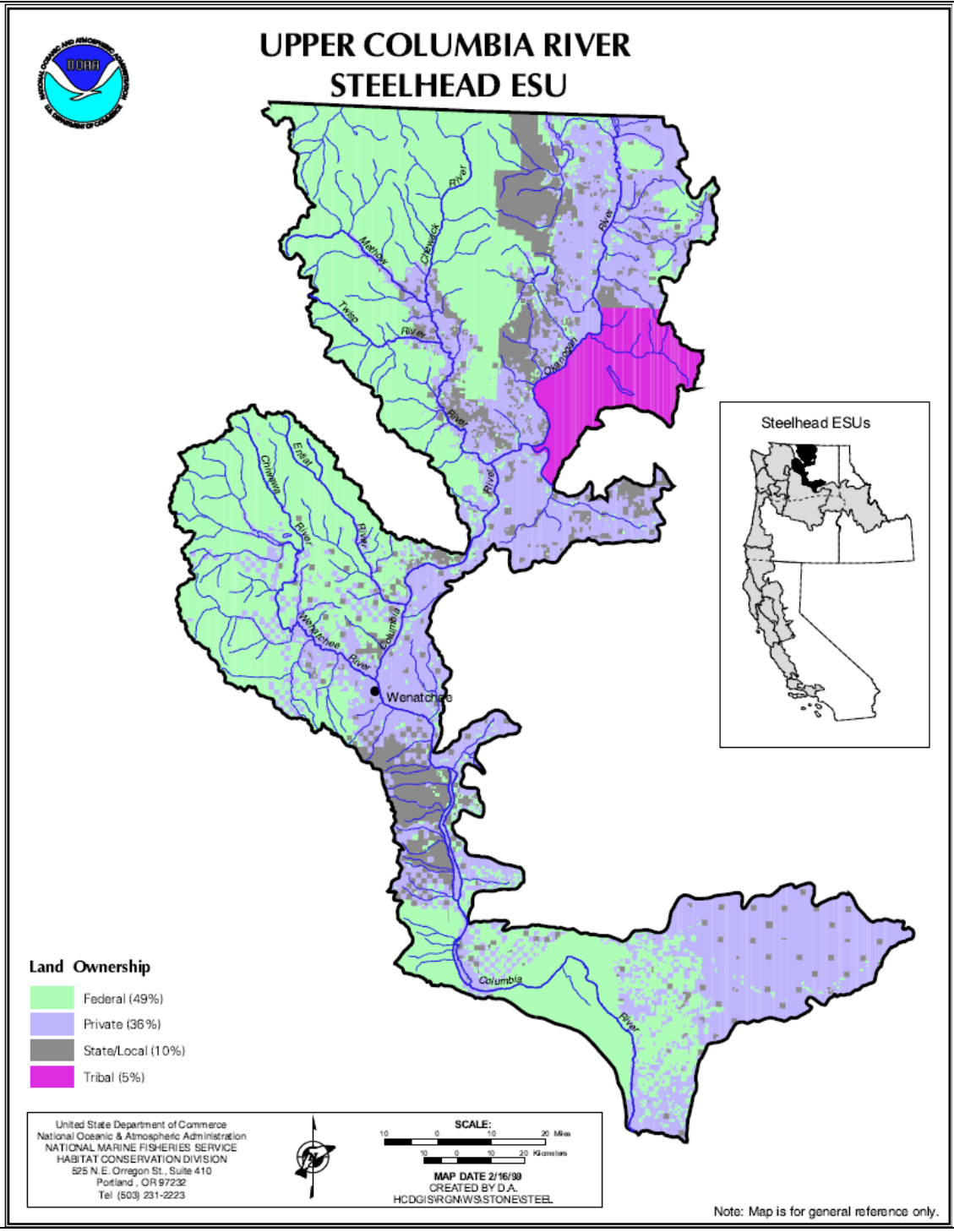

Figure C-26 Distribution of Steelhead (Upper Columbia River DPS) *Oncorhynchus mykiss* in Washington.

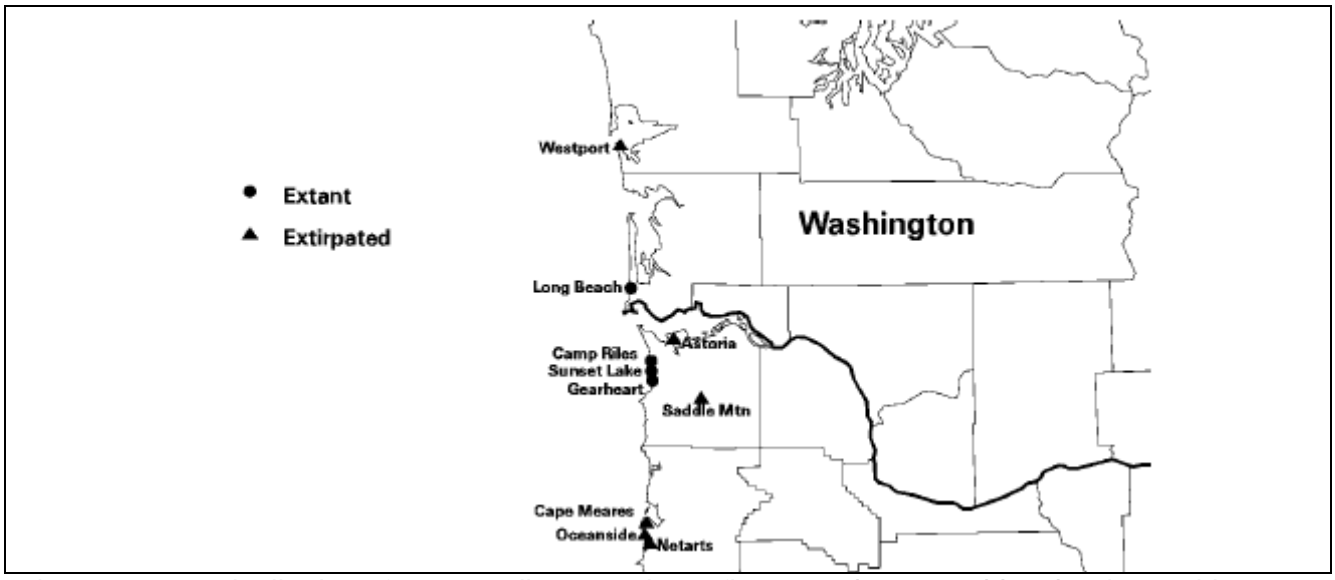

Figure C-27 Distribution of Oregon silver-spot butterfly *Speyeria zerene hippolyta* in Washington.

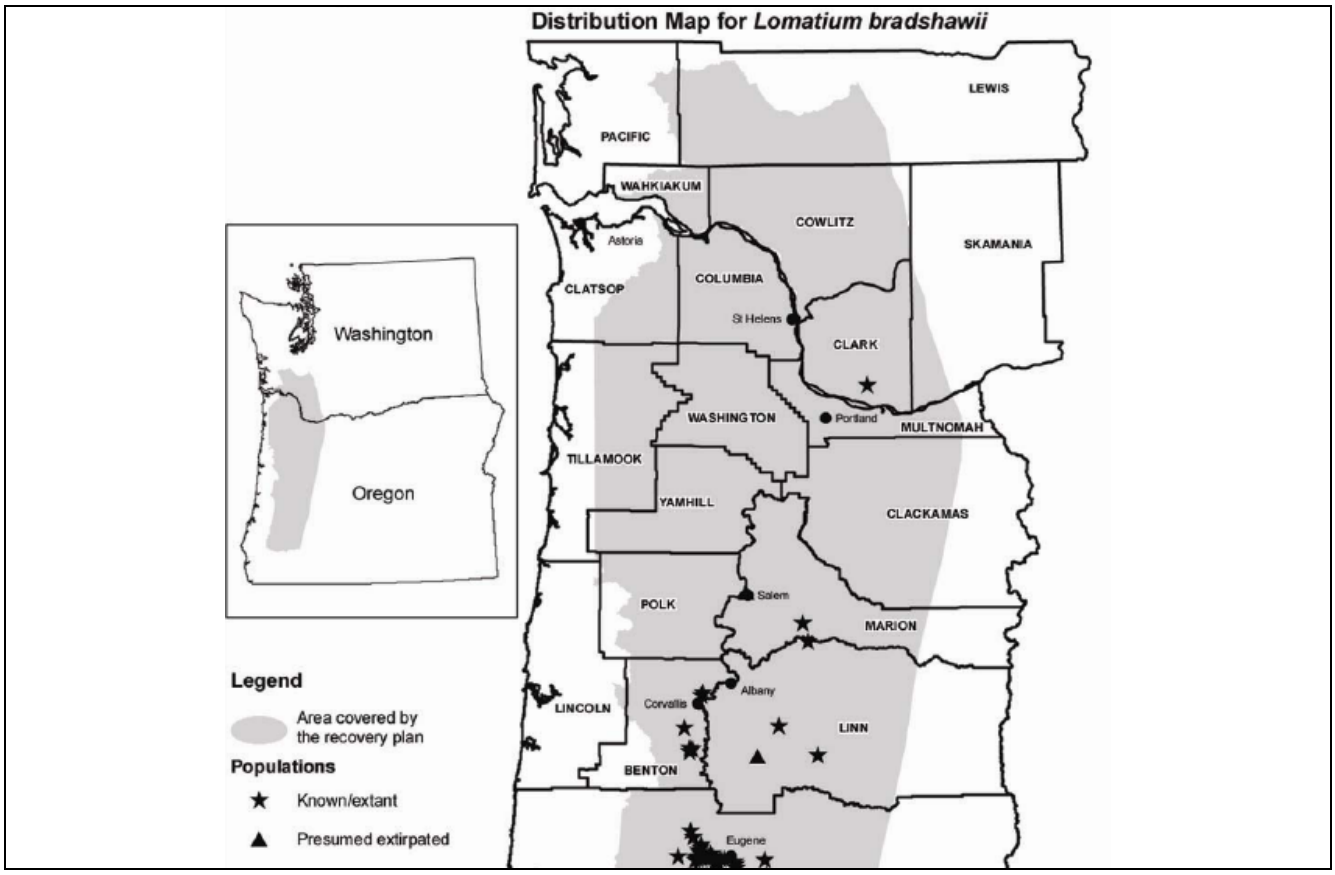

Figure C-28 Distribution of Bradshaw's desert-parsley *Lomatium bradshawii* in Washington.

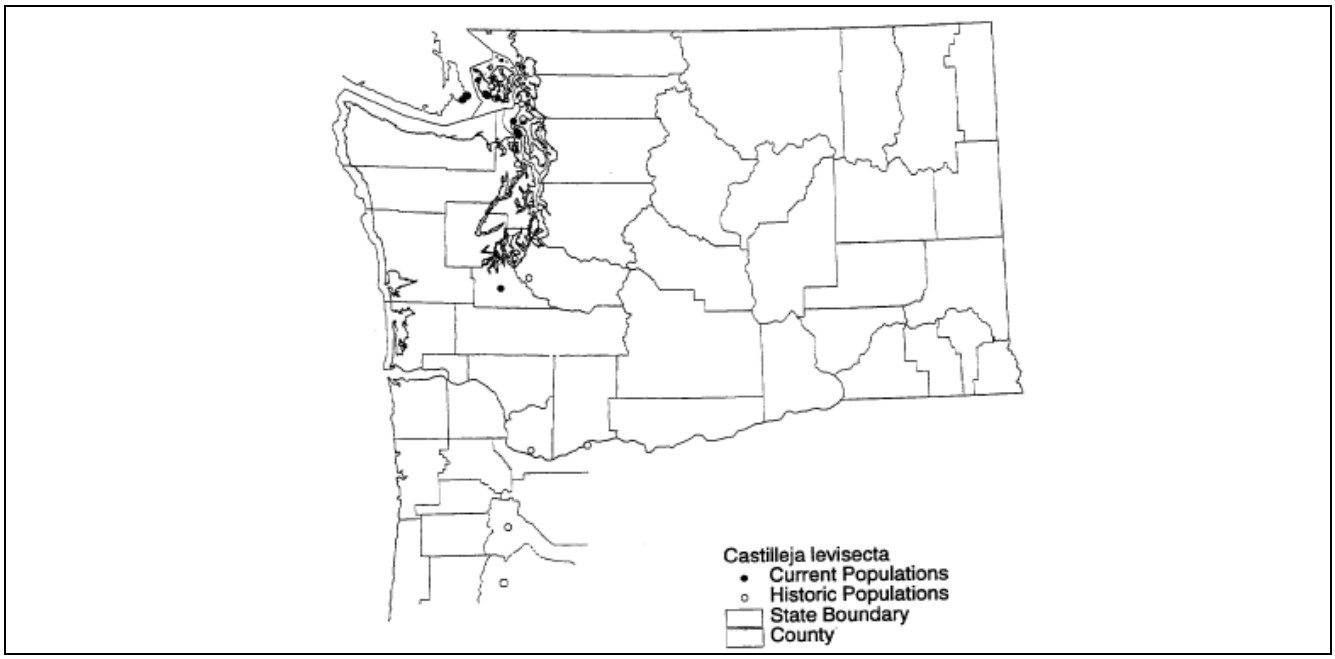

Figure C-29 Distribution of Golden paintbrush *Castilleja levisecta* in Washington.

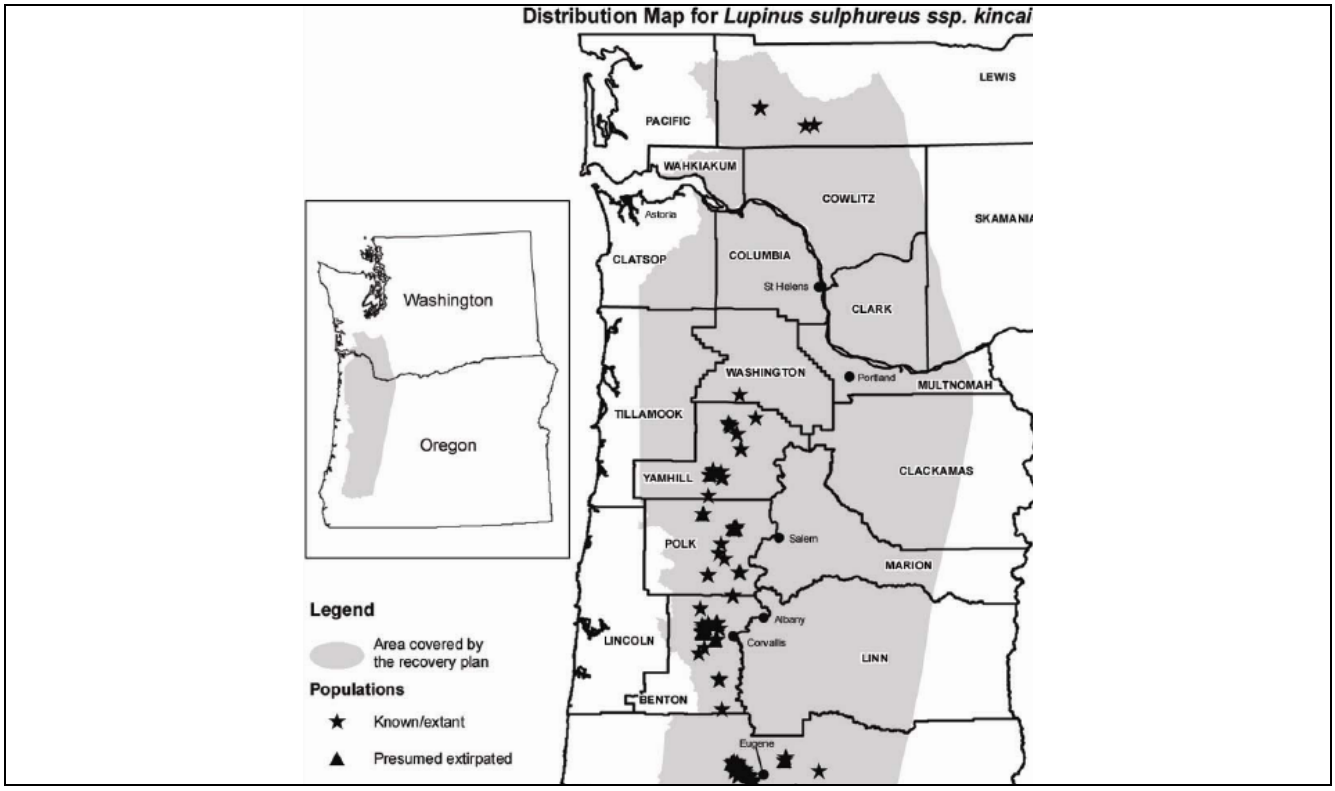

Figure C-30 Distribution of Kincaid's lupine *Lupinus sulphureus ssp. Kincaidii* in Washington.

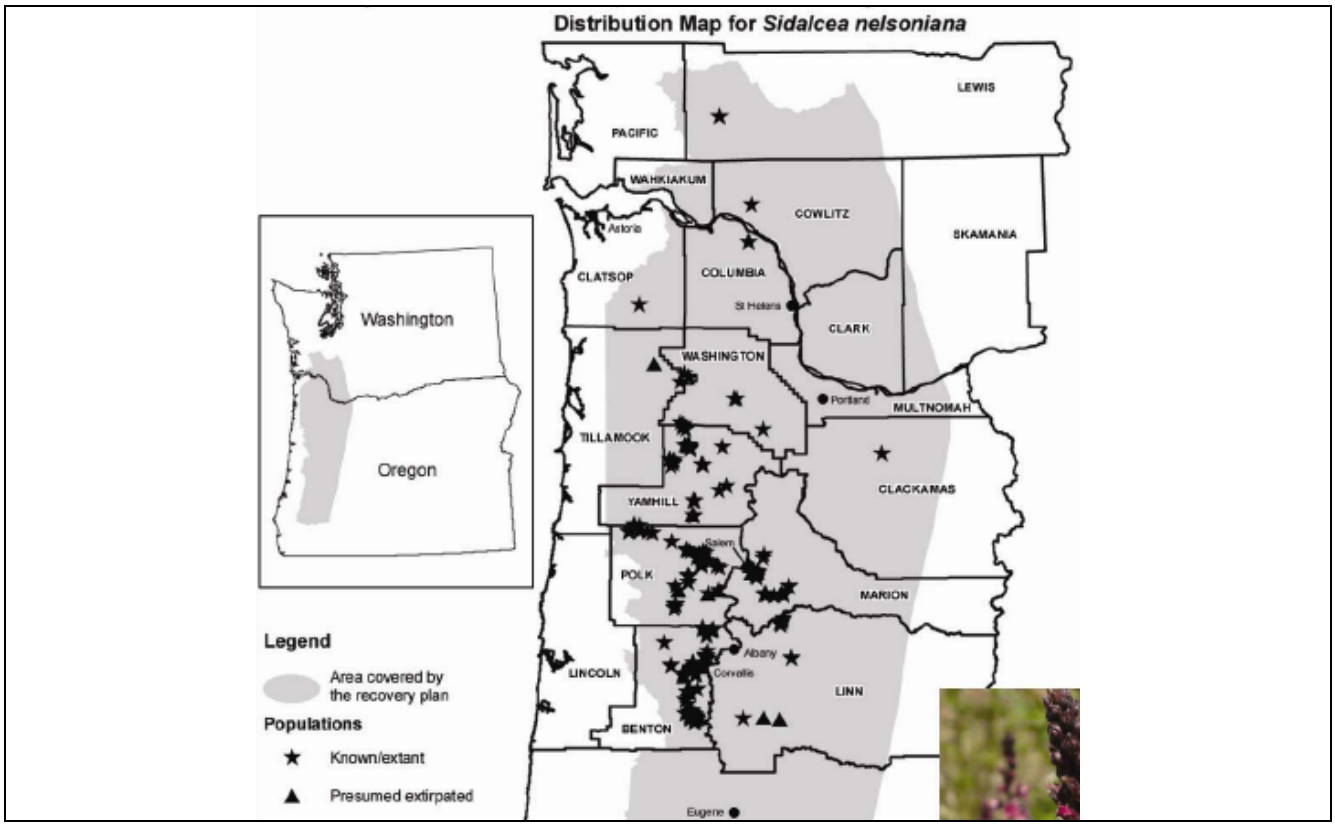

Figure C-31 Distribution of Nelson's checker-mallow *Sidalcea nelsoniana* in Washington.

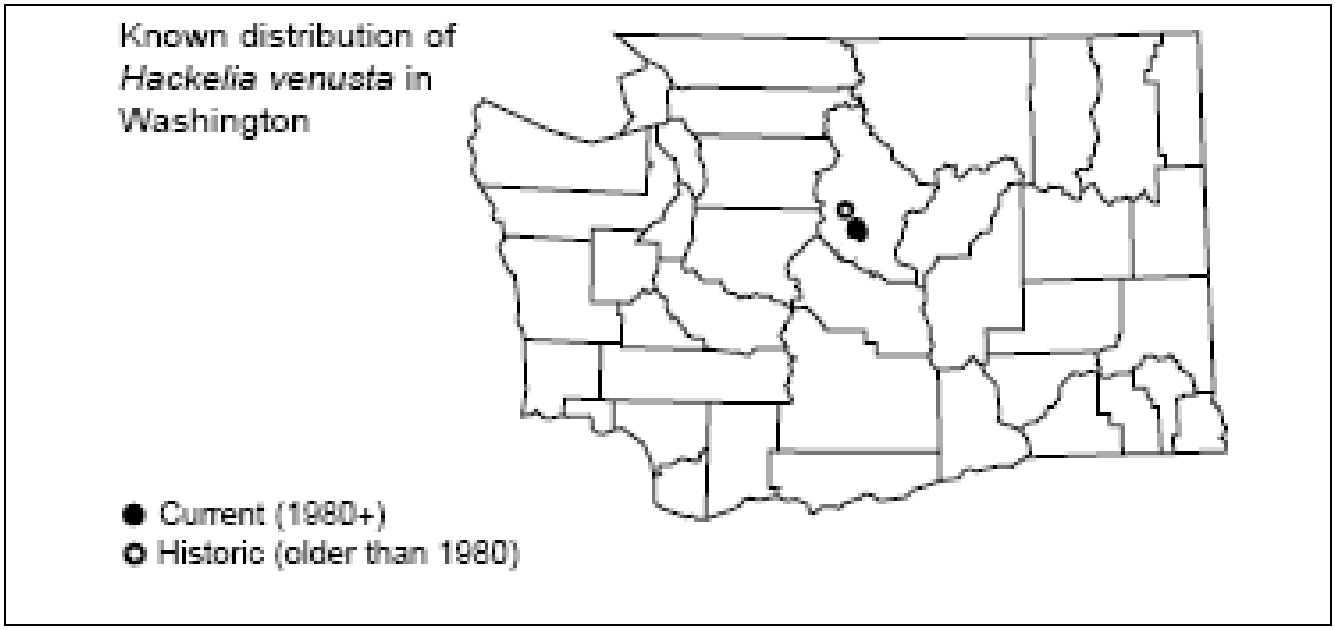

Figure C-32 Distribution of Showy stickseed *Hackelia venusta* in Washington.

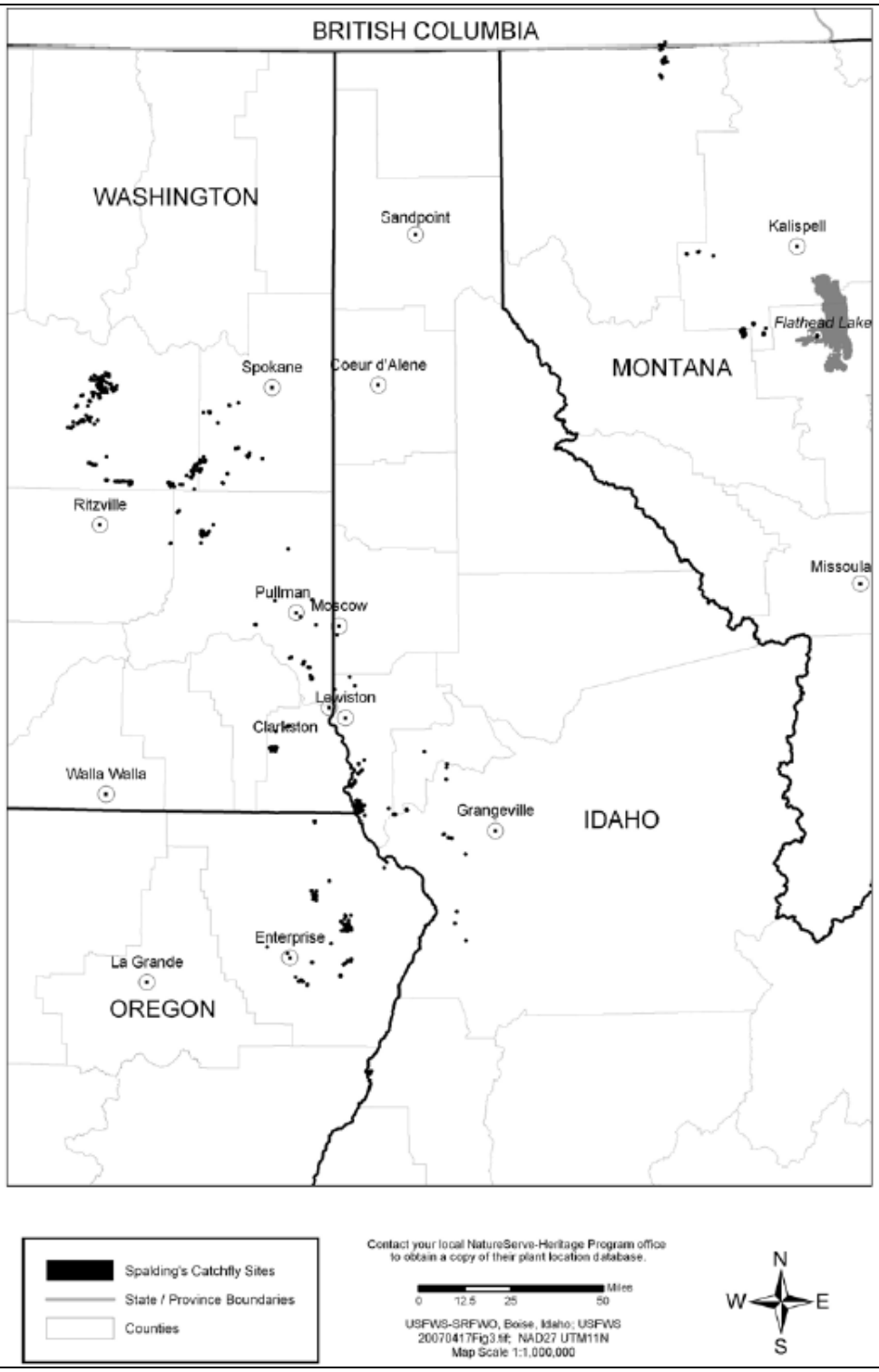

Figure C-33 Distribution of Spalding's catchfly *Silene spaldingii* in Washington.

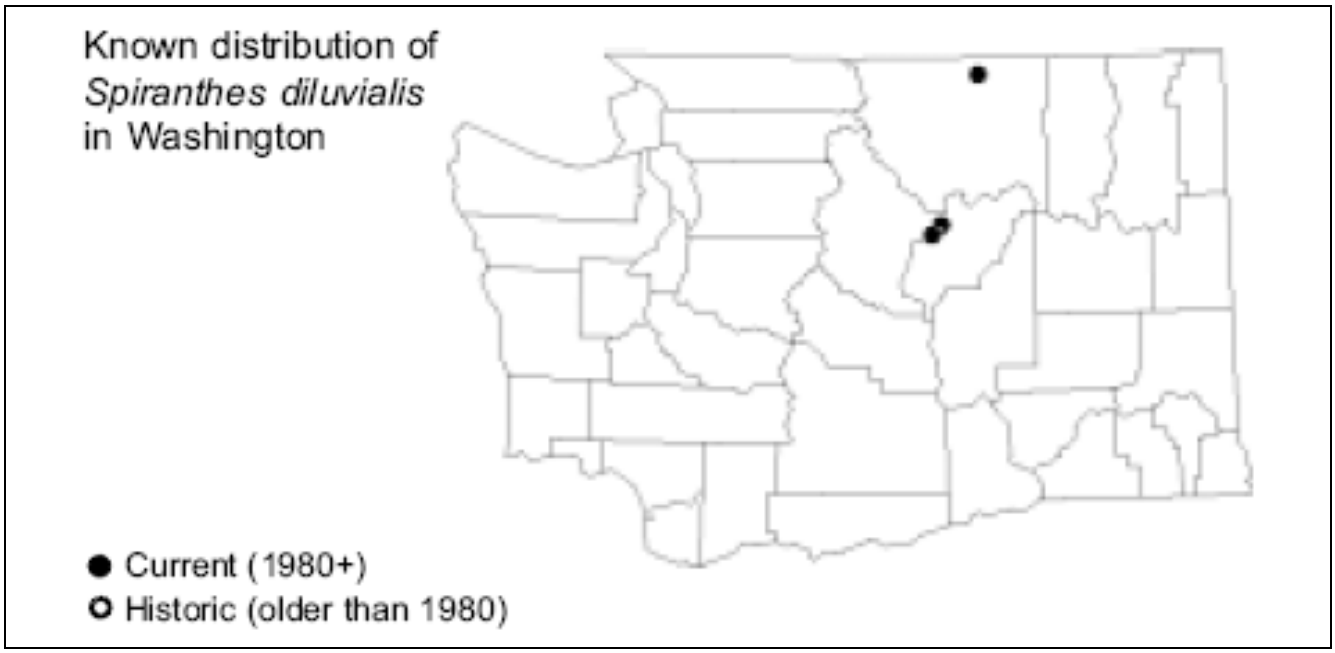

Figure C-34 Distribution of Ute Ladies' tresses *Spiranthes diluvialis* in Washington.

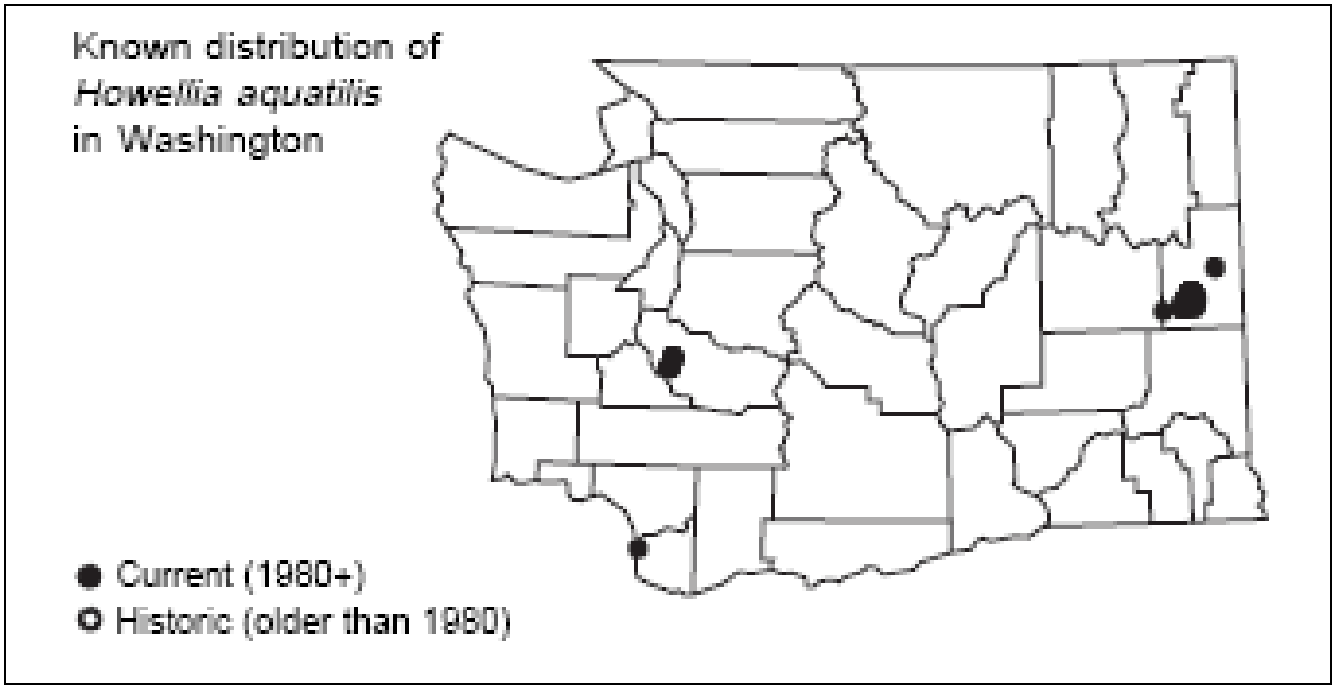

Figure C-35 Distribution of Water howellia *Howellia aquatilis* in Washington.

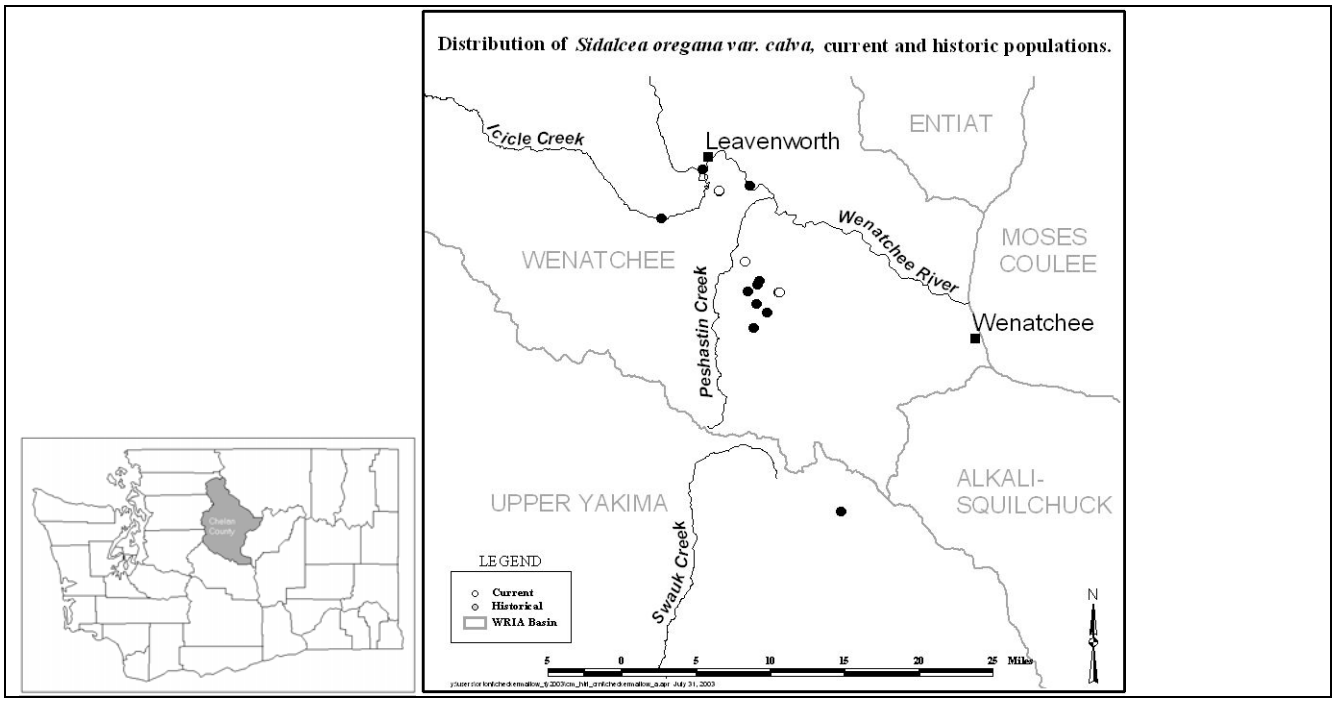

Figure C-36 Distribution of Wenatchee Mountain's checker-mallow *Sidalcea oregana* var. *calva* in Washington.

REFERENCES CITED IN APPENDIX C

Imazapyr Risk Assessment
Washington State

Figure C-1 Columbian White-Tailed Deer

U.S. Fish and Wildlife Service, 1983, Revised Columbian White-Tailed Deer Recovery Plan: USFWS, Denver, Colorado.

Figure C-2 Gray Wolf

U.S. Fish and Wildlife Service, 1987, Northern Rocky Mountain Wolf Recovery Plan: USFWS, Denver, Colorado.

Figure C-3 Grizzly Bear

U.S. Fish and Wildlife Service, 1997, Grizzly Bear Recovery Plan Supplement – North Cascades Ecosystem Recovery Plan: USFWS, Missoula, Montana.

Figure C-4 Canada Lynx

U.S. Fish and Wildlife Service, 2005, Recovery Outline – Contiguous United States Distinct Population Segment of the Canada Lynx: USFWS, Helena, Montana.

Figure C-5 Pygmy Rabbit

U.S. Fish and Wildlife Service, 2007, Draft Recovery Plan for the Columbia Basin Distinct Population Segment of the Pygmy Rabbit (*Brachylagus idahoensis*): USFWS, Portland, Oregon.

Figure C-6 Sea Otter

U.S. Fish and Wildlife Service, 2003, Final Revised Recovery Plan for the Southern Sea Otter (*Enhydra lutris nereis*): USFWS, Portland, Oregon.

Figure C-7 Woodland Caribou

U.S. Fish and Wildlife Service, 1993, Recovery Plan for Woodland Caribou in the Selkirk Mountains: USFWS, Portland, Oregon.

Figure C-8 Northern Spotted Owl

U.S. Fish and Wildlife Service, 2008, Final Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*): USFWS, Portland, Oregon.

Figure C-9 Short-tailed Albatross

U.S. Fish and Wildlife Service, 2008, Short-tailed Albatross Recovery Plan: USFWS, Anchorage, Alaska.

Figure C-10 Western Snowy Plover

U.S. Fish and Wildlife Service, 2007, Recovery Plan for the Pacific Coast Population of the Western Snowy Plover (*Charadrius alexandrinus nivosus*), Volume 2 – Appendices: USFWS, Sacramento, California.

Figure C-11 Green Sea Turtle

National Marine Fisheries Service and U.S. Fish and Wildlife Service, 1998, Recovery Plan for U.S. Pacific Populations of the Green Turtle (*Chelonia mydas*): NMFS, Silver Spring, Maryland.

Figure C-12 Leatherback Sea Turtle

National Marine Fisheries Service and U.S. Fish and Wildlife Service, 1998, Recovery Plan for U.S. Pacific Populations of the Leatherback Turtle (*Dermochelys coriacea*): NMFS, Silver Spring, Maryland.

Figure C-13 Bull Trout

U.S. Fish and Wildlife Service, 2004, Bull Trout (*Salvelinus confluentus*) Draft Recovery Plan: USFWS, Portland, Oregon.

Figure C-14 Chinook Salmon Snake Fall

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-15 Chinook Salmon Lower Columbia

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-16 Chinook Salmon Puget Sound

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-17 Chinook Salmon Upper Columbia Spring

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-18 Chinook Salmon Snake Spring/Summer

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-19 Chum Salmon Columbia

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-20 Chum Salmon Hood Canal Summer

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-21 Sockeye Salmon Lake Ozette

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-22 Steelhead Lower Columbia

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-23 Steelhead Middle Columbia

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-24 Steelhead Puget Sound

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-25 Steelhead Snake River Basin

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-26 Steelhead Upper Columbia

National Marine Fisheries Service, 2009, ESA Salmon Listing Maps: National Oceanic and Atmospheric Administration, NMFS, Seattle, Washington, http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Maps/Index.cfm.

Figure C-27 Oregon Silverspot Butterfly

U.S. Fish and Wildlife Service, 2001, Oregon Silverspot Butterfly (*Speyeria zerene hippolyta*) Revised Recovery Plan: USFWS, Portland, Oregon.

Figure C-28 Bradshaw's Lomatium

U.S. Fish and Wildlife Service, 2008, Draft Recovery Plan for the Prairie Species of Western Oregon and Southwestern Washington: USFWS, Portland, Oregon.

Figure C-29 Golden Paintbrush

U.S. Fish and Wildlife Service, 2000, Recovery Plan for the Golden Paintbrush (*Castilleja levisecta*): USFWS, Portland, Oregon.

Figure C-30 Kincaid' Lupine

U.S. Fish and Wildlife Service, 2008, Draft Recovery Plan for the Prairie Species of Western Oregon and Southwestern Washington: USFWS, Portland, Oregon.

Figure C-31 Nelson's Checker-Mallow

U.S. Fish and Wildlife Service, 2008, Draft Recovery Plan for the Prairie Species of Western Oregon and Southwestern Washington: USFWS, Portland, Oregon.

Figure C-32 Showy Stickseed

Washington Department of Natural Resources, 2005, Field Guide to Selected Rare Vascular Plants of Washington, Online Version: WDNR, Washington Natural History Program. Olympia, http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/fgmain.htm.

Figure C-33 Spalding's Catchfly

U.S. Fish and Wildlife Service, 2007, Recovery Plan for *Silene spaldingii* (Spalding's Catchfly): USFWS, Portland, Oregon.

Figure C-34 Ute Ladies' Tresses

Washington Department of Natural Resources, 2005, Field Guide to Selected Rare Vascular Plants of Washington, Online Version: WDNR, Washington Natural History Program, Olympia, http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/fgmain.htm.

Figure C-35 Howellia

Washington Department of Natural Resources, 2005, Field Guide to Selected Rare Vascular Plants of Washington, Online Version: WDNR, Washington Natural History Program, Olympia, http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/fgmain.htm.

Figure C-36 Wenatchee Checker-Mallow

U.S. Fish and Wildlife Service, 2004, Recovery plan for *Sidalcea oregano* var. *calva* (Wenatchee Mountains Checker-mallow): USFWS, Portland, Oregon.

DISTRIBUTION MAPS
WASHINGTON STATE RARE PLANTS
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Washington State
June 30, 2009

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