Ecological Risk Assessment of the Proposed Use of the Herbicide Imazapyr to Control Invasive Cordgrass (*Spartina spp.*) in Estuarine Habitat Of Washington State

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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). Cordgrass (*Spartina spp.*) a dominant invasive weed spreading throughout many of Washington's most productive estuarine tide flats, is considered a noxious weed under state code (WAC 16-750-011). Within the estuarine environments of Washington State only one herbicide, glyphosate (i.e. Rodeo$_{tm}$), is currently authorized for *Spartina spp*. control (NPDS Permit # WAG-993000). Glyphosate is relatively non-toxic to animals and is effective on a wide range of plant species. However, its use to control cordgrass is hindered by drying times that limit its efficacy under the tidal conditions inherent to estuaries. It also requires higher application rates than an alternative herbicide potentially available for use, imazapyr (i.e. Arsenal$_{tm}$). The goals of this ecological risk assessment are therefore to 1) summarize current knowledge concerning the toxicity of of imazapyr to target and non-target organisms, 2) estimate potential exposure to ecological receptors relevant to the aquatic (estuarine) environments where the herbicide may be applied, and 3) characterize risks from that exposure to the individual species and ecosystems where *Spartina spp.* is distributed.

This ecological risk assessment should be considered supplemental to the original 1993 Environmental Impact Statement that evaluated the potential benefits and risks from the use of the herbicide glyphosate (i.e. Rodeo$_{tm}$) and other mechanical management alternatives to control *Spartina* (WSDA 1993). Specifically, this assessment evaluates the risks to fish, wildlife and non-target vegetation from the proposed use of imazapyr (i.e. Arsenal$_{tm}$) to control smooth cordgrass in estuarine waters of Washington State. Under the EPA Section 3 for Section 24(c) pesticide registration sought for imazapyr use in an estuary, applications would be made directly to the plant during low tide, and it is this scenario for which risks were considered.

Appendix A to this supplement references the "no-action" alternative, which, in contrast to the earlier 1993 EIS, considers the "no-action" scenario to be a continuance of the current integrated pest management scheme for *Spartina* control that involves the use of chemical (glyphosate) and mechanical control means. That is, "no action" in the current context and in the vernacular of SEPA guidance, would constitute the environmental baseline upon which imazapyr use is compared; the potential inclusion of imazapyr into WSDA's integrated pest management scheme for *Spartina* control would therefore represent the "preferred alternative".

The outline and methods of the main body of this report reflect standard ecological risk assessment guidelines (EPA 1996). Thus, the report begins with the "problem formulation", which summarizes the scope of the problem, the need to consider alternative control mechanisms, and the approach to the assessment. The problem formulation is followed by the "hazard assessment" which relates the current understanding of imazapyr's environmental fate, and its toxicity to the range of target and non-target organisms where testing has been conducted. The hazard assessment is followed by the "exposure assessment," where the pathways and doses possible for imazapyr exposure to the representative biological receptors are evaluated. The exposure assessment considers the threatened and endangered (T&E) avian and aquatic species where imazapyr could be applied where data permit. If no toxicity data were available for species typical of the estuarine environments where impazapyr use is proposed, then toxicity data from surrogate species were used. The use of surrogate species with similar dietary and/or behavior patterns has

been shown to provide a relatively reliable predictor of aquatic toxicity when toxicity data are lacking for species of greater relevance to specific areas (Sappington et al. 2000).

Standard EPA and other test species were also used as surrogates to model potential exposure to terrestrial omnivores, herbivores and carnivores. It can be reasonably assumed that a similar relationship as found with aquatic species sensitivity exists for other wildlife. However, only site-specific risk assessments would be able to fully quantify risks to resident and migratory wildlife receptors from chemical exposure. Notwithstanding, this assessment used surrogate species such as the rat, rabbit, quail and mallard duck to gauge exposure to other wildlife that would be likely to use estuarine habitat within Washington State. The rat provides a reasonable surrogate of an omnivore, the rabbit an exclusive herbivore, and the quail and duck provide surrogates of upland and wetland bird species, respectively.

The effects of specific contaminants at the broader ecosystem level may also vary significantly among ecosystems based on the physical and chemical properties of the chemicals themselves, and the unique combination of physical, chemical, and biological processes occurring in each ecosystem. Such ecosystem differences can directly bring about differences in animal populations or indirectly affect habitat. For example, wildlife populations resident to environments naturally enriched with metals may tolerate a much higher concentration of metal exposure than naïve populations. That is, populations of exposed organisms may differ in their response to contaminants depending on their natural tolerance to the chemical, their behavioral and life history characteristics (e.g., pre-exposure), the dose to which they are exposed, and the duration of exposure. Furthermore, responses may be transient (and therefore reversible) or permanent (irreversible).

With the preceding discussion in mind, the objectives of this EIS supplement can be succinctly summarized as follows:

- To describe the toxicity hazards of imazapyr to marine and estuarine aquatic organisms, as known.
- To describe the toxicity hazards of imazapyr to terrestrial and amphibious wildlife, as known.
- To describe the toxicity hazards of imazapyr to non-target vegetation, as known.
- To identify sensitive species that may be impacted in different regions where imazapyr could be applied.
- To estimate (model) ecological receptor exposure (dose) by identifying complete and incomplete exposure pathways, taking into account environmental fate and transport through both physical and biological means.
- To characterize the risk or threat to other environmental components potentially affected by imazapyr.
- To compare risks from the potential use of imazapyr relative to the existing use of glyphosate and other existing control methodologies, such that the existing control methods can be considered the “no action alternatives”.
- To identify the method or integration of treatment methods, from review of new literature and WSDA’s existing program, that best controls *Spartina spp*. with the minimum amount of risk to the environment.

2.0 PROBLEM FORMULATION

To frame the scope of the *Spartina* problem in the State of Washington, the potential means to control it, and the probable risks and benefits of the use of Arsenal$_{tm}$ as a component in the integrated management of the invasive weed, a thorough understanding of the scope of the problem is needed. This chapter defines the scope of the problem, the assessment endpoints that best represent the management goals of the WSDA for *Spartina* control, the conceptual models we will use to consider exposure to relevant ecological receptors, and the methodology by which risks to ecological receptors are quantified and characterized.

Toxicology is the study of poisons. It examines and attempts to define the range in responses of an organism or organisms to variable doses of a chemical or chemicals. Thus, the most important factors regulating chemical toxicity are the exposure dose, the duration of exposure, and the potency of the chemical. The genotype, and nutritional and physiological, state of an ecological receptor at the time of exposure can also affect chemical toxicity. The introduction of chemicals into an ecosystem can cause direct harm to organisms, or may indirectly affect their fitness—the ability of an animal to survive and produce viable offspring. The results of chemical exposure may be immediately apparent or may become noticeable only after considerable delay. Recognizing the effects of exposure on animals may require analyses through a suite of measurement endpoints. Measurement endpoints may include physiological, neurological, behavioral, endocrine-mediated, or a variety of other indicators that could be construed to play a role in the survival of the organism.

Ecological risk assessment represents a branch of toxicology wherein the effects of putative poisons are examined not only at the individual organismal level as outlined above, but also at the broader population and ecosystem level. Thus, the purpose of this ecological risk assessment is to determine the nature, magnitude, and transience or permanence of observed or expected effects to animals and their habitat from exposure to imazapyr, based on WSDA's projected application rates and integrated pest management practices. The assessment relies heavily on ecological hazard studies that have been conducted over the past several years, product registration study results, and conservative deterministic exposure modeling at the organismal level. Effects at the organismal level are presumed to be reflective of potential effects at the population level, though no quantitative measures of effect at the population level are calculated

2.1 Overview of *Spartina* Infestation in Washington State

Spartina is an invasive weed that inhabits tideflats, salt marshes and estuaries throughout Washington State's coastal areas. There are now four species of *Spartina* found in Washington's waters, *Spartina alterniflora, Spartina patens, Spartina anglica* and a newly discovered species found in the fall of 2001 in Grays Harbor and Island County, *Spartina densiflora.* Sometimes referred to as cordgrass, *Spartina alterniflora* and *Spartina patens* are native to the Eastern and Gulf coasts of the United States and are integrated into these regions' natural ecosystem processes. *Spartina anglica* is an intentionally created hybrid. *Spartina densiflora* is native to South America which has also invaded Humboldt Bay in California. In its native environments, the spread of *Spartina* is controlled by natural biological agents, and by natural disturbance factors such as hurricanes and tidal action.

The potential of exotic species to change the physical structure and in so doing alter the ecological functioning of the entire habitat unit has been well documented (Zipperer 1996). In several of Washington State's coastal habitats, *Spartina spp.* outcompetes and displaces native vegetation and results in changes to local ecosystems by converting littoral mudflats to salt marshes. These changes threaten to impact native fisheries, shellfish beds, waterfowl migrations and other wildlife by reducing the habitats carrying capacity for these animals.

2.1.1 Distribution

Spartina alterniflora typifies an invasive species by having a wide tolerance to habitat requirements, fast dispersal rate, clonal reproduction and few to no natural predators in its invaded range (Zipperer 1996). *Spartina alterniflora* was most likely introduced to the Washington coast when it was used in the packing of East Coast oysters for shipping during the late 1800s. In addition to the accidental introduction, *S. alterniflora* was also intentionally planted by a gun club between 1941 and 1946 to stabilize bank erosion on their property in Padilla Bay. *Spartina anglica* was also intentionally introduced, to stabilize dikes and provide forge for cattle in Port Susan Bay. The pathways of introduction for both *Spartina patens* and the newly discovered *S. densiflora* are not known at this time.

Spartina species have spread throughout Washington State's coastal counties. Infestations range from only a few square feet to more than 6,800 solid acres. Currently there are an estimated 7,500 solid acres interspersed amongst 20,000 total invaded acres in Washington's coastal habitat. Table 2-1 summarizes the locations, size and recent treatments of *Spartina sp.* found in Washington State (WSDA Legislative Report 2002). Figures 2-1 and 2-2 demonstrate typical clone and field colonies (meadows) of *Spartina*, as occurring today in Willapa Bay.

Figure 2-1: Typical multi-clonal distribution of *Spartina alterniflora* in Willapa Bay.
(Source: WSDA 2003.)

Figure 2-2: Typical *Spartina alterniflora* meadow in Willapa Bay.
(photo credited to K. Patten, by permission.)

Table 2-1: *Spartina* Distribution and Treatment in Washington State, 1997-2002.

County	*Spartina* Present in 2002	*Spartina* Treated, 1997 - 2002	2002 Treatment Methods
Pacific (Willapa Bay)	Over 6,800 solid acres spread over > 15,000 acres	1997 –approx. 742 solid acres 1998 –approx. 450 solid acres 1999 –approx. 600 solid acres 2000 –approx. 800 solid acres 2001 –approx. 900 solid acres 2002 –approx. 1804 solid acres	Mow/herbicide, herbicide, seedling removal, various mechanical control.
Grays Harbor	Scattered clones and seedlings 0.25 acres each	1997 through 2002 - all treated	Herbicide, seedling removal, mow
Snohomish	Approx. 350 solid acres spread over >4,500 acres	1997 –approx. 89 solid acres 1998 –approx. 126 solid acres 1999 –approx. 90 solid acres 2000 –approx. 158 solid acres 2001 –approx. 75 solid acres 2002 –approx. 238 solid acres	Mow/herbicide, herbicide, seedling removal, dig, mechanically crush, mow.
Island	Approx. 350 solid acres spread over >1,000 acres	1997 –approx. 250 solid acres 1998 –approx. 160 solid acres 1999 –approx. 155 solid acres 2000 –approx. 130 solid acres 2001 –approx. 72 solid acres 2002 –approx. 180 solid acres	Mow/herbicide, herbicide, seedling removal, mechanically crush, mow.
Skagit	Approx. 40 solid acres spread over >2,000 acres	1997 –approx. 91 solid acres 1998 –approx. 57 solid acres 1999 - all treated 2000 –approx. 60 solid acres 2001 –approx. 33 solid acres 2002 –approx. 37 solid acres	Mow/herbicide, herbicide, seedling removal, dig, mow.
Clallam	1 infestation < 0.001 acres in size	1997 – treated twice 1998 – treated three times 1999 – treated twice 2000 – treated three times 2001-02 – treated four times	Dig
Jefferson	14 infestations - approx. 0.01 solid acres total	1997 - all treated 1998-2000- all treated twice 2001-02 – all treated three times	Mow, mow/herbicide, dig, seedling removal
Kitsap	8 infestations - approx. 1 solid acre total	1997 - all but 2 tribal sites 1998 - all treated once 1999 - all treated twice 2000-01 - all treated once 2002 - all treated twice	Mow, mow/herbicide, dig, seedling removal
King	2 infestations - single clones and a few seedling	1997 – monitored 1998-99 - all treated once 2000-02 - all treated twice	Dig
San Juan	Re-growth found at one site. 2 other sites clean for four consecutive years	97 - all treated 98 - all treated 99 – monitored 2000-02 - all treated once	Survey, dig

From Washington State Department of Agriculture's Report to the Legislature, Progress of the 2002 *Spartina* Eradication Program, December 15, 2002

2.1.2 Biology

Spartina is a rhizomatous perennial grass that can proliferate from either sexual reproduction or vegetative propagation. Shoots sprout from below ground rhizomes in the spring and reach a height of three to six feet by mid-summer. *Spartina* flowers from late June to October; however, not all populations within Washington State flower. Sexual reproduction may require a sufficient underground biomass to trigger. Populations that do not flower depend on vegetative propagation and/or lateral growth to spread. Temperature, photoperiod soil temperature, and soil salinity have been shown to influence occurrence and timing for the populations that do flower. Salinity has also been shown to affect growth rate, seedling development and spatial zonation (Feist 1999).

Dispersal of *Spartina* is accomplished when water currents, animals or humans transport seed, rhizome pieces or entire plants to new locations. Humans are the most prevalent cause of *Spartina* dispersal, either through intentionally plantings or accidental spread. Waterfowl and other birds are known to ingest seeds and rhizomes, spreading material through their feces. Water spread seeds and rhizomes fragments via natural currents and tidal actions. These mechanisms of dispersal create great difficulties in controlling the spread of the weed.

When new plants are established through either seeds or vegetative propagation, survival appears to be linked to competition with other plants. Low light levels caused from other plants may inhibit survival. Seed and vegetative propagation seems to be important in the colonization of disturbed or bare areas. In contrast, growth of established colonies out- competes native plant species resulting in a nearly complete monoculture of *Spartina* plants in invaded habitats. These colonies or clones reproduce by the lateral spread of underground rhizomes and aboveground tillers.

Spartina alterniflora, S. patens, and *S. anglica* become dormant during the winter and die back. However, *Spartina densiflora* does not become dormant and produces new plant material throughout the year. In addition, the seed viability of *S. densiflora* appears to be much higher than the other species of *Spartina*. These traits may potentially allow *S. densiflora* to invade new areas more rapidly than the other *Spartina* species in Washington State.

In its native habitats *S. alterniflora* functions as essential feeding grounds and nursery areas for numerous species of invertebrates, fish, shorebirds, migratory waterfowl, and small mammals. In contrast *S. alterniflora* alteration of mud flats could eliminate critical foraging habitat of juvenile salmonids, flatfish, shorebirds, and migratory waterfowl. In addition, composition and abundance of benthic invertebrates may be substantially altered by cordgrass colonization of mudflats because these species are strongly influenced by the physical environment (Zipperer 1996).

2.2 Ecological Receptors, Community Descriptions, and Threatened and Endangered Species In Primary Areas Where Spartina is Distributed

As demonstrated in Table 2-1, *Spartina* is found in multiple locations within Puget Sound, and on the Pacific Coast within Willapa Bay. Most areas of *Spartina* distribution in Puget Sound are localized and can be controlled by mechanical means (*see* Table 2-1). The two areas of varying size and distribution, Willapa Bay and Paddila Bay, require the use of chemical control means to achieve the goal of eradication, and chemical control must remain a viable alternative for all areas where Spartina is found if mechanical means prove ineffective in the future. With this understanding, an overview of the ecological communities and ecological receptors in Willapa and Padilla bays is provided below. The Willapa Bay and Padilla Bay ecosystems share many

similarities with the other areas *Spartina* has colonized in Washington State, although due to their size, the ecosystems support a greater diversity of species. These habitats, as well as other coastal habitats of Washington where smaller colonies of *Spartina* have established, support several priority species, some of which are listed as threatened or endangered (T&E) under the Endangered Species Act (ESA). Thus, this section also provides a summation of the T&E species in Washington State, and the potential for these species to occur in areas where imazapyr treatments of *Spartina* could occur.

Willapa Bay

Willapa Bay is located in the southwestern corner of the Washington coast. It is approximately 38 km long and 8 km wide (Gringas et al. 2000). At high tide, the aquatic environment of Willapa Bay is approximately 88,000 acres, however almost half of the Bay is drained at low tide (Cohen et al. 2001). Willapa Bay in almost fully enclosed by the Long Beach Peninsula, a 30 km-long barrier spit that was formed by the deposition of Columbia River sediments. The Willapa Basin has received an average of 85 inches of rain per year over the past 75 years of record (http://www.tidepool.org/wiscweb/wisc98nw2.html). Willapa Bay has a drainage basin of approximately 2,550 square miles, and the main tributaries that drain into the bay include the North, Willapa, and Naselle rivers. The Palix River is on of the minor contributors to the mean daily runoff. Mean daily runoff to Willapa Bay represents approximately < 0.05 percent of the bays total volume.

Willapa Bay is Washington's largest outer coast estuary (Cohen et al. 2001). Willapa Bay is a largely unaltered environment, however it has been significantly impacted by the colonization of non-indigenous/exotic species. Of the 892 vascular plants in the Willapa Basin (which includes headwater habitat outside of the brackish estuary) approximately 250 species have been introduced. Similarly, 30 of the 473 species of vertebrates identified in the basin have been introduced (www.tidepool.org/wiscweb/wisc98nw2.html). Approximately 34 exotic aquatic plant and animal species were recently identified within the Willapa Bay estuary during a 2000 research expedition sponsored by the Washington State Department of Natural Resources (WDNR) Nearshore Habitat Program (Cohen et al. 2001). Within the estuary habitat of the basin, the two most significant plant species introduced are the Japanese eelgrass (*Zostera japonica)* and the smooth cordgrass (*Spartina alterniflora).*

The most problematic exotic species found within Willipa Bay is the smooth cordgrass. This invasive species is outcompeting native aquatic vegetation for space and nutrient resources. *Spartina* also degrades habitat for aquatic, terrestrial and aviananimal species utilizing Willapa Bay. Between 1994 and 1997, *Spartina* populations expanded at a rate of 485 percent within the southern portion of Willapa Bay (Willapa Bay Estuary 2001).

In addition to the major issues created by the introduction of *Spartina*, numerous aquatic invertebrate animal species have been introduced intentionally or inadvertently into Willapa Bay during the past century. The degree to which these introductions have displaced native species is less understood than the displacement caused by *Spartina*. Some of the known non-native introductions are tabulated in Table 2-2.

Table 2-2: Common Non-native Invertebrates in Willapa Bay.

General Taxon	Species	First Puget Sound Record
Annelida (polychaeta)		
	Hobsonia florida	1940
	Polydora cornuta	1932
	Pseudopolydora bassarginensis	2000
	Pseudopolydora kempi japonica	1951
	Streblospio benedicti	1932
Molluska (prosobranchia)	*Crepidula fornicata*	1905
	Illyanassa obsoleta	1907
	Ocinebrellus inornatus	1924
	Urosalpinx inornatus	1890
Molluska (bivalve)	*Crassostrea gigas*	1875
	Mya arenaria	1874
	Neotrapezium liratum	1924
	Petricolaria pholadiformis	1927
	Venerupis philippinarum	1924
Anthropoda (crustacea)	***Eusariella zostericola***	1953
	Balanus improvisus	1853
	Nippoleucon hinumensis	1979
	Limnoria tripunctata	1871 or 1875
	Ampithoe valida	1941
	Corophium acherusicum	1905
	Corophium insidiosum	1915
	Grandidierella japonica	1966
	Jassa marmorata	1938
	Melita nitida	1938
Entoprocta (bryozoa)	***Bowerbanki gracilis***	1923
Urochordata (ascidiacea)	***Botrylloides violaceus***	1973
	Botryllus schlosseri	1944-47
	Molgula manhattensis	1949
Porifera	***Clathria prolifera***	1945-49
Cnidaria (hydrozoa)	***Cordylophora caspia***	1920
Cniidaria (anthozoa)	***Diadumene lineata***	1906

Source: Cohen et al. 2001

Several of the resident shellfish species in Willapa Bay support substantial commercial harvest and/or farming industries (Table 2-3). The most significant species include the Pacific Oyster (*Crassostrea gigas*) and the native Dungeness crab (PNCERS 1998).

Table 2-3: Commercial Shellfish Species within Willapa Bay.

Common Name	Scientific Name	Type of Species
Pacific oyster	*Crassostrea gigas*	Oyster
Dungeness crab	*Cancer magister*	Crab
Red rock crab	*Plagusia chabrus*	Crab
Geoduck	*Panopea abrupta*	Clam
Quahog (hardshell)	*Arctica islandica*	Clam
Softshell clam	*Mya arenaria*	Clam
Native littleneck	*Protothaca staminea*	Clam
Cherrystone	*Mercenaria mercenaria*	Clam

Source: PNCERS 1998

Anadromous salmonids use Willapa Bay's major tributaries for migration, spawning, incubation and early-rearing (Table 2-4). Habitat within Willapa Bay is also important habitat for larval and juvenile marine and anadromous fish rearing. It is, "arguably the most important nursery estuary on the coast for juvenile English sole" (B. Dumbauld, WDFW, personal communication to Wendy Sue Wheeler, WSDA, 11/14/2000). Pacific herring spawn on the eelgrass beds in the early spring, and the estuary also supports lesser-known smelt and sand lance runs; all three of these species are important forage fish for Pacific salmon. Anchovy, salmon and sturgeon have supported commercial fisheries in the outer bay in the past.

Willapa Bay is also a major migration stopover location for shorebirds in the spring and winter (Willapa National Wildlife 2001). An estimated 100,000 to 1,000,000 shorebirds stop to feed in the mudflats of Willapa Bay and other coastal regions of Washington State during the spring. However, spring and winter peak shorebird numbers have been declining by 54 and 67 percent, respectively since 1991 due to infestation of *Spartina*.

The distribution of ducks within Willapa Bay was modeled by Willapa National Wildlife (2001). The hierarchy of distribution within Willapa Bay according to mid-winter aerial waterfowl surveys is: South Bay (47.1%) > East Bay (28.6%) > North Bay (18.8%) > West Bay (4.2%) > Peninsula (1.2%). The most significant region for ducks, the South Bay, is also harbors the greatest density of *Spartina*. A summation of some of the common avian species found within Willapa Bay is provided in Appendix C. (USFWS 1991).

Willapa Bay, its surrounding wildlife refuge, and the extensive contigous lowland forests also support a diverse assemblage of terrestrial and amphibious wildlife. Some 53 species of mammals and 19 herptiles (reptiles and amphibians) have been reported, as summarized in Appendix D (USFWS 1991).

Table 2-4: Anadromous Salmonid Distribution and Utilization within Willapa Bay Tributaries.

River	Species	Run	Primary Use	River Miles Used	% of Stream Used
Naselle River	Chinook salmon	Fall	Migration	0.0-7.3	20%
			Spawning/ Rearing	7.3-31.2	63%
	Coho salmon	N/A	Migration	0.0-7.2	19%
			Spawning/ Rearing	7.2-26.8	52%
	Steelhead	Winter	Migration	0.0-7.4	20%
			Spawning/ Rearing	7.4-30.2	61%
	Chum salmon	N/A	Migration	0.0-9.9	26%
			Rearing/ Migration	9.9-15.2	14%
			Spawning/ Rearing	15.2-25.2	27%
			Migration	25.2-25.6	1%
North River	Chinook salmon	Fall	Migration	0.0-0.3	1%
			Spawning/ Rearing	0.3-59.3	98%
	Coho salmon	N/A	Migration	0.0-0.3	1%
			Spawning/ Rearing	0.3-60.0	99%
	Steelhead	Winter	Migration	0.0-0.6	1%
			Rearing/ Migration	0.6-22.0	36%
			Spawning/ Rearing	22.0-60.0	63%
	Chum salmon	N/A	Migration	0.0-5.8	10%
Palix River	Chinook salmon	Fall	Migration	0.8-4.0	34%
	Coho salmon	N/A	Migration	0.8-4.0	34%
	Steelhead	Winter	Migration	0.8-4.0	34%
	Chum salmon	N/A	Migration	0.8-4.0	34%
Willapa River	Chinook salmon	Fall	Migration	0.0-7.5	16%
			Spawning/ Rearing	7.5-41.3	72%
	Coho salmon	N/A	Migration	0.0-5.5	12%
			Rearing/ Migration	5.5-5.8	1%
			Spawning/ Rearing	5.8-41.8	76%
			Migration	41.8-44.1	5%
	Steelhead	Winter	Migration	0.0-5.5	12%
			Rearing/ Migration	5.5-28.2	48%
			Spawning/ Rearing	28.2-41.3	28%
	Chum salmon	N/A	Migration	0.0-28.3	60%
			Spawning/ Rearing	28.3-31.8	8%
			Migration	31.8-36.0	9%
Willapa Bay	Green sturgeon	N/A	Spawning/ Rearing	N/A	N/A

Source: StreamNet 2003

Padilla Bay

Padilla Bay is an 11,000 acre shallow-water bay in north Puget Sound, incorporating the deltas of the Skagit and Samish Rivers. Padilla Bay is delineated by the saltwater edge of the North Fork Skagit River delta in Puget Sound. Padilla Bay is approximately 8 miles long and 3 miles wide (Padilla Bay NERR 2002). The Skagit River provides the majority of the freshwater and sediment resources to the bay. The bottom of Padilla Bay is very shallow due to sediment transport from the Skagit River, which creates a broad tidal flat during low tide and flooded during high tide (Padilla Bay NERR 2002).

Eelgrass meadows occupy nearly 8,000 acres of the bay, and are made up primarily of two species: native eelgrass (*Zostera marina*) and a non-native species (*Zostera japonica*). The eelgrass meadows stabilize the mud-flat substrate that dominates the bay, and provide food and shelter for various fish and wildlife. Eelgrass and algae are the main primary producers within Padilla Bay (Thom 1988). The salt marsh associated with Padilla Bay was diked and drained before 1900 for farm land, leaving a small fringe of the salt marsh that includes species such as salt grass (*Distichlis spicata*), salt brush (*Ariplex patula*), pickleweed (*Salicornia virginica*), and seaside arrowgrass (*Triglochin maritimum*).

The salt marsh and mudflat of Padilla Bay has problems with two non-native invasive species of cordgrass (*Spartina alterniflora* and *Spartina anglica*) that are competing for resources held by native species (WSDA 2000). *S. alterniflora* (smooth cordgrass) was first introduced into Padilla Bay in the early 1940s and by 1979 approximately 3.5 acres were reported in Padilla Bay; *S. alterniflora* was reported to have increased to 17 acres by 1997 (WSDA 2000). *S. anglica* (common cordgrass) formed from allopolyploidy of the sterile hybrid *S. X townsendii* in England. *S. anglica* has strong hybrid vigor and has taken over approximately 25,000 acres of intertidal salt marsh on the British coast within the past 100 years (WSDA 2000). *S. anglica* was reported in the Puget Sound by 1979 in an estimated coverage of 15 acres; by September 1997, approximately 1,000 solid acres was reported within North Puget Sound (over 8,000 acres of this region was impacted).

Aquatic organisms found within Padilla Bay include crabs, shrimp, mud snail, and various organisms that are supported in salt marsh/mud flat habitat. Extensive eelgrass meadows in the bay provide excellent habitat for finfish such as salmon, perch, and herring, but also many invertebrate species (e.g. worms, shrimp, clams). These species in turn support great blue heron, eagle, otter, and seal populations. The eelgrass meadows of the Padilla Bay estuary provide suitable habitat for many different life stages of aquatic organisms. For example, young Dungeness crabs, one of the most economically important aquatic organisms in Padilla Bay, utilize intertidal cobble found within the eelgrass meadows (Dinnel et al. 1986).

Table 2-4: Marine Invertebrate Species within Padilla Bay.

Phylum	Common Name	Scientific Name	Exotic
Nemertea	Sand nemertean	*Cerebratulus californiensis*	no
Nemertea	Green nemertean	*Emplectonema gracile*	no
Nemertea	Restless worm	*Paranemertes peregrina*	no
Annelida	Lugworm	*Abarenicola pacifica*	no
Annelida	Rough-skinned lugworm	*Abarenicola claparedii*	no
Annelida	Thread worm	*Notomastus tenuis*	no
Cnidaria	Sea pen	*Abietinaria sp.*	no
Cnidaria	Orange-striped jellyfish	*Gonionemus vertens*	no
Cnidaria	Aggregate anemone	*Anthopleura elegantissima*	no
Cnidaria	Brooding anemone	*Epiactis prolifera*	no
Cnidaria	Tealia	*Tealia sp.*	no
Cnidaria	Stalked jellyfish	*Haliclystus auricula*	no
Ctenophora	Sea gooseberry	*Pleurobrachia bachei*	no
Brachiopoda	Lamp shell	*Terebratalia transversa*	no
Echinodermata	Blood star	*Henricia leviuscula*	no
Echinodermata	Six-rayed sea star	*Leptasterias hexactis*	no
Echinodermata	Purple star	*Pisaster ochraceus*	no
Echinodermata	Sunflower star	*Pycnopodia helianthoides*	no
Echinodermata	Green sea urchin	*Strongylocentrotus droebachiensis*	no
Echinodermata	Red sea cucumber	*Cucumaria miniata*	no
Echinodermata	White sea cucumber	*Eupentacta quinquesemita*	no
Chaetognatha	Arrow worm	*Sagitta elegans*	no
Chordata	Hairy sea squirt	*Boltenia villosa*	no
Chordata	Broad base sea squirt	*Cnemidocarpa finmarkiensis*	no
Chordata	Warty sea squirt	*Pyura haustor*	no
Mollusca	Mossy chiton	*Mopalia muscosa*	no
Mollusca	Large variegated limpet	*Notoacmea persona*	no
Mollusca	Plate limpet	*Notoacmea scutum*	no
Mollusca	Finger limpet	*Collisella digitalis*	no
Mollusca	Shield limpet	*Collisella pelta*	no
Mollusca	Limpet	*Unidentified sp.*	no
Mollusca	Spindle whelk	*Searlesia dira*	no
Mollusca	Chinese hat	*Calyptraea fastigiata*	no
Mollusca	Hooked slipper shell	*Crepidula adunca*	no
Mollusca	Slipper shell	*Crepidula sp.*	no
Mollusca	Screw snail	*Bittium sp.*	no
Mollusca	Hairy shell	*Trichotropis sp.*	no
Mollusca	Amphissa	*Amphissa sp.*	no
Mollusca	Keyhole limpet	*Diodora aspera*	no
Mollusca	Chink shell	*Lacuna variegata*	no
Mollusca	Sitka periwinkle	*Littorina sitkana*	no

Phylum	Common Name	Scientific Name	Exotic
Mollusca	Checkered periwinkle	*Littorina scutulata*	no
Mollusca	Cowry?	*Cypraeolina pyriformis*	no
Mollusca	Japanese hornmouth	*Ocenebra inornata (=japonica)*	yes
Mollusca	Atlantic oyster drill	*Urosalpinx cinerea*	yes
Mollusca	Basket shell	*Nassarius fraterculus*	yes
Mollusca	Lean basket shell	*Nassarius mendicus*	no
Mollusca	Lewis' moon snail	*Polinices lewisii*	no
Mollusca	Turret shell	*Batillaria attramentaria*	yes
Mollusca	Japanese false cerith	*Batillaria zonalis*	yes
Mollusca	Wrinkled thais	*Thais lamellosa*	no
Mollusca	Blue top shell	*Calliostoma ligatum*	no
Mollusca	Puppet margarite	*Margarites pupillus*	no
Mollusca	Taylor's sea slug	*Phyllaplysia taylori*	no
Mollusca	Bubble shell	*Acteocina sp.*	no
Mollusca	Barrel bubble	*Acteocina harpa (Retusa harpa)*	no
Mollusca	Bubble shell	*Haminoea sp.*	no
Mollusca	Blister paper bubble	*Haminoea vesicula*	no
Mollusca	Barrel bubble	*Cylichna sp.*	no
Mollusca	Odostome	*Odostomia sp.*	no
Mollusca	Opalescent nudibranch	*Hermissenda crassicornis*	no
Mollusca	Sculptured nut clam	*Acila castraensis*	no
Mollusca	Heart cockle	*Clinocardium nuttallii*	no
Mollusca	Japanese oyster	*Crassostrea gigas*	yes
Mollusca	Dipper clam	*Lyonsia striata*	no
Mollusca	Polluted macoma	*Macoma inquinata*	no
Mollusca	Bent-nosed clam	*Macoma nasuta*	no
Mollusca	Sand clam	*Macoma secta*	no
Mollusca	Eastern soft-shell clam	*Mya arenaria*	yes
Mollusca	Blunt soft-shell clam	*Mya truncata*	no
Mollusca	Blue mussel	*Mytilus edulis*	no
Mollusca	purple varnish clam	*Nuttallia obscurata*	yes
Mollusca	Rock oyster	*Pododesmus macroschisma*	no
Mollusca	Native littleneck clam	*Protothaca staminea*	no
Mollusca	Washington clam	*Saxidomus giganteus*	no
Mollusca	Butter clam	*Saxidomus nuttalli*	no
Mollusca	Horse clam	*Schizothaerus nuttallii*	no
Mollusca	Jackknife clam	*Solen sicarius*	no
Mollusca	Japanese littleneck clam	*Venerupis philliparum*	yes
Mollusca	White tellen	*Tellina modesta*	no
Mollusca	Horse clam	*Tresus capax*	no
Mollusca	Dentalium	*Dentalium rectuis*	no
Arthropoda	Horse barnacle	*Balanus cariosus*	no
Arthropoda	Smooth acorn barnacle	*Balanus crenatus*	no
Arthropoda	Acorn barnacle	*Balanus glandula*	no

Phylum	Common Name	Scientific Name	Exotic
Arthropoda	Eelgrass isopod	*Idotea resecata*	no
Arthropoda	Olive-green isopod	*Idotea wosnesenskii*	no
Arthropoda	Oregon pill bug	*Gnorimosphaeroma oregonense*	no
Arthropoda	Beach hopper	*Orchestia traskiana*	no
Arthropoda	Skeleton shrimp	*Caprella laeviscula*	no
Arthropoda	Coon-striped shrimp	*Pandalus danae*	no
Arthropoda	Gray shrimp	*Crangon nigricauda*	no
Arthropoda	Short-spined shrimp	*Heptacarpus brevirostrus*	no
Arthropoda	Ghost shrimp	*Callianassa californiensis*	no
Arthropoda	Mud shrimp	*Upogebia pugettensis*	no
Arthropoda	Porcelain crab	*Petrolisthes eriomerus*	no
Arthropoda	Hermit crab	*Pagurus granosimanus*	no
Arthropoda	Hairy hermit crab	*Pagurus hirsutiusculus*	no
Arthropoda	Decorator crab	*Oregonia gracilis*	no
Arthropoda	Spider crab	*Pugettia gracilis*	no
Arthropoda	Kelp crab	*Pugettia producta*	no
Arthropoda	Dungeness crab	*Cancer magister*	no
Arthropoda	Red rock crab	*Cancer productus*	no
Arthropoda	Graceful cancer	*Cancer gracilis*	no
Arthropoda	Purple shore crab	*Hemigrapsus nudus*	no
Arthropoda	Green shore crab	*Hemigrapsus oregonensis*	no
Arthropoda	Pea crab	*Pinnixa occidentalis*	no
Arthropoda	Pea crab	*Pinnixa schmitti*	no
Arthropoda	Burrow crab	*Pinnixa tubicola*	no
Arthropoda	Helmet crab	*Telmessus cheiragonus*	no
Arthropoda	Sea spider	*Halosoma viridintestinale*	no

Source: S. Riggs, Personal Communication, Padilla Bay National Estuarine Research Reserve, 2003

The complex of aquatic and intertidal habitats supported in Padilla Bay and its conjoined freshwater deltaic environments support the early rearing and the saltwater/freshwater physiological transitions of substantial anadromous salmonid stocks (Table 2-5). In addition, over 50 other resident fish species have been reported in the bay (Table 2-5). Both herring and smelt use the eelgrass meadows of Padilla Bay for spawning, and both species are significant salmonid forage species.

Table 2-5. Anadromous and Resident Fish Species Found within Padilla Bay and Associated Tributaries.

Common name	Scientific Name	Anadromous/ Resident
Pink salmon	*Oncorhynchus gorbuscha*	Anadromous
Chum salmon	*Oncorhynchus keta*	Anadromous
Coho salmon	*Oncorhynchus kisutch*	Anadromous
Sockeye salmon	*Oncorhynchus nerka*	Anadromous
Chinook salmon	*Oncorhynchus tshawytscha*	Anadromous
Coastal cutthroat trout	*Salmo clarki clarki*	Anadromous
Steelhead	*Oncorhynchus mykiss*	Anadromous
Dolly varden/ bull trout	*Salvelinus malma*	Anadromous
Spiny dogfish	*Squalus acanthias*	Resident
Big skate	*Raja binoculata*	Resident
Ratfish	*Hydrolagus colliei*	Resident
Pacific herring	*Clupea harengus pallasi*	Resident
Northern anchovy	*Engraulis mordax mordax*	Resident
Surf smelt	*Hypomesus pretiosus pretiosus*	Resident
Longfin smelt	*Spirinchus thaleichthys*	Resident
Northern lampfish	*Stenobrachius leucopsarus*	Resident
Plainfin midshipman	*Porichthys notatus*	Resident
Northern clingfish	*Gobiesox maeandricus*	Resident
Pacific tomcod	*Microgadus proximus*	Resident
Red brotula	*Brosmophycis marginata*	Resident
Blackbelly eelpout	*Lycodopsis pacifica*	Resident
Tube-snout	*Aulorhynchus flavidus*	Resident
Three-spined stickleback	*Gasterosteus aculeatus*	Resident
Bay pipefish	*Syngnathus griseolineatus*	Resident
Shiner perch	*Cymatogaster aggregata*	Resident
Pile perch	*Rhacochilus vacca*	Resident
Striped seaperch	*Embiotoca lateralis*	Resident
Pacific sandfish	*Trichodon trichodon*	Resident
Northern ronquil	*Ronquilus jordani*	Resident
(Pacific) snake prickleback	*Lumpenus sagitta*	Resident
Bluebarred prickleback	*Plectobranchus evides*	Resident
Black prickleback	*Xiphister atropurpureus*	Resident
Penpoint gunnel	*Apodicthys flavidus*	Resident
Crescent gunnel	*Pholis laeta*	Resident
Saddleback gunnel	*Pholis ornata*	Resident
Pacific sand lance	*Ammodytes hexapterus*	Resident
Yellowtail rockfish	*Sebastes flavidus*	Resident
Sharpchin rockfish	*Sebastes zacentrus*	Resident
Rock greenling	*Hexagrammos lagocephalus*	Resident

Common name	Scientific Name	Anadromous/ Resident
Whitespotted greenling	*Hexagrammos stelleri*	Resident
Lingcod	*Ophiodon elongatus*	Resident
Padded sculpin	*Artedius fenestralis*	Resident
Silverspotted sculpin	*Blepsias cirrhosus*	Resident
Sharpnose sculpin	*Clinocottus acuticeps*	Resident
Buffalo sculpin	*Enophrys bison*	Resident
Soft sculpin	*Gilbertidia sigalutes*	Resident
Pacific staghorn sculpin	*Leptocottus armatus*	Resident
Great sculpin	*Myoxocephalus polyacanthocephalus*	Resident
Sailfin sculpin	*Nautichthys oculofasciatus*	Resident
Tadpole sculpin	*Pyschrolutes paradoxus*	Resident
Grunt sculpin	*Rhamphocottus richardsoni*	Resident
Ribbed sculpin	*Triglops pingeli*	Resident
Cabezon	*Scorpaenichtyhys marmoratus*	Resident
Sturgeon poacher	*Agonus acipenserinus*	Resident
Tubenose poacher	*Pallasina barbata aix*	Resident
Smooth alligator fish	*Anoplagonus inermis*	Resident
Pacific spiny lumpsucker	*Eumicrotremus orbis*	Resident
Spotted snailfish	*Liparis callyodon*	Resident
Ribbon snailfish	*Liparis cyclopus*	Resident
Marbled snailfish	*Liparis dennyi*	Resident
Tidepool snailfish	*Liparis florae*	Resident
Showy snailfish	*Liparis pulchellus*	Resident
Speckled sanddab	*Citharichthys stigmaeus*	Resident
Arrowtooth flounder	*Atheresthes stomias*	Resident
Starry flounder	*Platichthys stellatus*	Resident
Butter sole	*Isopsetta isolepis*	Resident
Rock sole	*Lepidopsetta bilineata*	Resident
Slender sole	*Lyopsetta exilis*	Resident
Dover sole	*Microstomus pacificus*	Resident
English sole	*Parophrys vetulus*	Resident
Sand sole	*Psettichthys melanostictus*	Resident

Source: S. Riggs, Personal Communication, Padilla Bay National Estuarine Research Reserve, 2003

Padilla Bay is a reserve for migratory avian species in the winter (approximately 50,000 ducks, covering 26 species), as well as resident species (Padilla Bay NERR 2002). Resident species include great blue heron, dunlin (a shorebird), bald eagle, peregrine falcon, merlin, and snowy owl. There are approximately 240 species of birds that utilize Padilla Bay as either a foraging resource, nesting area, or migratory route.

Terrestrial mammals in the Padilla Bay reserve include black-tailed deer, raccoon, skunks, coyote, muskrat, and long-tailed weasel; marine mammals that use Padilla Bay include harbor seals, and occasionally California sea lions and porpoises (Table 2-6).

Table 2-6: Terrestrial and Aquatic Mammalian Species in the Padilla Bay Region.

Order	Common name	Scientific name	Exotic
Marsupiala	Virginia opossum	*Didelphis virginiana*	yes
Insectivora	Vagrant shrew	*Sorex vagrans*	no
	Mole	*Unidentified sp.*	no
Chiroptera	Bat	*Myotis spp.*	no
Lagomorpha	Eastern cottontail	*Sylvilagus floridanus*	yes
Rodentia	Douglas' squirrel	*Tamiasciurus douglasii (i or ii)*	no
	Northern flying squirrel	*Glaucomys sabrinus*	no
	Beaver	*Castor canadensis*	no
	Townsend's vole	*Microtus townsendii (i or ii)*	no
	Muskrat	*Ondatra zibethicus (zibethica?)*	no
	Deer (white-footed) mouse	*Peromyscus maniculatus*	no
Carnivora	Coyote	*Canis latrans*	no
	Red fox	*Vulpes vulpes (fulva?)*	no
	Raccoon	*Procyon lotor*	no
	Striped skunk	*Mephitis mephitis*	no
	River otter	*Lutra candensis*	no
	Longtailed weasel	*Mustela frenata*	no
Artiodactyla	Mule (black-tailed) deer	*Odocoileus hemionus columbianus*	no
Cetacea	Porpoise	*Unidentified sp.*	no
Pinnipedia	Harbor seal	*Phoca vitulina*	no
	Sea lion	*Unidentified sp.*	no

Source: S. Riggs, Personal Communication, Padilla Bay National Estuarine Research Reserve, 2003

Specific Receptors Examined for Exposure

Plants typical to the environments where imazapyr could be used to control *Spartina* include such species as eelgrass (*Zostera marina* and *Zostera japonica*), and a variety of algal species such as sea lettuce (*Ulva sp.)*. Animals could include ungulates such as deer, elk and rabbit, omnivores such as raccoons, terrestrial carnivores such as bobcat and coyote, avian species such as osprey, eagles and gulls; reptiles such as turtles; amphibians such as frogs; and insects such as mosquitoes. Obligate aquatic animal species include the array of Pacific salmonids native to Washington's waters, such as coho salmon, but also other fish species such as juvenile flatfish (Pleuronectidae), juvenile sturgeon (Ascipenseridae), and bullhead (Cottidae). Additional aquatic species potentially exposed to imazapyr include the vast list of benthic and mobile invertebrates common to the intertidal zone of Washington's estuaries such as dungeness and rock crab (*Cancer spp*). As opposed to modeling exposure to all of these (and other) possible plants and animals that could be potentially exposed to imazapyr from *Spartina* treatment, we evaluated exposure in select surrogate "guilds".

Receptor "guilds," species with similar life histories or niches in the environment, are used to estimate exposure rather than estimating exposure for each individual species where a chemical could be applied. The assumption of this approach is that the general characteristics of each guild will provide risk estimates that are representative of the entire guild. As such, each guild can be extrapolated more broadly than single species estimates. The underlying concept is that each receptor falls into a group of potential receptors that function in similar ecological niches or "guilds." For example, many species of heron and egret feed on small fish and invertebrates and require trees for roosts. As such, herons and egrets display similar life histories and would be anticipated to have similar exposures to imazapyr. A single surrogate, such as the great blue heron, for which reliable life-history information is available, may be used for calculating risk and the results may then be extrapolated to the guild as a whole. This approach allows the risk assessment to directly evaluate species for which the best exposure information is available. This approach also allows results to be extrapolated to a broader range of potential receptors, thereby maximizing data usage and applicability of results.

Surrogate species were selected in each identified receptor guild. The selected surrogates have been studied sufficiently to enable risk calculations to be made even though a surrogate itself may not necessarily be present within the study area (e.g., mallard). All of the other receptors are present in Washington State and are representative of feeding guilds present. The fundamental assumption that was made in this study was that if negligible risk is determined for the surrogate species, then the entire guild is protected.

Specific wildlife receptor guilds were selected based on the evaluation of exposure pathways and the possibility that a given receptor could come into contact with imazapyr applied for Spartina control. The receptor selections were limited mainly to those receptors (species) that are found in the areas where *Spartina* is distributed, and to surrogate species for which sufficient life history and/or toxicological information existed so that reasonable exposure factors could be used to estimate exposure and risk. The following bullets briefly summarize the ecological receptor guilds for which exposure calculations were evaluated. Life history characteristics of these receptors are described fully in Chapter 4.

- **Mallard Duck *(Anas platyrhynchus)*.** This avian species was considered a representative (primarily herbivorous) waterfowl species bird that is common to the areas of interest. This species was evaluated due to its direct and indirect exposure through the consumption of aquatic plants.
- **Scaup (*Aythya* sp. [*marila* = greater; *affines* = lesser]).** These species are more omnivorous than the mallard, consuming a high proportion of their diet as animal protein, especially during spring and fall migration periods. Animal sources in the diet include mussels, small fish, and other benthic and pelagic invertebrates. The lesser scaup is considerably more common in Washington, but both are coastal species.
- **Red Fox (*Vulpes vulpes*).** This mammalian species is a medium-sized primarily carnivorous mammal of the canine family that is resident to much of western Washington, and whose range is expanding. It is a surrogate for other carnivorous species such as the wolf, coyote, and mustellids.
- **Norway Rat *(Rattus norvegicus).*** A mammalian species of near ubiquitous distribution in lowland areas throughout Washington State and the U.S.. It is particulalry common around

coastal areas where it has been introduced through trade vectors of shipping. Rats are commonly used for toxicity testing.

- **Deer Mouse (*Peromyscus manisculatus).*** A common herbivorous mammal species found in a variety of ecosystems, including coastal grasslands. Mice are also commonly used in toxicity testing.
- **Bobwhite Quail (*Colinus virginianus)*** A common avian test species. This species is not found in Washington State, but serves as a good surrogate for the introduced California (valley) quail, *Lophortyx californica,* which is relatively common in western Washington. This species is primarily herbivorous, eating mostly seeds. Quail are commonly used to test avian sensitivity to toxicants.
- **Marsh Wren *(Cistothorus* palustris).** A common native avian species to coastal grasslands and salt marsh habitats in Washington State. This species consumes a high proportion of its diet in animal protein.
- **Cottontail Rabbit *(Sylvilagus sp).*** A strictly herbivorous species common to much of western Washington, but introduced originally from the east coast. It is also a typical EPA test species used particularly to evaluate dermal sensitivity.

Threatened and Endangered Species and Species of Concern

Threatened and endangered species are those species that have been given special legal and protective designations by federal or state government resource agencies. A federally endangered species is one that is in danger of extinction throughout all or a significant portion of its range. A federally threatened species is one likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. A species of concern is one for which status information suggests the species is not abundant, and for which additional informatin is sought.

Addressing exposure and risk to threatened and endangered species generally requires the use of surrogate receptor guilds because they are rarely used (for obvious reasons) to establish toxicity information on new chemicals (Sappington et al. 2000). A summary of all federal T&E species in Washington State, their Washington State status, and their potential for existence in areas where imazapyr treatments of *Spartina* could occur based on their habitat preferences is included in this report as Appendix E. From this information, the potential exposure of T&E species is truncated to only a few select species. In brief, utilization of Washington's coastal areas by threatened and endangered (T&E) species is primarily limited to the listed salmonid species from the Columbia and Puget Sound basins. In addition, several coastal avian species listed as sensitive, candidate, or state-monitor species are common to Willapa Bay and other areas where *Spartina* is distributed.

2.3 Conceptual Model

A conceptual model was developed for imazapyr (Figures 2-3 and 2-4). This conceptual model accounted for the sources, pathways, and routes of exposure to the different trophic levels and ecological receptors. Exposure of ecological receptors to imazapyr used to control *Spartina spp*. could occur directly or inadvertantly (indirectly) through ingestion of contaminated food, water, or sediment, through inhalation of aerosol, or through direct contact (e.g., insects).

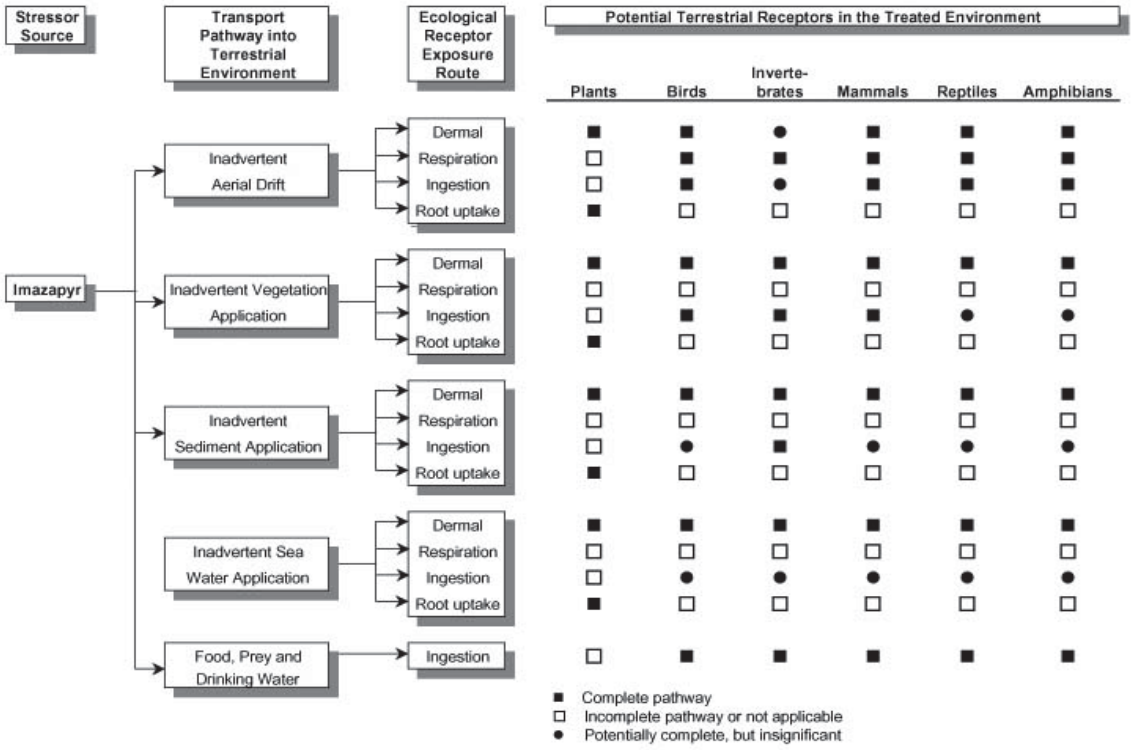

Figure 2.3: Conceptual site model for imazapyr stressor impacts to terrestrial receptors.

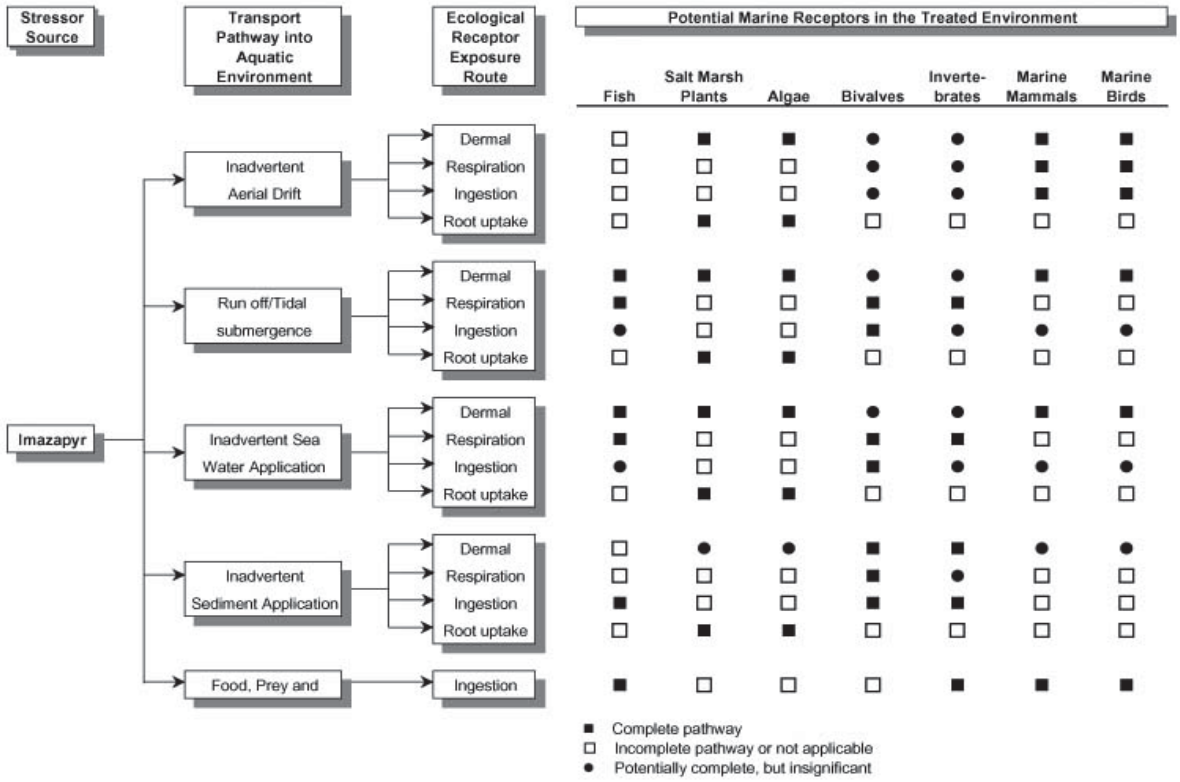

Figure 2.4: Conceptual site model for Imazapyr stressor impact to aquatic receptors.

3.0 HAZARD ASSESSMENT

The hazard assessment portion of a risk assessment summarizes environmental fate and toxicity data developed on the compound(s) of interest. To understand chemical hazards, some fundamental aspects of toxicology should be clarified. A central tenet of toxicology is that there is some exposure dose at which no effect is measurable in the response tested, and this paradigm is considered a valid model for this assessment. This dose or concentration is known as the no observable effect level or concentration (NOEL or NOEC). The lowest observable effect level or LOEL corresponds to the lowest dose at which a statistically significant difference is measurable relative to an unexposed control group. Beyond these typical measures, standard toxicological terms include the LC_{50}, the exposure concentration that kills 50% of the animals tested; the EC_{50}, the concentration that elicits a non-lethal effect in 50% of the organisms tested with the measurement endpoint. Measures such as the LC_{90} or EC_{90} simply reference variations in the proportion of the population tested that responds to the test (in this case, 90%). Other terms such as the IC50 or IC10, reference a concentration that results in inhibition of an endpoint—in this case 50% and 10% inhibition respectively. These terms are often used to gauge the effect of a chemical on endpoints such as growth, or in-vitro endpoints such as the inhibition of an enzyme.

In considering the hazards of imazapyr, it is important to recognize how the chemical can first enter into commercial use. Imazapyr has been produced under different commercial formulations with technical imazapyr and imazapyr isopropylamine salt (49 percent water solution) (Table 3-1). The formulations have the same mechanism of action on target plants, but different environmental factors control the efficacy of each formulation and where they might be applied. Most testing related to the toxicity of imazapyr is related to the technical compound instead of the commercial formulation. The Arsenal® formulation listed below is the formulation projected for use in the estuary setting for *Spartina* control. Mechanism of action, environmental fate, and toxicity studies described in detail below reference these general formulations.

Table 3-1: Product formulations of imazapyr.

Commercial Product	% Imazapyr Technical	% Imazapyr Isopropylamine salt	% Inert Ingredient	Source
Arsenal®	N/A	25	75 other inert ingredients	Cyanamid 1997
Chopper®	N/A	1	99 other inert ingredients	Cyanamid 1997
Arsenal® Herbicide	28.7	N/A	71.3 other inert ingredients	BPA 2000
Arsenal® Railroad Herbicide	27.6	N/A	72.4 other inert ingredients	BPA 2000, USDA 1995
Arsenal® Applicators Concentrate Herbicide	53.1	N/A	46.9 other inert ingredients	BPA 2000
Chopper® Herbicide	27.6	N/A	72.4 other inert ingredients	BPA 2000
Chopper®	22.6	5.4	72 other inert ingredients	USDA 1995
Chopper® RTU	N/A	3.6	30 propylene glycol 5.0 isopropanol 61.4 other inert ingredients	USDA 1995

3.1 Mechanism of Action and Efficacy

3.1.1 Mechanism of Action

The mechanism of action of an herbicide is the biochemical and/or physical method by which it has been engineered to kill or suppress the growth of specific plants. Imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H- imidazol-2-yl]-3pyridinecarboxylic acid) is the active ingredient in the commercially available formulations Arsenal®, Chopper®, Stalker®, Assault®, and Contain®. The herbicide is commonly produced in either a weak acid form or as an isopropylamine salt (Figure 3-1). The isopropylamine salt form is generally dissolved in a solution containing 49% water, and most commercial products sold are in this salt form. Imazapyr was first registered under the commercial formulation of the isopropylamine salt Arsenal® in 1984 and again with the weak acid formulation Chopper® in 1993 (Cyanamid Ltd. 1997).

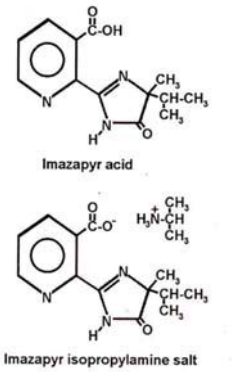

Figure 3-1: Chemical structures of the two forms of imazapyr.

The specificity of an herbicide for target vegetation varies by herbicide family. Imazapyr belongs to the chemical family imidazolinone. The imidazolinones are non-selective herbicides used to control weeds, broadleaved herbs, and woody species. Imazapyr is primarily adsorbed through plant tissue, but can also be adsorbed through roots in the soil. The compound is translocated in the xylem and phloem to the meristematic tissues. The mechanism of action is through inhibition of branched-chain amino acid synthesis. Specifically, imazapyr inhibits the enzyme acetohydroxy acid synthase (AHAS) or acetolactate synthase (ALS) which catalyzes the production of three branched-chain aliphatic amino acids (valine, leucine, and isoleucine) that controls protein synthesis and cell growth (Cox 1996).

Imazapyr is slow-acting and is generally most effective during post emergence axillary budding (Hanlon and Langeland 2000). Plants stop growth initially in the roots and continue in the above ground portions, with complete death occurring approximately one month after treatment, depending on environmental conditions (Cox 1996).

Animals do not synthesize their own three branched-chain aliphatic amino acids, but obtain them by eating plants and other animals; therefore the engineered mechanism for plant toxicity is not generally relevant to birds, mammals, fish or invertebrates. Toxicity associated with excessive doses administered to animals occurs by different mechanisms.

3.1.2 Efficacy on Target Vegetation

Non*-Spartina *Studies

Kay (1995) examined the efficacy of wipe-on applications of imazapyr on the common reed (*Phragmites australis*) in aquatic systems. Similar to *Spartina* in the Pacific Northwest, the common reed is considered highly invasive in the midwest and Atlantic states, as well as Washington, serving little habitat value for fish and wildlife. In this field-based experiment, both imazapyr (Arsenal$_{tm}$) and glyphosate (Rodeo$_{tm}$) were tested at 0.5 and 0.25-strength dilutions with 1% surfactant (X-77$_{tm}$) added to the application mixtures. Control and cut plots received no herbicide treatment. When examined at the end of the growing season, Kay observed significantly improved *Phragmites* suppression with Arsenal $_{tm}$ relative to Rodeo$_{tm}$, at both treatment concentrations (Table 3-2). However, the overall control for either treatment chemical using the wipe-on application method was not considered acceptable. Short plants were shrouded from wipe treatment by larger plants, rendering complete control impossible. In addition, effects on non-target emergent plants were documented.

Table 3-2: Efficacy of Wipe-on Applications of Imazapyr and Glyphosate.
(source: Kay 1995)[1]

Treatment	Rate	% Dead in 1991	% Surface Covered with Live Reeds in 1992	% Surface Covered with Live Reeds in 1993
Control—No Herbicide or Mechanical Control	0	3a	80a	78a
Cut Treatment—No Herbicide	0	100e	2d	4c
Arsenal	25%	57c	55b	64a
Arsenal	50%	75d	16c	55a
Rodeo	25%	38b	65ab	70a
Rodeo	50%	33b	47b	70a
Rodeo (spray)	1.25%	100e	<1d	15b

1: Data in columns represent the mean of three replicates. Within column comparisons are not significant if the letter following the value listed in a cell is found in another cell within the same column. Estimates of kill and survival were visually based.

In a study looking at the response of torpedo grass (*Panicum repens*) to different application rates of imazapyr and imazapyr with fluridone, the level of control observed in the different plots varied spatially and substantially depending on conditions where it was applied (Hanlon and Langeland 2000). In this study, imazapyr (Arsenal$_{TM}$) was applied in three canal systems of Lake Okeechobee at a rate of 0.28, 0.56, 0.84 or 1.12 kg acid equivalents (ae)/ha in a total tank mix volume of 187 L/ha (20 gal/acre) that contained 0.5% nonionic surfactant (Kenetic$_{tm}$). Some treatment plots also had the imazapyr combined with 0.43 kg fluridone/ha. In one canal system where applied, highly effective control was obtained with imazapyr on one side of the canal, yet little or no control was obtained on the opposite side of the canal, despite similar treatment volumes and conditions. The authors speculated that floating periphyton mats in abundance on one side of the canal reduced the stem density of torpedo grass there and also may have bound up the applied herbicide such that the torpedo grass along that side of the canal received a lower dose. Other key factors that may have affected the results of this study included: (1) soil moisture affected by hydroperiod fluctuations (from dry to 1.7 m inundation depth between areas), and (2) canopy of emergent thatch reducing the regrowth of the species is enhanced. Unfortunately, the authors did not attempt to analyze tissue concentrations in either target or non-target vegetation, or in the water such that differentiating the causes of the treatment differences could be resolved with less uncertainty. Notwithstanding, the

study demonstrated clear control with imazapyr, particularly when the thatch overburden was burned before herbicide treatment, as was done in one of the other canals where treatments were applied. When the thatch was not removed or burned, as was done in the third canal, no effective plant suppression was obtained. The addition of fluridone to the mixture did not appear to influence efficacy at any of the treatment concentrations. Although the results of these studies show that environmental conditions can highly affect the efficacy of imazapyr treatments in the aquatic environment, it could be concluded that predicting efficacy is far from a stochastic (random) process provided a basic understanding of the application conditions is considered prior to treatment.

Table 3-3 summarizes some of the target aquatic and terrestrial nuisance plant species for which imazapyr has had reported efficacy (USACE 2003).

Table 3-3: Examples of Aquatic Species Effectively Controlled by Imazapyr.
(Source ACOE 2003)

Common Name	Scientific Name
Giant Reed	Arundo donax L.
Buttonbush	Cephalanthus occidentalis
Purple Loosestrife	Lythrum salicaria L.
Melaleuca	Melaleuca quinquenervia (Cav.) Blake
Torpedo Grass	Panicum repens L.
Common Reed	*Phragmites australis* (Cav.) Trin. ex Steud.
Brazilian Peppertree	Schinus terebinthifolius Raddi
Giant Foxtail	Setaria magna Griseb.
Tamarisk or Salt Cedar	Tamarix spp.
Cattails	*Typha* spp.
Para Grass	*Urochloa mutica* (Forsk.) T.Q. Nguyen

There are a number of weeds that have developed resistance to imazapyr (Table 3-4). It is suspected that these plants have developed cross-resistance to imazapyr following the use of herbicides with the same mode of action (i.e., acetolactate synthase inhibition), primarily the sulfonylurea herbicides (Cox 1996). Resistance is afforded plants by developing a structurally similar form of the enzyme acetolactase synthase that is not blocked by imazapyr to the same degree. The resistant enzyme form is thought to have developed primarily from a single point mutation (Sathasivan et al. 1991).

Table 3-4: Plants known to be resistant to the use of imazapyr.
(source Cox 1996)

Common Name	Scientific Name
Rigid ryegrass	Lolium rigidum
Kochia	Kochia scoparia
Common chickweed	Stellaria media
Russian thistle	Salsola iberica
Perennial ryegrass	Lolium perenne
Annual sowthistle	Sonchus oleraceus
Brassicaceae spp.	Arabidopsis thaliana
Algae spp.	Chlorella emersonii

Spartina *Control Studies*

Comparison studies of the efficacy of imazapyr relative to glyphosate on *S. alterniflora* control have been recently conducted by Patten and Stenvall (2002) and Patten 2002. In these studies each herbicide was tested at different application rates and/or drying times before tidal submergence or rain. Comparisons were made in treated *Spartina* meadows at application rates of 0.84 and 1.68 kg ae/ha for imazapyr and 4.2, 8.4, and 18 kg-ae/ha for glyphosate. Imazapyr was dissolved in a crop-oil surfactant while glyphosate was dissolved in a non-ionic surfactant at 1% v/v. The herbicides were applied using a backpack sprayer equipped with a 1.5 or 3m boom equipped with Teejet 11001 or 11002 nozzles that dispersed the herbicide mixtures at a rate of 94 to 940 L/ha. Efficacy was evaluated based on a visual rating of percent control in a treated plot assessed approximately one year following treatment compared to an untreated plot. The results of this study, representing numerous trials between 1997 and 2000, are reflected in the box plot in Figure 3-2 on the following page.

As demonstrated in Figure 3-2, a treatment concentration of 0.84 kg-ae/ha of imazapyr was slightly more effective than 8.4 kg/ha glyphosate for control of *Spartina*, but both treatments at these rates had high variability and produced incomplete control. At the higher rates of application of each herbicide nearly complete control was obtained (generally greater than 90%), and imazapyr had less variability around the median and slightly greater effectiveness at *Spartina* control than glyphosate. As depicted, more than 10-times the amount of glyphosate was required to achieve similar control as was obtained with imazapyr, but imazapyr treatments produced a greater number of outliers at the higher treatment rate. The variability in treatment response for either herbicide was not discussed by the authors. Treatment variability may have been due to factors such as overlying thatch (Hanlon and Langeland 2000), differences in plot size between years, or surfactant differences.

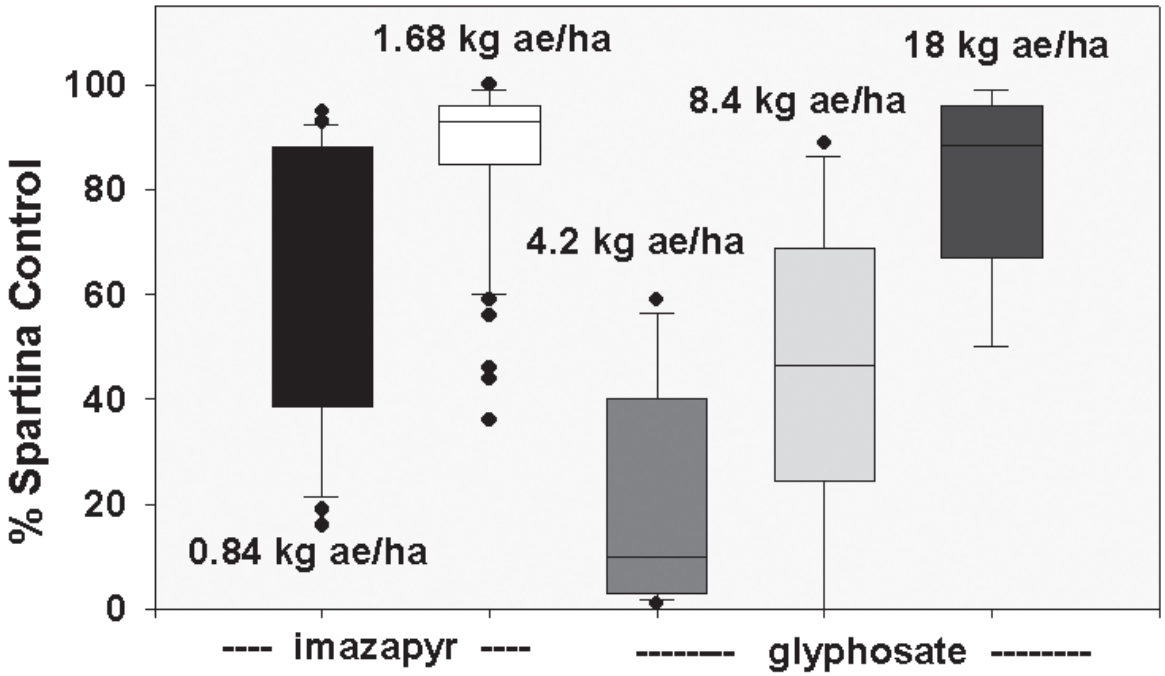

Figure 3-2: Box and whisker graph of *Spartina* control as a function of rate of imazapyr and glyphosate use in experiments conducted in Willapa Bay, WA from 1997 to 2000.
(Source: Patten and Stenvall 2002.)

Note: Boxes in box-plots depict the data between the 25th and 75th percentiles, with the cross bar in the box representing the median of the data, and the hinges (whiskers) representing the highest and lowest data values for the main body of data (5th and 95th percentiles); dots beyond the whiskers are considered outliers by standard statistical convention.

Effects of drying time were examined in a separate experiment using the 1.68 kg/ha imazapyr treatment and 8.4 kg ae/ha glyphosate treatment only (Patten and Stenvall 2002). Drying times for this experiment were segregated by 4-7 hours and greater than 7 hours. Patten and Stenvall's study found that imazapyr provided more control with less variability and shorter dry time requirements when compared to glyphosate (Figure 3-3). Glyphosate at 8.4 kg/ha was not as effective at *Spartina* control when provided a drying time of only 4-7 hours. Even when allowed at least seven hours of dry time, the glyphosate treatment exhibited greater variability around the median than either of the imazapyr dry-time treatments. In contrast, imazapyr efficacy was not significantly different between the 4-7 and > 7 hour dry times investigated. While the results of this experiment demonstrate the sensitivity of glyphosate to drying time, the results would have been more useful if the glyphosate treatment concentration that provided nearly complete control (18 kg ae/ha) was compared against the imazapyr treatment that provided similar Figure 3-3). The comparison depicted in Figure 3-3 leaves in question what factor dose may have played in this efficacy trial.

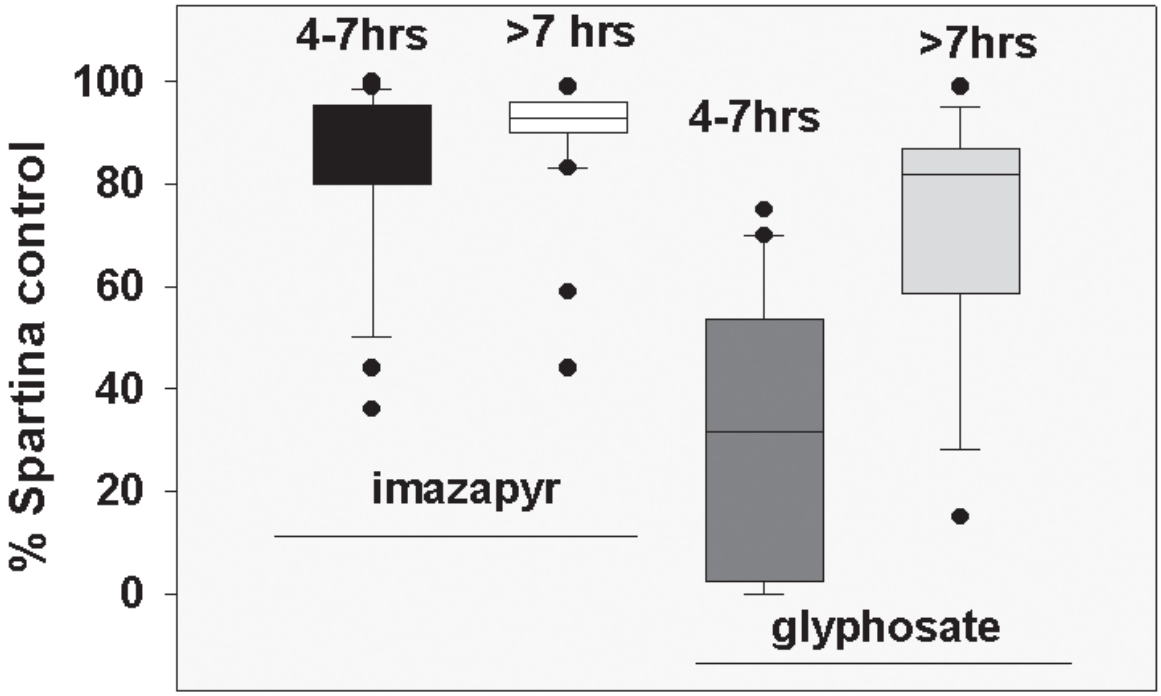

Figure 3-3: Box and whisker graph of *Spartina* control as a function of dry time for imazapyr (1.68 kg/ha) and glyphosate (8.4 kg/ha) use in experiments conducted in Willapa Bay, WA form 1997 to 2000.
(Source: Patten and Stenvall 2002.)

Additional studies by Patten (2002) examined the efficacy of imazapyr and glyphosate with various seasonal timings, spray volumes and with several surfactants. Formulations of these surfactants are proprietary and therefore a full analysis of their components is not possible (their toxicity is discussed in Section 3.5). Seasonal application timings corresponded to the stage of plant development from preanthesis (late June to mid-July), anthesis (mid-July to August), or seed filling (September). Application volumes ranged from 23 to 374 L/ha at active ingredient concentrations of 0.84 and 1.68 kg-ae/ha for imazapyr, and 7.2 and 8.4 kg/ha for glyphosate and application volumes from 94 to 748 L/ha at concentrations of 3.63 to 8.4 kg/ha for glyphosate. Surfactants evaluated included R11$_{tm}$, Agri-Dex$_{tm}$, Hasten$_{tm}$, LI100$_{tm}$, Syl-Tac$_{tm}$, Kinetic$_{tm}$, and Dyne-Amic$_{tm}$.

The efficacy of imazapyr and glyphosate relative to application date were inconsistent, and shown to be more influenced by spray volume than by application timing, provided application occurred during the growing season. Higher spray volumes tended to result in more consistent *Spartina* control; however, this trend was not consistent across all dates and sites (Table 3-5). This inconsistency was considered due more to changes in estuarine conditions (e.g., storms, tides, mud-covered leaves) than to physiological changes in *Spartina* during different seasons. The least effective dates for imazapyr efficacy were early July and October.

Table 3-5: Effect of rate, timing and spray volume in 2000 on the efficacy of imazapyr and glyphosate for smooth cordgrass control in Willapa Bay, WA.
(Source: Patten, 2002.)

Herbicide	Rate kg/ha	Application Date in Year 2000	Application Spray Volume L/ha	Treatment Efficacy % Control Site 1	Site 2
Imazapyr	0.84	July 6	94	40	35
		August 2	94	81	
		August 31	94	47	89
		September 14	94	63	
		October 7	94	19	90
		July 6	468	44	
		August 2	468	49	
		August 31	468	92	
		September 14	468	84	
		October 7	468	23	46
Imazapyr	1.68	July 6	94	83	
		August 2	94	94	99
		August 31	94	36	
		September 14	94	94	96
		October 7	94	44	
		July 6	468	77	
		August 2	468	97	
		August 31	468	92	
		September 14	468	93	
		October 7	468	59	
Glyphosate	8.4	July 6	94	20	0
		August 2	94	30	
		August 31	94	0	69
		September 14	94	32	
		October 7	94	62	46
Untreated				0	0

Imazapyr at 1.68 kg/ha provided excellent control of *Spartina* when applied at ultra-low application volumes (23 and 47 L/ha) (Table 3-6). The study showed that as long as drying time was sufficient, good control could be achieved with low volume applications. Across all sites and experiments described in Patten's 2002 paper, 58 and 88% cordgrass control was obtained with imazapyr applications at 0.84 and 1.68 kg ae/ha, respectively. Glyphosate, by comparison, provided 45 and 81% control, which was obtained at the 7.2 and 8.4 kg/ha application rates, respectively. All surfactants used in the study provided delivery of the herbicides to yield effective control of the target organism.

Table 3-6: Effects of herbicide rate and application spray volume in August 1999 on smooth cordgrass control in Willapa Bay, WA.
(Source: Patten, 2002,)

Herbicide	Rate kg/ha	Spray Volume L/ha	Treatment efficacy % control					
			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Imazapyr	1.68	23			93	93		
Imazapyr	1.68	47	96	99	93	84	96	95
Glyphosate	8.4	94			85	52	89	48
Untreated			0	0	0	0	0	0

3.2 Environmental Fate and Chemistry

3.2.1 Physical Chemistry

Solubility

Imazapyr is ionized under typical environmental conditions of pH 5-9, and is therefore highly soluble in water. The solubility of imazapyr varies somewhat with the product formulation. The solubility of imazapyr increases with temperature. For example, the solubility of the compound is reported as 9,740, 11,272, and 13,470 mg/L (ppm) at 15 ^{o}C, 25 ^{o}C, and 35 ^{o}C, respectively (Mangels and Ritter 2000). Typical temperatures of application in Washington State would bracket the solubility measures recorded between 15 ^{o}C and 25 ^{o}C. Generally, solubility will bracket the range of 1 to 1.5% (i.e., 10,000 to 15,000 mg/L) in water at 25 ^{o}C. A saturated 1% solution of imazapyr in freshwater at 25 ^{o}C will exhibit a pH of approximately 3 to 3.5 (Toxnet 2003). Because of the high solubility of the compound, it has inherently low sorption potential, and relatively high potential for mobility through soils.

The octanol:water partition coefficient (LogP) of imazapyr is reported as 1.3, reflecting its high solubility in water, low solubility in lipid (octanol), and hence low propensity to bioconcentrate or bioaccumulate (ToxNet 2003).

Imazapyr has a melting point range of 169 to 173 ^{o}C.

Dissociation constants reported for imazapyr reflect its ionization potential under typical environmental conditions. For reader clarification, the pH at which an acid is 50 percent dissociated between its non-ionized and ionized forms is called its pK*a*. Thus, when the pH of a solution is equal to its pK*a* the chemical will be dispersed equally between an ionized and unionized state. Imazapyr dissociates at two different pH levels, with dissocation constants (pKa) of 1.9 and 3.6. In general, ionized forms of chemicals represent lower ecological risk because they are unable to penetrate cell membranes due to low lipid solubility. For acids such as impazapyr, as the pH is elevated above the pK*a* the proportion of the compound in an ionized state will increase. In the marine intertidal mudflats where the imazapyr would be applied to control *Spartina*, the pH of sediment surfaces and sediment pore water should be elevated above neutral, and the compound will be entirely in an ionized state (Figure 3-4). However, surfactants applied with the product are designed to facilitate uptake for product efficacy, and therefore reduce this element of protection.

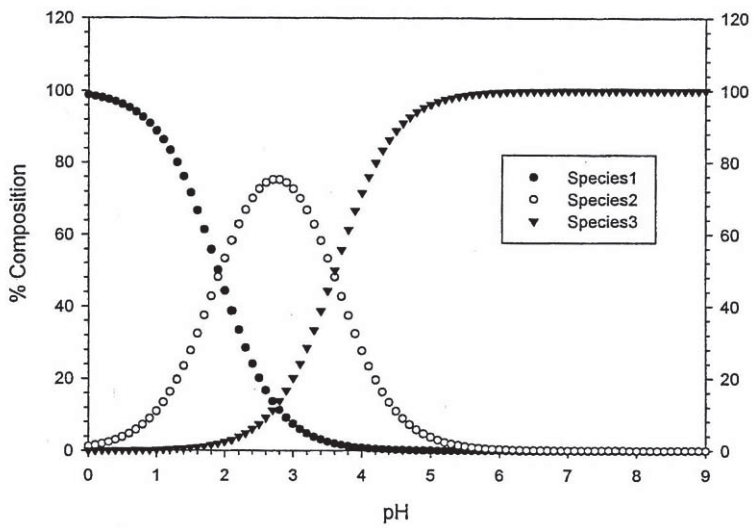

Figure 3-4: Imazapyr Dissociation Under Different pH Conditions.

(Source: Mangels and Ritter 2000.)

3.2.2 Environmental Degradation

Synopsis

The rate and form of degradation of imazapyr varies somewhat with the environment where it is applied. Movement within the environment (e.g., through soils, water, plants, sediments) of the weak acid is primarily determined through by the pH of the host system. The primary form of degradation in water is via photodegradation. Photolysis half-lives in water have been reported at 2 days; however degradation decreases with increasing pH. Ozone may also degrade imazapyr when applied in a water treatment setting (Rashin and Graber 1993). Imazapyr has been detected in surface and ground water samples taken by the Washington State Department of Ecology following aerial application on forest lands, although regular monitoring of the herbicide is lacking (Cox 1996). In soils, degradation is primarily driven by microbial metabolism. Microbial metabolism in sediments has not been thoroughly investigated.

Soil Adsorption and Degradation

Imazapyr will adsorb to soils and sediment weakly. It has a reported organic carbon partition coefficient (Koc) in soil of 142 cc/g (Mangels and Ritter 2000). Thus, imazapyr is considered relatively mobile in soils. Adsorption is pH dependent, again, reflecting its propensity for ionization at pH levels above its pK*a* (Figure 3-4). For example, a pH below 5.0 in soil limits movement due to an increased adsorption capacity within the soil; whereas above a pH of 5.0 concentrations of imazapyr become negatively charged (i.e., ionized) and do not bind well with soils, which increases its mobility. The adsorption coefficient for Arsenal$_{tm}$, an isopropylamine salt formulation, varies for different types of soil. The adsorption coefficient reported for clay loam soils is 1.7 verses 4.9 for silt loam soils with 4.0 percent organic matter (PMEP 1985). Leaching has been observed up to 50 cm in soil. Another study related to imazapyr mobility in soil observed significant residues to a depth of 1.5 to 3 m (4.9 to 9.9 feet), depending on application rate (Cox 1996). Leaching has been observed up to 50 cm in soil. Another study related to

imazapyr mobility in soil observed significant residues to a depth of 1.5 to 3 m (4.9 to 9.9 feet), depending on application rate (Cox 1996).

The primary degradation pathway for imazapyr in soils is through microbial metabolism, with photolysis and other degradation pathways providing a limited source of degradation. During aerobic microbial metabolism, the imidazolinone ring is opened and a hydroxy metabolite is formed as a result of the conversion of the carboxilic acid group on the pyridine ring (Figure 3-5). Reported half-lives of imazapyr (technical grade) in soil range from 25-141 days (Cyanamid Ltd. 1997, Cox 1996). Most of the reported variation in soil half-life is related to detection method applied in the study: plant injury versus laboratory analysis.

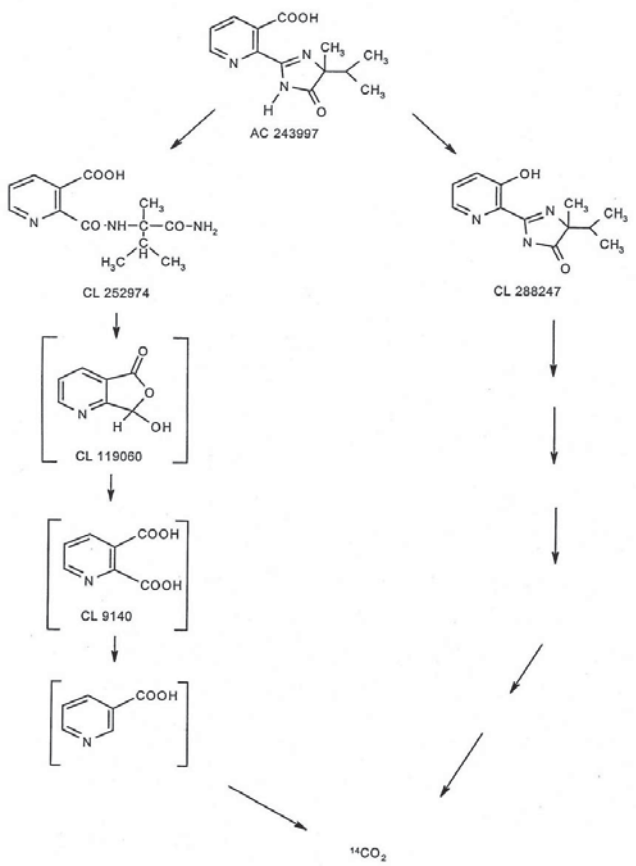

Figure 3-5: Degradation Pathway of Imazapyr.
(Source: Mangels and Ritter 2000.)

Recent studies by the manufacturer examined the aerobic metabolism of imazapyr in sandy loam soils (Mangels and Ritter 2000). They proposed a half-life of 117 days based on degradation through the first 28 days of the study. However, after 4 months, when the study concluded, only 26% of the dose applied had degraded, and only 5.6% of the dose had completely mineralized (degraded) to CO_2 . The authors considered the rapid early degradation to reflect the more active microbial community in the soil initially available, as the soils used in the testing were derived from an agricultural field (Figure 3-4). In a second, 12-month study also using sandy loam soil with an application rate of 1.0 to 1.5 ppm, 66% of the applied dose still remained at the end of the study. No volatilization of the parent compound occurred. When using the data from 0 to 9 months

only, the half-life was estimated at 12.8 months, but the final three months of the study revealed no significant additional degradation, extending the half-life estimate to 17 months. A replicate 12 month study showed 88% of the applied imazapyr was recoverable after 365 days. These collective results reveal that degradation rates can vary substantially even within an experiment.

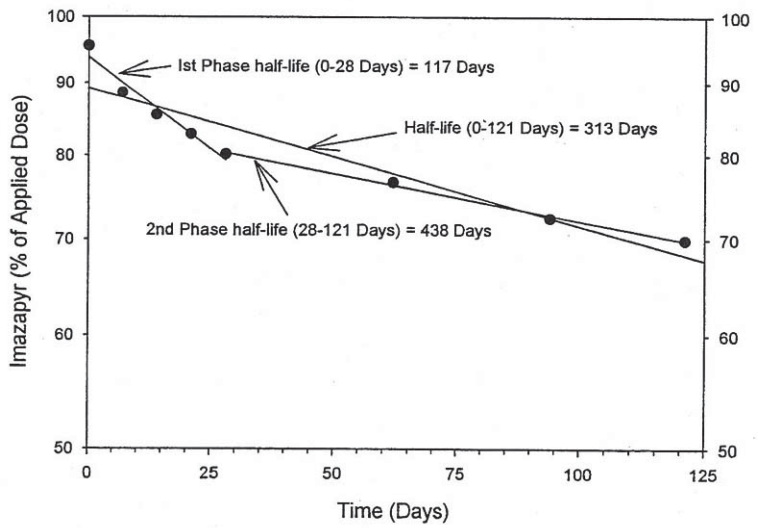

Figure 3-6: Degradation Rate of Imazapyr in Sandy-Loam Soil.
(Source: Mangels and Ritter 2000.)

The key parameters that appear to effect the soil degradation rate of imazapyr in the field include temperature, organic carbon, and particle size. In a study by McDowell et al. (1996), the half-life for imazapyr (from Arsenal$_{tm}$) was addressed using a bioassay approach that gauged the time taken for the amount of herbicide in the "plant-available" pool to equal half of that which was applied. Using the lentil growth bioassay in New Zealand Templeton silt loam soils, the half-lives varied by approximately 87 days depending on temperature, soil organic matter, and microbial biomass carbon (µg-C/g soil), with a range of 68.6 to 155.4 days. Degradation of the technical grade imazapyr in soils through microbial activity reportedly increased with the following environmental conditions (1) warmer temperatures (15°C vs. 30°C), (2) presence of sandier soils (i.e., sandy loam vs. clay loam), (3) aerobic soil conditions, (4) increasing soil moisture, (5) increasing pH, (6) lower organic matter soil. However, the effect of organic matter could not be isolated from the effect of pH under their experimental design, so the impact of these variables on degradation rate was not entirely conclusive.

In another study by the manufacturers of imazapyr, Cyanamid Ltd. (1997), reported that the imazapyr isopropylamine salt degraded 6 months faster (3 verses 9 months) at 45°C than at 37°C. The related imazapyr acid formulation also degraded faster with the same conditions as the technical grade imazapyr.

Anearobic soil metabolism of impazapyr appears to be insignificant from the existing studies conducted to date. In one study, soil was treated with impazapyr at 1.0 ae/acre.

There are also reports of imazapyr "leaking" out of the roots of treated plants and impacting surrounding native vegetation. A study by Lee et al. (1991) reported an increase of imazapyr

residues 231 days after treatment due to runoff of residues from plant surfaces after rainfall and release from decaying plant matter. Rainfall after application of imazapyr has shown to increase the ability of the chemical to be adsorbed, however impacts due to increased mobility in the soil column may outweigh efficacy improvement.

Degradation in Aquatic Environments

Conditions in aquatic environments differ substantially from those of terrestrial soils, both in terms of the regular exchange of waters within the sediment (porewater) and over it, and in the range of oxygenation experienced in typical sediments that can affect microbial metabolism (i.e., aerobic verses anaerobic ratios). Early studies in freshwater, primarily by the product registrant, examined the pathways and mechanisms of degradation in water and underlying sediment (Mangels and Ritter 2000). Typical controlled degradation studies examine the rate of degradation by the accumulation of radiolabled CO_2, which represents the final breakdown product of a radiolabled parent compound and its intermediate degradation products. These studies are done either in water, moist sediment, or in slurries of water and sediment.

The degradation of imazapyr when applied directly to water largely mimics the pathway by which the herbicide would be solubilized at high tide after application to *Spartina* during low tide. Residual imazapyr on the plants that may not have completely dried or adsorbed will be inundated by the incoming tide and presumably solubilize. Aquatic degradation studies with imazapyr applied to a freshwater surface directly have shown that imazapyr initially photodegrades rapidly to two primary products, "CL 119060", and "CL9140" (Figure 3-5). According to the manufacturers, CL119060 is biologically oxidized to CL 9140, and eventually mineralizes to carbon dioxide (CO_2) following the cleavage of the pyridine ring structure. Hydrolysis of the parent compound was found to be negligible, with controlled experiments in distilled water, documenting only 3% of hydrolysis product (CL252974—see Figure 3-5) accumulated after 12 days of incubation in pH 9 water. This hydrolysis product gradually increased over a 30 day incubation period to 6.9% of the recovered product, but the pH 9 value as tested would rarely be seen in the estuarine environment and hydrolytic mechanisms of degradation in situ would probably be less than observed in this study.

In a controlled aerobic aquatic study with both photodegradation products applied at 0.083 ppm in Missouri and Florida pond water, less than 22% of the applied radioactive dose dissipated from the water phase into the sediment phase. The quantity of CL 119060 decreased from 77 to 0.5% of the administered dose in this replicated laboratory experiment while the concentration of CL 9140 initially increased (Figure 3-7—Missouri data only). However, both imazapyr degradation products rapidly degraded, with half lives less than or equal to 3 days (Mangels and Ritter 2000).

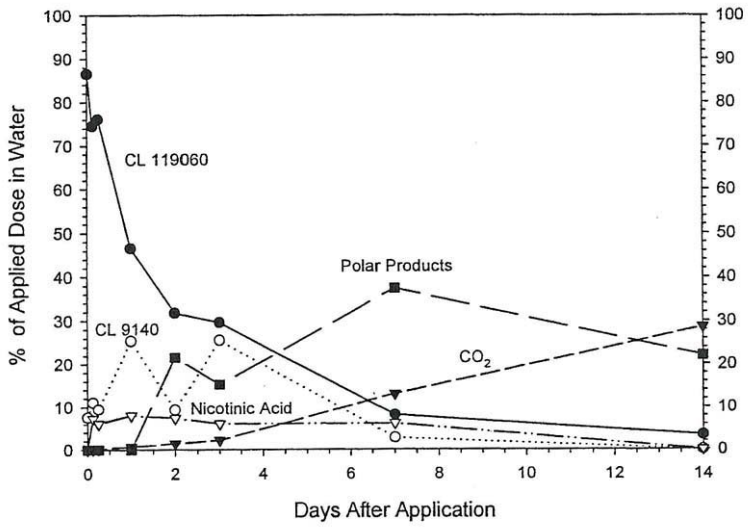

Figure 3-7: Degradation of Imazapyr's Initial Photodegradation Products CL 119060 and CL 9140 in a controlled aerobic aquatic system using Missouri pond water.
(Source: Mangels and Ritter 2000.)

Unlike lab degradation experiments where more variables can be controlled and measured, field experiments are generally termed "dissipation" studies, as the multiple variables inherent to such systems limit the range of analyses that can be conducted. With this understanding, complementary field dissipation experiments were conducted by the product registrant in shallow Florida and Louisiana freshwater pond systems where the parent product imazapyr (as Arsenal$_{tm}$) was applied to the surface of the water at 1.5 lb ae/acre (883 ppb). Dissipation (field degradation) was followed in water and sediment over 180 days. Figure 3-8 reflects study results from water and sediment analyses from the Louisiana pond study through the first 30 days of study, over which period the vast majority of dissipation had occurred. Similar results were obtained with the Florida pond system (not shown) although degradation was slightly faster and there did not appear to be the initial spike in the sediment concentration that was observed in the Louisiana pond system (Figure 3-8). The first-order half-lives in the water and sediment were 1.9 and 12.8 days, respectively. No detectable residues of imazapyr were found in the water and sediment after 14 and 59 days, respectively.

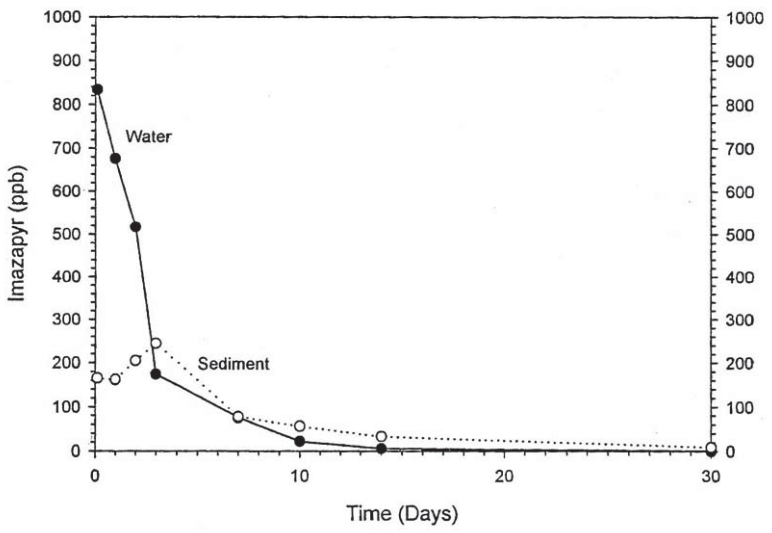

Figure 3-8: Residues of imazapyr in water and sediment from a Louisiana pond treated with 1.5 lb ae/acre.
(Source: Mangels and Ritter 2000.)

Tidal flux in estuarine environments also provides a consistent and predictable rinsing effect that will solubilize applied herbicide and contribute to its removal from an area where recently applied. Freshwater degradation studies in slurries probably represent the most similar laboratory conditions for degradation comparisons to tidal environments. However, to our knowledge these tests have been done in freshwater only. These conditions challenge the researcher attempting to isolate the variety of mechanisms that could be responsible for degradation of imazapyr in an estuarine setting. Recent studies have addressed some of the uncertainty. Patten and Stenvall (2002) examined the fate of imazapyr applied directly to sediment to gauge its persistence over time. In this study, imazapyr concentrations were measured in intertidal waters and sediments adjacent to a *Spartina* meadow. Analyses were conducted 3, >24 and > 48 hours after application at the standard treatment concentration of 1.68 kg ae/ha used in the efficacy trials discussed earlier. Sediment samples collected three hours after application were retrieved immediately after the first tidal wash over the treated area. The study design was conservative in that there was no intercepting algal or emergent vegetation overlying the sediment where the herbicide was applied. In this study, the maximum geometric mean concentration of imazapyr detected in sediments from four replicated trials detected 3-hours application was 5.4 mg/kg-sediment. Twenty-four to seventy-six hours after application the geometric mean maximum detection was 2.26 mg/kg-sediment, roughly half of that detected after three hours. In the water, 0.119 mg/L imazapyr was detected after 3-hours, and less than 0.00006 mg/L (the method detection limit) was detected after 24 to 48 hours. The intent of this study, however, was primarily geared towards addressing ecological risk under a conservative application scenario, as opposed to the *in situ* degradation. No "time zero" data were reported in the study results, nor were other environmental conditions that may have effected the results reported such as temperature, organic carbon, etc. Without such data, the *in situ* degradation can only be estimated.

Some of the experimental design issues with the preceding experiment were addressed in a more intensive fate study conducted by Patten subsequently (2003). In this study, imazapyr was again applied to bare mud flat at 1.68 kg/ha with 1% (v/v) Agridex surfactant to a plot size of 30 x 33 m in the upper intertidal zone. The tidal front at this site could cover the application area in 13

minutes. A standard backpack sprayer with a 3 m boom was used to apply the herbicide/ surfactant mixture at a rate of 97L/ha in the early morning. The pH 7.9 sediment contained 49% water, and 51% dry matter. The solid constituents of the sediment contained 5.4% organic matter, and 18.3, 65.5, 16.2 percent sand, silt and clay, respectively. Water was collected in 1L jars buried within 1 cm of their lips in the sediment to capture the incoming tidal front after application, and the jars were spaced in triplicate at 10 m intervals along the tidal front "grid". Water samples were collected after the 1st, 2nd, 3rd, and 7th tides, corresponding to 3.5, 14, 28 and 77 hours after treatment. Square sediment cores 8-cm deep were obtained in similar positions along the grid as the water samples, but unlike the previous experiment, samples were taken immediately after application (time 0), as well as the 1st, 2nd, 6th, 14th, 28th and 56th tidal exchange after treatment. These exchanges corresponded with 1, 14, 27, 77, 184, 366 and 703 hours after the initial sediment application. Finally, sediment sub-samples were obtained from triplicate *Spartina* plots (3x4 m) treated with the same application regime as the bare sediment to gauge canopy interception under typical treatment regimes. In this trial, the treated *Spartina* was 1.7 m tall, and was concentrated in an area approximately 2 m above Mean Lower Low Water (MLLW) MLLW. All of these areas of treatment were then compared against samples taken from untreated bare sediments.

Figures 3-9 and 3-10 reflect Patten's (2003) results on the water and sediment persistence of imazapyr. As depicted, measurable concentrations of imazapyr declined exponentially in both the water and sediment. Following applications to the bare intertidal mud flat, the maximum average water concentration detected was 3.4 µg/L (ppb) and the maximum average sediment concentration detected was 5.4 mg/kg (ppm). The "zero asymptote" was approached at 40 and 400 hours for the water and sediment, respectively (Figures 3-9 and 3-10).

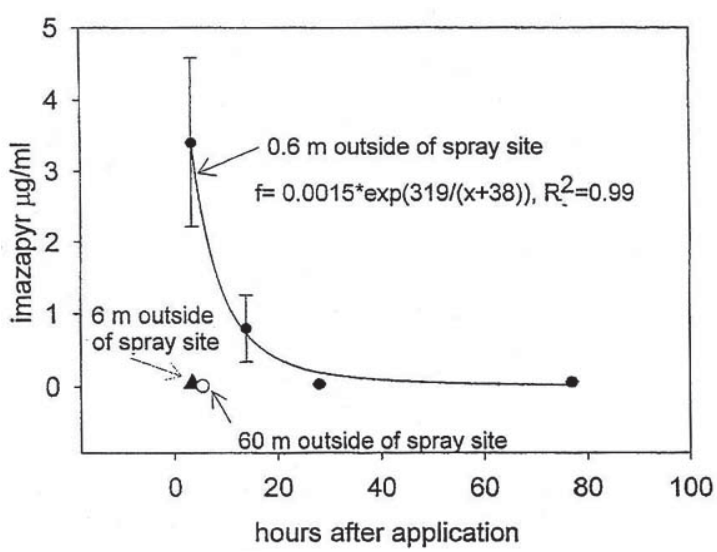

Figure 3-9: Persistence of imazapyr in estuarine waters of Willapa Bay following direct application to an unvegetated tidal mud flat. Data represented are mean values of triplicate samples +/- SE.
(Source: Patten 2003.)

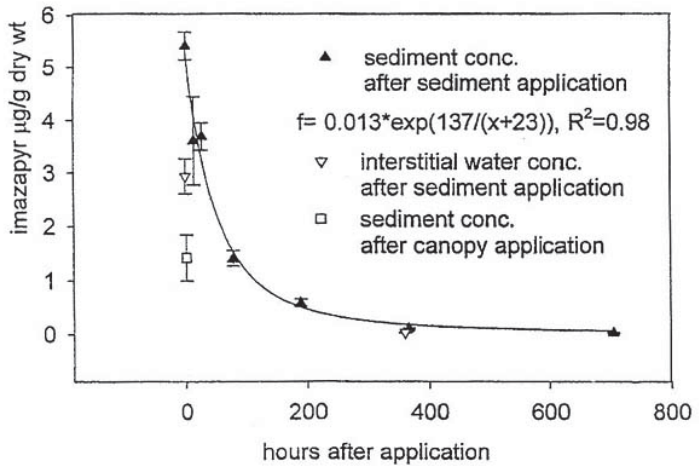

Figure 3-10: Persistence of imazapyr in estuarine sediment in Willapa Bay, WA after direct application to an unvegetated tidal mud flat. Data represented are mean values of triplicate samples +/- SE.
(Source: Patten 2003.)

Persistence in Biological Tissues

Biological tissues may act as an additional reservoir for chemicals applied intentionally or inadvertently to the environment. When an organism accumulates chemicals in its tissues following direct exposure it is known as *bioconcentration*. If the organism is consumed (predated upon) by another organism resulting in a higher concentration of the chemical in the predator, the chemical is considered to *bioaccumulate* in the "food web". In simple terms, the chemical accumulates at a rate faster than normal metabolic processes eliminate it. Although bioconcentration and bioaccumulation may have toxicity implications, toxicity varies by chemical and dose, thus these mechanisms should be considered independently when evaluating the biological fate of applied herbicides. As indicated in the discussion of physical chemistry (Section 3.1) the octanol:water partition coefficient and its high solubility indicate the compound is not apt to concentrate in tissue. Notwithstanding, to address imazapyr and its degradation products in biological tissues, several treatment studies of relevance have been conducted in Florida and Missouri pond systems that contained bluegill, tilapia, catfish and crayfish (Mangels and Ritter 2000). The ponds contained 75, 28, 213 or 261 ppb imazapyr following treatments of Arsenal$_{tm}$ to the banks and outer edges of the ponds at a rate of 1.6 lb ae/acre in spray solutions of 21 to 23 gal. Ultimate concentrations in the ponds varied due to dilutional profiles inherent to the ponds (e.g., volumes). Table 3-7 summarizes the principal findings from this study in each of the pond systems evaluated.

Table 3-7: Persistence and Bioconcentration of Imazapyr in Missouri and Florida Pond Water, Sediment and Resident Aquatic Biota.

(Source: Mangels and Ritter 2000.)

Metric Measured	**Untreated Control Pond**	**Pond 1 (MO Pond #11)**	Pond 2 (Fl pond # 11)	**Pond 3 (MO Pond #21)**	**Pond 4 (FL Pond #21)**
Initial Water Concentration µg/L (ppb)	< 0.207	28	75	213	261
Initial Sediment Concentration µg/kg (ppb)	<0.475	~1.5[1]	~2.5[1]	~10.2[1]	~ 10.2[1]
Half-life in Pond Water (days)	Not applicable	14.1	8.4	14.5	3.9
Half-life in Pond Sediments	Not applicable	Not calculated[2]	Not calculated, (too few data)	Not calculated[2]	9.2
Residue in bluegill	All samples <5.35 ppb	< 50 ppb (MDL[3])	< 50 ppb (MDL[3])	3 hrs post trt. = 0.636 ppm, thereafter < 50 ppb (MDL[3]),	< 50 ppb (MDL[3])
Residue in catfish	All samples <5.35 (except 1 sample at 14.1)	< 50 ppb (MDL[3])	< 50 ppb (MDL[3])	3 hrs post trt. = 0.233 ppm, thereafter < 50 ppb (MDL[3])	< 50 ppb (MDL[3])
Residue in tilapia	All samples < 5.35	< 50 ppb (MDL[3])	< 50 ppb (MDL[3])	3 hrs post trt. = 0.068 ppm, thereafter < 50 ppb (MDL[3])	< 50 ppb (MDL[3])
Residue in crayfish	All < 5.35 (except 1 @ 10.6)	< 50 ppb (MDL[3])	< 50 ppb (MDL[3])	3 hrs post trt. = 0.059 ppm, thereafter < 50 ppb (MDL[3])	< 50 ppb (MDL[3])

1: Based on interpretation of graphical data prepared by the researchers

2: Sediment levels persisted in these ponds; the authors attributed this to an unusual inversion that resulted in pond turbidity prior to pond treatment and reduced the rate of photodegradation

3: MDL = method detection limit

A separate study examined the potential for bioconcentration and persistence in a mollusc species, the freshwater clam (*Corbicula fluminea*). In this study, clams were exposed to the Arsenal$_{tm}$ formulation of imazapyr in a mesocosm containing water and sediment, and the water was inoculated with 0.091 mg ae/L. Similar to the study results reported above, no imazapyr was detected in the clam tissue at or above the 50 µg/kg (ppb) 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. No toxicity was reported.

3.3 Toxicity to Terrestrial Receptors

In this section we examine data from acute, sub-chronic, and chronic imazapyr exposure studies with terrestrial wildlife and invertebrates. The toxicity of imazapyr to these ecological receptors is

discussed, as known, and data gaps are identified. The descriptions of toxicity in Table 3-8 established by the Environmental Protection Agency (EPA) are used as a template to qualitatively gauge study results discussed. As depicted, these descriptions vary slightly depending on the class of animal being tested (avian or mammalian) and the study being performed (acute oral LD_{50} or dietary LC_{50}). The LD_{50} is the statistical derivation of a dietary or drinking water dose, which is predicted to cause 50% mortality in the given population being tested. The LC_{50} is a similar number, based on the concentration of a compound in air or water. The criteria for these descriptions are presented below in Table 3-8. The specific toxicity data discussed below are separated into simple animal classifications (e.g., mammals, birds, insects, etc.) and the studies conducted generally reflect EPA protocols with standard test species. In using this toxicity classification scheme it becomes possible to qualitatively compare toxicity values of the active ingredient and product formulations amongst species.

Table 3-8: Hazard Classifications to Address Wildlife Risk from Herbicide Use.
(EPA 1995)

Hazard Category	Mammals Acute Oral or Dermal LD_{50} (mg/kg)	Mammals Acute Inhalation LC50 (ppm)	Avian Acute Oral LD_{50} (mg/kg)	Avian Acute Inhalation LC50 (ppm)
Very highly toxic	<10	<50	<10	<50
Highly toxic	10-50	51-500	10-50	50-500
Moderately toxic	51-500	501-1000	51-500	501-1,000
Slightly toxic	501-2,000	1001-5000	501-2,000	1,001-5,000
Practically non-toxic	>2,000	>5,000	>2,000	>5,000

It must be recognized that species differences in terrestrial ecological receptors (mammals, birds, etc.) may exist that are not predictable from the classification scheme represented in Table 3-9. Some wildlife receptors that may be at risk of exposure to imazapyr are rarely used in toxicity testing for lack of a consistent supply and approved protocols. For example, we found few data on omnivorous and carnivorous species such as the raccoon and coyote, large ungulates such as the black-tailed deer that commonly forage along estuary margins, and migratory shorebirds, passerines, and reptiles and amphibians.

The use of surrogate test species with similar dietary and/or behavior patterns has been shown to provide a relatively reliable predictor of toxicity for the most sensitive species of fish (Sappington et al. 2000). A similar relationship likely exists for other wildlife receptors that are not routinely used for toxicity testing when compared against surrogates. However, only site-specific risk assessments would be able to fully quantify risks to resident and migratory wildlife receptors from chemical exposure in each location where *Spartina* control with imazapyr is envisioned. This assessment therefore must use surrogate species such as the rat and rabbit to gauge toxicity to other wildlife that may be more likely to be found using the habitat found along the state-managed roadways of Washington State. The rat provides a reasonable surrogate of an omnivore, the rabbit an exclusive herbivore, and the quail and duck provide surrogates of upland and wetland bird species, respectively.

3.3.1 Mammals

Based on EPA criteria specified in Table 3-9, imazapyr would be considered practically non-toxic to mammals based on acute and chronic studies conducted with a variety of mammalian species. For

example, the reported acute oral LD_{50} concentration for rats is >5,000 mg/kg. No significant bioaccumulation has been reported in mammals. Rats were observed to rapidly excrete imazapyr in urine and feces with no residues detected in their liver, kidney, muscle, fat, or blood. Results from a series of tests looking at the mammalian response to acute oral, dermal, and inhalation administrations of imazapyr isopropylamine technical, imazapyr technical, and imazapyr isopropylamine was compiled by Cyanamid Ltd. (1997) (Table 3-9).

Table 3-9: Acute and Subchronic Mammalian Toxicicity to Imazapyr.

Test Substance	Animal Species	Administration Route	Gender	LD_{50} or ED_{50} body wt., (or) ppm diet*	Effect	Testing Facility, (reporting year)
Imazapyr isopropylamine technical (49.3%)	Rat	Oral	Male	> 10,000*	DA	Medical Scientific Research, Laboratory (1983)
			Female	> 10,000*	DA	
		Intraperitoneal	Male	4,200	DA, B, A, S, CY, C, DBW	
			Female	3,700	DA, B, A, S, CY, C, DBW	
		Subcutaneous	Male	> 5,000	DA	
			Female	> 5,000	DA	
		Dermal	Male	> 2,000	NOEL	
			Female	> 2,000	NOEL	
	Mouse	Oral	Male	> 10,000	DA	
			Female	> 10,000	DA	
		Intraperitoneal	Male	3,450	DA, B, A, S, CY, C, DBW	
			Female	3,000	DA, B, A, S, CY, C, DBW	
		Subcutaneous	Male	> 5,000	DA, B, S	
			Female	> 5,000	DA, B, S	
Imazapyr technical	Rat	Oral	Male	> 5,000	NOEL	American Cyanamid Company (1983)
			Female	> 5,000	NOEL	
	Rabbit	Dermal	Male	> 2,000	NOEL	
			Female	> 2,000	NOEL	
	Rat	Inhalation	Male	> 1.	ND	Food and Drug Research Laboratories (1983)
			Female	> 1. (analytical)	ND	
Imazapyr isoproplyamine 25% AS	Rat	Oral	Male	> 5,000	DA	American Cyanamid Company (1983)
			Female	> 5,000	DA	
	Mouse	Oral	Male	> 5,000	DA	American Cyanamid Company (1986)
			Female	> 5,000	DA	
	Rabbit	Dermal	Male	> 2,148	NOEL	American Cyanamid Company (1983)
			Female	> 2,148	NOEL	
	Rat	Inhalation	Male	> 0.2	NOEL	Food and Drug Research Laboratories (1983)
			Female	> 0.2 (analytical)	NOEL	

NOEL = no toxic signs, DA = decreased activity, ND = nasal discharge, B = blepharoptosis, A = ataxia, S = sedation, CY = cyanosis, C = convulsion, DBW = decreased body weight

Source: Cyanamid Ltd. (1997)

Significant sub-lethal effects were reported for each formulation of imazapyr tested at doses that exceeded the "practically non-toxic" acute lethal criteria for administration routes, except the inhalation route, where sublethal effects occurred at lower doses (Table 3-9). The most significant effect was found with technical grade imazapyr isopropylamine administered via intraperitoneal injection, although because the other forms of imazapyr did not test reactions using this method, it is hard to draw conclusions on the relative toxicity of imazapyr isopropylamine technical grade. Furthermore, this method of toxicant administration is not environmentally relevant because mammals would not be dosed in this manner in a natural setting. No overall observable effect was noted for any formulation of imazapyr administered dermally, and effects in mammals exposed to imazapyr via inhalation were only observed with imazapyr technical grade.

Technical grade imazapyr is reported as moderately irritating to rabbit eyes, with complete recovery within 7 days of exposure (BPA 2000, Cyanamid Ltd. 1997). The same result was found with imazapyr isopropylamine 25% AS. Imazapyr technical is also reported as mildly irritating to rabbit skin (BPA 2000, Cyanamid Ltd. 1997). Studies reviewed by the EPA concluded that imazapyr technical is corrosive to the eyes and can cause irreversible eye damage (Cox 1996). Commercial formulations of imazapyr appear to be less toxic by this route of exposure.

Dermal exposure studies have shown imazapyr to yield statistically inconsistent sublethal effects. Where an effect was observed, it was usually observed as erythema, a localized increase in blood flow observed as a 'reddening' or rash-like symptom. A 21-day sub-acute rabbit dermal toxicity study at doses of 0, 100, 200, or 400 mg/kg/day revealed no consistent pattern of toxicity, and the NOEL was concluded to be the highest dose tested (HDT) (400 mg/kg/day) (Fed Reg, 62, 1997) even though a higher dose would most likely be more accurate. Another study with imazapyr isopropylamine (25% AS) was reported to cause slight erythema at 24 and 72 hours post-dermal exposure in rabbits; however, the same formulation was observed to form no dermal reaction in guinea pigs (Cyanamid Ltd. 1997). Other dermal exposure studies in both rats and rabbits report LD_{50} concentrations at > 2,000 mg/kg, and > 2,148 mg/kg, respectively (Table 3-9).

The product registrant conducted subchronic dietary toxicity tests where imazapyr isopropylamine was administered orally at concentrations of 0, 1000, 5000 and 10,000 ppm for 13 consecutive weeks (Cyanamid Ltd. 1997). The study reported the maximum NOEL for rat diets as 5,000 ppm (325 mg/kg/day in males and 370 mg/kg/day in females). Another 90-day rat feeding study at doses of 0, 15,000, and 20,000 mg/kg-diet yielded a NOEL values of 1,695 mg/kg/day the HDT, and an estimated (Fed Reg 1997).

Chronic Testing

Chronic toxicity studies have been conducted with mice, rats, dogs and rabbits to address effects on survival, carcinogenesis, teratogenecity and intergenerational effects. Dogs fed doses of 0, 25, 125 and 250 mg/kg/day imazapyr showed no statistically significant effects on survival or other endpoints monitored. The product registrant concluded the NOEL at 250 mg/kg/day, the HDT.

Rats and mice fed imazapyr for 2 and 1.5 years (respectively) exhibited an increased incidence of congestion of the brain in females (mice), fluid accumulation in the air sacs of the lungs in females (mice), increased incidence of kidney cysts in males (mice), increase in abnormal blood formation in the spleen (rats), increase of blood pooling in the liver (rats), increase in thyroid cysts (rats), and a decrease in food efficiency (rats). The diets contained 0, 1,000, 5,000, or 10,000 ppm imazapyr. However, the results from these chronic dietary exposure studies revealed no significant

differences amongst the treatment concentrations, and the EPA has concluded NOEL concentrations at the highest dose tested—in this case, 1,301 mg/kg/day in mice, and 503 mg/kg/day in male rats (Fed Reg 62, 1997). Tumors were identified in both the high-dose and control groups at insignificantly different rates and the EPA therefore concluded the herbicide is not considered to be carcinogenic. *In vitro* gene mutation studies using the Ames Salmonella assay, chromosome aberration assay, point mutation assay, unscheduled DNA synthesis, and dominant-lethal assay yielded no significant results, and the herbicide was concluded to lack mutagenic activity (Fed Reg 62, 1997).

Chronic concentrations of imazapyr at dose levels up to 1,000 mg/kg per day in rats and up to 400 mg/kg per day in rabbits resulted in no significant differences amongst the doses tested for mutations or birth defects (Cyanamid Ltd. 1997). Once again, the NOEL for Arsenal$_{tm}$ in these developmental toxicity studies was reported at the HDT for rabbits (400 mg/kg/day), but lowered to 300 mg/kg/day for the rats, as the highest dose tested (1,000 mg/kg/day) increased salivation in the gravid females, even though no specific developmental toxicity endpoint was altered in the rats. No intergenerational effects were observed in a subsequent two-generation rat study conducted at dietary concentrations up to 10,000 ppm (738 mg/kg/day) and the HDT was again accepted as the NOEL.

3.3.2 Birds

The reported acute oral LD_{50} concentration for bobwhite quail and mallards is >5,000 mg/kg-diet. The reported subacute oral LD_{50} concentration for bobwhite quail and mallards reproduction is >1,890 mg/kg-diet. These values represent the highest doses tested to date. No significant bioaccumulation has been reported in avian species. Results from past avian studies conducted by the product registrant with Arsenal$_{tm}$ and/or technical grade imazapyr are summarized in Table 3-10.

Table 3-10: Lethal and Sublethal Toxicity of Arsenal in Controlled Avian Experiments.

Species/Test	LD_{50} or LC_{50}	NOEL (of test substance)
Northern Bobwhite Quail LD_{50}/18-week dietary exposure effects on egg production, hatchability, & hatchling survival)	> 1,890 mg/kg (~200 mg/kg-quail)	1,890 mg/kg (~200 mg/kg-quail = the HDT)
Mallard Duck LD_{50}/18-week dietary exposure effects on egg production, hatchability, & hatchling survival	>1,890 mg/kg-diet (~200 mg/kg-duck)	1,890 mg/kg-diet (~200 mg/kg-duck)
Northern Bobwhite LD_{50}/5 day acute dietary exposure effects on survival)	>5,000 mg/kg-diet (~674mg/kg-quail)	5,000 mg/kg-diet (~674mg/kg-quail)
Mallard Duck LD_{50}/test 850.2200 (5 day acute dietary exposure effects on survival)	>5,000 mg/kg-diet (~1149 mg/kg-duck)	5,000 mg/kg-diet (~1149 mg/kg-duck)

Willapa Bay, Padilla Bay, and other locations in the state where *Spartina* has colonized provide substantial and significant waterfowl habitat (see Appendix B for review of ecology in these areas). As such, testing with the mallard duck provides a good surrogate for other waterfowl species that use these areas and could potentially be exposed to imazapyr after a *Spartina* treatment. Shorebirds also use these estuarine habitats, and Willapa Bay supports the most significant stop-over point along the west coast for migrating shorebirds. Shorebirds are greatly affected by the colonization of *Spartina*, as it reduces available foraging habitat for these species. Indeed, monitoring studies have shown that shorebirds will not use *Spartina* meadows to feed in (Patten

and Stenvall 2002). Notwithstanding, the toxicological risks to shorebirds must be considered. Unfortunately, we found no data to address the potential toxicity of imazapyr to shorebirds. One study, however, examined the penetration force required to penetrate mudflat sediment colonized with *Spartina* relative to an uncolonized mudflat, and a colonized mudflat treated with tilling or herbicide. In that study, an artificial Dunlin beak penetrated a similar (insignificantly different) distance in the tilled *Spartina* meadow as in the bare mudflat. Herbicide treated meadows killed the *Spartina*, but did not soften the sediment, like the tilling. These results suggest that the habitat risks from *Spartina* infestation are not necessarily alleviated by herbicide treatment alone.

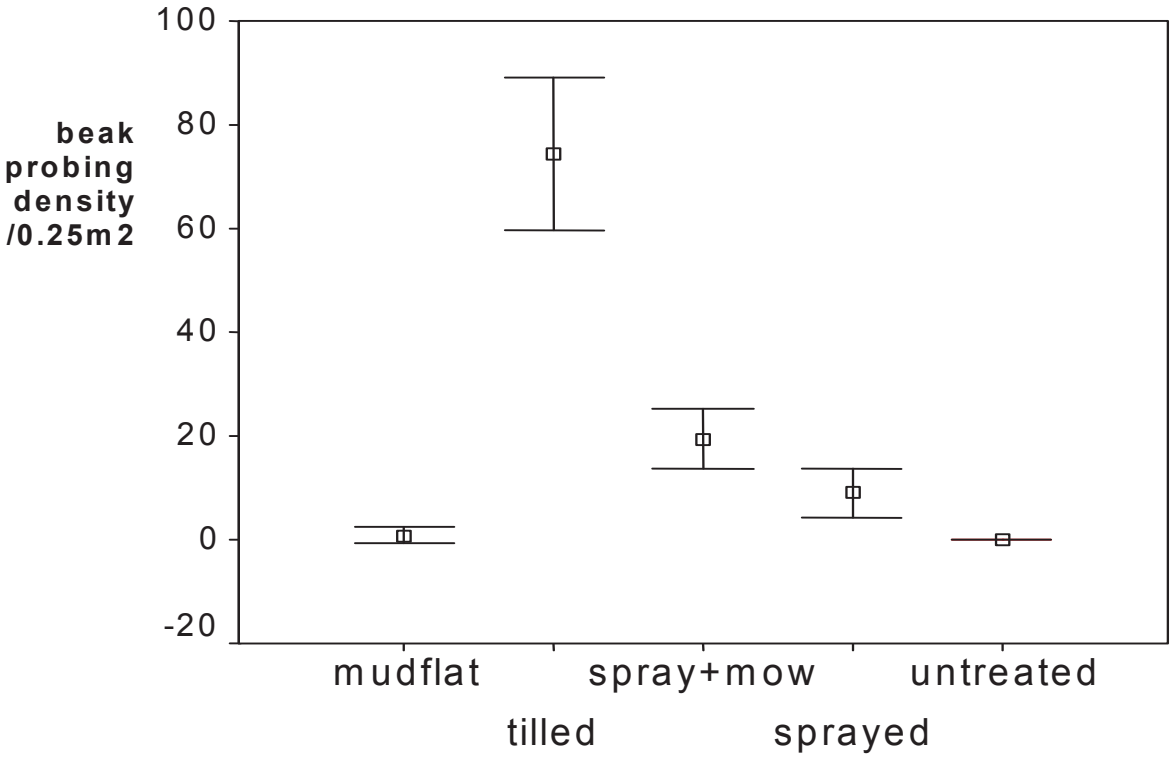

Figure 3-11: Penetration distance in artificial beak tests.
(Source: Patten and Stenvall 2002.)

In addition to the toxicological data gap on shorebird and raptor species, no data were identified on preening exposure or inhalation exposure potentials associated with imazapyr.

3.3.3 Insects

The reported acute contact LD50 toxicity concentration for the honey bee is approximately > 0.1 mg imazapyr/bee (Gagne et al. 1991). SERA (1999) estimated this dose to be greater than 1,000 mg/kg-bw, assuming 100% absorption of the applied dose, and an average body weight of 0.093 g/bee [0.1 mg/0.000093 kg = 1075 mg/kg-bee, or ~ 1,000 mg/kg-bw]. Similar to the avian and mammalian studies previously addressed, there was no dose tested that resulted in acute or chronic mortality, and the NOEL for the bee was taken to be the highest dose tested, or 100 ug/bee (1075 mg/kg). Using the mammalian toxicity criteria adopted by the EPA (Table 3-9), imazapyr would be considered practically non-toxic to the bee.

In terrestrial environments, herbicide treatment has been shown to increase the local abundance of arthropods—likely as a response to the increased food supply for these detritivores from the dead and decaying vegetation. Arthropods serve as a substantial, high-energy food source for many bird species, and this relationship holds true both for terrestrial birds, as well as waterfowl and shorebirds during periods of migration (Cohen et al. 2000). A careful examination of the use of dead and decaying (post-treated) *Spartina* has not been conducted; however, it is conceivable that a similar relationship would be observed during the decay process.

3.3.4 Reptiles and Amphibians

Toxicity information of imazapyr with regards to reptiles and amphibians was not found through standard literature search engines.

3.4 Toxicity to Aquatic Receptors

A wide range of freshwater and marine fish and aquatic invertebrates occur in the surface waters of Washington. The type of species found depends upon such factors as water temperature, salinity, pH, and flow conditions. Because of the diversity of aquatic habitats throughout the state no single species is representative of all habitats where fish and invertebrates could be exposed to imazapyr. Although Washington State supports several Endangered Species Act (ESA)-listed aquatic species, these species are often not those that are used for toxicity testing. Indeed, most testing that has been conducted has focused on freshwater species, or marine species that are not generally found in Washington State's estuaries . Thus, although the central focus of this risk assessment considers the potential use and risks from imazapyr when applied in an estuarine environment, the following discussion on imazapyr's aquatic toxicity considers the total weight of evidence acquired from aquatic species from various systems.

In this section we examine the acute and chronic toxicity studies conducted on imazapyr in the aquatic environment. Specifically, the acute and chronic toxicity and accumulation potential of imazapyr to fish, aquatic invertebrates, and non-target aquatic plants are discussed. Acute data are generated by the conduct of 2 to 4 day-long studies under controlled conditions. Table 3-11 provides general risk assessment standards for fish and aquatic invertebrates based on acute toxicity LC_{50} concentrations. This guide was used as a preliminary template to gauge risks associated with project actions that are broad in scope, such as the use of imazapyr by WSDA for agricultural management. Chronic effects in aquatic organisms are usually based upon adverse reproductive or growth effects, such as decreased hatching success, decreased survival of larvae, decreased growth of larvae or juveniles, and decreased reproductive capability. Chronic effects may occur from either acute or chronic exposures. In the majority of studies reviewed in this section, little or no chronic toxicity data were available because earlier tier acute testing did not indicate the need for further data development.

Table 3-11: Toxicity Classifications to Address Acute Risk to Aquatic Organisms from Chemical Use.

Hazard Category	Fish or Aquatic Invertebrates Acute Concentration LC_{50} (mg/L)
Very highly toxic	<0.1
Highly toxic	0.1-1
Moderately toxic	>1-10
Slightly toxic	>10-100
Practically non-toxic	>100

3.4.1 Fish

The reported acute toxicity LC_{50} concentration for rainbow trout, bluegill sunfish, and channel catfish is >100 mg/L based on product registrant studies with technical grade imazapyr using standard 96-hr exposure studies (Mangels and Ritter 2000). Tests were also conducted with the Atlantic silverside to address the potential toxicity of imazapyr to marine fish. In those tests the highest concentration tested was 184 mg/L, which yielded no significant toxicity (mortality). As with studies with terrestrial animals, the NOEC was taken as the HDT, or 100 mg/L for freshwater fish and 184 mg/L for marine fish. On this basis, imazapyr was considered practically non-toxic to freshwater fish based on toxicity criteria outlined in Table 3-11.

Imazapyr has not been thoroughly tested for chronic or sub-lethal effects with a wide variety of aquatic organisms, but those few tests conducted are worth summarizing. Early life stage survival tests with rainbow trout and fathead minnow embryos and sac-fry continuously exposed to imazapyr revealed no effects on hatching or survival at concentrations as high as 92.4 a.i. mg/L and 118 mg a.i/L, respectively. Again, these were the highest concentrations tested. A full life cycle test with fathead minnow with concentrations up to 120 mg a.i./L also did not elicit toxicity.

It is unclear why the product registrant did not pursue testing with higher concentrations to establish the true maximum tolerated dose. Such testing has applications when addressing potential spill scenarios with the highly soluble herbicide. However, recent results by University of Washington researchers help to eliminate this uncertainty (C. Grue personal communication, 2003). Grue and others examined the toxicity of imazapyr in 96-hr tank tests with juvenile rainbow trout (Table 3-12). As demonstrated in these tests, the concentrations required to achieve 50% mortality are exceedingly high. Indeed, the concentration of the formulations required exceed the total salt concentration of full strength sea-water (typically 30,000 to 38,000 mg/L). The NOEC concentrations have not been calculated from this work as of the publication date of this assessment. As one purpose of the studies was to compare the toxicity of imazapyr with Rodeo$_{tm}$ (glyphosate), data are summarized for this herbicide as well. As further demonstrated in Table 3-12, the LC50 of glyphosate established in the same trials was approximately two orders of magnitude more toxic than the Arsenal$_{tm}$ herbicide.

Table 3-12: 96-hour LC_{50} Values with 0.3 g juvenile rainbow trout exposed to imazapyr (Arsenal) or glyphosate (Rodeo) tank mixes.
(Source: C. Grue 2003, personal communication.)

Product Tested	LC_{50} of Concentrate	LC_{50} Expressed as Active Ingredient
Arsenal Herbicide	77,716 ppm Arsenal (72,183-72,243)*	22,305 mg/L imazapyr (20,718-20,891)*
Arsenal Concentrate	43,947 mg/L (41,446-46,408)*	23,336 (22,024-22,643)*
Rodeo	782 mg/L (719-845)*	782 (719-845)*

* 95% confidence interval of four replicated trials with geometrically arranged concentrations and a negative control.

Sub-lethal endpoints other than the early-life-stage and life cycle tests conducted with the standard test species have not been fully explored with imazapyr. One recent study examined the potential for imazapyr (Arsenal) and glyphosate (Rodeo) to elicit micronuclei in the African cichlid fish (*Tilapia rendalli*) abdominally injected with the herbicides (Grisolia 2002). Micronuclei have been proposed as a reliable indicator of environmental mutagenesis in aquatic and terrestrial animals, and have been evaluated in a variety of mollusc, fish and amphibians as an indicator of potential mutagenicity (Al-Sabti and Metcalfe 1995, Vernier et al. 1997). Micronuclei are reflected as chromosomal abnormalities in blood smears. However, the significance of elevated micronuclei frequency at the population level has not been fully determined. In the Grisolia (2002) study, significantly elevated numbers of micronuceil were observed following imazapyr exposure, but only at 80 mg/kg-bw, the maximum tolerated dose (MTD). Evidence of sub-lethal effects at the MTD are not considered valid indicators of sub-lethal toxicity, as the fish are exhibiting overt cytotoxicity (cell death) signs. Chromosomal aberrations such as micronuclei are common during cell death; their significance to mutagenicity studies is relevant when occurring as a sub-lethal toxicological response to chemical exposure doses below those which cause cell death.

Threatened and Endangered Fish Species Hazards

Resident fish populations managed by the USFWS under the Endangered Species Act (ESA) are delineated as "distinct population segments" (DPS), while the NOAA-Fisheries, which manages marine and anadromous ESA-listed stocks, delineates populations as "evolutionarily significant units" (ESUs). Addressing the uncertainty posed by using surrogate test species that may or may not be as sensitive as the threatened and endangered (T&E) populations unique to an area is always problematic in ecological risk assessments. For example, Mayer and Ellersieck (1986), in their compilation of an acute toxicity database for 410 chemicals tested on aquatic organisms, found that toxicity amongst species could range by as much as five orders of magnitude, and for a given species, toxicity could range by as much as 9 orders of magnitude. This data base, however, lacked critical review to thoroughly filter test comparisons that were appropriate (e.g., standardized test conditions). In Willapa Bay, where the *Spartina* infestation is the greatest, no fish populations are considered "threatened" or "endangered" under the ESA. In Puget Sound locations where *Spartina* has colonized, the native chinook salmon and coastal bull trout are both considered threatened, with the former managed by the NOAA-fisheries, and latter by the USFWS.

No imazapyr toxicity tests have been conducted with DPS or ESUs' of fish listed as threatened or endangered in the State of Washington. Although testing has not been conducted with these specific native populations that may utilize *Spartina* infested habitats in Washington, the standard testing conducted with the closely related rainbow trout discussed in the preceding section provides a good surrogate for predicting survival effects in these closely related native stocks. Toxicity testing under FIFRA requires data to be collected on surrogate species that addresses acute toxicity, embryo-larval

survival, and life-cycle tests. As indicated by those tests, imazapyr would be considered practically non-toxic on the basis of results in rainbow trout, bluegill and fathead minnow.

Studies conducted in the early 1970s examined the sensitivity of four fish families to 65 different chemicals (Macek and McAllister 1970); salmonids were the most sensitive of the four families (12 species) represented. A more recent study by Sappington et al. (2000) evaluated the comparative sensitivity of eight ESA-listed fish species to standard test organisms exposed to five different pesticides or metals in order to validate the use of surrogate species as a predictive tool in toxcilogical assessments. Acute 96-hr exposure trials were conducted, but none of the chemicals tested by these authors were herbicides, and all but nonylphenol had had significant previous testing. The sensitivity of listed cold-water species tested (Apache trout, Lahontan cutthroat trout, greenback cutthroat trout) did not differ significantly after 96-hr exposures from rainbow trout for copper, nonylphenol, or carbaryl. However, they were significantly more sensitive to the organophosphate permethrin and pentachlorophenol than the rainbow trout. Toxicities exhibited throughout the testing varied with chemical, with some listed species exhibiting greater or lesser sensitivity than the standard test species at some time points (e.g., 12 hours). Although differences were documented which were sometimes statistically significant depending on the time point, the listed species were not always the most sensitive. Most importantly, the maximum degree of difference recorded was less than two-fold, except pentachlorphenol and permethrin for which the listed species exhibited LC_{50} concentrations less than half of the surrogate rainbow trout. The authors concluded that a safety factor of two would provide a conservative estimate in risk assessments for listed cold-water, warm-water and euryhaline fish species based on these findings.

Another common criticism of ecological risk assessments relying on surrogate species to address potential T&E species effects is the lack of data on sublethal endpoints of site-specific relevance. The coastal estuaries where imazapyr could be applied to control *Spartina* serve as a primary staging area for salmon smolts that are migrating to the sea to mature. The brackish salinties found in the estuaries provide a range of salinities salmon smolts use to adapt to full strength sea-water. The osmoregulatory capacity has been used as one test to establish whether a chemical might affect this sensitive life stage. Patten (2003) examined this capacity, measured as plasma sodium level and gill ATPase activity in a 24-hr seawater challenge, in chinook salmon smolts exposed to imazapyr concentrations up to 1.6 mg/L (Figure 3-12). This maximum test concentration was over 470-fold greater than the maximum water concentration recovered in the companion study where imazapyr was applied to bare-mud and measured in waters from the first tidal wash (Patten 2003). As demonstrated in Figure 3-12, there was no consistent dose-response effect recorded on these endpoints of sublethal physiological relevance.

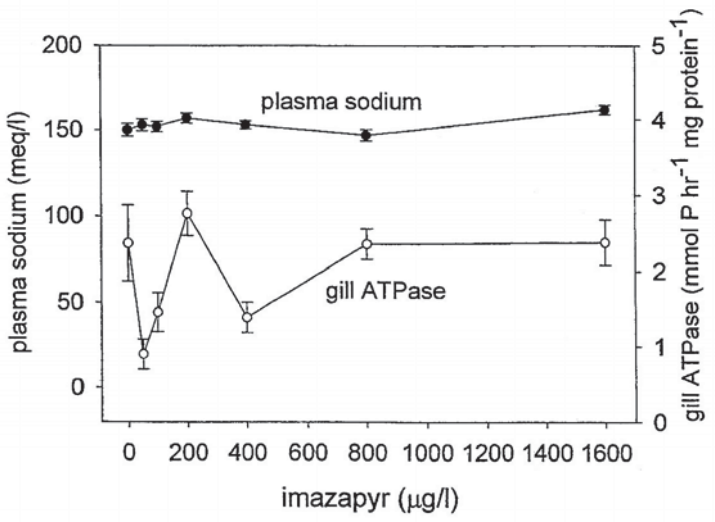

Figure 3-12: Plasma sodium and gill ATPase activity of chinook salmon exposed to imazapyr.
(source: Patten 2003.)

3.4.2 Aquatic Invertebrates

One study where Arsenal was applied with a surfactant (not defined) with the freshwater water flea (*Daphnia magna*) yielded a 48-hr LC50 of 350 mg-Arsenal/L (79.1 mg ae imazapyr/L) and an NOEC of 180 mg-Arsenal/L (40.7 mg ae/L). Other product registrant studies where *Daphnia* was exposed to an imazapyr formulation (~50%) lacking the surfactant produced 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 (1983) also reported 24 and 48-hour LC_{50} concentrations of greater than 100 mg/L (the HDT), in static tests conducted with newly-hatched *Daphnia* (less than 24 hours old). Chronic studies have also been conducted with the water flea (Manning 1989). In that study, no adverse effects on survival, reproduction or growth of 1st generation *Daphia* were recorded 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 pink shrimp. Although these species are not native to coastal Washington, they do provide reasonable surrogates for the Pacific oyster (*Crassostrea gigas*) and burrowing shrimp (*Neotrypaea sp*.) that are common to areas where *Spartina* has become established. 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).

3.4.3 Non-target Aquatic Vegetation

Native salt marsh plants and algae resident to the estuarine environments where imazapyr could be applied have the potential to be negatively affected by the broad spectrum herbicide, and a range of studies by both the product registrant and others document this possibility. Table 3-13 summarizes

product registrant studies with a variety of freshwater and marine algae and aquatic plants exposed to either technical grade imazapyr, or to Arsenal with surfactant. As indicated in Table 3-13, toxicity to the vascular plant duckweed was nearly three-orders of magnitude greater than the toxicity associated with the algal species tested. Notably, the toxicity of the Arsenal formulation did not differ from that of the technical grade imazapyr for duckweed, although it was found to be approximately 5-fold more toxic to green algae.

Table 3-13: Toxicity of Technical Grade Imazapyr and Arsenal* (with surfactant) to Algae and Aquatic Plants, as Established Through Controlled Product Registrant Studies.
(Source: Mangells and Ritter 2000.)

Species/Test	EC_{50}	EC_{25}
Green Algae Growth (*Selenastrum capricornutum*)	71 mg/L 14.1 mg/L*	48 mg/L 8.36 mg/L*
Freshwater diatom (*Navicula pelliculosa)*	> 59 mg/L	> 59 mg/L
Saltwater diatom (*Skeletonema costatum)*	85.5 mg/L	42.2 mg/L
Blue-green algae (*Anabaena flos-aquae)*	11.7 mg/L	7.3 mg/L
Duckweed (*Lemna gibba*)	0.024 mg/L 0.0216 mg/L*	0.013 mg/L 0.0132 mg/L*

Recent studies conducted by Patten (2003) also document the potential for imazapyr to impact non-target vegetation in those areas where *Spartina* control is envisioned. In this study, the effects of imazapyr were examined on the non-native Japanese eelgrass (*Zostera japonica*) and compared against glyphosate. This species of eelgrass dominates the intertidal zone unlike the native eelgrass (*Z. marina*) which is primarily found sub-tidal. For both herbicides the eelgrass canopy was killed if herbicide was applied on dry eelgrass at low tide, although the imazapyr was more toxic. If applied with a film of water overlying the bed, then no effect was recorded. Within 12 months post-treatment, all impacted eelgrass beds had recovered. There was no difference in toxicity over the range of doses tested, (0.84 kg ae/ha and 1.68 kg ae/ha). Persistence was not recorded in the sediment underlying these eelgrass beds, hence resistance to the establishment of native salt marsh plants such as *Salicornia* was not considered a risk.

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

Adjuvants are carriers mixed with herbicides that increase the binding and/or uptake of the herbicide into target plants. Typical adjuvants include surfactants and crop oils that are mixed with the herbicide prior to application. Inert ingredients are components within the patented herbicide product formulations that are reported to have no herbicidal activity. 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 formulations of the various imazapyr products on the market 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 adsorption and uptake of the herbicide. For some ecological receptors, particularly aquatic receptors, the choice of which surfactant is used to administer the herbicide 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. This section of the hazard assessment therefore attempts to summarize the existing information on the toxicity inherent to the inert ingredients and surfactants that could be used in the application of imazapyr to control *Spartina*.

3.5.1 Inert Ingredients

Two of the inert ingredients in Arsenal® are listed as glacial acetic acid (CAS #64-19-7) and water (CAS #7732-18-5) (NCAP 2003). Water is non-toxic and required for life. The toxicity of acetic acid is tabulated below (Table 3-14), as summarized by Merck (1989) and Verchueren (1983). Acetic acid is also a component of LI 700, a common non-ionic surfactant with potential use with imazapyr.

Table 3-14: Acetic Acid Toxicity to Ecological Receptors.

Test species	Class of organism	Toxicity test	Toxicity end point	Value	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	2850	mg/l
Microcystis aeruginosa	Algae	Toxicity threshold	Multiplication inhibition	90	mg/l
Scenedesmus quadricauda	Green algae	Toxicity threshold	Multiplication inhibition	4000	mg/l
Entosiphon sulcatum	Protozoa	Toxicity threshold	Multiplication inhibition	78	mg/l
Uronema parduczi	Protozoa	Toxicity threshold	Multiplication inhibition	1350	mg/l
Vorticella campanula	Protozoa	Toxicity threshold	Perturbation level	12	mg/l
Brine shrimp	Arthropoda	TLm*		32-47	mg/l
Grammarus pulex	Arthropoda	TLm*		6	mg/l
Limnea ovata	Mollusca		Perturbation level	15	mg/l
Bluegill	Fish	TLm* (24, 96-hr--respectively)		100-1000, 75	mg/l
Mosquito fish	Fish	TLm (24-96 hr)		251	mg/l
Fathead minnow	Fish	LC_{50} (1, 24, 48, 72, 96-hr--respectively)	Death	175, 106, 106, 79, 79)	mg/l
Culex sp. larvae	Insects	TLm (24-48 hr)		1500	mg/l
Mice	Mammals	LC50 (l hr)	Inhalation	5000	ppm

*median tolerance limit

3.5.2 Surfactants

Surfactants are used to reduce the surface tension of water, enabling a "bridge" to form between two chemicals or media that would not normally mix (e.g., oil and water). When used with herbicides, they are intended to maximize the amount of spray solution that sticks to the leaf surface, and hence increase uptake. Surfactants commonly used to promote imazapyr and glyphosate adsorption and uptake are generally of two classes: non-ionic nonylphenol alcohols and/or fatty acids, and crop-oil based concentrates. Studies evaluating the efficacy of imazapyr and glyphosate with various surfactants have revealed few differences in the efficacy of the herbicides

based on the surfactant (Patten 2002). All surfactants tested with imazapyr provided effective control, but R-11, the approved surfactant for use with glyphosate, was not tested with imazapyr, making a direct comparison difficult (Table 3-15). However, the author states that "application made with short dry time might better distinguish surfactant effects than did these trials, all of which had ample dry time".

Table 3-15: Effect of surfactant applied in September 1999 and 2000 on the efficacy of imazapyr for smooth cordgrass control in Willapa Bay, WA.
(Source: Patten, 2002.)

Herbicide	Rate (kg/ha)	Surfactant	Percent (v/v)	Percent control 13 months after treatment		
				Site 1	Site 2	Site 3
Imazapyr	1.68	Agri-Dex	1.0	99	85	96
	1.68	Agri-Dex	2.0		96	
	1.68	Hasten	1.0	100	83	94
	1.68	Kinetic	0.5		89	
	1.68	Dyn-Amic	1.0		96	
	1.68	Syl-Tac	1.0		92	
Glyphosate	8.4	R11	1.0		69	85
Untreated	na	na	Na	0	0	0

Although there appears to be little difference amongst surfactants in their potentiation of herbicide efficacy, their inherent chemical properties can have a range of environmental issues that are independent of the herbicide formulation they may be applied with. For this reason, it is prudent to examine their properties and toxicity independently. Table 3-16 summarizes descriptions of surfactant environmental fate, chemistry and toxicity as provided in the original EIS and obtained from the manufacturer's material safety data sheets (WSDA 1993E, chapter 11.00). In brief, the acute toxicity of alkylphenol ethoxylate surfactants like R-11$_{tm}$ and X-77 $_{tm}$ to fish and other aquatic species has been reported in the range of 4 to 12 mg/L. Acidifying agents like LI-700, and crop-oil based surfactants like Hasten $_{tm}$ and Agri-Dex $_{tm}$ exhibit lower toxicity. On the basis of EPA aquatic toxicity criteria, all the surfactants used would be considered practically non-toxic (LI700 $_{tm}$, Hasten $_{tm}$ and Agri-Dex $_{tm}$) to moderately toxic (R-11, X-77). 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 pt scale) irritation in mammals (Table 3-17). By oral administration, the limited testing done with the surfactants in mammals indicates they would classify as "practically non-toxic".

Table 3-16: Chemistry and Fate of Surfactants Potentially Used With Imazapyr and Glyphosate.

Surfactant	Known Ingredients* & Surfactant Class	Chemical Properties	Degradation Rate and Pathway	General Toxicity Rating*
R-11tm (surface activator), Wilbur-Ellis Co.	Isopropyl (butyl) alcohol 20%, nonionic surfactants 80% (octyl phenoxy polyethoxy), silicone. Class: Nonionic alkylphenol ethoxylate	Soluble in lipid & water, Flammable, Spec. Gravity = 1.0	Slowly biodegraded by progressive shortening of ethoxylate chain; intermediate breakdown products of polytheylene glycol (anti-freeze) and short-chain ethoxylates.	Mammals: practically non-toxic orally, mild skin irritation possible Fish and other aquatic biota: moderately toxic
LI-700 tm (penetrating surfactant), Loveland Industries, Inc.	Phosphatidylcholine (lecithin) at 800 g/L, propionic acid, and alkylphenyl hydroxypolyoxyethylene Class: Acidifying agent	Soluble in lipid & water, Not Flammable Spec. Gravity = 1.03	Biodegradation presumed rapid due to natural lecithin ingredients.	Mammals: practically non-toxic orally, but causes skin irritation Fish and other aquatic biota: moderately toxic
X-77 tm (spreader activator), Valent Corp.	Alkylarylpoly (oxyethylene), glycols, free fatty acids, isopropyl alcohol. Class: Nonionic alkylphenol ethoxylate	Soluble in lipid &water, Flammable	Slowly biodegraded by progressive shortening of ethoxylate chain; intermediate breakdown products of polytheylene glycol (anti-freeze) and short-chain ethoxylates.	Mammals: practically non-toxic orally Fish and other aquatic biota: moderately toxic
HASTEN tm	Proprietary: fatty acids from seed oils esterified with alcohol Class: oil based surfactant	Non-ionic, dispersible in water as micelles, but unknown solubility. Sp. Gravity = 0.9	Biodegradation presumed rapid, but no formal studies conducted of which we are aware.	Mammals: practically non-toxic through oral routes Fish and other aquatic biota: slightly toxic
AGRI-DEX tm	Proprietary: heavy range paraffin-based petroleum oil with polyol fatty acid esters and polyethoxylyated derivatives Class: oil based surfactant	Dispersible in water (forms micelles), moderate flammability,	Biodegradation presumed rapid, but no formal studies conducted of which we are aware	Mammals: practically non-toxic through oral ingestion, mild skin and eye irritant, Fish and other aquatic biota: practically non-toxic

*See tables 3-9 and 3-12 for toxicity classification schemes

Past studies with glyphosate have shown that the toxicity of surfactants is generally greater than the toxicity of the herbicide formulation or active ingredient alone. For example, studies with Rodeo formerly discussed in the original EIS 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. 2002, unpublished data). As demonstrated in Table 3-17, the toxicity of the seed and crop-oil based surfactants Hasten and Agri-Dex to rainbow trout was two to three orders of magnitude lower (respectively) than R-11 in this study. 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, Hasten, LI700, X-77 and R-11. It is noteworthy, that only R-11, the surfactant that appears most toxic from the recent

tests, is approved for use with glyphosate in the estuarine environment where herbicide treatment of *Spartina* is conducted.

Table 3-17 Toxicity of Surfactants With and Without Herbicide.
(Sources: Smith et al. 2002, Henry 1992, Mitchell et al. 1987, WSDA 1993E.)

Chemical Tested	Mammalian Toxicity LD_{50} (ppm)	Aquatic Toxicity (ppm)
R-11 surfactant	5,840 oral, 13000 dermal (rabbit)	6.0, rainbow trout 96-hr LC_{50}* 4.2, bluegill sunfish 96-hr LC_{50}
LI-700 surfactant	>5,000 oral, 5,000 dermal (rat)	17, rainbow trout 96-hr LC_{50}* 22, rainbow trout 24-hr LC_{50}* 210, bluegill sunfish 96-hr LC_{50} 190, daphnia 48-hr LC_{50}
Hasten surfactant	No Data	74, rainbow trout 96-hr LC_{50}* 98, rainbow trout 24-hr LC_{50}*
Agri-Dex surfactant	>5,010 oral (rat), > 2,020 dermal (rabbit)	271, rainbow trout 96-hr LC_{50}* 386, rainbow trout 24-hr LC_{50}*
X-77 surfactant	> 5,000 oral (rat), > 5,000 dermal (rabbit)	4.2, rainbow trout 96-hr LC_{50} 4.3, bluegill sunfish 96-hr LC_{50} 2, water flea (daphnia) 48-hr LC_{50}
Rodeo (as glyphosate)	3,800 oral, 5,000 dermal (rabbit)	580, rainbow trout 96-hr LC_{50} 545, water flea (daphnia) 48-hr LC_{50}
Rodeo + X-77	No Data	130, rainbow trout 96-hr LC50 130, water flea (daphnia) 48-hr LC_{50}
Rodeo + R-11	No Data	5.4, mg/L rainbow trout 96-hr LC_{50}*
Rodeo + LI700	No Data	23, mg/L rainbow trout 96-hr LC_{50}*
Arsenal + Hasten	No Data	113, mg/L rainbow trout 96-hr LC_{50}
Arsenal + Agri-dex	No Data	479, mg/L rainbow trout 96-hr LC_{50}*

*Unpublished data from Smith et al. (submitted to Bull. Env. Of Contam. And Tox.). Data represents mean of 4 trials, upper 95% confidence limit within 5 to 20% of mean over all herbicide trials (not shown)

The non-ionic alkylphenol derived surfactants may pose additional hazards beyond the evidence provided in acute toxicity tests. The alkylphenols and octyl phenol ethoxylates belong to a broader class of chemicals known as the "nonylphenols". It has been estimated that approximately 80 percent of the alkyl phenol ethoxylates are nonyl phenol ethoxylates and the other 20 percent are octyl phenol ethoxylates (Cox 1998). Because these compounds are not part of the herbicide formulation, their exact formulations are patent protected and are not reportable under FIFRA. However, the EPA considers the nonylphenols as an "inert of toxicological concern." Nonylphenol ethoxylates degrade to nonyl phenol and related compounds that can be somewhat persistent in the environment. Sublethal effects at exposure concentrations below acutely toxic level were previously described (WSDA 1993E) and included 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. Lethal effects as reported in the literature are summarized in Table 3-18. The intermediate breakdown products of these surfactants can include both linear and branched chain alkylphenols, which may also have inherent toxicity. Some of these products have been shown to elicit weak estrogenic effects when administered at high doses to laboratory animals (reference). Determining the actual quantity of alkylphenols in each surfactant formulation, and their potential

environmental concentrations and risks is not entirely possible because the proportions in each surfactant formulation are not known.

Table 3-18: Acute toxicity of nonylphenol to aquatic biota.

Test species	Class of organism	Toxicity test	Toxicity end point	Value	Units
Mytilus edulis[1]	Mussel	Bioconcentration Factor	NA	10	Wet weight
Caenorhabditis elegons[2]	Nematode	LC50 (24 hr)	Death	7.2	mg/l
Mysidopsis bahia[2]	Mysid	LC50 (96 HR)	Death	43	mg/l
Fathead minnow[2]	Fish	LC50 (96 HR)	Death	135	mg/l
Gadus morhua[2]	Fish	LC50 (96 HR)	Death	3000	mg/l

4.0 EXPOSURE ASSESSMENT

In this chapter we characterize the potential exposure to fish and wildlife receptors from the use of imazapyr to control *Spartina* based on exposure parameters generated from current and projected application practices. Wildlife species are predominantly exposed to herbicides by consuming treated vegetation and/or water, and/or by transfer of the chemical through natural food chains. Contact (dermal) and inhalation exposure can provide additional, although marginal, exposure. Inhalation exposure of drift is generally extremely limited because application equipment creates noise that causes mobile birds and mammals to avoid the immediate area. Nocturnal animals such as the rat would largely avoid inhalation exposure because WSDA applies herbicides only during daylight hours. For this assessment drinking water exposure would also be limited because treatments will occur in estuarine waters where freshwater is limited, although rain is generally abundant, and consumption of freshwater accumulated on the plants is possible. Our ability to characterize imazapyr exposure for some sectors of wildlife such as amphibians and reptiles is limited because of a lack of basic biological (life history) and toxicological information. Site specific studies would be required to address quantitative risk assessment in each area where *Spartina* has infested, so exposure modeling was conducted in lieu of site specific work to gauge exposure doses based on application rates and delivery mechanisms of relevance to wildlife receptors. Exposure doses were then compared to reference doses from the toxicity literature to gauge the potential toxicity to relevant ecological receptors.

4.1 Estimated Environmental Exposure Concentrations (EEC)

The exposure concentrations or dose experienced by biota will differ by media (i.e., air, water, food, and sediment), the habitat they use, how frequent they use the habitat, and the application rates of impazapyr. Estimates of environmental exposure concentrations (EEC) of imazapyr can be derived from empirical studies, and also from modeling, although the former is preferred. This section summarizes the exposure concentrations that have been measured empirically, and those from the literature that have been developed through modeling exercises. Table 4-1 summarizes empirical results where imazapyr was detected in environmental media. The derivation of many of these values was summarized in Chapter 3 of this document. The discussion below provides assumptions applicable to EEC and exposure modeling.

4.1.1 Application Rate

For *Spartina* control, only the Arsenal$_{tm}$ imazapyr formulation is projected for use, however, no product endorsement is assumed. To model the estimated environmental concentrations of imazapyr in Arsenal$_{tm}$, the different methods used for application must be understood. This includes application rates, frequency, application volumes, and interception rates. The following assumptions were used regarding application rates.

- Although lower rates may be used in certain areas, for ecological exposure and risk interpretations we assume that Arsenal will be applied at the maximum concentration recommended on the manufacturers label for aquatic use—6 pints Arsenal/acre. Six pints per acre is equivalent to 1.5 lbs active ingredient (acid equivalents)/acre = 0.68 kg/acre = 1.68 kg/ha.
- Applications will occur a maximum of one time per year until eradication is complete.

- The neat herbicide formulation will be diluted with water and surfactant prior to application. Surfactant will be added to the herbicide/water mixture to yield 1% of the spray solution applied.
- Three methods of herbicide administration are possible for *Spartina* control: (1) hand-held sprayer unit, (2) boom-mounted sprayer, and (3) aerial sprayer. Spray volumes by these methods can vary from a minimum of approximately 2.5 gallons/acre to a maximum of 80 gallons/acre.
- Herbicide quantity (mass) per unit area will not vary by spray volume (i.e., 1.5 lb/acre) but surfactant rates will, as these are normalized to spray volume. Ultra-low to low spray volumes of 2.5 to 20 gallons/acre are the most likely application rates, but risks of surfactant toxicity are also considered with high volume applications up to 80 gallons per acre.

4.1.2 Water Concentrations

Concentrations that reach the water will be affected by *Spartina* canopy interception, adsorption onto the *Spartina* , uptake into the root zone, and aerial drift. However, the "worst case" imazapyr water concentrations are assumed by considering no adsorption to sediment and/or vegetation, no foliar interception, and complete solubility on an incoming tide. Under these highly conservative conditions, water concentrations will change with depth, as represented in Figure 4-2. As demonstrated in this figure, the modeled water concentration at the lowest depths evaluated are consistent with an incoming tidal prism and are also reflective of the empirical results of Patten (2003) discussed earlier and summarized in Table 4-1. Under the worst case scenario, where the herbicide was applied to bare-mud, Patten (2003) projected extremely rapid dissipation from the equation $f = 0.0015 \exp((319/x+38))$. These field experiments suggested that applied imazapyr would not be measurable after approximately 40 hours.

Under typical treatment conditions the *Spartina* canopy will intercept herbicide, and will thus effectively titrate the herbicide into the incoming waters as they rise over the *Spartina* canopy. The highest concentration of applied herbicide will be deposited in the upper canopy and hence will not be solubilized until the water depth reaches this portion of the canopy, allowing for greater dilution than would be expected if the herbicide was distributed uniformly on the plants. Although the herbicide is highly soluble, adsorption and uptake into plant matter is facilitated by surfactant and will also reduce the available herbicide for solubilization under typical applications.

Figure 4-1: Mud-boat applicator used to apply herbicide in Willapa Bay to control *Spartina.*

Linders at al. (2000) proposed a foliar interception rate of 40% in grasses based on a recent review of retention values from pesticide and herbicide applications throughout the world. Patten (2003) has proposed a foliar interception rate of 75% for *Spartina* treated with imazapyr based on empirical results, and this same value has been proposed by the manufacturers of Arsenal$_{tm}$ (Mangels et al. 2000). High interception rates will maximize potential exposure for terrestrial herbivores, and minimize potential exposure to aquatic receptors whereas the reverse is true when interception rates are lower.

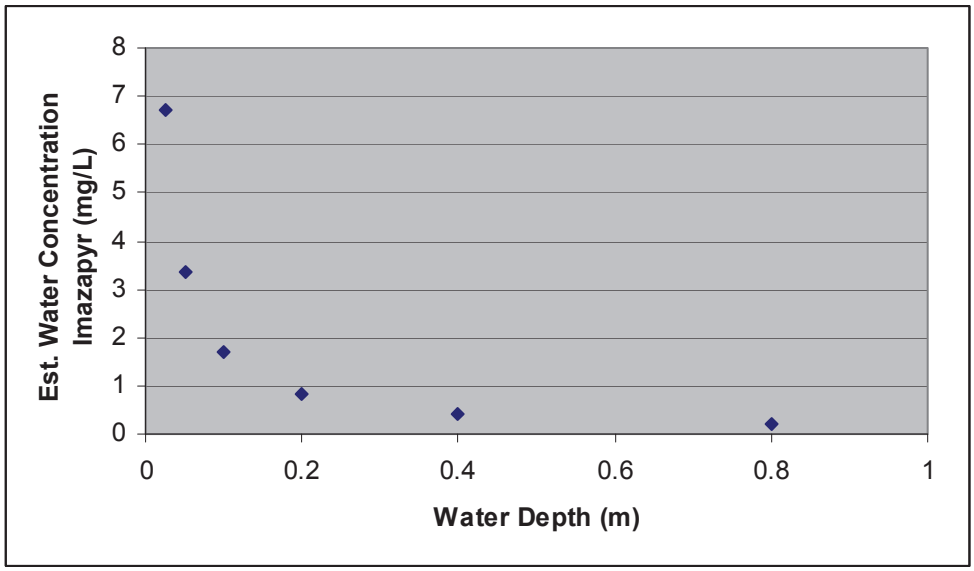

Figure 4-2: Estimated water concentrations of imazapyr in tidal waters with no canopy interception and an application rate of 1.5 lbs/acre (0.68 kg/acre).

4.1.3 Expected Plant and Animal Residues

As discussed above, interception rates will affect both plant residues as well as potential water concentrations. For *Spartina* clones, the Linder et al. interception value of 40% is more realistic with field applications because of the greater amount of edge around the clones and potential for greater drift off the application site. For *Spartina* meadows, higher interception rates are more likely, and the 75% interception value of Patten (2003) will be considered valid. Where the foliar interception rate is 40%, it is assumed that 10% of the non-intercepted imazapyr will drift off-site (or on non-target vegetation) and the remaining 50% will make contact with underlying sediment and be solubilized upon the first tidal wash. These latter values were derived from studies conducted in grasslands in the Netherlands during the growing phase (USES 2.0, 1998).

Pesticide residues following applications of 1 lb/acre were estimated in a variety of plants and insects by Hoerger & Kenaga (1972) and more recently recorded from empirical data by Fletcher et al. (1984). In the Hoerger and Kenaga study, tall grass had estimated average residue concentrations of 73 mg/kg and estimated maximum concentrations of 87 mg/kg. In the 1984 study by Fletcher and others, tall grass had average empirical residues of 29 mg/kg, and estimated maximum concentrations of 87 mg/kg. At the 1.5 lb/acre rate proposed for *Spartina* control with imazapyr, the estimated average residue concentration detectable shortly after spraying would be approximately 110 mg/kg based on the model of Hoerger and Kenaga, and 43 mg/kg based on the empirical results of Fletcher et al. (1984) (extrapolated to the higher application rate). The estimated maximum residue would be 131 mg/kg under both studies (Table 4-1). No field data on imazapyr residues in treated *Spartina* meadows or clones were available for review to compare against these residue estimates.

The residue of imazapyr in plant tissues will change over time, and this degradation has not been examined empirically in treated *Spartina*. For the chronic dietary exposure assessments described in Section 4.2, the concentration in plant tissues over time was therefore modeled for this portion

of the assessment using the methods of SERA (2001). Empirical residue concentrations in *Spartina* over time following treatment remain a source of uncertainty.

Table 4-1: Summary of Maximum and Average Imazapyr Detections in Relevant Environmental Media with Application Rates of 1.5 lbs a.i./acre.

Environmental Media	Maximum Measured	Average Maximum Measured, or Estimated Maximum*	Average of all samples Measured, or Typical Estimated*
Surface Water	5.77 mg/L[1a]	3.40 mg/L[1b]	0.1 mg/L[1c]
Pore Water	3.29 mg/L[2a]	2.94 mg/L[2b]	0.042 mg/L[2c]
Treated Sediment with no Overlying Canopy	5.7 mg/kg[3a]	5.4 mg/kg[3b]	3.2 mg/kg[3c]
Sediment Under Treated Canopy	2.27 mg/kg[4a]	1.42 mg/kg[4b]	1.4 mg/kg[4c]
Plant Tissue (long grass)	No data	131 mg/kg[5a]	43 mg/kg[5b], 110 mg/kg[5c]
Animal Tissue	No data	No data	< 50 ug/kg-wet wt.

[1] a. First tidal flush, 0.6m outside immediate spray zone atop bare mud with no foliar interception, 3.5 hrs post trtmnt; b—average of 3 samples taken at first flush 0.6 m outside spray zone; c—geometric mean of all samples collected 3.5 to 4 hours post treatment at 0.6, 6.0 and 60 m outside spray zone (Patten 2003)

[2] a—Highest value of three replicates taken 1 hr post treatment; b—average of three samples; c—average of three samples taken in sediment under canopy 15 days after treatment. (Patten 2003)

[3] a—1-hr post treatment within treatment zone of bare mud; b—1-hr post treatment, average of 3 samples; c—geometric mean of all samples collected 3.5 to 4 hours post treatment at 0.6, 6.0 and 60 m outside spray zone (Patten 2003)

[4] a—1-hr post treatment within treatment zone under canopy; b—1-hr post treatment, average of 3 samples (75% interception rate); c—geometric mean of all samples collected 3.5 to 4 hours post treatment (Patten 2003)

[5] a—Empirical measurements from Hoerger and Kenag (1972) and Fletcher et al. (1984); b—from empirical measurements of Fletcher et al. (1984); c—from modeled results of Hoerger and Kenaga (1972)

4.1.4 Sediment Concentrations

Limited testing of marine sediment concentrations following imazapyr treatment has been conducted by Patten (2003), as described in section 3.0. The worst case value in sediment is represented by the maximum sediment concentration detected in treated bare mud (5.7 mg/kg), the upper limit would be represented by the average of the maximum values from Patten's trials, and the typical environmental concentration presumes canopy interception, or 1.42 mg/kg (Table 4-1). All of these values are conservative in that the measurements were taken after the first tidal wash, and hence represent "acute" sediment conditions as opposed to more chronic sediment conditions. The half-life in estuarine sediments will be substantially less than the 12.2-day half-life determined in freshwater pond sediments by Mangels and Ritter (2000) because of the tidal exchange of waters. However, due to the non-static nature of the estuarine environment, true sediment half-lives cannot be determined from empirical measurements and "dissipation" rates more accurately describe what is actually occurring in the estuarine environment—capturing the multiple mechanisms that reduce sediment concentrations over time. Patten (2002) projects that the sediment concentration of imazapyr after bare-mud treatment followed an exponential decline and could be predicted from the equation $f = 0.0013\ e^{((137/(x+23))}$. In those studies, approximately one fourth of the maximum detected concentration of imazapyr in sediment one hour after treatment (5.7 mg/kg) was detectable after roughly 4 days post treatment (Figure 3-9), and the decay equation predicted the complete dissipation of the herbicide from sediment in 400 hours.

4.2 Ecological Receptor Exposures

In this section, specific doses are estimated for imazpyr to terrestrial and aquatic receptors, by a variety of exposure pathways of relevance to the habitats where *Spartina* treatments could occur. Life history data for terrestrial wildlife were acquired from the Wildlife Exposure Handbook (USEPA 1993) and from anonymous (2003) for the bobwhite quail, marsh wren, deer mouse, cottontail rabbit, mallard duck, Norway rat and lesser scaup. These species, or closely related species, utilize habits where *Spartina* is distributed, and/or they are test species for which toxicological data have been developed. The marsh wren is primarily a wetland and salt marsh species that consumes a diet almost exclusively of animals and insects, and is particularly common in coastal areas. The deer mouse consumes a diet of seeds and nuts primarily and is found in a wide variety of habitats throughout the state. The mallard is a "puddle" duck that consumes primarily vegetation, but also some invertebrates. The scaup is a "diving" duck and is more omnivorous in its dietary habits than the mallard. Both duck species will consume more high protein/fat animal foods prior to periods of migration and breeding (Cohen et al. 2000). The cottontail rabbit is an obligate herbivore and a test species used commonly to address dermal sensitivity. The Norway rat is a representative omnivore common to coastal areas, and the rat is also a commonly used test species. Average weights, surface areas, and daily consumption rates were used to represent exposure to wildlife species. These numbers can exhibit a great deal variation among populations, but population-specific data from each of the areas where *Spartina* is distributed was not available.

Acute Dietary Exposure Modeling Method

The acute dietary exposure was determined from the modeled empirical plant residue studies discussed in section 4.1, taking the average plant residue detected from grassland applications of herbicide at 1.5 lb ae/acre. Dose was modeled by the method of SERA (1999) used to address the ecological risks of imazapyr use in forestry applications for the USDA. Briefly, dose (D) = A x C(Prop)/W, where A = food consumption per day (kg), C = concentration in food (mg/kg), Prop = proportion of diet as treated vegetation (percent), and W = average body weight (in kg). Typical and upper food concentration limits were obtained from residue studies outlined in Table 4-1, as previously discussed. Body weight and food consumption parameters were obtained from the Wildlife Exposure Handbook or anonymous (2002) and are presented in Table 4-2. No dissipation or degradation is assumed, and the acute exposure is presumed to equate to a "bolus" (single dose) dietary exposure of the herbicide. The following parameters were assumed for this modeling:

- Concentration in food: = 131 mg/kg (upper), 43 mg/kg (typical)
- Proportion of Diet Contaminated (Prop):

  = 0.75 (obligate herbivore in treated *Spartina* meadow, based on 75% interception rate of Patten 2003) = upper limit exposure

  = 0.4 (based on 40% interception rate from Linders et al.2000) = typical proportion of diet assumed for omnivore and carnivore exposure.

Table 4-2: Exposure Parameters for Addressing Risks from WSDA's Imazapyr Applications for *Spartina* Control.

Species	Adult Body Weight (grams)	Daily Food Intake (g)	Daily Water Intake (ml)	Inhalation Rate (m^3/day)	Surface Area (cm^2)	Diet Preference	Relevant Life History Characteristics Relevant to Exposure	Conceptual Exposure Pathways
Bobwhite Quail	B: 190	15	20	F: 0.10 M: 0.11	F: 298 M: 320	Plants and insects. Max insects 20% in summer	Breeding in April-July; hatching May to August; Non-migratory; annual mortality rate of approx. 80%	Unlikely for *Spartina* application, but considered surrogate for non-water dependent bird species
Marsh Wren	B: 11.25	8	3	No data	F: 45 M: 48	Insects, spiders, mollusks, and crustaceans	Breed in April; hatch in May; Migration in fall and spring; likely to be found within coastal marsh habitat where *Spartina* is abundant	Primary: Dietary Secondary: Inhalation of drift Tertiary: Water Intake
Deer Mouse	B:21	9 (lactating)	7	F: .025 M: 023	F: 86 M: 91	Mixture of nuts, seeds, and insects	Breed several times during the year	Primary: ingestion of grain, habitat use limited, however. Secondary; inhalation of drift
Cottontail Rabbit	B: 1,286	180	125	0.63	1,254	Grasses, shrubs, woody plants	Breed several times during the year	Primary: ingestion of treated plant matter
Norway Rat	B: 300	15	33	No data	500	Omnivorous	Breed several times during the year	Primary: dietary ingestion of marine invertebrates Secondary: water intake Tertiary: skin contact Inhalation exposure unlikely due to nocturnal behavior
Mallard Duck	F: 1,043 M: 1,225	250	F: 0.042 M: 0.055	F; 0.42 M: 0.48	F: 1,030 M: 1,148	A surface feeding "puddle" duck, feeds on an omnivorous diet. Dietary patterns vary with season. In winter, mallards feed mostly on seeds mast, and to a lesser extent invertebrates. In the migratory and breeding seasons, high protein and fat diets are consumed, with more invertebrate biomass .		Primary: dietary exposure through animal, plant and sediment ingestion, and feather preening. Secondary: inhalation of drift Tertiary: water intake
Red Fox	F: 4,130 M: 5,250	F: 285 M: 362	F: 355 M: 441	F: 1.7 M: 2.0	F: 2760 M: 3220	Omnivorous: mostly small mammals, birds, insects, and fruit. Plant material is common in summer and fall diet.	Breeding in December - February	Primary: dietary ingestion of marine invertebrates Secondary: water intake Tertiary: skin contact

Species	Adult Body Weight (grams)	Daily Food Intake (g)	Daily Water Intake (ml)	Inhalation Rate (m^3/day)	Surface Area (cm^2)	Diet Preference	Relevant Life History Characteristics Relevant to Exposure	Conceptual Exposure Pathways
Scaup	F: 770 M: 860	50	F: 0.064 M: 0.062	F: 0.34 M: 0.36	F: 842 M: 906	Juveniles ate entirely animal matter in NW territories study; 61% animal matter in Louisiana study,	Pacific Flyway spring migration from March—April; fall migration from September-mid-October.	

Chronic Dietary Exposure Method—On Site

Chronic dietary exposure was evaluated using the same method adopted by the USFS in their evaluation of imazpyr use for forestry applications (SERA 1999), with several modifications relevant to the proposed application rates to control *Spartina*. In the chronic dietary assessment, it is assumed that consumption of treated vegetation will occur for a 90-day period beginning immediately after chemical application. Food consumption parameters are based on the Wildlife Exposure Handbook reference as cited in Table 4-2. The residue of imazapyr in *Spartina* grain at time zero (C*o*) is based on the acute dietary exposure scenario described above. The residue over time was based on the foliar decay coefficient (k) = $\ln(2)/t_{50}$, where t_{50} = the foliar half-life. The concentration on the vegetation after time (C*t*) is calculated as $Ct = Coe^{-kt}$, and is reflected in Figure 4-3 below.

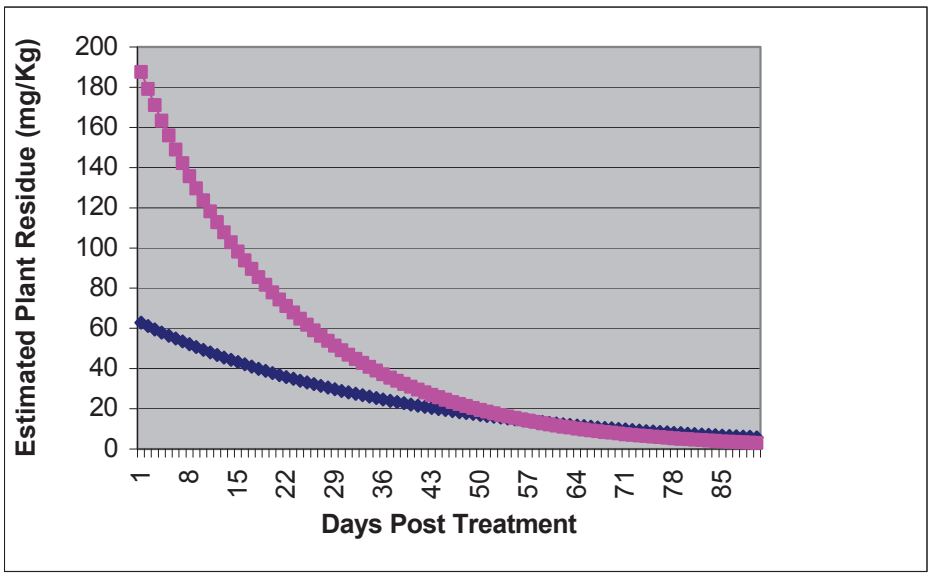

Figure 4-3: Estimated plant residue concentrations over time, with an initial application rate of 1.5 lbs/acre.

The integral of the concentration after time *t* (C*t)* is divided by the duration of dietary exposure to calculate the time-weighted average concentration on vegetation. Daily dose is calculated from the proportion of the diet contaminated, divided by body weight (which varies by animal). The specific parameters used are as follows:

- Duration of exposure (T) = 90 days
- Body weight (*W)*—average varies by animal, from Table 4-2, units in kg
- Food consumption per day—varies by animal, from Table 4-2, units in kg
- Foliar halftime (t_{50}) = 37 days (upper limit), 26 days (typical exposure)
- Foliar residue (rr): = 131 mg/kg (upper limit), 43 mg/kg (typical exposure)
- Drift = 1.0
- Decay coefficient (k) = $\ln(2)/t_{50}$ = 0.0462/day (upper limit); 0.0267/day (typical exposure)
- Initial Concentration on Vegetation (Co) = Application Rate x (rr) x Drift
  = 196.5 (upper); = 64.5 (typical)

- Concentration on Vegetation at time T (Ct) = $Co\ e^{-kT}$
- Time-weighted average concentration on Vegetation (C_{twa}) = $Co(1-e^{-kt})/(kT)$
  = 46.5 mg/kg (upper); 24.4 mg/kg (typical)
- Proportion of Diet Contaminated (Prop):
  = 0.75 (obligate herbivore in treated *Spartina* meadow)
  = 0.4 (omnivore on meadow fringe, or transient wildlife)
- Chronic Dietary Dose Absorbed (CD) = (C_{twa})(food intake/day)(Prop)/W

Drinking Water Consumption Modeling

Exposure to imazapyr through drinking water is unlikely due to the brackish water conditions where *Spartina* is found. It is possible, however, that small animals and insects will collect drinking water from the *Spartina* canopy after a rain. Thus, the drinking water pathway is considered complete for the terrestrial wildlife considered in this assessment.

Spill Scenario

For this exposure scenario, the upper limit of exposure was taken to be drinking water obtained from the applied (undiluted) solution that could accumulate on the plants and be consumed (e.g., via licking). The concentration of imazapyr in the undiluted solution will vary by the spray volume, as depicted in Figure 4-4. As demonstrated in this figure, the ultra-low spray volumes result in the highest "neat" concentration of imazapyr, whereas high spray volumes dilute the imazapyr in solution. Most application techniques envisioned would apply the herbicide in the 10 gal/acre to 40 gal/acre range. Exposure via this method would be consistent with an accidental spill scenario. Dose (D), in units of mg/kg-bw, is calculated as the product of (C x A)/W, where C =

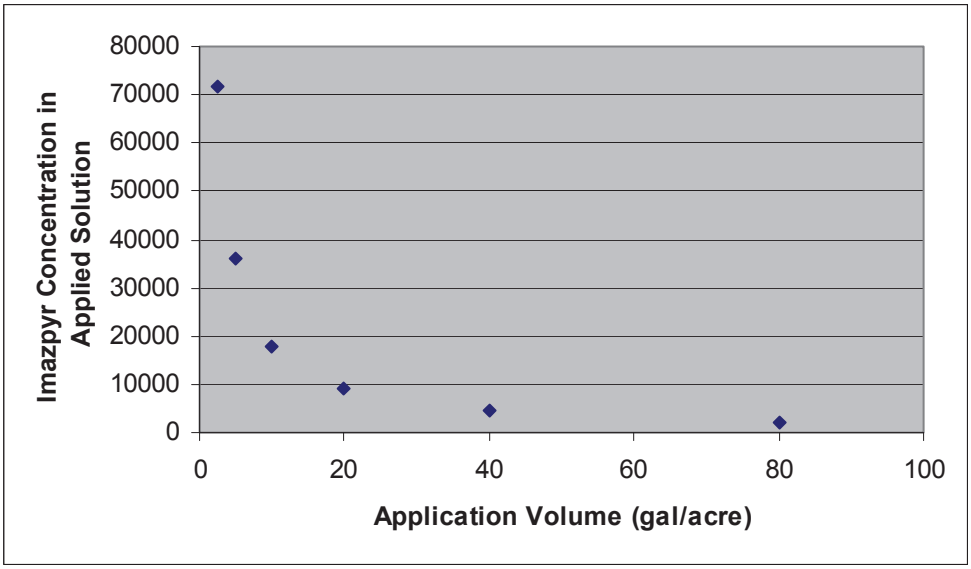

Figure 4-4: Estimated concentration of undiluted imazapyr in various spray volume applications.

Note: Higher spray volumes could be used and would result in lower exposures, as predicted.

concentration in ambient water (mg/L), A = water consumed per day (in liters), and W = body weight (in kg). This dose calculation was adopted from SERA (2001), with modifications to reflect the estimated exposure concentration. Body weight data for each of the animals are represented in Table 4-2. For the exposure calculations, the upper limit exposure concentration (C) for the drinking water (spill) scenario presumed a spill (and ingestion) of concentrated spray solution that was to be applied at a rate of presumed to 10 gal/acre (17,966 mg-imazapyr/L), and the typical exposure was presumed to occur from a spill at the standard application rate of 20 gal/acre (8,983 mg-imazapyr/L).

Runoff scenario

Ingestion of contaminated water from an acute exposure scenario for runoff represents a more realistic case for what might actually occur in the treated environment. Again, however, due to the brackish conditions where *Spartina* is found, it is unlikely that significant drinking would occur by any small mammal. Salt glands in ducks enable their ingestion of brackish water and for this reason, an estimation of uptake from a runoff concentration is legitimate. The calculation of dose is consistent with the equation used to predict uptake from a spill scenario (D = CxA/W), and the estimated environmental concentrations used for modeling are taken from the empirical results summarized in Table 4-2 (Patten 2003). Thus, the upper limit exposure was based on an EEC of 3.4 mg-imazapyr/L, and the typical exposure was based on an EEC of 0.1 mg/L.

Dermal (Contact) Exposure Modeling Method

The 'worst case' (upper limit) scenario for contact exposure was based on the presumption of an animal being exposed directly to the spray, with 100% absorption ocurring over the first 24-hour period. This is a highly conservative exposure model, in that it assumes 100% absorption of the dose, which would overestimate fur bearing animal and bird exposures due to fur and feather interference, respectively. Also, the dermis is largely impermeable to water soluble substances, thus, although adjuvants delivered with the herbicide will facilitate uptake, absorbtion of herbicide that reaches the skin will not be complete. The assumptions for the dermal absorbtion model were as follows:

- Period of exposure (T) = 24 hrs
- Body weight (W) = average weight in kg, as indicated from Wildlife Exposure Handbook, or other literature if no data were available within the exposure handbook.
- Exposed surface area (SA): $cm^2 = 1110(W)^{0.65}$
- Application Rate (AR) = (1.5 lbs/acre)(0.01121—a conversion factor) = 0.0168 mg/cm^2
- Amount deposited on the animal (Amnt) = 0.5 x SA x AR (note: typical dermal exposure assumes 50% of animal is covered by direct spray, upper limit exposure presumes 75% of animal is covered and the product of SA x AR is multiplied by 0.75.
- Estimated Absorbed Dose = D_{abs} = Amnt/W

Other Exposure Pathways

Additional routes of exposure are acknowledged both in the conceptual model (Figure 2-1) and also in Table 4-2. However, we consider the above exposure scenarios to represent the pathways where exposure could be maximal. Pathways such as chronic exposure to contaminated water are incomplete for the proposed use of *Spartina* in an estuarine setting. The acute run-off scenario to

contaminated water—where an animal might drink water that has been in contact with treated vegetation is also unlikely to be completed in the estuarine setting because the brackish waters where *Spartina* is distributed are not potable to most wildlife (although waterfowl with salt glands are capable of drinking a limited amount of salt water). We did not model this type of exposure, as the more severe exposure scenario, the acute spill based on the drinking of neat solution, addressed a more significant exposure.

Acute inhalation exposure is possible, but considered insignificant because the disturbance created during treatment will cause most animals to avoid the area being immediately treated. Aerial drift will vary by nozzle type and application volume, and has been estimated at 10% in grasslands in the Netherlands (Linder et al. 2000). Such drift can be both a component of inhalation exposure off-site, and/or oral or dermal exposure off-site. The probability of this occurrence representing substantive exposure is considered insignificant, and the exposure modeling conducted for on-site exposures will yield substantially higher doses than potential exposures off-site. Since these results indicated insignificant risk (as described below), off-site exposure from drift was not modeled.

4.2.1 Mamalian Exposure

Mammalian wildlife can be exposed to imazapyr through dermal, oral (ingestion) or inhalation routes, although the dietary route is considered most likely in practical settings (USDA 1996a). We modeled exposure to the rabbit, rat, mouse and fox as representative mammalian herbivores and omnivores for those areas where imazapyr could be applied to control *Spartina*. As demonstrated in Table 4-3, the acute dermal and dietary exposures yielded the highest modeled doses to all of the mammalian wildlife examined for this study for those pathways that are most realistic *in-situ* (i.e., not involving a spill scenario) Based on life history characteristics of food intake, body weight, and surface area, the deer mouse would have the highest estimated exposure of the mammalian ecological receptors considered, for all of the exposure pathways considered. This finding is relatively intuitive in that the species has the smallest home range, and highest food and water intake and surface area relative to body weight. Estimates of dose within each exposure pathway varied by slightly more than one order of magnitude amongst the mammalian species examined (Table 4-3). The red fox had the lowest modeled exposure from contact exposure, whereas the Norway rat had the lowest modeled exposure for the acute and chronic dietary scenarios. The smaller surface area/body weight ratio of the fox, and the omnivorous habits of both the fox and rat, were largely responsible for the lower estimated exposures by these species, relative to the mouse and rabbit.

Estimates of imazapyr exposure ingested from an acute spill scenario were high for all mammalian species, yielding acute dose estimates in the high mg/kg-bw to low g/kg-bw range, for the upper and typical spill concentration estimates. These acute "drinking water/spill" scenario values exceeded the estimated exposure for other pathways by two to three orders of magnitude. However, it is likely that all of the mammalian species modeled would voluntarily avoid drinking water containing imazapyr from a spilled, undiluted spray solution; thus, the practical use of these modeled exposures requires field validation. Drinking water consumption under the run-off scenarios yields more realistic estimates of exposure, and reduced the exposure doses to the modeled mammals by over three orders of magnitude, with a maximum estimated exposure in the deer mouse of 1.133 mg/kg, and a minimum in the male fox of 0.008 mg/kg—the lowest dose estimated by all exposure routes considered.

Table 4-3: Estimated Exposures to Terrestrial Wildlife Receptors from Imazapyr Applications (mg/kg-body wt)*

Receptor	Acute Dietary Exposure	Chronic Dietary Exposure	Acute Drinking Water Exposure (Runoff)	Acute Drinking Water (Spill) Exposure	Dermal (Direct Contact) Exposure
Deer Mouse	Upper: 42.11 Typical: 13.82	Upper: 14.95 Typical: 7.84	Upper: 1.133 Typical: 0.033	Upper: 5 989 Typical: 2 994	Upper: 54.07 Typical:36.04
Scaup	Upper: 3.05 M, 3.40 F Typical: 1.00 M, 1.12 F	Upper: 1.08 M, 1.21 F Typical: 0.57 M, 0.63 F	Upper: 0.210 M, 0.216 F Typical: 0.006 M, 0.006 F	Upper: 1107 M, 1143 F Typical: 554 M, 572 F	Upper: 14.74 M, 15.33 F Typical: 9.83 M, 10.22 F
Mallard Duck	Upper: 20.05 M, 6.58 F Typical: 6.58 M, 7.73 F	Upper: 7.12 M, 8.36 F Typical: 3.73 M, 4.39 F	Upper: 0.186 M, 0.143 F Typical: 0.004 M, 0.005 F	Upper: 983 M, 758 F Typical: 491 M, 379 F	Upper: 13.03 M, 13.78 F Typical: 8.68 M, 9.19 F
Norway Rat	Upper: 2.62 Typical: 0.86	Upper: 0.49 Typical: 0.93	Upper: 0.374 Typical:0.011	Upper: 1 976 Typical: 988	Upper: 21.32 Typical: 14.21
Marsh Wren	Upper: 37.26 Typical: 12.23	Upper: 13.23 Typical: 6.94	Upper: 0.903 Typical: 0.027	Upper: 4 7910 Typical: 2 395	Upper: 67.27 Typical: 44.84
Bobwhite Quail	Upper: 7.757 Typical:2.546	Upper: 2.75 Typical: 1.44	Upper: 0.358 Typical: 0.011	Upper: 1 891 Typical: 946	Upper: 25.01 Typical: 16.67
Cottontail Rabbit	Upper: 13.75 Typical: 4.51	Upper: 4.88 Typical: 2.56	Upper: 0.330 Typical: 0.010	Upper: 1 746 Typical: 873	Upper: 12.81 Typical: 8.54
Red Fox	Upper: 3.61 Typical: 1.19	Upper: 1.28 Typical: 0.67	Upper: 0.286 M, 0.292 F Typical: 0.008 M, 0.009 F	Upper: 1509 M, 1544 F Typical: 755 M, 772 F	Upper: 7.83 M, 8.51 F Typical: 5.22 M, 5.68 F

*See Appendix B for full calculations of dose by exposure pathway for each receptor species modeled.

The lowest dietary dose was modeled in the rat at 0.049 mg/kg, for a "typical" chronic dietary dose (see Table 4.2). The highest dietary dose was calculated for the acute dietary exposure in the deer mouse consuming a diet with the "upper" limit EEC, to yield a dose of 42.11 mg/kg. The highest non-spill dose was estimated in the deer mouse via direct contact to spray, yielding a dose estimate of 54.07 mg/kg-bw.

4.2.2 Avian Exposure

Exposure for birds may occur via the same pathways as mammals: ingestion, contact and inhalation. The broad array of life history behaviors prevents an assessment of all bird species. We modeled potential doses to the bobwhite quail, marsh wren, mallard duck and greater scaup, to provide for a range of dietary habits and life history behaviors. All of these species, with the exception of the bobwhite quail, could be found in the regions of Washington State where *Spartina* is currently distributed (western Washington's lowlands support California quail, a closely related species). As demonstrated in Table 4-3, the marsh wren had the highest projected dose among the species via the non-drinking exposure pathways considered (i.e., 67 mg/kg via direct contact application). The highest acute and chronic dietary doses were also projected for the marsh wren of all the bird species, primarily due to its high food intake relative to its body weight. Similarly, the mallard duck was estimated to consume roughly six-fold more imazapyr than the greater scaup because of the assumed dietary differences considered between these species (i.e., primary herbivore vs. omnivore).

4.2.3 Insect Exposure

Exposure for insects was modeled in the bee for the direct contact exposure scenario due to spray from an acute exposure only (Meade 1983). Dose was estimated as described in Section 4.1 for direct contact exposure, using the bee as a surrogate for all terrestrial insects. The direct contact exposure for the bee yielded an estimated dose of 0.0223 mg/kg for a typical exposure (assuming 50% of the insect was covered), and 0.0335 mg/kg for the upper limit estimate (assuming 75% of the animal was covered). Dietary and drinking water consumption were not considered, as previously discussed.

4.2.4 Reptiles and Amphibian Exposure

Reptiles and amphibians (herptiles) can be exposed to herbicides through the same pathways as mammals, birds and terrestrial invertebrates—via dietary consumption, inhalation and direct contact. Amphibians may be particularly susceptible to contact exposure from direct spray applications whereas contact exposure to reptiles is unlikely to yield significant doses due to the relative impermeability of their skin. Exposure parameters have not been developed to accurately gauge reptile or amphibian exposures and no toxicity information was identified from the literature from which to quantify or estimate exposure to these groups of animals.

Although a formal dose cannot be estimated for herptiles, the potential for exposure can be considered by evaluating the potential herptile inhabitants of the estuarine areas where *Spartina* treatments could occur. The USGS (2003b) reports a total of 19 herptiles potentially resident in the broader Willapa Bay area (http://www.npwrc.usgs.gov/resource/othrdata/chekbird/r1/willrept.htm). These species are also possible in other areas of Puget Sound and coastal Washington. Twelve of these 19 species are amphibians and are therefore intolerant of the saline conditions inherent to estuaries where *Spartina* is distributed. Exposure to these 12 species is therefore considered an incomplete pathway.

Three of the 19 herptile species recognized to Willapa Bay are sea turtles, and include the leatherback (*Caretta caretta*), loggerhead (*Dermochleys coriacea*) and green sea turtle (*Chelonia mydas*). All of these species are listed as either threatened or endangered. Willapa Bay is not designated as critical habitat for any of these species (50 CFR Part 226), and we could not verify that individuals of these species' have been specifically sighted in the area. Documentation reviewed suggests very infrequent sightings of these sea turtles are possible in the outer bay and marine areas due to their relatively cosmopolitan oceanic distributions. However, the green turtle is considered primarily a tropical species whereas the loggerhead and leatherback turtles have a greater tolerance for colder waters and would be more likely to be observed off of coastal Washington. Where *Spartina* is distributed, the probability of turtle occurrences is sufficiently low to consider exposure an incomplete pathway for these threatened and endangered species.

Only two snake species are recognized as typical inhabitants of the Willapa Bay area, the common gartersnake (*Thamnophis sirtalis*) and the northwestern gartersnake (*Thamnophis ordinoides)*. These species may be also found elsewhere in coastal regions of western Washington environments near where *Spartina* occurs. These species can be found occasionally in or near water, although they would be considered very uncommon in salt marsh habitats. The northwestern garter snake is primarily a terrestrial species and the common garter is commonly found near freshwater which it may use to escape predation or other disturbance (Stebbins 1985). The potential for exposure to these animals is extremely low due to their life history behavior that would largely preclude their use of salt marsh habitat where *Spartina* is distributed. No doses are estimated for these receptors.

4.2.5 Aquatic Animal Exposure

Exposure to fish and aquatic invertebrates could occur from drift entering water during application, from runoff from plants following application from rain and tidal inundation, and/or from leaching from treated vegetation and sediment underlying treatment areas. The estimated water concentrations to which aquatic animals could be exposed will vary with depth following initial application, as depicted in Figure 4-2. For the exposure calculations, the worst case exposure concentration (C) for water was assumed to be 5.77 mg/L, the maximum concentration detected on the edge of the treatment zone on an incoming tide after application to bare mud (Patten 2003). The upper limit was assumed to be 3.40 mg/L, and the typical concentration was 0.1 mg/L, as summarized in Table 4-1. Benthic infauna and epifauna atop mudflat sediments will be exposed to the highest concentrations. Sediment detritivores, benthic epifauna and benthic infauna were assumed to be exposed to concentrations of 2.27, 1.42 and 1.4 mg-imazapyr/kg-sediment to represent the worst case, upper limit and typical concentrations found in sediment by Patten (2003). Benthic infauna were assumed to be exposed to the pore water levels detected in the Patten study (2003), 3.29, 2.94 and 0.042 mg/L to represent the worst case, upper limit and typical exposure scenarios.

As previously discussed, the bioconcentration and bioaccumulation of imazapyr in aquatic organisms is extremely low due to the compounds high water solubility and low lipid solubility. Empirical results detailed in Table 4-1 of this document highlight how measurable concentrations in fish and aquatic invertebrate tissues were detected only in samples collected 3 hours after treatment, but subsequent measurements were not detectable. Therefore the potential of exposure through ingestion of exposed aquatic invertebrates or other food sources is substantially reduced. No bioaccumulated doses are therefore estimated.

4.3 Adjuvant and Inert Ingredient Exposure Assessment

The mass of surfactant applied per unit surface area can change with the application volume used to dilute the herbicide. As a result, it is essential to consider the potential exposure to aquatic animals at the range of potential application volumes. A variety of surfactants could be used, on the basis of past practices, but all are assumed to be mixed with herbicide at a rate of 1% (w/v). We evaluated the potential concentration of surfactant over a range of potential application volumes used, ranging from the ultra-low range (2.5 gal/acre) as applied in some treatment trials by Patten (2002) to 80 gal/acre, which is consistent with the rates used to apply glyphosate under the current chemical control program (WSDA 1993). As demonstrated in Table 4-2, initial concentrations of surfactant could be projected to be quite high under the most conservative of assumptions and highest application rates. At a water depth of 0.0125 m (approx. ½ in), as would be consistent with an incoming tidal lens, the spray volume of 80 gal/acre could be projected to yield nearly 60 mg/L surfactant, whereas low and ultra-low rates of application yield correspondingly lower concentrations.

Table 4-4: Estimated surfactant concentrations in estuary waters where Spartina could be treated with imazapyr, assuming constant surfactant rate of 1% in spray volume, complete solubility on incoming tide, and the "worst case" scenario of no adsorption on sediment or *Spartina* canopy. Surfactant concentrations are in mg/L

Depth (m)	2.5 gal/acre	5 gal/acre	10 gal/acre	20 gal/acre	40 gal/acre	80 gal/acre
0.0125	1.872	3.744	7.48	14.96	29.92	59.84
0.025	0.936	1.872	3.74	7.48	14.96	29.92
0.05	0.468	0.936	1.87	3.74	7.48	14.96
0.1	0.234	0.468	0.935	1.87	3.74	7.48
0.2	0.117	0.234	0.468	0.935	1.87	3.74
0.4	0.058	0.117	0.234	0.467	0.935	1.87
0.8	0.029	0.058	0.117	0.234	0.468	0.935

5.0 RISK CHARACTERIZATION TO ECOLOGICAL RECEPTORS FROM THE USE OF IMAZAPYR TO CONTROL *SPARTINA*

To characterize risks from the potential practice of applying imazapyr in an estuary setting, the potential imazapyr exposure and effects to ecological receptors are integrated in a total 'weight of evidence analysis'. The analysis examines the estimated dose and chemical properties (toxicity, metabolism, environmental fate and transport) that influence the impact that imazapyr could have on biota. Characterization of risk was made by calculating the hazard quotient from the estimated environmental concentrations or exposure doses calculated in section 4.0 of this report. The hazard quotient is derived by dividing the estimated exposure concentration or dose by the toxicity reference dose (NOEL) reported for the species (or closest surrogate species) for which toxicity testing has been conducted (Table 5-1). When possible, we used the NOEL derived for the same exposure pathway for which a dose was estimated to calculate 'pathway-specific' hazard quotients. When pathway-specific NOEL's were not available, we used the most conservative NOEL from the literature for all of the exposure pathways considered, defaulting to the one-compartment model assumption for uptake and elimination kinetics.

Based on past toxicological research and the physical chemistry of imazapyr, it is assumed that uptake of imazapyr into an animal follows a first compartment model with first-order elimination kinetics. That is, it is assumed that once exposed, the imazapyr does not preferentially concentrate in one tissue over another, and that it is eliminated from all tissues at effectively the same rate. Under a one-compartment model, uptake of imazapyr by one pathway will have an equivalent effect as the same dose acquired by another pathway. Thus, the most conservative toxicological criteria would be applicable to all means of exposure. However, in practice, even with a one-compartment conceptual model, this scenario is rarely observed and differences in the doses required to elicit a toxicological response are often observed among different exposure pathways. For example, skin barriers may prevent full absorption of a dermally applied dose, or portions of an ingested quantity of herbicide may pass through an animal's system without systemic absorption in the small intestine.

5.0.1 Mammal Risk

As discussed in chapter 3 the acute oral toxicity of imazapyr to mammals is rated as **practically non-toxic**, based on the EPA criteria outlined in Table 2-1 (i.e., an acute oral LD_{50} of > 2,000, mg/kg-body weight). None of the exposure doses estimated in chapter 4 (see Table 4-3) exceeded a hazard quotient of 1 for any of the species or exposure pathways modeled relative to the NOEL (Table 5-1), with the exception of the deer mouse spill scenario exposure (HQ = 1.198). The spill scenario modeled (i.e., where an animal would effectively drink undiluted spilled spray solution) is highly conservative and unlikely to be realized *in situ* because best management practices would

Table 5-1: Hazard quotient calculations from estimated exposure doses of imazapyr to terrestrial wildlife.*

Ecological Receptor	Acute Dietary Upper Exposure[1]	Acute Dietary Typical Exposure[1]	Chronic Dietary Upper Exposure[2]	Chronic Dietary Typical Exposure[2]	Dermal/ Contact Upper Exposure[3]	Dermal/ Contact Typical Exposure[3]	Drinking Water (Spill) Upper Exposure[4]	Drinking Water (Spill) Typical Exposure[4]	Drinking Water (Runoff) Upper Exposure[4]	Drinking Water (Runoff) Typical Exposure[4]
Deer Mouse	0.0084214	0.000524	0.014946429	0.007842857	0.02703254	0.0180217	1.19773333	0.59886667	0.0002267	6.667E-06
Norway Rat	0.000524	0.000172	0.00093	0.000488	0.01065789	0.0071053	0.395252	0.197626	0.0000748	0.0000022
Cottontail Rabbit	0.0027504	0.0009028	0.012203538	0.006403577	0.13516268	0.0901085	0.34926128	0.17463064	6.61E-05	1.944E-06
Red Fox M	0.0007226	0.0002372	0.005130057	0.002691901	0.05328943	0.0355263	0.3018288	0.1509144	5.712E-05	1.68E-06
Red Fox F	0.0007232	0.0002374	0.00513414	0.002691901	0.03201837	0.0213456	0.3088586	0.1544293	5.845E-05	1.719E-06
Marsh Wren	0.0552852	0.018147	0.066133333	0.034702222	0.01956941	0.0130463	7.07675744	3.53837872	0.0013393	3.939E-05
Bobwhite Quail	0.0115083	0.0037775	0.013766447	0.007223684	0.02128389	0.0141893	2.80587225	1.40293612	0.000531	1.562E-05
Scaup M	0.0152326	0.0008703	0.005406977	0.002837209	0.16816289	0.1121086	0.96362661	0.48181331	0.0001824	5.364E-06
Scaup F	0.017013	0.000972	0.006038961	0.003168831	0.06252731	0.0416849	0.99503125	0.49751563	0.0001883	5.538E-06
Mallard Duck M	0.1002551	0.0057281	0.035586735	0.018673469	0.03686032	0.0245735	0.8552047	0.42760235	0.0001618	4.76E-06
Mallard Duck F	0.1177493	0.0067277	0.0417965	0.021931927	0.03831438	0.0255429	0.65962899	0.3298145	0.0001248	3.672E-06

1: acute dietary reference NOEL = 5,000 mg/kg-bw for mouse, rat, rabbit, and fox; 1149 mg/kg for mallard and scaup; and 674 mg/kg for quail and wren

2: chronic reference NOEL dose for mouse and rate = 1,000 mg/kg; for rabbits = 400 mg/kg; for dogs = 250 mg/kg; for avian species = 200 mg/kg

3: dermal/contact NOEL dose for mouse & rat= 2,000 mg/kg; 400 mg/kg for rabbit. No data on fox or avian species, so assumed rabbit value of 400 mg/kg

4: same reference doses as acute oral

be employed immediately to clean up spilled herbicide, and the disturbance of the cleanup action would discourage wildlife from the area. All other exposure scenarios and estimated doses for the terrestrial mammals modeled yielded hazard quotients two to four orders of magnitude lower than the NOEL values for the species or guild from which toxicological data were derived. This results indicates insignificant risk to these receptors can be expected from imazapyr treatments. Characterizing risk based on absolute lethal thresholds such as the LD_{50} is not possible for mammals because the dose ranges administered over the variety of tests performed have never yielded lethality in mammals. Thus, the estimates of the LD_{50}, as reported in Table 3-9, are prefaced with the '>' sign, and no empirical results are available to substantiate these values.

Substantial conservatism was factored into the exposure assessment such that the modeled doses can be assumed to overestimate the conditions *in-situ*, particularly for chronic exposures because applications will occur only every other year and tidal flushing over the *Spartina* results in the loss of the herbicide over time. Conservatism was also factored into the hazard quotient calculations, in that most NOELs reported simply referenced the highest dose tested (HDT), and therefore were not based on actual empirical findings from a dose-response curve. It is therefore the conclusion of this assessment that the use of imazapyr at the indicated application rate of 1.5 lbs/acre (0.68 kg/acre) will not pose a risk to mammalian ecological receptors, even under the worst case (upper) exposure scenarios. No threatened or endangered mammalian species occupy habitats where *Spartina* is distributed or where imazapyr could be applied. Since the chemical does not bioaccumulate, and best management practices will prevent significant drift off-site, it can be reasonably assumed that such species occurring off-site would not be affected by the use of imazapyr in the estuary setting.

5.0.2 Avian Risk

As discussed in chapter 3 the acute oral toxicity of imazapyr to birds is also rated as **practically non-toxic**, based on the EPA criteria outlined in Table 2-1. None of the exposure doses estimated in chapter 4 (see Table 4-3) yielded a hazard quotient of 1 or greater for any of the species or exposure pathways modeled relative to the NOEL except, again for the spill scenario where both the marsh wren and bobwhite quail had upper limit exposure HQs of approximately 7 and 3, respectively, and lower limit HQs of 3.5 and 1.4 (Table 5-1). The same argument holds true for avian wildlife as it would for terrestrial wildlife regarding the spill scenario—namely that best management practices that obligate WSDA to immediate clean-up actions create disturbance that would be expected to greatly eliminate exposure to birds of this guild when herbicide concentrations are at their highest. The more realisitic exposure scenarios-- run-off drinking water, dietary and direct contact yielded hazard quotients generally two to three orders of magnitude below 1, indicating insignificant risk to these receptors can be expected.

Similar to mammals, characterizing risk based on lethal thresholds is not possible for birds. Like mammals, in the toxicity tests conducted where survival was a measurement endpoint, the dose ranges administered did not yield toxicity (lethality), so the estimates of the LD_{50}, as reported in Table 3-10, are prefaced with the '>' sign, and no empirical results are available to substantiate these values. Substantial conservatism was therefore factored into the exposure assessment such that the modeled doses can be assumed to overestimate the conditions *in-situ*, particularly for chronic exposures. By considering avian species with a range of life history behaviors and dietary habits, we have screened for a range of avian receptors that could be exposed to imazapyr in the environments where it might be applied. It is the conclusion of this assessment that the use of

imazapyr at the indicated application rate of 1.5 lbs/acre will not pose a risk to avian receptors, even under the worst case exposure scenarios.

5.0.3 Insects

Imazapyr is **practically non-toxic** to honey bees (BPA 2000). Direct contact exposure resulted in an estimated dose of 0.0223 mg/kg and 0.0335 mg/kg for typical, and upper limit exposure, respectively. The estimated NOEL for insects is 1000 mg/kg (the HDT), and the LD_{50} is considered > 1,000 mg/kg. On this basis, the hazard quotients would be 0.000223 and 0.000335, respectively, and the risks can be characterized as insignificant to terrestrial insects, even from the "worst case" contact exposure scenario.

5.0.4 Reptiles and Amphibians

No imazapyr toxicity values have been reported for reptiles and amphibians for imazapyr, and exposure parameters have not been fully developed, as discussed in Section 4. Although a formal dose (and hence risk calculation) cannot be extrapolated, the life history behaviors of the herptiles native to western Washington suggests that risk for reptiles and amphibians is insignificant because they would not be found in the brackish water and estuarine habitat where *Spartina* could be treated with imazapyr, and thus exposure is precluded, as described in section 4.2.

5.0.5 Fish

Risk to aquatic ecological receptors from exposure to a potentially hazardous substance is determined by two equally important factors: duration of exposure and the concentration or dose of the chemical (which is a function of the potency or toxicity of the chemical).The acute toxicity (LC_{50}) concentration for rainbow trout, bluegill sunfish, and channel catfish was formerly reported at >100 mg/L (the HDT), and as such the herbicide has been considered **practically non toxic** based on EPA hazard criteria (Table 3-12) . As discussed in this assessment, more recent toxicity testing has established an empirical LC_{50} of 22,305 mg-imazapyr ae/L using the $Arsenal_{tm}$ formulation. This toxicity value actually exceeds the imazapyr concentration in a neat (undiluted) spray solution applied at the normal 10 gal/acre application rate (i.e., 17,966 mg-imazapyr/L), and is within one order of magnitude of the neat concentrations if applied at the ultra-low rates of 5 or 2.5 gal/acre (35,931 and 71,862 mg/L, respectively). Based on the worst case, upper limit and typical exposure concentrations outlined in chapter 4.0 (Table 4-1), as developed from empirical studies, the hazard quotients for water exposures to rainbow trout would be 0.00258, 00152, and 0.000045, respectively (Table 5-2). These values represent insignificant risk to fish.

It should also be understood that these exposures are relevant only for an acute exposure scenario. No significant chronic exposures should occur due to the tidal exchange of waters in the areas where *Spartina* is distributed. Based on the dissipation experiments of Patten (2002), all readily solubilized imazapyr applied during a typical application would be dissipated (diluted beyond detection) in approximately 40 hours or less—roughly four to five tidal exchanges in the coastal waters of Washington. This duration of exposure is less than half the time of a typical 96-hr toxicity test.

Risks to Threatened and Endangered Fish

Based on the hazard quotient calculations described above, and the threatened and endangered species sensitivity fish toxicity study recently conducted (Sappington et al. 2000), it can be

reasonably assumed, with high certainty, that exposure to the active ingredients in imazapy pose no significant risk to the Columbia River ESU chum salmon, chinook salmon, or candidate coho salmon stocks, nor to any of the Puget Sound salmonid stocks that are listed as threatened or endangered under the ESA. Only under the accidental spill scenario of undiluted neat solution that was to be applied at a rate of 2.5 or 5 gal/acre is there potential to exceed the acutely toxicity criteria for salmonids (as active ingredient). However, if a spill were to occur in an aquatic environment where salmon were inhabitants (i.e., as opposed to a bare mud-flat at low tide), water must be present. Thus, some dilution would occur immediately and the dilution would likely lower the concentration below the toxicity threshold.

5.0.6 Aquatic Invertebrates

The reported acute toxicity LC_{50} concentration for the water flea *Daphnia magna* is >100 mg/L and the reported acute toxicity LC_{50} concentration for the eastern oyster growth inhibitation is > 132 mg/L (see section 3.1.9). On the basis of these toxicity measurements, imazapyr would be considered **practically non-toxic** to both freshwater and marine invertebrates according to EPA hazard screening criteria (Table 3-11). However, similar to mammal studies, and most fish studies (beyond those recently conducted by Smith et al. 2003) it should be recognized that no formal measurements have been documented that establish imazapyr concentrations that were empirically toxic or yielded sub-lethal effects such as growth inhibition. Thus, the measures of > 100 and > 132 mg/L provide only screening values for this current effort. To differentiate risks from motile epibenthic or pelagic invertebrates from benthic infauna we used the pore water concentrations depicted in Table 4-1. No sediment quality data have been derived to enable risk characterization from potential sediment contamination, although epibenthic invertebrates such as the oyster and crayfish have been tested. Using these toxicity measures and the estimated worst case, upper limit and typical exposure concentrations from Table 4-1, the hazard quotients have been summarized in Table 5-2.

As depicted in Table 5-2, conservative risk modeling assuming acute exposure conditions most likely to be experienced by invertebrates yielded hazard quotients two to three orders of magnitude below 1 for the active ingredient of imazapyr. These results suggest that invertebrate exposure to imazapyr in water represents an insignificant risk.

Table 5-2. Hazard Quotient Calculations from Estimated Aquatic Biota Exposures*

Species	Worst Case Exposure	Upper Limit Exposure	Typical Exposure
Rainbow Trout (LC50 = 22,305 mg/L)	0.00258	0.00152	0.000045
Rainbow Trout, Arsenal (w/1% surfactant) a) Hasten 113 mg/L LC50 b) W/Agridex: 459 mg/L LC50	a) 0.511 b) 0.126	a) 0.301 b) 0.074	a) 0.0088 b) 0.0021
Marine Invertebrates (surface water exposure, NOEL = 100 mg/L)	0.0577	0.034	0.001
Marine Benthic Infauna Invertebrates (pore water exposure; NOEL = 100 mg/L)	0.0329	0.0294	0.00042
Non-target algae (e.g., Ulva sp., etc.—EC50 = 71 mg/L in *Selenastrum*)	0.076	0.0447	0.0013
Non-target vascular plants (e.g., eelgrass, Salicornia; EC50 =0.0214 mg/L in duckweed for growth)	270	159	4.7

*Hazard quotient defined as: estimated exposure concentration/sub-lethal EC_{50}, or estimated exposure concentration/LC_{50}

5.0.7 Non-target Aquatic Vegetation Risk

It is not surprising that risks to non-target aquatic vegetation appear to pose the most significant risk element from the potential use of imazapyr, as the herbicide has been engineered as a broad-spectrum agent to control unwanted plant growth. Risks to algae, based on hazard quotient calculations, are insignificant—within the same order of magnitude as risks characterized for aquatic invertebrates (Table 5-3). Risks to vascular plants such as eelgrass (e.g., *Z. marina and Z. japonica*) may be significant, based on EC_{50} concentrations developed in duckweed, a floating vascular plant and expected water concentrations of the herbicide. Hazard quotients exceeded 1.0 under each of the exposure scenarios considered for vascular plants, ranging from 4.7 fold above the EC_{50} for duckweed growth inhibitation for typical exposures to 270 for "worst case" exposures. The impact of imazapyr use on non-target vegetation should be largely controllable by the use of best management practices that limit the potential for non-target vegetation exposure. Patten (2003) showed that even after direct exposure to the herbicide, regrowth of eelgrass to its pre-application state was evident less than one year after treatment. This effect was observed in eelgrass specifically treated with the herbicide, not treated through exposure to water as is considered the most realistic means of exposure in this context. The monoculture growth typical of *Spartina* reduces the potential for non-target plant exposure during herbicide application.

5.1 Relative Hazard and Risk Characterization of Imazapyr, Glyphosate, Surfactants, Inert Ingredients, And The Use of No Chemical Control Or Other Agents For Spartina Eradication

Glyphosate

The full suite of ecological hazards and risks associated with glyphosate use to control *Spartina* were thoroughly addressed in the original EIS (WSDA 1993). The conclusion of that document was that the use of the compound to control *Spartina* had limited risks associated with it to ecological receptors and therefore only those elements relevant to a comparison with imazapyr will be evaluated here. On the basis of the multitude of factors evaluated in this assessment it can be summarized that imazapyr presents a substantially improved relative risk scenario to aquatic animals over that of glyphosate. Reported LC_{50} values for glyphosate in rainbow trout range over two orders of magnitude, from low values of 2 to 50 mg/L (Folmar et al. 1979, Hildenbrand et al. 1982, Wan et al. 1989—*as cited in* Pan et al. 2002), to high values of > 1,000 mg/L (Geisy et al. 2000). As presented in this report, the most recent (unpublished) data from EPA standard (1991) 96-hour static renewal tests of glyphosate ($Rodeo_{tm}$) with rainbow trout conducted concurrently with a comparison to imazapyr yielded an LC_{50} of 782 mg/L for Rodeo (95% confidence interval of 719-845 mg/L), relative to the LC_{50} of the $Arsenal_{tm}$ herbicide formulation of 77,716 mg/L (22,305 mg imazapyr/L) (Grue, C., personal communication 2003). Because these latter tests were conducted with fish from the same origin and age, in the same laboratory, the relative toxicity comparison is perhaps the most relevant of all the previous testing conducted. Based on these results, the inherent aquatic toxicity of Rodeo may be approximately 28.5 to 99-fold more acutely toxic to fish than imazapyr—depending on whether the comparison is made to the active ingredient or the herbicide formulation, respectively. Using the more conservative toxicity estimates established by the other researchers previously referenced, this difference could increase up to two orders of magnitude more than that developed from the data of Smith et al. (2002) and Grue (pers comm). The wide variation in glyphosate's aquatic toxicity has been attributed to the dilution water, temperature, formulation, and the amount of suspended sediment in the water. Toxicity appears to increase with temperature, and decrease with elevated pH and suspended sediment (WSDA 1993E, Schuette 1998).

A similar comparison of the relative hazards to invertebrates between glyphosate and imazapyr cannot be provided because no tests have been conducted with invertebrates at high enough concentrations of imazapyr to elicit mortality (i.e., NOEL and LC_{50} values represented were the highest doses tested). However, the relationship between fish and aquatic invertebrate toxicity for a given chemical rarely differs by more than an order of magnitude (generally less than ½) so it is reasonable to expect a similar relationship to exist for the relative invertebrate hazards from glyphosate verses imazapyr.

Glyphosate is an organophosphate compound, but it does not inhibit acetylcholinesterase activity like organophosphate insecticides such as $Nuvan_{tm}$ or $Diazinon_{tm}$ because the herbicide is missing an ester in its chemical structure (Pan et al. 2002). It elicits its herbicidal activity by inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate synthase, which is needed by plants to synthesize chorismate—needed in turn for protein synthesis in plants. Although highly soluble like imazapyr (solubility = 11,600 mg/L at $25^{o}C$) with low potential for bioaccumulation, glyphosate—unlike imazapyr—is not degraded significantly in water by photodegradation (Schuette 1998). It appears to adsorb readily to sediment, with half-lives on the order of 1.5 to 11.2 days, and sediment appears to be the principal environmental sink for this widely used herbicide. By comparison with

imazapyr, glyphosate has a low organic carbon partition coefficient indicating it can be expected to be substantially less mobile than imazapyr. In an estuary setting, the physical chemistry of glyphosate such as its lack of photodegradation and ready adsorption to sediment, suggests that glyphosate will be more persistent than imazapyr. Recent results in *Spartina* treated meadows have demonstrated that the rhizome concentrations of glyphosate increased 231 to 591% over a three year period, while sediment concentrations adjacent to the plots declined 88 to 96% (Kilbride and Paveglio 2001). These recent results show that the residual biomass of *Spartina* could also serve as a residual compartment of glyphosate for eventual release to the intertidal environment.

Although significantly more toxic than imazapyr, the aquatic toxicity hazard rating of the herbicide would still qualify as **practically non-toxic** to **slightly toxic** based on EPA toxicity criteria (Table 3-12) and the species tested. (The terrestrial wildlife toxicity rates similar to imazapyr--practically non-toxic). However, at issue in the relative risk comparison is not simply the inherent aquatic toxicity of the compound, but also the estimated application rates relative to imazapyr. According to recent results by Patten and Stenvall (2002), effective control with glyphosate was obtained only with minimum application rates of 18 kg ae/ha, 10.7-fold greater than the 1.68 kg ae/ha needed for control with imazapyr. Thus, based on active ingredient concentrations required for herbicide efficacy and inherent toxicity, the use of glyphosate reduces the margin of safety relative to potential environmental exposure concentrations by up to three orders of magnitude—irrespective of the other associated risks from the surfactants required for application.

Surfactants

The inherent risks of using either herbicide (i.e., imazapyr or glyphosate) rises significantly when mixed with surfactants, thus the choice of which surfactant is used is not trivial. In addition spray volumes required differ by herbicide. Glyphosate applications require 80 to 100 gal/acre for efficacy, in comparison to the 5 to 20 gal/acre that can be used for imazapyr to yield equivalent results. As specified on the product label, glyphosate (as Rodeo$_{tm}$) requires the use of a non-ionic surfactant for application. These would include surfactants such as R-11 and LI-700, which, as previously discussed, are one to two orders of magnitude more toxic to rainbow trout than surfactants such as Hasten or Agridex that can be used with imazapyr (*see* Table 3-16). Figure 5-1 depicts the range of potential hazard quotients of four surfactants used with either imazapyr or glyphosate under the range of application rates commonly used. This modeling, conducted at an assumed water depth of 0.1 m (10 cm or approximately 4 inches) shows how at least one surfactant used, R-11, has potential to exceed a hazard quotient of 1.0, when equated to the 96-hr LC_{50} toxicity values developed by Smith et al. (2003) for juvenile rainbow trout. The potential exceedance in the sea-surface microlayer on the incoming tide would yield even higher hazard quotients, if only for a short period until dilution was achieved. However, as demonstrated in Figure 5-1, the crop-oil surfactants Agri-Dex and Hasten provide a substantial margin of safety relative to their application rates to ensure that neither would pose a toxic risk during application, even at high application rates above those required for adequate *Spartina* control with imazapyr.

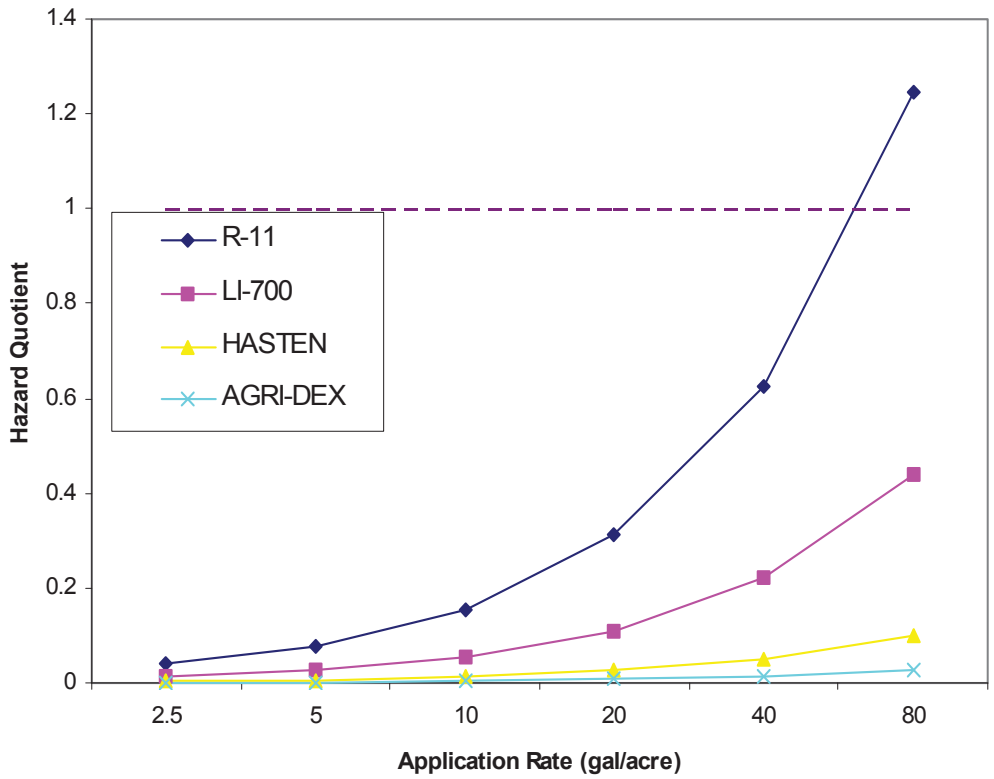

Figure 5-1: Hazard quotient (HQ) estimation based on rainbow trout LC50 values of these surfactants as developed by Smith et al. (2003), where HQ = estimated water concentration/LC50.

5.2 Uncertainties and Data Gaps

Every ecological risk assessment has inherent uncertainties that can only be addressed from additional studies. The fundamental question in addressing the significance of the uncertainty in any risk assessment is the degree to which it could qualify the risk conclusions. That is, in this report we reviewed the most recent data developed on the toxicity, fate, and degradation of imazapyr. These results indicated that imazapyr has insignificant toxicity to aquatic and terrestrial wildlife, is not environmentally persistent, and does not bioconcentrate or bioaccumulate. While the risks to ecological receptors appear extremely low, several data gaps exist. The following bullets summarize some of the main data gaps that, if resolved,would eliminate elements of the uncertainty in this assessment. Uncertainties associated specifically with the manner of preparation and conclusions of this risk assessment are summarized in Table 5-4.

- Studies pertaining to the effect of imazapyr on aquatic or water-dependent species other than fish are limited. No studies examining the toxicity of imazapyr to amphibians and reptiles were discovered in our literature review. No studies on the toxicity of imazapyr to marine fish typical of those areas where invasive *Spartina* is distributed in Washington State have been conducted.
- Specific data on the toxicity of imazapyr to sediment-associated organisms typical of north-temperate marine environments is generally lacking and represents a significant data gap.
- Residues of imazapyr in treated *Spartina*, and the degradation of the herbicide over time in plant tissue were not identified in the literature. Exposure calculations in this assessment

therefore relied on estimated concentrations in the plant tissue. Empirical residues from plants would increase confidence in the exposure and risk estimates.

- Effects on the micorhizosphere and microflora in a treated estuary have not been explored. This subject area has not been investigated thoroughly for any herbicide used in an estuary setting to our knowledge. Long term implications of herbicide use on nutrient dynamics could effect microflora.
- Effects on non-target salt-marsh plants native to areas *Spartina* has colonized are poorly understood. Limited data on only a few species have been reported.
- Persistence and stability of imazapyr in dead and decaying *Spartina* is not known. Can leachate from decaying vegetation retain herbicidal activity thereby potentially delaying the recovery of native salt marsh plants?
- Drift concentrations of imazapyr off-site by treatment method (e.g., backpack, boom sprayer, etc.,) have not been quantified. However, worst-case scenario exposure conditions in direct application sites did not indicate significant risk.
- Effects on marine phytoplankton: could herbicide treatments effect nutrient transfer to higher trophic levels if phytoplankton are inhibited?
- Effects on sea-surface microlayer associated organisms and microflora in this surface water film are not known.

While the above data gaps represent uncertainty, the existing information on the toxicity and fate of the compound is substantial and suggests that significant negative impacts would be unlikely in studies to address the above data gaps—with the possible exceptions of effects on other non-target plants and phytoplankton.

Table 5-4: Uncertainties associated with ecological risk modeling for imazapyr.

Parameter	Source and Results
Missing Information (data gaps)	Information gaps where sources or stressors are not identified or important aspects of the ecology are not known can affect risk conclusions. Although it is believed that the important potential sources of adverse effects have been addressed, it is possible that there were unmeasured or unconsidered chemical constituents in the bay that are contributing an unevaluated degree of risk to receptors in target areas.
Conceptual Model	If relationships between sources and receptors are missing or incorrectly identified, risks could be under- or overestimated. To reduce this uncertainty, a conceptual model was developed that identified all known pathways (both complete and incomplete) and receptor trophic levels. The overall impact of this source of uncertainty on risk conclusions is unknown.
Use of Uncertainty (Safety) Factors for Calculating TRVs	Uncertainty (safety) factors used to derive TRVs may not accurately reflect site conditions. However, the UFs applied were considered realistic based on data from various published studies. Since published TRVs were not available for all ROIs, UFs were applied. Risk estimates could be under- or over-estimated using this approach, as the UFs applied were considered reasonable.
Laboratory verses Field Populations	Species used in laboratory toxicity tests are not necessarily subjected to the same degree of non-chemical related stresses as receptors in natural conditions. As such, cumulative effects of multiple stressors (including chemicals) are not necessarily the same. It is difficult to predict the effect on ERA results since laboratory versus natural conditions may stress species differently. Due to likely differences in the health of laboratory populations and those inhabiting target areas, differences in genetic diversity (hence resistance to stressors), and possible impacts of non-chemical stressors, some unavoidable uncertainty exists when extrapolating laboratory derived data to field situations.
Use of Representative or Surrogate Species	Toxicological studies used species that are related to taxa present in the target areas, but are not identical. In general, the greater the taxonomic difference, the greater the uncertainty in application of laboratory toxicity data to receptors. It is not known whether laboratory test species or receptors in target areas are the most sensitive to a given chemical constituent.
Feeding Rates	Feeding rates were assumed not to vary with season, breeding condition, or with other local factors. Reported feeding rates undoubtedly vary with all of these factors because metabolic needs change as does food availability. Where possible, estimates of average feeding rates were derived from studies that reported for multiple seasons and areas to compensate for this potential uncertainty. As such, while uncertainty is introduced, the effect on ERA conclusions (if any) is not quantifiable.

5.3 Conclusions and Recommendations

With current technologies, non-native *Spartina* eradication cannot be realized in Washington State without some element of chemical control factored into the WSDA integrated pest management program. Current mechanical and biological control methods have not been wholly effective, and the distribution of *Spartina* is spreading at a rate of approximately 20 percent per year in some locations. As *Spartina* spreads, critical habitat for shorebirds, juvenile fish and shellfish is lost. These impacts directly or indirectly impact threatened species such as chinook salmon, and commerical enterprises such as shellfish culture. The use of Rodeo$_{tm}$ (glyphosate) is the only currently approved herbicide for *Spartina* treatments, but its efficacy is hindered by minimum dry-time limits that are not possible under all estuary conditions where *Spartina* is considered a noxious weed. Additional contol means are under investigation, and the use of imazapyr has been explored in this report as another possible chemical control means.

We examined the potential ecological risks from the use of imazapyr in an estuary setting to control and eventually eradicate non-native *Spartina* in Washington State. Realistic imazapyr exposure scenarios in the estuary settings envisioned for *Spartina* control did not yield aquatic concentrations or terrestrial doses that would pose significant risks to aquatic or terrestrial wildlife, even under the improbable "upper limit" conditions modeled. Only for spill scenarios where it was assumed that avian and mammalian wildlife could ingest undiluted spray solution was there the potential for significant risk identified, but wildlife behavioral mechanisms make this risk scenario largely untenable.

Both imazapyr and glyphosate can be effective at *Spartina* control and both are essentially safe for terrestrial and aquatic animals if used in accordance with manufacturers recommendations with adequate dry-time. However, the use of imazapyr improves the margin of safety relative to potentially toxic environmental concentrations by three to four orders of magnitude over the existing use of glyphosate—depending on which species is considered in the risk assessment. This improvement is due to the lower toxicity of imazapyr, lower active ingredient concentration needed for *Spartina* control, lower spray volumes of the herbicide/surfactant solution required for effective treatment, and the ability to use crop-oil based surfactants which are themselves one to two orders of magnitude less toxic than the non-ionic surfactants required for glyphosate use.

Imazapyr is highly mobile, persistent in soils, and is a broad-spectrum herbicide. Although risks to animals from imazapyr use are insignificant, its use can cause significant impacts to non-target vegetation if inappropriately applied. These risks are particularly acute for vascular plants (like *Spartina*), although risks to algae appear to be significantly less. In sediment, imazapyr is significantly less persistent than in soils, but it can still be expected to be detectable for several weeks after treatment. It should therefore be applied only to target species, avoiding drift or seepage to non-target species and sediment through observation of weather patterns such as high rains or wind. Imazapyr should be used primarily in areas where total vegetation control or eradication is desired, or in isolated spot applications due to reports of its potential to "leak" out of target plant roots into soil that contains non-target plants. Hand spray applications should be used on *Spartina* clones and on the periphery of *Spartina* meadows to minimize spraying of non-target plants and poor canopy interception. Broadcast system spraying can be conducted in the central portions of *Spartina* meadows with minimal risk of drift and maximum efficacy for *Spartina* control.

Photodegradation of imazapyr in water is extremely rapid. In the tidal exhange conditions where *Spartina* is found, dilution is also extremely rapid due to the frequency of tidal exchange. For example, in Willapa Bay, the primary area where *Spartina spp.* is distributed and poses the greatest threat to habitat, there are generally two high and two low tides within a 24-hour period. The average difference between the high and low tide in Willapa ranges from 8.1 to 10.2 feet, with an average tidal prism of 4.8×10^8 cubic yards (cy) and an average tidal flow discharge of 25,000 cy/second. Potentially toxic concentrations to aquatic animals will not occur under the range of application rates considered in this risk assessment and the dilution profiles presented in the estuary settings where *Spartina* occurs. The time of exposure is also reduced because of tidal exchange rates inherent to Washington's coastal environments. The overall weight of evidence from this analysis suggests that imazapyr can be a safe, highly effective treatment for *Spartina* control and eradication in an estuary setting, and offers a significantly improved risk scenario over existing treatment regimes.

6.0 REFERENCES

Anonymous. 2003. Animal weights and their food and water requirements. http://wlapwww.gov.bc.ca/wat/wq/reference/foodandwater.html. Visited 7/10/03.

Ali-Sabti, K and C.D. Metcalfe. 1995. Fish micronuclei for assessing genotoxicity in water. Mutat. Res. 343. 121-135.

Army Corps of Engineers (ACOE). 2003. Imazapyr: Plant species effectively controlled by imazapyr. Website: http://www.wes.army.mil/el/aqua/apis/herbicides/html/imazap10.html Visited 2/18/03.

Bonneville Power Administration (BPA). 2000. Imazapyr: Herbicide Fact Sheet. US Department of Energy. March 2000.

Cohen, A.N., HD. Berry, C.E. Mills, D. Milne, K. Britton-Simmons, M.J. Wonham, D.L. Secord, J.A. Barkas, B. Bingham, B.E. Bookheim, J.E. Byers, J.W. Chapman, J.R. Cordell, B. Dumbauld, A. Fukuyama, L.H. Harris, A.J. Kohn, K. Li, T.F. Mumford Jr., V. Radashvsky, A.T. Sewell, K. Welch. 2001. Washington State Exotics Expedition 2000: A Rapid Survey of Exotic Species in the Shallow Waters of Elliot Bay, Totten and Eld Inlets, and Willapa Bay. The Nearshore Habitat Program, Washington State Department of Natural Resources. October 2001.

Cohen, J.B., J.S. Barclay, A.R. Major, and J.P. Fisher. 2000. Greater scaup as bioindicators of metal contamination at national wildlife refuges in the Long Island Sound region. Archives of Environmental Contamination and Toxicology 38: 83-92.

Cox, C. 1996. Imazapyr: Herbicide Factsheet. J.of Pest.Ref. 16(3): 16-20.

Cyanamid Ltd. 1997. Summary of Toxicity Studies on Imazapyr. Technical Department, Cyanamid (Japan) Ltd. August 20, 1997.

Denny, J.W. 1991. DuPont Agricultural Products. Personal Communication.

Dinnel, P.A., R.O. McMillan, D.A. Armstrong, T.C. Wainwright, A.J. Whiley, R. Burge, and R. Bumgarner. 1986. Padilla Bay Dungeness Crab, Cancer Magister, Habitat Survey.

Extension Toxicology Network (EXTOXNET). 1996. Imazapyr: Pesticide Information Profiles. Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, and the University of California Davis and the Institute for Environmental Toxicology, Michigan State University. Major support and funding provided by the USDA/Extension Service/National Agricultural Pesticide Impact Assessment Program. Revised June 1996. Website: http://ace.ace.orst.edu/info/EXTOXNET/pips/imazapyr.htm Visited 1/31/03.

Federal Register. 1997. Availability of Draft Environmental Assessment (EA) Regarding Spartina Control Cost-Share Program for Willapa Bay Estuary. Federal Register: March 21, 1997. Volume 62, Number 55. Page 13589. From the Federal Register Online via GPO Access (wais.access.gpo.gov).

Feist, B.E. 1999. A spatio-temporal analysis of the environmental and climatic factors controlling the expansion of *Spartina* alterniflora in Willapa Bay, Washington. Doctor of Philosophy dissertation. University of Washington. School of Fisheries.

Fletcher, J.S., J.E. Nellessen, T.G. Pfleeger. 1984. Environmental Toxicology and Chemistry 13:1383-1391.

Folmar, L.C., H.O. Sanders and A.M. Julin. 1979. Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates. Arch. Environ. Contam. Toxicol. 8:269-278.

Frid, C.L.J., W.U. Chandrasekara and P. Davey. 1999. The restoration of mud flats invaded by common cord-grass (*Spartina anglica*, CE Hubbard) using mechanical disturbance and its effects on the macrobenthic fauna. Aquatic Cons: Mar. Freshw. Ecosyst. 9: 47-61.

Futch, S.H. and M. Singh. 1999. Herbicide Mobility Using Soil Leaching Columns. Bull. Environ. Contam. Toxicol. 62: 520-529.

Gagne, J.A. et al. 1991. Toxicology of the imidazolinone herbicides. In Shaner, D.L. and L.S. O'Connor (eds.). The imidazolinone herbicides. Boca Raton, FL: CRC Press. Pp. 179-182.

Geisy, J., S. Dobson, K. Solomon. 2000. Ecotoxicological risk assessment for roundup herbicide. Rev. Environ. Contam. Toxicol 167:37-120

Gomez de Barreda, D., E. Lorenzo, M. Gamon, A. Walker, C. Ramos, A. Saez, E.A. Carbonell, J. Garcia de la Cuadra, N. Munoz, A. del Busto, and A.L. Lidon. 1996. Persistence and Leaching of Some Residual Herbicides in Uncropped Soils. Bull. Environ. Contam. Toxicol. 56: 219-224.

Gray, AJ, AF Raybould and SL Brown. 1997. The environmental impact of *Spartina anglica*: past, present and predicted. Proc. 2nd Int. Spartina Conf. pp. 39-44.

Grevstad, F.S., D.R. Strong, D. Garcia-Rossi, R.W. Switzer, and M.S. Wecker. 2003. Biological control of *Spartina alterniflora* in Willapa Bay, Washington using the planthopper *Prokelisia marginata*: agent specificity and early results.

Gringas, M.K., S.M. Hubbard, S.G. Pemberton, and T. Saunders. 2000. The Significance of Pleistocene Psilonichnus at Willapa Bay, Washington.

Grisolia, C.K. 2002. A comparison between mouse and fish micronucleus test using cyclophosphamide, mitomycin C and various pesticides. Mutation Research. 518: 145-150.

Grollier Interactive, Inc. 1997. Shellfish and Fin-Fish of Willapa Bay and Some Things about the Chinook Indians. Website: Visited: 3/7/03.

Grosholz, E. 2002. Ecological and evolutionary consequences of coastal invasions. Trends Ecol. & Evol. 17: 22-27.

Hanlon, C.G. and K. Langeland. 2000. Comparison of experimental strategies to control torpedograss. J. Aquat. Plant Manage. 38: 40-47.

Hartley, D. and H. Kidd (ed.). 1987. *The Agrochemicals Handbook*, 2nd ed. Royal Society of Chemistry, Unwin Brothers Ltd. Old Woking, Surrey.

Hildenbrand, L.D., D.S. Sullivan, and T.P. Sullivan. 1982. Experimental studies of rainbow trout populations exposed to field applications of roundup herbicide. Arch. Environ. Contam. Toxicol. 11:93-98.

Hinkle, S. 1979. Avian Dietary Toxicity (LC_{50}) in Bobwhite Quail and Mallard Ducks. H-12361. HLO-0706-79 and HLO-0565-79.

Hoerger, F. and E.E. Kenaga. 1972. *In*: Environmental Quality and Safety: Chemistry, Toxicology and Technology. F. Coulston and F. Kort (Eds.) pp. 9-28. Georg Theime, Stuttgart, West Germany (1972)

Hubert, M. 1968. Pesticide Manual. British Crop Protection Council. Clacks Farm. Boreley, Ombersley, Droitwich, Worcester, U.K.

Hung, H. and D. Mackay. 1997. A novel and simple model of the uptake of organic chemicals by vegetation from air and soil. Chemosphere. 35(5): 959-977.

Indelman, P., I. Touber-Yasur, B. Yaron, and G. Dagan. 1998. Stochastic analysis of water flow and pesticides transport in a field experiment. Journal of Contaminant Hydrology. 32: 77-97.

Jordan, L. S. and Cudney, D. W. 1987. Herbicides. *In* Fate of Pesticides in the Environment, Biggar, J. W., and Seiber, J. N., Eds. Agricultural Experiment Station, Division of Agriculture and Natural Resources, University of California, CA. 9-3

Kay, S.H. 1995. Efficacy of wipe-on applications of glyphosate and imazapyr on common reed in aquatic sites. J. Aquat. Plant Manage. 33: 25-26.

Kidd, H. and D.R. James, eds. 1991. *The Agrochemicals Handbook, Third Edition*. Royal Society of Chemistry Information Services, Cambridge, UK, 1991 (as updated). 10-2.

Kilbride, K.M. and F.L. Paveglio. 2001. Long term fate of glypohosate associated with repeated Rodeo applications to control smooth cordgrass (*Spartina alterniflora*) in Willapa Bay, Washington. Arch. Environ. Contam. Toxicol. 40:179-183.

Kintner, D., and A. Forbis. 1983. Acute toxicity of AC 243,997 to *Daphnia magna*:static bioassay report #30098 (as cited in SERA 1999, this report).

Kriwoken, L.K. and P. Hedge. 2000. Exotic species and estuaries: managing *Spartina anglica* in Tasmania, Australia. Ocean & Coastal Management 43:573-584.

Lee, A., P.E. Gatterdam, T.Y. Chiu, N.M. Mallipudi, and R. Fiala. 1991. Plant metabolism. Chapter 11 in The Imidazolinone Herbicides, D.L. Shaner and S.L. O'Connor, eds. CRC Press. Boca Raton, FL. 290 pgs.

Levin, J.M. 2000. Species diversity and biological invasions: relating local process to community pattern. Science 288:852-854.

Li, Q.X., E.C. Hwang, and F. Guo. 2001. Occurrence of herbicides and their degradates in Hawaii's groundwater. Bull. Environ. Contam. Toxicol. 66: 653-659.

Linders, J., J. Mensink, G. Stephenson, D. Wauchope, and K. Racke. 2000. Foliar interception and retention values after pesticide application. A proposal for standardized values for environmental risk assessment. Pure Appl. Chem. 72:2199-2218.

Mangels, G.A. and A. Ritter. 2000. Estimated environmental concentration of imazapyr resulting from aquatic uses of Arsenal herbicide. Pesticide Registration Report # EXA 00-008, American Cyanamid Co.; Report Archived at Waterborne Environmental Inc., Leesburg, VA

Manning, C. 1989. Chronic toxicity estimate of AC 243,997 to the water flea (Daphnia magna in a 21-day flow-through exposure (as cited in SERA 1999).

Mayer, J.R. 1989. Potential Impact of Agricultural Pesticide Runoff in *Zostera marina* and *Zostera japonica* (eelgrass communities) in Padilla Bay, Washington.

Mayer FL, Ellersieck MR. 1986. Manual of acute toxicity: Interpretation and database for 410 chemicals and 66 species of freshwater animals: Resource Publication 160. U.S. Fish and Wildlife Service, Washington, DC.

McDowell, R.W., F. Dastgheib, and L.M. Condron. 1996. Persistence of Acetolactate Synthase Inhibiting Herbicides in a Canterbury Soil. NZPPA paper. Department of Soil Science and Department of Plant Science, Lincoln University, Canterbury. Website: http://www.hornet.co.nz/publications/nzpps/proceedings/96/96_198.htm Visited: 2/18/03.

Merck. 1989. The Merck Index, 11th edition. Merck Inc. CRC Press.

Miles, C.J. and R.J. Pfeuffer. 1997. Pesticides in canals of south Florida. Archives of Environ. Contamination and Toxicology. 32: 337-345.

Mitchell, D.G., P.M. Chapman, and T.J. Long. 1987. Acute toxicity of Roundup and Rodea herbicides to rainbow trout, chinook, and coho salmon. Bulletin of Environmental Contamination and Toxicology. 39: 1028-1035.

Monsanto Company (Monsanto). 2001. Roundup. Original Herbicide Material Safety Data Sheet (MSDS). Monsanto Company, St. Louis, Missouri.

Newton, M. et al. 1984. Fate of Glyphosate in an Oregon forest ecosystem. 32: 1144-1151.

Northwest Coalition for Alternatives to Pesticides (NCAP). 2003. Arsenal Herbicide Applicators Concentrates EPA Registration No. 241-299. Website: http://www.pesticide.org/FOIA/imazapyr.html Visited: 2/18/03.

Pacific Northwest Coastal Ecosystems Regional Study (PNCERS). 1998. Meeting Summary: Protecting and Restoring Pacific Northwest Estuaries: The Task Before Us. Conducted December 8-9, 1998. Troutdale, Oregon.

Pacific Northwest Coastal Ecosystems Regional Study (PNCERS). 1999. Meeting Summary: Protecting and Restoring Pacific Northwest Estuaries: Human Activities and Valued Ecosystem Components. Conducted December 8-9, 1999. Vancouver, Washington.

Padilla Bay National Estuarine Research Reserve (NERR). 2002. About Padilla Bay. Website: http://www.padillabay.gov/aboutbay Visited: 3/7/03. Updated: November, 2002.

Pan, Y., E. Foster, A. Vaivoda. 2002. Effects of bromacil, diuron, glyphosate, and sulfometuron on periphyton assemblages and rainbow trout. *Prepared for:* Oregon Department of Transportation. *Prepared by:* Oregon Department of Environmental Quality.

Patten, K. and C. Stenvall. 2002. Managing *Spartina* with glyphosate and imazapyr. Proc. 11th Int. Conf. On Aquatic Invasive Species.

Patten, K. 2002. Smooth cordgrass (*Spartina alterniflora*) control with imazapyr. Weed Technology 16:826-832.

Patten, K. 2003. Persistence and non-target impact of imazapyr associated with smooth cordgrass control in an estuary. J. Aquat. Plant Manage. 41:1-6.

Pesticide Dictionary. 1976. Published by Farm Chemicals, Meister Publishing Company, Willoughby, Ohio.

PMEP. 1985. Imazapyr (Arsenal) Herbicide Profile, Chemical Fact Sheet. Cornell University. September 5, 1985. Website: http://pmep.cce.cornell.edu/profiles/herb-growthreg/fatty-alcohol-monuron/imazapyr/herb-prof-arsenal.html Visited: 2/18/03.

Rashin, E. and C. Grabler. 1993. Effectiveness of best management practices for aerial application of forest pesticides. Olympia, WA: Washington Department of Ecology. Environmental Investigations and Laboratory Services Program. Watershed Assessments Section (October).

Reno, F.E. 1979. Acute Oral LD_{50} in Bobwhite Quail and Mallard Ducks, H-11, 627. Project Number 201-515 and 201-517.

Retnakaran, A. and Wright, J.E., Eds. 1987. Control of Insect Pests with Benzoylphenyl Urea. *In* Chitin and Benzoylphenyl Ureas (Series Entomologica Volume 38), Wright, J.E. and Retnakaran, A. Eds. Kluwer Academic Publishers Group, Dordrecht, Netherlands. 9-2

Sanders, H.O. and O.B. Cope. 1966. Toxicities of several pesticides to two species of cladocerans. Trans. Amer. Fish. Soc. 95 (2):165-169.

Sappington, L.C., F.L. Mayer, F.J. Dwyer, D.R. Buckler, J.R. Jones and M.R. Elllersieck. 2000. Contaminant sensitivity of threatened and endangered fishes compared to standard surrogate species. Environ. Tox. and Chem. 20:2869-2876.

Sathasivan, K., G.W. Haughn, and N. Murai. 1991. Molecular basis of imidazolinone herbicide resistance in Arabidopsis thaliana var. Columbia. Plant Physiol. 97: 1044-1050.

Schuette, J. 1998. Environmental fate of glyphosate. Env. Monitoring & pest management department of pesticide regulation, Sacramento, CA 95824-5624.

Shaw, W.B. and D. S. Gosling. 1997. Spartina ecology, control and eradication—recent New Zealand experience. Proc. 2nd Int. Spartina Conf. 32-38.

Smith, B. C., CA Curran, KW Brown, JL Cabarrus, JB Gown, JK McIntyre, EE Moreland, VL Wong, JM Grassley and CE Grue. 2003. Toxicity of four surfactants to juvenile rainbow trout: implications for over-water use. Bull. Environ. Contam. Toxicol. (accepted).

Stebbins, R.C. 1985. *Western Reptiles and Amphibians*: Roger Tory Peterson Field Guide. Easton Press, Norwalk, CT.

StreamNet. 2003. Internet information on fisheries resources in the Pacific Northwest: Willapa and Padilla Bay tributaries. Website: http://.streamnet.org Visited: 3/7/03.

Syracuse Environmental Research (SERA). 1999. Imazapyr (Arsenal, Chopper and Stalker Formulations Final Report). Prepared for USDA Forest Service. Riverdale, MD.

The Nature Conservancy (TNC). 1998. Foulweather Bluff: Nature Conservancy Preserve. Marine Protected Areas in Puget Sound, Volume 2: MPA Site Profiles and Appendices. March 1998.

Thom, R.M. 1988. Benthic Primary Production in the Eelgrass Meadow at the Padilla Bay National Estuarine Research Reserve, Washington. All About Estuaries: A Set of Readings to Prepare for a Field Trip to Padilla Bay. .

Thompson, J.D. 1991. The biology of an invasive plant. Bioscience 41: 393-401.

Tu, M., C. Hurd, and J.M. Randall. 2001b. *Weed Control Methods Handbook: Imazapyr*. The Nature Conservancy. Section 7H. April 2001. Website: http://tncweeds.ucdavis.edu/handbook.html Visited: 2/18/03.

Tu, M., C. Hurd, and J.M. Randall. 2001c. *Weed Control Methods Handbook: Glyphosate*. The Nature Conservancy. Section 7E. April 2001. Website: http://tncweeds.ucdavis.edu/handbook.html Visited: 2/3/03.

RIVM, VROM, VWS. 1998. Uniform System for the Evaluation of Substances 2.0 (USES 2.0). National Institute of Publich Health and the Environment (RIVM), Ministry of Housing, Spatial Planning and the Environment (VROM), Ministry of Health, Welfare and Sport (VWS), the Netherlands. RIVM report no. 679102044.

U.S. Department of Agriculture (USDA). 1989. Final Environmental Impact Statement: Vegetation Management in the Coastal Plain/Peidmont. Volume II. Appendices. Management Bulletin R8-MB-23. U.S. Department of Agriculture, Forest Service Southern Region, Atlanta, Georgia.

US Department of Agriculture (USDA). 1995. Imazapyr: Pesticide Fact Sheet. Prepared by Ventures, Inc. November 1995. Website: http://infoventures.com/e-hlth/pestcide/imazapyr.html Visited: 2/18/03.

US Department of Health and Human Services (USDHHS). 1980. Registry of Toxic Effects of Chemical Substances.

US Environmental Protection Agency (EPA). 1991. Guidance on FIFRA 24(c) Registrations, as posted at www.epa.gov/opprd001/24c/

US Environmental Protection Agency (EPA). 1993. National Center for Environmental Assessment--Wildlife Exposure Factors Handbook. EPA/600/R-93/187a. Office of Research and Development, Washington, DC. Website: http://cfpub.epa.gov/ncea/cfm/wefh.cfm?ActType=default

US Environmental Protection Agency. 1995. Use of surrogate species in assessing contaminant risk to threatened and endangered fishes: EPA 600/R-96/029. Office of Research and Development, Environmental Research Laboratory, Gulf Breeze, FL.

US Environmental Protection Agency (EPA). 1995. Integrated Risk Information System Database, Washington, DC. 9-32. 1996.

US Environmental Protection Agency. 1997. Imazapyr, Pesticide Tolerances. Final Rule. Federal Register 62:68:17096-17100.

US Environmental Protection Agency. 1998. Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F. Office of Research and Development, Washington, DC.

US Fish and Wildlife Service. 1991. Wildlife of Willapa National Wildlife Refuge and the Columbia River Estuary, Ilwaco, Washington. Unpaginated.

US Forest Service (USFS). 1988. Managing Competing and Unwanted Vegetation. Pacific Northwest Region. Final Environmental Impact Statement.

US Forest Service (USFS). 1989. Vegetation Management in the Appalachian Mountains. Vol. I, Final Environmental Impact Study, July 1989.

US Geological Survey (USGS). 2003a. Bird checklist of the United States: Willapa National Wildlife Refuge and Columbia River Estuary. http://www.npwrc.usgs.gov/resource/othdata/chekbird/r1/willapa.htm.

US Geological Survey (USGS). 2003b. Reptiles and amphibian checklist of the United States: Willapa National Wildlife Refuge and Columbia River Estuary. http://www.npwrc.usgs.gov/resource/othdata/chekbird/r1/willrept.htm.

US Geological Survey (USGS). 2003c. Mammal checklist of the United States: Willapa National Wildlife Reguge and the Columbia River Estuary. http://www.npwrc.usgs.gov/resource/othdata/chekbird/r1/willmam.htm

Verschueren, K. 1983. *Handbook of Environmental Data on Organic Chemicals, Second Edition*. Van Nostrand Reinhold Company, Inc. New York, New York.

Vernier, P., S. Maron, and S. Canova. 1997. Detection of micronuclei in gill and haemocytes of mussels exposed to benzo[a]pyrene. Mutat. Res. 390: 33-44.

Wan, M.T., R.G. Watts, and D.J. Joul. 1989. Effects of different dilution water types on the acute toxicity to juvenile Pacific salmonids and rainbow trout of glyphosate and its formulated products. Bull. Environ. Contam. Tox. 43:378-385.

Washington State Department of Agriculture (WSDA). 2000. 2000 *Spartina* Management Plan for North Puget Sound. Prepared by WSDA in cooperation with the North Puget Sound *Spartina* Task Force.

Washington Department of Fish and Wildlife & Washington Department of Natural Resources (WDFW&WDNR). 2003. Bivalve Management Plan for Public Tidelands in Region 5: Admiralty Inlet. January 13, 2003. Website: http://www.pnptc.org/PNPTC_Web_data/Publications/Management_Plans/2003_Plans/Region_5_Bivalve_Finl.doc Visited: 3/10/03.

Washington Department of Agriculture (WSDA). 1993a. December 1993.

Willapa National Wildlife Refuge. 2001. *Spartina* Infestation. Website: Visited: 3/10/03.

Williams, R.W., R.M. Laramie, and J.J. Ames. 1975. A Catalog of Washington Streams and Salmon Utilization. Volume 1: Puget Sound Region. Washington Department of Fisheries. November 1975.

Yorgason-Quinn, D. 2001. Fair Weather at Foulweather Bluff. Tahoma Audubon Society: The Pierce County Chapter of the National Audubon Society. Tacoma, Washington. Website: Visited: 3/7/03.

Zipperer, V.T. 1996. Ecological Effects of the Introduced Cordgrass, *Spartina* alterniflora, on the Benthic Community Structure of Willapa Bay, Washington. Masters of Science Thesis. University of Washington.

Appendix A

No Action Alternative for *Spartina* Control

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1.0 INTRODUCTION

This appendix provides a description of the No Action Alternative (NAA) for smooth cordgrass (*Spartina spp.)* control as practiced by the Washington State Department of Agriculture (WSDA). The NAA is described as the program that is presently being employed to eradicate *Spartina* species. The Washington State *Spartina* control program is a cooperative effort between federal, state, local, tribal and private entities to eradicate this invasive weed. *Spartina* is rapidly colonizing critical mudflat habitat that is used extensively by native shellfish, cultured shellfish, salt marsh plants, migratory birds, juvenile fish and other wildlife (WSDA, 2002). The efficacy of current methods is not as high as desired to control the invasion of this exotic species and *Spartina* infestation along Washington State 's coastal areas is spreading rapidly. Current control measures have inherent costs and environmental risks associated with them which additional and/or alternative methods may alleviate, and thereby facilitate greater efficiency in *Spartina* control.

The focus of the NAA description is control of *Spartina* by herbicides and mechanical and physical methods. The Ecological Risk Assessment (ERA) presents information for a potential change in the existing integrated pest management plan (IPMP) for the purpose of providing more effective means of *Spartina* control. The focus of the ERA is to evaluate the risks of using a more effective control through changes in the chemical (herbicide) component of the existing program.

Glyphosate (i.e. Rodeo®) is currently the only chemical registered for aquatic use in the U.S. and its use has certain shortcomings. Glyphosate readily binds to sediment particles, which reduces the translocation (transfer) of chemical down to the roots. Daily inundation by tides cover plants with mud and dirt, reducing herbicide effectiveness. In addition, application must be timed with tidal fluctuations to allow glyphosate to dry in roughly 6 hours. Decreased drying time is directly related to decreased efficiency or success in eliminating the plant (IVM Technical Bulletin 2003). Hand spraying with Rodeo requires re-treatment, is poorly adapted to large meadows and the logistics of water transport are problematic. The efficacy of broadcast spraying of Rodeo has been questionable and the aerial spraying of Rodeo does not work well (Patten 2002). Physical control methods are labor intensive, expensive, and have small effective areas of control. Mechanical control is effective if used correctly but is limited by sediment type (soft mud) and by season. Changes that have been suggested to improve the present program include a cost-effective chemical control and/or a relatively inexpensive large-scale mechanical control (USFWS 1997). Patten (2002) suggests that a solution may be a chemical control that is applied in low volumes and small concentrations in salt water, that has a minimal non-target impact with no aquatic risk, is able to treat large areas with a minimal need for re-treatment and is non-persistent in the water. One chemical that may fit these criteria is imazapyr, available in the formulations Arsenal$_{tm}$ and Chopper$_{tm}$, amongst others. The ecological hazards and risks from the use of imazapyr are the primary subject of the Ecological Risk Assessment for which this NAA is appended.

The objective of this appendix is to present a description of the IPMP in controlling populations of *Spartina* spp. in Washington State including effectiveness and potential environmental impacts of the program. This following sections provide 1) a general background of the *Spartina* problem in Washington State, 2) a description of the present control program, 3) the potential environmental impacts of the control methods, and 4) the efficacy of these control methodologies.

2.0 OVERVIEW OF NO ACTION ALTERNATIVE

The goal of the NAA is to eradicate *Spartina* using conventional mechanical, physical, biological and chemical methods (glyphosate). The problem is that *Spartina* spreads quickly and is extremely difficult to eradicate. The purpose of the NAA program is to control the spread of *Spartina* using methods with minimal environmental impacts and greatest cost effectiveness.

Prior to the present eradication program, passive management was used to control *Spartina* spp. infestations. Natural processes involving environmental variables, plant genetics and biotic interactions were thought to regulate distribution and spread of *Spartina* spp. (WSDA 1993). Agencies were to monitor infestations of *Spartina* spp. and participate in public outreach activities under what can be described as a no control alternative. The no control program was characterized as not being successful in the eradicating or slowing the spread of *Spartina* infestations (USFWS 1997).

The 1995 Legislature designated Washington State Department of Agriculture (WSDA) as the lead agency to develop a Statewide *Spartina* Management Plan. Since that time, WSDA has since served as the lead state agency for the eradication of *Spartina*. To accomplish this, six area-wide *Spartina* management plans (one for each waterbody covered by a permit) were developed by WSDA for North Puget Sound, South Puget Sound, Hood Canal/Central Puget Sound, Grays Harbor and Willapa Bay (Figure A1). These programs were developed in conjunction with Washington Department of Fish and Wildlife (WDFW), Washington Department of Natural Resources (DNR), United States Fish and Wildlife Service (USFWS), Washington State Noxious Weed Control Board, tribal communities, and private landowners. These management plans detailed historical information on known infestations, past treatment efforts, and plans for future control seasons. WSDA consolidated information from the six area-wide management plans into a single draft document. The Statewide *Spartina* Management Plan is updated yearly as new control and survey data/techniques become available. Current methodologies in place to control *Spartina* in Washington State include digging, mowing, mowing in combination with herbicide, herbicide use only, seedling removal, and various mechanical control methods.

The NAA presently in operation is referred to as the Integrated Pest Management (IPMP) plan. The IPMP is based on the coordinated use of multiple preventative, biological, mechanical, physical, and chemical treatments methodologies to control and eradicate the *Spartina* infestation in Washington State.

2.1 IMPACTS OF *SPARTINA*

Spartina can alter ecological processes that govern wetland ecosystem function. Infestations can alter the physical aspect, structure, and spatial configuration of wetlands through dense growth and sediment accumulation. The four species now found in Washington State out compete and displace beneficial native vegetation and also threaten to severely impact economically important shellfish cultures. Shellfish are impacted by *Spartina* encroaching on the available area for oyster cultivation and reduction of oyster growth by decreasing the amount of nutrients reaching the oyster beds (WSDA 2002). This occurs as the plants trap sediment, which reduces the flow of water through river channels and changes the elevation of mudflats. Although the amount of sediment accumulation is variable from site to site, *Spartina*'s dense root and stems effectively trap sediment at higher rates than normal, altering water movement by filling shorelines and river deltas

and possibly causing flooding during periods of heavy rain. *Spartina* spp. destroy important migratory shorebird and waterfowl habitat by reducing their ability to move, rest and forage on open mudflats. *Spartina* also affects fisheries because fish utilize estuaries as nursing grounds or foraging sites. *Spartina* can also overtake intertidal sea grass beds that provide important habitat for juvenile fish (USFWS 1997).

2.2 DESCRIPTION OF NAA

Spartina poses challenges to implementing control methodologies and is particularly difficult to eradicate because it grows in soft mud and has an extensive root network. It also spreads rapidly in areas that are hard to traverse and apply treatment. These large infestations of *Spartina* are difficult to control with present methodologies and no individual method currently being used is able to effectively control *Spartina* infestations (USFWS 1997). Currently there are over 15,000 acres infested in Willapa Bay, over 4,000 acres in Snohomish County and minor infestations in eight other counties in western Washington (WSDA 2002).

The current control program involves active Integrated Pest Management IPM to combat infestations of *Spartina spp.* using mechanical, physical, biological, chemical and/or a combination of these methods. The IPMP was chosen as the current program control methodology because it is a comprehensive approach that combines a management process with the best components of the other methods (WSDA 2002). The current eradication program involves four steps:

1. Preventing an existing infestation from producing seed;
2. Treating an existing infestation for several consecutive years using IPM;
3. After successful eradication is achieved, monitoring the area and removing new seedlings to ensure no re-establishment occurs and; and
4. Continuing to survey shorelines, educate the public and follow-up on possible sightings of new infestations.

This is the most promising approach to regionally stabilize and decrease noxious weed distributions. The current program involves the deliberate selection, integration, and directed use of plant population suppression measures on the basis of predicted economic, environmental, and sociological consequences. When these measures are successfully applied, plant populations should be prevented from attaining economically and/or environmentally damaging densities (USFWS 1997).

3.0 DESCRIPTION OF NO ACTION ALTERNATIVE (NAA)

3.1 *SPARTINA* DESCRIPTION

Spartina is commonly known as cordgrass and is an invasive weed that inhabits mudflats, salt marshes and estuaries throughout Washington State's coastal areas. There are now four species of *Spartina* found in Washington's waters including *Spartina alterniflora, Spartina patens, Spartina anglica* and a newly discovered species found in the fall of 2001, which is *Spartina densiflora. Spartina spp.* are currently disrupting several native Pacific coastal ecosystems in western Washington.

Spartina is a successful invader because of its high rate of spread, its tall and dense canopy that can shade out other plants, and its ability to colonize low intertidal regions (Daehler and Strong 1994; WSDA 1993). The stems are stout and the rhizomes form an extensive root system that is roughly five times larger than its aboveground biomass. Once established, *Spartina* spreads vegetatively, forming ring-shaped clumps of individual clones. These clones are tall and conspicuous against open mudflats. New stems grow along the outer edge of the ring, gradually increasing its diameter with each growing season, while old, dying vegetation can be found in the middle. As clones spread, they grow into each other, forming a dense *Spartina* monoculture that overgrows native plants (Daehler and Strong 1994). Zipperer (1996) has documented the potential of exotic species to change the physical structure and alter the ecological functioning of regional ecosystems. *Spartina* follows this pattern well since it out competes and physically displaces native vegetation by converting littoral mudflats to salt marshes. This invasion could manifest into large-scale ecological changes that threaten to adversely impact fisheries, shellfish beds, waterfowl migrations and other wildlife dependant on native coastal marshes.

3.1.1 Origin and Geographic Area

Spartina alterniflora typifies an invasive species by having a wide tolerance to habitat requirements, fast dispersal rate, clonal reproduction (from a single plant spreading asexually) and few to no natural predators in its invaded range (Zipperer 1996). *Spartina alterniflora* was most likely introduced to the Washington coast when it was used in the packing of oysters from the East Coast for shipping during the late 1800s. *Spartina alterniflora* was also intentionally planted by a gun club between 1941 and 1946 to stabilize bank erosion on their property in Padilla Bay. *Spartina anglica* was also intentionally introduced to stabilize dikes and provide forge for cattle in Port Susan Bay (Fig. A-1). The pathways of introduction for both *Spartina patens* and the newly discovered *S. densiflora* are not currently known. *Spartina* species have spread throughout coastal Washington State and presently, ten counties in western Washington have one or more infestations of *Spartina alterniflora, Spartina anglica, Spartina patens* or *Spartina densiflora* (Figures A1 through A3). These include Clallam, Grays Harbor, Island, Jefferson, King, Kitsap, Pacific, San Juan, Skagit and Snohomish counties. *Spartina* infestations range from one colony in Clallam County measuring 50 feet in diameter to more than 7,800 solid acres spread throughout Willapa Bay in Pacific County (Figure A2). *Spartina* infests over 8,000 solid acres and has spread over more than 20,000 total acres in Washington State.

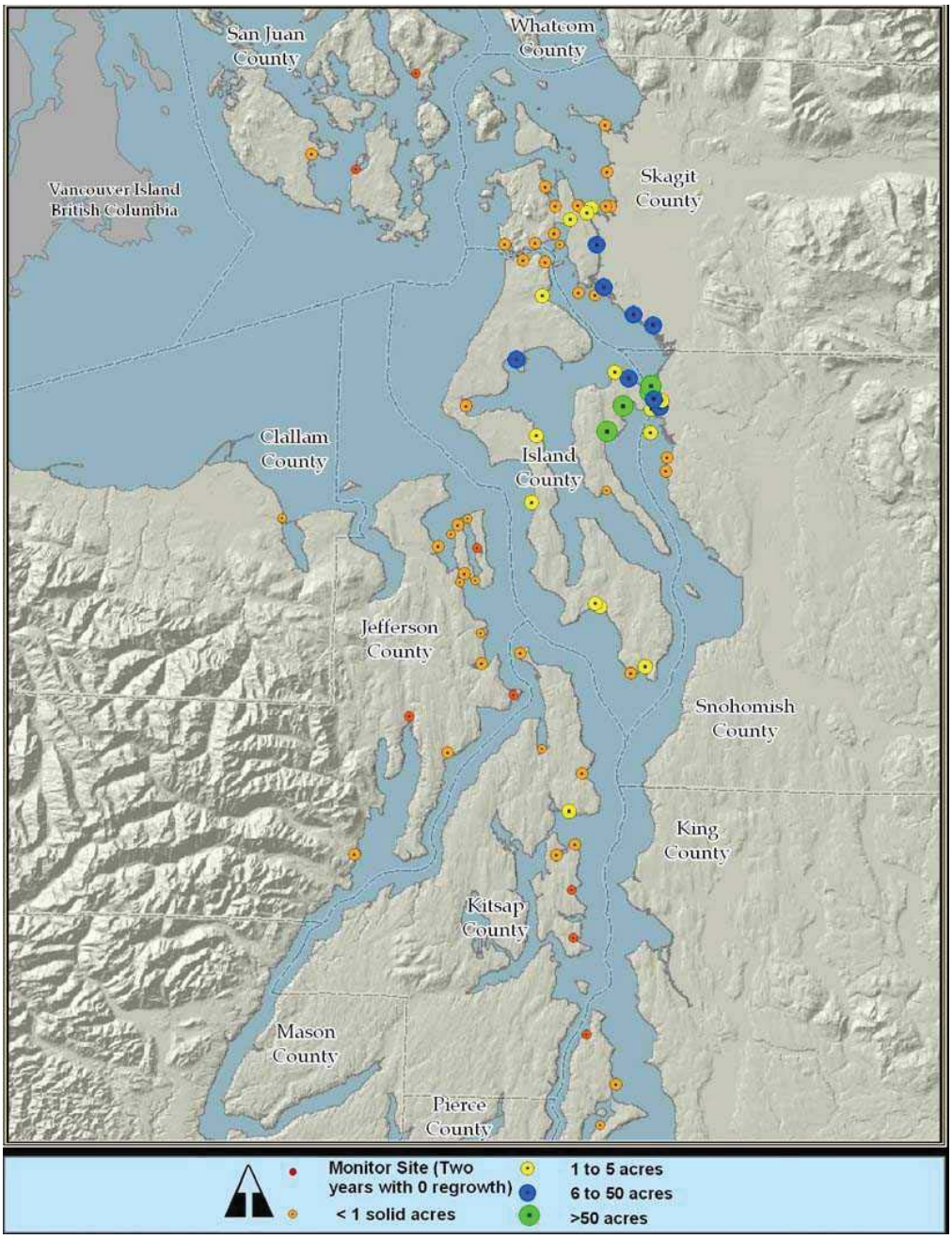

Figure A1. Locations of known *Spartina* spp. infestations in Puget Sound, Hood Canal and San Juan Islands (Source: WSDA 2002)

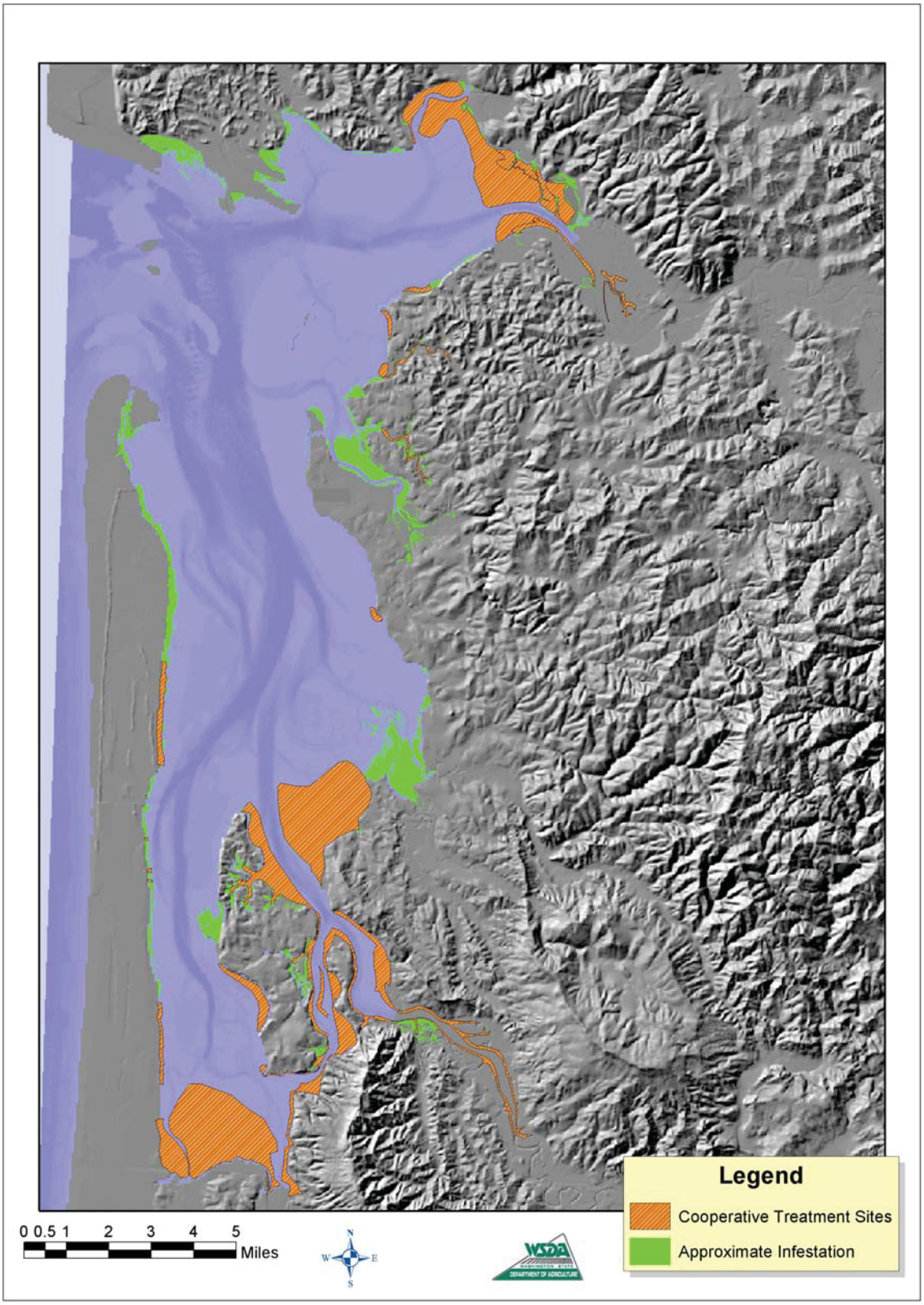

Figure A2. Locations of known *Spartina* spp. infestations and treatment sites in Willapa Bay (Source: WSDA 2003)

Figure A3. Locations of known *Spartina* SPP. infestations in Grays Harbor (Source: WSDA 2002)

4.0 DESCRIPTION OF CURRENT CONTROL METHODOLOGIES AND EFFECTIVENESS

Current control methods vary in effectiveness, depending on size of infestation, age of plants, topography, and proximity to agricultural, aquacultural, or built environments.

4.1 PHYSICAL REMOVAL

The Physical Removal Method primarily involves manual labor methods. Current physical control methods being used include the following:

- **Hand pulling, Digging**

  This method is effective for small patches and on young plants.

- **Covering**

  This involves layering (covering) *Spartina* infestations with geo-textile fabric mats that inhibit light penetration in order to stop photosynthesis. This method is only used for small patches of *Spartina*.

Most physical control methods are labor intensive and time consuming but manual removal can be effective for removing seedlings and very small infestations or to prevent seed production and spread (Table A1). Volunteer organizations and tribal agencies have conducted small-scale removal projects successfully.

Table A-1. Physical Control Methods
(source WSDA 1993)

Physical Control Method	Current Use	Most Practical Applications / Use in present program	Use Constraints
Hand pulling or digging	yes	Eradication of small, isolated clumps, seedlings, or sparse infestations / limited use	Labor-intensive; multiple treatments may be required; plants must be accessible by foot; pulling limited to seedlings small enough to pull
Covering	yes	Eradication of small colonies / limited use	Labor-intensive over a large area; wind or waves may dislodge covers; monitoring during treatment required; biodegradable materials are preferred; non-biodegradable materials will require removal after use; covers may be buried by sediment
Dewatering/ Draining	no	Eradication of medium-sized colonies, etc	Not practical for large areas or gradual slopes near sea level; difficulty in obtaining permits; efficacy unknown
Flooding/ inundating	no	Eradication of medium- sized colonies / etc.	Not practical; shoreline topography must be amenable; difficulty in obtaining permits
Burning/flaming	no	Eradication of medium- sized colonies	Treatment should be done prior to seed set, during dry weather, and when wind blows smoke away from inhabited areas; smoke might be toxic to workers; flaming is labor-intensive; difficulty in obtaining permits

4.2 MECHANICAL

This methodology involves the use of machinery to control *Spartina* from a large area. Machines include tools with power sources and range from hand-held brush cutters to amphibious track vehicles and barge-mounted dredges. State and federal agencies have aggressively pursued the

treatment of *Spartina* meadows using mechanical control. The goal of mechanically treating *Spartina* meadows is to reduce current seed production, kill *Spartina* plants, stress the remaining plants sufficiently to reduce seed production in subsequent years, and reduce the amount of herbicide used in future applications while increasing spray efficacy and reducing cost (USFWS 1997; WSDA 2002). This method is not selective and can damage desirable vegetation and disturb soil. This method is normally used only on even terrain with few obstacles. As with manual removal, control efforts are normally timed to pre-empt seed production. Mechanical control efforts are always followed by measures (mechanical or other) to kill shoots from resprouting plants and seedlings sprouting from the seedbank. Mechanical control methods evaluated in the EIS (WSDA 1993) include dredging, digging, plowing, rototilling, crushing, mowing, and harvesting (Table A-2). Current mechanical control methods being used include:

- **Mowing**

  Repeated mowing in late spring and summer can prevent seed production, delay colony expansion, weaken root vigor and reduce same season re-growth. Mowing can increase susceptibility to other control methods and can reduce the amount of herbicide needed to control *Spartina*.

- **Mechanical sub-soiling and Rototilling**

  Mechanical sub-soiling and rototilling involve the mechanical disruption of *Spartina,* its root system, and the supporting substrate by a ripping implement mounted to a amphibious tracked vehicle (WSDA 1993). This is effective on some upland weeds because it results in the desiccation of roots. Rototilling can increase susceptibility to other control methods and can reduce the amount of herbicide needed to control *Spartina*.

- **Crushing**

  This method destroys the aboveground portion, and can affect the below ground rootmass. Crushing is only used in solid meadows of *Spartina*. Treatment of *Spartina* clones would involve having to transit across open mudflat from one clone to another. Some of the potential environmental impacts may be minimized since this method is only used on meadows and not used on clones.

Table A-2. Mechanical Control Methods
(source WSDA 1993)

Mechanical Control Method	Current Use	Most Practical Applications	Use Constraints
Mowing	yes	Prevention or reduction of seed set; delay of expansion of small to large monotypic colonies	Multiple treatments required to kill plants; labor intensive if handheld equipment used; treatment before seed set
Digging	yes	Eradication of small monotypic colonies where sediment has accreted	Must be accessible from shore; might not be possible on soft sediments
Crushing	yes	Prevention or reduction of seed set; reduction of small to large monotypic colonies.	Multiple treatments required for eradication; crushing by foot should be limited to small clones, whereas mechanical crushers can be used for large clones; heavy machinery not appropriated for use in soft substrates; labor intensive if done by foot; treatment should be done early in the growing season if possible.
Rototilling	yes	Prevention or reduction of seed set; delay of expansion of small to large monotypic colonies	Effective during winter but extremely slow; expensive to operate machinery
Dredging	no	Eradication of large monotypic infestations where sediment accretion has destroyed navigable channels	Must be accessible from water
Harvesting	no	Prevention or reduction of seed set	Requires market for products; could only be done where colony spread would not be problematic; should be conducted to augment control efforts and not to maximize yield.

4.3 CHEMICAL

The Washington State Department of Agriculture (WSDA) has legislative responsibility over the control of noxious and invasive weeds in the State of Washington. Under this mandate, the agency is authorized to use herbicides selectively to control invasive weeds. Glyposate (Rodeo®) and 2,4-dichlorophenoxyacetic acid (2,4-D) were the two chemicals evaluated in the Environmental Impact Statement (EIS) (WSDA 1993). 2,4-D has not been used since it is not registered for use for *Spartina* control in marine environments in Washington State. Rodeo® has been registered for use in the marine environment. It is a non-selective herbicide that affects the growth processes in plants. Glyphosate (the active ingredient) tightly binds to soil particles, reducing its ability to contaminate groundwater while microorganisms break it down in water and sediment. Rodeo® is an effective and relatively non-toxic herbicide that is effective on a wide range of plant species but it must be used with a nonionic surfactant (R-11® Spreader Acitvator, X-77® Spreader, or LI-700®) to help cover the plant and reduce the surface tension of spray droplets (WSDA, 2002). Two different methodologies are used to apply the herbicide (Table A-3) as summarized below.

- **Herbicide (handheld ground application)**

  Ground application of glyphosate from a backpack unit, low pressure or high pressure unit, is effective for treating clones and meadows.

- **Herbicide (broadcast ground application)**

  Application by precision sprayer vehicle or airboat is timed to coincide with the maximum susceptibility of the plant to increase efficacy (i.e. application at low tide). Broadcast application is effective for treating clones and meadows.

- **Herbicide (aerial application) –**

  Aerial application by helicopter is timed to coincide with the maximum susceptibility of the plant to increase efficacy (i.e., application at low tide). Aerial application is effective at seed prevention, and in upper elevation *Spartina* meadows, can reduce plant density.

Table A-3. Chemical (Glyphosate) Control Methods
(source WSDA 1993)

Chemical Control	Most Practical Applications	Use Constraints
Aerial Spray	Eradication of large monotypic infestations where sediment accretion has destroyed navigable channels	Helicopter: quick for large area; spray ball can minimize drift and overspray. Boat, Truck, ATV Spraying: more control than helicopter; reduced possibility of drift overspray; more time and labor than helicopter.
Ground Application	Eradication of small monotypic colonies where sediment has accreted	Wicking: may require less herbicide for control; no possibility of overspray; may require several passes across plant; labor intensive. Back-pack Spray: almost twice as rapid application as wicking; easier than wicking; some drift or overspray could occur.

In several studies, glyphosate applications have had mixed effectiveness (efficacy ranged from 0 to 100 percent) in controlling *Spartina*. Short drying times cause the tides to wash glyphosate off the treated plants and thus limit its efficacy in controlling *Spartina*. A recent study in Willapa Bay found no significant reduction in *Spartina* stem density when applied by helicopter using a 5 percent solution. However, the same concentration of Rodeo® (5 percent Rodeo®, 95 percent water/surfactant) applied with a hand-held wand resulted in an 84 percent reduction in *Spartina* stem density (WSDA 2002). Killbride et al., (1995) also indicated that ground rather than aerial treatments obtained greater control. Ground treatments also increased herbicide contact by applying higher concentrations of chemical with a brush and by the cleaning action of wiping the chemical on the plant leaves. Wiping herbicide onto plants both cleans the dirt off plants and applies herbicide, but is labor intensive. Ground, compared to aerial applications decreases the amount of herbicide drift.

Applying the herbicide to plants before seeds are produced and when the weed is most susceptible is crucial to the effectiveness of the treatment. The herbicide must be applied during an outgoing tide for maximum drying time. Glyphosate is effective for clone and seedling control if using high rate and spray volume. It is also good for high meadows where drying time is greater than 12 hours but is problematic in intertidal meadows with short dry times (Patten 2002). Decreased drying time usually results in decreased efficiency (IVM Technical Bulletin 1987).

4.4 BIOLOGICAL

The Biological methods involve the use of biologically based controls, such as pathogens, insects, livestock, genetic engineering, and competitive plant species to manage infestations of noxious species (Table A-4). The purpose of biological control is not to eradicate weeds, but to reduce the

infestation and keep them at low, manageable levels. After their introduction, biocontrol agents can take 5 to 12 years to become established and increase to numbers large enough to cause damage. There is also a long time frame to complete testing and gain regulatory approvals. Once established, effective biological controls provide an inexpensive, long-term, and non-toxic means to control weed populations. The planthopper, *Prokelisia marginata,* was selected as the most promising natural enemy because of its known potency against *Spartina alterniflora* and its narrow host range. This insect sucks the sap from the leaf veins of *Spartina*, depleting its energy supply. In addition, *P. marginata* harms *Spartina* by inserting its eggs between the leaf layers, scarring the leaves and causing structural damage to the vascular system. Approximately 200,000 planthoppers were released in 2001 and observations indicated these insects have reproduced and their offspring are currently feeding and developing on the plants (Grevstad 2001). *Prokelisia marginata*, had an unusually devastating effect on *Spartina alterniflora* from Willapa Bay and damage to the plants is just beginning to be visible (Grevstad 2001). Released of *Prokelisia marginata* were made to a remote population of *Spartina anglica* in Puget Sound during 2003. Potential insect agents for control of *S. densiflora* and *S. patens* have not been investigated.

Direct grazing by domestic livestock could affect the health and vigor of *Spartina* infestations and might be a possible biological control mechanism where the mudflat substrate would support grazing livestock.

Table A-4 . Biological Control Methods
(source WSDA 1993)

Biological Control Method	Most Practical Applications	Use Constraints
Target Insect	Planthopper, *Prokelisia marginata*, holds promise for large-scale control of seed production in *Spartina alterniflora*	Need to release insects at many sites throughout the infested area to build up high densities needed to control *Spartina*
Livestock Grazing	Eradication of small colonies monospecific stands of *Spartina*	Soft mud substrate will hinder grazing

5.0 IMPACTS OF CONTROL METHODS

5.1 PHYSICAL METHODS

Environmental impacts associated with physical methods include soil erosion, sediment mobilization, non-target species mortality, noxious plant dispersal, soil compaction, disruption of aquatic food webs, and safety of laborers. The severity of impacts is dependent both on the specific physical method chosen and size of area treated. Impacts associated with all physical methods would be expected to increase with the size of area treated. Depending on treatment method, many impacts can be mitigated by using appropriate procedures and materials and by carefully timing treatments (USFWS 1997).

5.2 MECHANICAL METHODS

Significant impacts include noxious plant dispersal, soil compaction, sediment mobilization, non-target plant and animal mortality, increased water turbidity, and disruption of aquatic food webs. The extent of these impacts varies with treatment method and size of treatment area. Many impacts can be mitigated by using appropriate procedures and materials, and by carefully timing treatments. Harvesting does not halt infestation spread and requires a market for plant products, but could be beneficial as a method of controlling seed production. Digging, rototilling, crushing, and/or mowing would be applicable in some situations for some species (USFWS 1997).

5.3 CHEMICAL METHODS

The potential impacts from use of glyphosate result from the toxicity of the herbicide or from other factors, such as loss of vegetation, algal blooms, loss of oxygen in water, and erosion and sediment instability from loss of plant cover. The magnitude of the toxic impacts depends on the concentration of glyphosate in the environment, the toxicity of glyphosate, and the extent to which humans, wildlife, and nontarget plants could be exposed to glyphosate. Although no significant impacts from glyphosate are expected for wildlife and humans, there could be toxic effects on eelgrass and algae.

Biodegradation and toxicity studies in fish, invertebrates, and mammals of the surfactants approved for use in Washington and chemicals similar to the surfactants, indicate that the environmental concentrations of surfactants that would result from spraying are not expected to have significant adverse impacts to human health or the environment. If the herbicide is not applied appropriately, it could affect non-target vegetation. However, results of human health risk assessments indicate that the concentrations of glyphosate to which the public could be exposed are expected to be below levels of concern. (USFWS 1997).

5.4 BIOLOGICAL CONTROL METHODS

There is an ecological risk involved in introduction of non-indigenous bio-control organisms. These organisms might cause possible death or injury of native species or agricultural grasses. Livestock grazing might negatively impact sediments, soils, water quality, and non-target biota .

5.5 INTEGRATED PEST MANAGEMENT PLAN

Impacts due to implementation of the IPMP control methods can have combined impacts from implementation of the individual methods, with some method combinations having additional synergistic effects. Combination of methods can expose *Spartina* to multiple stresses, resulting in a reduction in environmental impacts and frequency of use of each control methodology (USFWS 1997)

Tables A-5a through A5c summarize the impacts of the different control methodologies on Willapa Bay (USFWS 1997). These tables are excerpted from the EA conducted by USFWS in 1997 (EA based on the 1993 EIS for western Washington coastal areas). These impacts are specific to Willapa Bay but they can be generalized and extrapolated to include all of the *Spartina* infested areas along the Washington coast.

The USFWS, (1997) has indicated that *Spartina* is changing habitat for fish species. *Spartina* converts usable intertidal habitat to high meadow that is available to fish only during the highest tides. There is concern that the *Spartina* meadows are less complex from an ecological perspective and will negatively impact fish. There are also concerns that control methods negatively impact fish. The primary concern is that chemicals used to kill *Spartina* might impact or compromise fish health.

Table A-5a. Potential Physical Habitat Impacts of Different Control Methodologies (USFWS 1997)

Physical Issues	IPMP	Physical/Mechanical Only	Chemical Only
Soils and Topography	*Spartina*-facilitated sediment buildup in scattered clones and meadows would be slowed or halted in the shortest amount of time. Low concentrations of chemicals would bind to soil and then break down.	*Spartina*-facilitated sediment buildup in scattered clones would be slowed or halted, but some meadows would continue to capture sediment for many years	*Spartina*-facilitated sediment buildup in scattered clones and meadows would be slowed or halted, but over a longer period of time than with IPMP. Chemicals would bind to soil and then break down.
Hydrology	Alteration of natural flow patterns would be slowed over the next few years and reversed in the long- run.	Alteration of natural flow patterns would likely be slowed over the next few years. Changes in water movement due to *Spartina* would continue in areas where control could not be accomplished.	Alteration of natural flow patterns would be slowed over the next decade, and possibly reversed eventually.
Water Quality	Potential for short-term herbicide contamination. Greatest potential for reducing temperature increases and changes in salinity and oxygen levels caused by *Spartina*.	Greatest localized increases in suspended sediments. Reduced potential for temperature increases and changes in salinity and oxygen levels, but to a lesser degree than other methods.	Potential for herbicide contamination. Reduced potential for temperature increases and changes in salinity and oxygen levels.
Ambient Sound	Short term increased ambient noise levels associated with use of aircraft, airboats, weed cutters, etc.	A higher reliance on large machinery that could work night and day would likely result in more noise than other methods.	Even with use of aircraft, this method would generate less total noise than other methods mainly because of reduced work opportunity. Ground-based chemical application machinery tends to generate less noise than mechanical methods.
Air Quality	Of methods, least potential for air pollution from combustion of fossil fuels due to higher efficiency. Less potential for herbicide drift than Chemical Only Method.	Of methods, highest potential for pollution from combustion of fossil fuels.	Of methods, there would be a higher potential for herbicide spray drift due to total reliance on chemical control. Pollution from burning fossil fuels may be comparable to that of the Physical/Mechanical Method.

Table A-5b. Potential Biological Impacts of Control Methodologies
(USFWS 1997)

Biological Issues	PMP	Physical/Mechanical Only	Chemical Only
Vegetation	The greatest acreage of native plant habitat would be preserved and eventually restored. All existing mudflat habitat supporting macroalgae and eelgrass would be maintained. Some *Spartina* dominated areas would be converted to mudflat and some would convert to native saltmarsh. Existing native saltmarsh would be preserved. Impacts to vegetation due to *Spartina* spread would be minimized.	Of the methods, this will preserve the smallest acreage of native plant habitat. Mudflats supporting eelgrass and macroalgae would be maintained. Some *Spartina* meadow would likely remain and expand on tidelands. Less efficient at controlling *Spartina* tidelands would have more impacts to adjacent vegetation than other methods.	Mudflat supporting eelgrass and macroalgae on the would be maintained. Most of the existing *Spartina* meadow would convert to native saltmarsh. Seed production would likely be stopped over time, reducing impacts an adjacent areas.
Spartina	*Spartina* would not increase. Seed production could be stopped within a short timeframe. *Spartina* meadows and clones would be mostly eliminated.	*Spartina* expansion would be slowed. Seed production would be stopped. Some *Spartina* meadows would likely remain after years of control effort.	Seed production would likely be stopped in about a decade. Meadows would be eliminated and greatly reduced.
Wildlife	Existing mudflat and native saltmarsh habitat would be maintained. Former areas of this habitat, now occupied by *Spartina* would revert mostly to native saltmarsh. Wildlife use would be sustained.	Some existing mudflat habitat would continue to be lost to *Spartina*. Nearly all *Spartina* meadow killed by this method would convert to native saltmarsh. Of the methods, this would preserve the least mudflat habitat for migratory bird use.	Most of the existing mudflat and native saltmarsh habitat would be maintained. Former areas of this habitat, now occupied by *Spartina* would revert mostly to native saltmarsh. Wildlife use would be sustained.
Fish	More habitat would be protected for existing fish populations than in other methods.	Some habitat would become unusable for fish due to this method's likely inability to fully control *Spartina*.	Most of the habitat would be protected for existing fish populations.
Invertebrates	Potential for trampling of invertebrates at work sites. More habitat for the existing invertebrate community would be protected than with other methods.	Potential for trampling of invertebrates at work sites. Where *Spartina* is not controlled, species composition would change.	This action would have the least potential for trampling of invertebrates at work sites. Most of the habitat for the existing invertebrate community would be protected.

Table A-5c. Potential Human Impacts
(USFWS 1997)

Social Issues	IPMP	Physical/Mechanical Only	Chemical Only
Human Health	Health problems associated with *Spartina* pollen production and Mosquitos that breed in *Spartina* meadows would be reduced by *Spartina* control. This method provides the greatest opportunity to reduce such impacts.	There could be some reduction in pollen production and in mosquito habitat however, this method's inability to fully control *Spartina* would allow these problems to persist to a degree. Greater risk of injury to control workers.	Health problems associated with *Spartina* pollen production and mosquitos that breed in *Spartina* meadows would be reduced by this method, but to a slightly lesser extent than IPMP.
Concerns	Concerns about chemical use would be reduced to the degree that control would not depend Exclusively on chemical methods. *Spartina* spread would be stopped, reducing concerns over the loss of aquatic resources.	The absence of chemical use would remove concerns about chemical risk. *Spartina* spread would be slowed, but not as much as with IPMP or chemical only.	Concerns about chemical risk would be greatest under this method. Concerns about *Spartina* spread would be reduced.
Recreation	Noise from airboats, hovercraft, and aircraft. Disturbance of waterbirds would reduce bird Observations. In the long term, would be beneficial to recreational uses.	Due to reduced control, some recreational opportunities would decline. Noise disturbance to recreational users would like be greater than with other methods.	Noise would be generated by airboats, hovercraft, and aircraft, but over shorter periods of time. Disturbance of waterbirds would reduce bird observations. In the long term, would be beneficial to recreational uses.

6.0 DISCUSSION

WSDA has been developing regional management plans since 1998. The Statewide *Spartina* management plan provides information for the effects of *Spartina* on the intertidal ecology of these areas, describe previous control efforts/results, and outline the control strategy for the coming years (Table A-6). In 2002, the WSDA *Spartina* eradication program worked collaboratively with partner agencies to continue *Spartina* control, as outlined in five regional integrated pest management plans. The program included hiring, equipping and coordinating workers to treat infestations in Clallam, Jefferson, Kitsap and King counties. WSDA also assisted the Swinomish and Suquamish tribal communities with control work on their property and worked cooperatively with the WDFW and DNR on infestations in Willapa Bay. WSDA worked cooperatively with Ecology to develop a NPDES permit for aquatic noxious weed control, providing NPDES coverage to numerous federal, state and local governmental agencies, and private entities for herbicide applications to both marine and freshwater (WSDA, 2002).

Table A-6. Total Treatment Area and Methodology for *Spartina* in Washington State from 1997 through 2002 (WSDA 2002)

County	*Spartina* Present in 2002	*Spartina* Treated, 1997 - 2002	2002 Treatment Methods
Pacific (Willapa Bay)	Over 6,800 solid acres spread over > 15,000 acres	'97 – approx. 742 solid acres '98 – approx. 450 solid acres '99 – approx. 600 solid acres '00 – approx. 800 solid acres '01 – approx. 900 solid acres '02 – approx. 1804 solid acres	Mow/herbicide, herbicide, seedling removal, various mechanical control (rototilling, sub-soiling, etc).
Grays Harbor	Scattered clones and seedlings 0.25 acres in size	'97 – all treated '98 - all treated '99 – all treated '00 – all treated '01 – all treated '02 – all treated	Herbicide, seedling removal, mow
Snohomish	Approx. 350 solid acres spread over > 4,500 acres	'97 – approx. 89 solid acres '98 – approx. 126 solid acres '99 – approx. 90 solid acres '00 – approx. 158 solid acres '01 – approx. 75 solid acres '02 – approx. 238 solid acres	Mow/herbicide, herbicide, seedling removal, dig, mechanically crush, mow
Island	Approx. 350 solid acres spread over >1,000 acres	'97 – approx. 250 solid acres '98 – approx. 160 solid acres '99 – approx. 155 solid acres '00 – approx. 130 solid acres '01 – approx. 72 solid acres '02 – approx. 180 solid acres	Mow/herbicide, herbicide, seedling removal, mechanically crush, mow

Table A-6. Total Treatment Area and Methodology for *Spartina* in Washington State from 1997 through 2002 (WSDA 2002), Continued

County	*Spartina* Present in 2002	*Spartina* Treated, 1997 - 2002	2002 Treatment Methods
Skagit	Approx. 40 solid acres spread over > 2,000 acres	'97 – approx. 91 solid acres '98 – approx. 57 solid acres '99 – all treated '00 – approx. 60 solid acres '01 – approx. 33 solid acres '02 – approx. 37 solid acres	Mow/herbicide, herbicide, seedling removal, dig, mow
Clallam	1 infestation < 0.001 acres in size	'97 – treated twice '98 – treated three times '99 – treated twice '00 – treated three times '01 – treated four times '02 – treated four times	Dig
Jefferson	14 infestations – approx. 0.01 solid acres total	'97 - all treated '98 - all treated twice '99 – all treated twice '00 – all treated twice '01 – all treated three times '02 – all treated three times	Mow, mow/herbicide, dig, seedling removal
Kitsap	8 infestations - approx. 1 solid acre total	'97 - all but 2 tribal sites '98 - all treated '99 – all treated twice '00 – all treated '01 – all treated '02 – all treated twice	Mow mow/herbicide, dig, seedling removal
King	2 infestations – single clones and a few seedlings	'97 – monitored '98 – all treated '99 – all treated '00 – all treated twice '01 – all treated twice '02 – all treated twice	Dig
San Juan	Re-growth found at one site. 2 other sites clean for four consecutive years	'97 - all treated '98 - all treated '99 – monitored '00 – all treated '01 – all treated '02 – all treated	Survey, dig

The potential efficacy of the control methods is outlined in Table A-7. Mowing and herbicide application seem to have the highest efficacy for containment and reduction of *Spartina*.

Table A-7. Potential Efficacy of Treatment Methods on *Spartina* Infestations in Washington State (source: WSDA 1993)

Infestation Threat	Objective	Management Method	Potential Efficacy[/]		Plant Growth Stage
			Small Area	Large Area	
Established Invader Core	Containment, Reduction	Herbicide	Low to High	Low to High	Actively growing, especially pre-flowering
		Cutting/mowing	Medium to High	Medium to High	Pre-flowering or early flowering, every month
		Mechanical crushing	Low to High	Low to High	Pre-flowering or early flowering, May through August
		Covering	Medium	Low	All stages during growing season
Established Invader Outliers	Containment or Control	Herbicide	Low to High	Low to High	Seedlings, pre-flowering
		Hand pulling	Medium to High	Medium to High	Seedlings to small plants
		Covering	High	Medium to High	All stages during growing season, treatments repeated every month
New Invader	Eradication, Reduction, Containment, Control	Herbicide	Low to High	Low to High	Seedling, pre-flowering
		Hand pulling/digging	Medium to High	Medium	Seedling to small plants
		Covering	High	Medium to High	All stages during growing season, treatments repeated every month
		Mechanical crushing	Low to High	Low to High	Pre-flowering or early flowering, May through August
All Infestations	Prevention (applies to all infestations)	Education/awareness	Medium to High	Medium to High	
		Surveys	Medium to High	Medium to High	

Patten (1997) has indicated that mowing followed by herbicide application provides the highest efficacy but at an increased cost (Table A-8). Aerial application is more cost effective and covers wider areas but the efficacy is questionable.

Table A-8. Summary of the most cost-effective, integrated *Spartina* Management Practices (Norman and Patten, 1997)

Method	% Kill (Efficacy)	Acreage	$/Acre
Mow only	95	low	312
Mow + Rodeo	98	low	431
Rodeo hand wipe	91	low	310
Rodeo hand spray	81	low	585
Rodeo aerial spray	?	high	165

WSDA has demonstrated that *Spartina* eradication is feasible. The current strategies for control in each region are founded upon the 1998 plans. Many of these plans are proving successful, especially in North Puget Sound where the strategy has resulted in a 27% decline in the overall size of the infestation (WSDA, 2001a; WSDA, 2002). The overall Puget Sound infestation was reduced by 10% from 1997 to 1999, *Spartina* establishment in Grays Harbor has been prevented, and populations of *Spartina* at select sites in Willapa Bay have been eradicated (WSDA, 2001b; WSDA, 2002). This is the positive aspect concerning the present program, but the *Spartina* infestation continues to grow. At current levels, it could take decades to eradicate *Spartina* in Puget Sound and it may never be eradicated in Willapa Bay (WSDA, 2002).

Methodologies and equipment for eradicating *Spartina* have evolved over time with treatment efforts. The agencies now use airboats to transport equipment and personnel, large-scale amphibious mowing machines to stop seed production, small tracked vehicles to shred and rip apart isolated infestations, high pressure spray systems to treat large clones and fringes of meadows, and volunteers, landowners and students to dig seedlings (WSDA 2002). WSDA (2002), concluded that, large-scale mechanical eradication of *Spartina* is not feasible at this time. A potential alternative at this time, might be an effective chemical control. The chemical control solution would need to be a cost-effective chemical that can be applied in low volumes and small concentrations in salt water and would integrate minimal non-target impact with acceptable aquatic risk and non-persistent in the water. This would allow for large areas to be treated with a minimal need for re-treatment.

7.0 REFERENCES

Daehler, C.C. and D.R. Strong. 1994. Variable reproductive output among clones of *Spartina alterniflora* (Poacea) invading San Francisco Bay, California: the influence of herbivory, pollination, and establishment Site. American Journal of Botany 81(3):307-313.

Grevstad, F. 2001. *Spartina* Biocontrol—Background and Progress. University of Washington, Olympic Natural Resources Center. Website: http://www.willapabay.org/~coastal/nospartina/biocontrol/biocontrol_overview2001.pdf

IVM Technical Bulletin, 1998. Smooth Cordgrass (*Spartina*). In Integrated Pest Management Practitioner's Association: Bio-Integral Resource Center (BIRC)'s *I*PMP Access: Noxious Weed Integrated Vegetation Management Guide: IVM Technical Bulletin. Website: http://www.efn.org/~ipmpa/Noxspart.html. Visited: 6/5/03.

Killbride, K.M, F.L. Paveglio, and C.E. Grue. 1995. Control of smooth cordgrass with Rodeo in a southwestern Washington estuary. *Wildlife Society Bulletin* 23(3): 520-524.

Major III, W. and C.E. Grue. 1997. Control of *Spartina alterniflora* in Willapa Bay, Washington: efficacy of mechanical and chemical control techniques and their off target impacts on eelgrass *(Z. japonica*). *Second International Spartina Conf. Proc.* 1997: 76-81.

Norman, M. and K. Patten. 1997. Cost-efficacy of integrated *Spartina* control practices in Willapa Bay, Washington. 1997. *Second International Spartina Conference Proceedings* 1997: 89-92.

Patten, K. 2002. Imazapyr- efficacy, toxicity, costs and registration. Presentation at *Spartina* Conference, May 13-14. Olympia, WA. Website: http://www.willapabay.org/~coastal/nospartina/conferences/conf2002/conference_may2002.htm Visited: 6/5/03.

U.S. Department of Agriculture (USDA). 1995. Imazapyr: Pesticide Fact Sheet. Prepared by Ventures, Inc. November 1995. Website: http://infoventures.com/e-hlth/pestcide/imazapyr.html Visited: 6/5/03.

U.S. Fish and Wildlife Service (USFWS). 1997. Environmental Assessment for Control of Smooth Cordgrass (*Spartina Altierniflora*) on Willapa National Wildlife Refuge. U.S. Fish and Wildlife Service. Washington.

Washington State Departments of Agriculture, (WSDA). 1993. Noxious emergent plant management: final environmental impact statement. State of Washington. Olympia. 204 pp + app.

Washington State Department of Agriculture (WSDA). 2000, *Spartina* and Purple Loosestrife Report to the Legislature Eradication and Control Programs (as required by RCW 17.26.015). 44 pp.

Washington State Department of Agriculture (WSDA). 2001a. 2001 *Spartina* Management Plan for North Puget Sound. Prepared by WSDA in cooperation with the North Puget Sound *Spartina* Task Force.

Washington State Department of Agriculture (WSDA). 2001b. 2001 *Spartina* Management Plan for Willapa Bay. Prepared by WSDA in cooperation with the Willapa Bay *Spartina* Task Force.

Washington State Department of Agriculture (WSDA). 2002. Report to the Legislature. State of Washington. Olympia.

Zipperer, V.T. 1996. Ecological Effects of the Introduced Cordgrass, Spartina alterniflora, on the Benthic Community Structure of Willapa Bay, Washington. Masters of Science Thesis. University of Washington.

Appendix B

Exposure Calculation Worksheets

APPENDIX B:
Exposure Calculation Worksheets

	Dermal Absorbed Dose			Amt Deposited on Animal (mg)		Dose Absorbed (mg/kg-bw)	
Terrestrial Receptor	**AR mg/cm^2**	**Body Weight**	**SA**	**Upper Amnt**	**Typical Amnt**	**Upper Dose**	**Typical Dose**
Deer Mouse	0.0168	0.021	90.11	1.14	0.76	54.07	36.04
Norway Rat	0.0168	0.300	507.52	6.39	4.26	21.32	14.21
Cottontail Rabbit	0.0168	1.286	1307.16	16.47	10.98	12.81	8.54
Red Fox M	0.0168	5.250	3261.57	41.10	27.40	7.83	5.22
Red Fox F	0.0168	4.130	2790.55	35.16	23.44	8.51	5.68
Marsh Wren	0.0168	0.011	60.06	0.76	0.50	67.27	44.84
Bobwhite Quail	0.0168	0.190	377.15	4.75	3.17	25.01	16.67
Greater Scaup M	0.0168	0.860	1006.35	12.68	8.45	14.74	9.83
Greater Scaup F	0.0168	0.770	936.57	11.80	7.87	15.33	10.22
Mallard Duck M	0.0168	1.225	1266.52	15.96	10.64	13.03	8.68
Mallard Duck F	0.0168	1.043	1140.80	14.37	9.58	13.78	9.19

W = body weight (kg); SA = exposed surface area
Estimated Absorbed Dose = Dabs = Amnt/W
Typical Amount deposited on the animal (Amnt) = 0.5 x SA x AR
Upper Amount Deposited On the Animal (Amnt) = 0.75 x SA x AR

Application Rate AR= 0.0168 mg/cm^2
Exposed Surface Area SA= $1110(W)^{0.65}$

Ecological Receptor	Acute Dietary Upper Exposure[1]	Acute Dietary Typical Exposure[1]	Chronic Dietary Upper Exposure[2]	Chronic Dietary Typical Exposure[2]	Dermal/ Contact Upper Exposure[3]	Dermal/ Contact Typical Exposure[3]	Drinking Water (Spill) Upper Exposure[4]	Drinking Water (Spill) Typical Exposure[4]	Drinking Water (Runoff) Upper Exposure[4]	Drinking Water (Runoff) Typical Exposure[4]
Deer Mouse	0.0084214	0.000524	0.014946429	0.007842857	0.02703254	0.0180217	1.19773333	0.59886667	0.0002267	6.667E-06
Norway Rat	0.000524	0.000172	0.00093	0.000488	0.01065789	0.0071053	0.395252	0.197626	0.0000748	0.0000022
Cottontail Rabbit	0.0027504	0.0009028	0.012203538	0.006403577	0.13516268	0.0901085	0.34926128	0.17463064	6.61E-05	1.944E-06
Red Fox M	0.0007226	0.0002372	0.005130057	0.002691901	0.05328943	0.0355263	0.3018288	0.1509144	5.712E-05	1.68E-06
Red Fox F	0.0007232	0.0002374	0.00513414	0.002691901	0.03201837	0.0213456	0.3088586	0.1544293	5.845E-05	1.719E-06
Marsh Wren	0.0552852	0.018147	0.066133333	0.034702222	0.01956941	0.0130463	7.07675744	3.53837872	0.0013393	3.939E-05
Bobwhite Quail	0.0115083	0.0037775	0.013766447	0.007223684	0.02128389	0.0141893	2.80587225	1.40293612	0.000531	1.562E-05
Scaup M	0.0152326	0.0008703	0.005406977	0.002837209	0.16816289	0.1121086	0.96362661	0.48181331	0.0001824	5.364E-06
Scaup F	0.017013	0.000972	0.006038961	0.003168831	0.06252731	0.0416849	0.99503125	0.49751563	0.0001883	5.538E-06
Mallard Duck M	0.1002551	0.0057281	0.035586735	0.018673469	0.03686032	0.0245735	0.8552047	0.42760235	0.0001618	4.76E-06
Mallard Duck F	0.1177493	0.0067277	0.0417965	0.021931927	0.03831438	0.0255429	0.65962899	0.3298145	0.0001248	3.672E-06

1: acute dietary reference NOEL = 5,000 mg/kg-bw for mouse, rat, rabbit, and fox; 1149 mg/kg for mallard and scaup; and 674 mg/kg for quail and wren
2: chronic reference NOEL dose for mouse and rate = 1,000 mg/kg; for rabbits = 400 mg/kg; for dogs = 250 mg/kg; for avian species = 200 mg/kg
3: dermal/contact NOEL dose for mouse & rat= 2,000 mg/kg; 400 mg/kg for rabbit. No data on fox or avian species, so assumed rabbit value of 400 mg/kg
4: same reference doses as acute oral

Ecological Receptor	$C_{upper\ in\ mg/L}$	$C_{lower\ in\ mg/L}$	A	W	Dose Ingested from Upper	Dose Ingested from Typical
Deer Mouse	3.4	0.1	0.007	0.021	1.133	0.033
Norway Rat	3.4	0.1	0.033	0.3	0.374	0.011
Cottontail Rabbit	3.4	0.1	0.125	1.286	0.330	0.010
Red Fox M	3.4	0.1	0.441	5.25	0.286	0.008
Red Fox F	3.4	0.1	0.355	4.13	0.292	0.009
Marsh Wren	3.4	0.1	0.003	0.0113	0.903	0.027
Bobwhite Quail	3.4	0.1	0.02	0.19	0.358	0.011
Scaup M	3.4	0.1	0.053	0.86	0.210	0.006
Scaup F	3.4	0.1	0.049	0.77	0.216	0.006
Mallard Duck M	3.4	0.1	0.067	1.225	0.186	0.005
Mallard Duck F	3.4	0.1	0.044	1.043	0.143	0.004

Dose is calculated as (C x A)/W
A = water consumed per day (in L); and W = average body weight (in kg)
C = concentration of neat solution in spill (mg/L) based on application rates of 10 gal/acre (upper), and 20 gal/acre (typical)
[note: lower application volumes result in higher neat concentrations of herbicide, hence higher concentrations)

Terrestrial Ecological Receptor	$C_{upper\ in\ mg/L}$	$C_{lower\ in\ mg/L}$	A	W	Dose Ingested from Spill Solution (mg/kg-bw) Upper	Typical
Deer Mouse	17966	8983	0.007	0.021	5988.7	2994.3
Norway Rat	17966	8983	0.033	0.3	1976.3	988.1
Cottontail Rabbit	17966	8983	0.125	1.286	1746.3	873.2
Red Fox M	17966	8983	0.441	5.25	1509.1	754.6
Red Fox F	17966	8983	0.355	4.13	1544.3	772.1
Marsh Wren	17966	8983	0.003	0.0113	4769.7	2384.9
Bobwhite Quail	17966	8983	0.02	0.19	1891.2	945.6
Scaup M	17966	8983	0.053	0.86	1107.2	553.6
Scaup F	17966	8983	0.049	0.77	1143.3	571.6
Mallard Duck M	17966	8983	0.067	1.225	982.6	491.3
Mallard Duck F	17966	8983	0.044	1.043	757.9	379.0

Dose is calculated as (C x A)/W
A = water consumed per day (in L); and W = average body weight (in kg)
C = concentration of neat solution in spill (mg/L) based on application rates of 10 gal/acre (upper), and 20 gal/acre (typical)
[note: lower application volumes result in higher neat concentrations of herbicide, hence higher concentrations)

Chronic Dietary Dose

Terrestrial Receptor	C_{twa} upper	C_{twa} typical	food intake/day (kg/1000))	Prop	(W)	Upper Limit Dose	Typical Dose
Deer Mouse	46.5	24.4	9	0.75	21	14.95	7.84
Norway Rat	46.5	24.4	15	0.4	300	0.93	0.49
Cottontail Rabbit	46.5	24.4	180	0.75	1286	4.88	2.56
Red Fox M	46.5	24.4	362	0.4	5250	1.28	0.67
Red Fox F	46.5	24.4	285	0.4	4130	1.28	0.67
Marsh Wren	46.5	24.4	8	0.4	11.25	13.23	6.94
Bobwhite Quail	46.5	24.4	15	0.75	190	2.75	1.44
Greater Scaup M	46.5	24.4	50	0.4	860	1.08	0.57
Greater Scaup F	46.5	24.4	50	0.4	770	1.21	0.63
Mallard Duck M	46.5	24.4	250	0.75	1225	7.12	3.73
Mallard Duck F	46.5	24.4	250	0.75	1043	8.36	4.39

Time-weighted average concentration on Vegetation (Ctwa) = Co(1-e-kt)/(kT) (note: units in mg/kg)
food intake per day is in kg/1000, from Wildlife exposure handbook
W = body weight in kg/1000

- Chronic Dietary Dose Absorbed (CD) = (Ctwa)(food intake/day)(Prop)/W

Acute Dietary Dose

Terrestrial Receptor	C_{upper}	$C_{typical}$	A	Prop	W	Upper Dose (mg/kg-bw)	Typical Dose (mg/kg-bw)
Deer Mouse	131	43	9	0.75	21	42.11	13.82
Norway Rat	131	43	15	0.4	300	2.62	0.86
Cottontail Rabbit	131	43	180	0.75	1286	13.75	4.51
Red Fox M	131	43	362	0.4	5250	3.61	1.19
Red Fox F	131	43	285	0.4	4130	3.62	1.19
Marsh Wren	131	43	8	0.4	11.25	37.26	12.23
Bobwhite Quail	131	43	15	0.75	190	7.76	2.55
Greater Scaup M	131	43	50	0.4	860	3.05	1.00
Greater Scaup F	131	43	50	0.4	770	3.40	1.12
Mallard Duck M	131	43	250	0.75	1225	20.05	6.58
Mallard Duck F	131	43	250	0.75	1043	23.55	7.73

Dose= AxC(Prop)/W
A = daily food intake in grams
Prop is unitless estimate of percent of total diet assumed from contaminated vegetation
C = residue concentration in food (mg/kg)
W = body weight in grams

Appendix C

Avian Species in Willapa Bay

APPENDIX C:
Avian Species in Willapa Bay

Species	Scientific Name	Abundance by season			
LOONS		Spring	Summer	Fall	Winter
_____ Red-throated Loon	*GAVIA STELLATA*	c	-	c	c
_____ Pacific Loon	*GAVIA PACIFICA*	c	r	c	u
_____ Common Loon	*GAVIA IMMER*	c	r	c	u
GREBES		Spring	Summer	Fall	Winter
_____ Pied-billed Grebe*	*PODILYMBUS PODICEPS*	u	u	u	u
_____ Horned Grebe	*PODICEPS AURITUS*	c	r	c	c
_____ Red-necked Grebe	*PODICEPS GRISEGENA*	r	-	o	o
_____ Western Grebe	*AECHMOPHORUS OCCIDENTALIS*	a	u	a	a
FULMARS, PETRELS AND SHEARWATERS		Spring	Summer	Fall	Winter
_____ Northern Fulmar	*FULMARUS GLACIALIS*	-	r	r	u
_____ Pink-footed Shearwater	*PUFFINUS CREATOPUS*	-	-	r	-
_____ Sooty Shearwater	*PUFFINUS GRISEUS*	u	c	a	-
_____ Short-tailed Shearwater	*PUFFINUS TENUIROSTRIS*	-	-	-	o
STORM PETRELS		Spring	Summer	Fall	Winter
_____ Fork-tailed Storm-Petrel	*OCEANODROMA FURCATA*	-	-	r	-
_____ Leach's Storm-Petrel*	*OCEANODROMA LEUCORHOA*	-	-	r	-
PELICANS AND CORMORANTS		Spring	Summer	Fall	Winter
_____ Brown Pelican	*PELECANUS OCCIDENTALIS*	o	c	c	-
_____ Double-crested Cormorant*	*PHALACROCORAX AURITUS*	c	c	c	c
_____ Brandt's Cormorant*	*PHALACROCORAX PENICILLATUS*	c	c	c	c
BITTERNS, HERONS AND EGRETS		Spring	Summer	Fall	Winter
_____ American Bittern*	*BOTAURUS LENTIGINOSUS*	o	u	u	o
_____ Great Blue Heron*	*ARDEA HERODIAS*	c	c	c	c
_____ Great Egret	*ARDEA ALBA*	o	-	o	-
_____ Cattle Egret	*BUBULCUS IBIS*	-	-	r	-
_____ Green Heron	*BUTORIDES VIRESCENS*	r	r	r	-

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Species	Scientific Name	Abundance by season			
WATERFOWL		Spring	Summer	Fall	Winter
_____ Tundra Swan	*CYGNUS COLUMBIANUS*	-	-	u	u"
_____ Trumpeter Swan	*CYGNUS BUCCINATOR*	-	-	u	u"
_____ Greater White-fronted Goose	*ANSER ALBIFRONS*	o	-	o	o
_____ Snow Goose	*CHEN CAERULESCENS*	o	-	o	o
_____ Ross' Goose	*CHEN ROSSII*	r	-	-	-
_____ Emperor Goose	*CHEN CANAGICA*	r	-	o	r
_____ Brant	*BRANTA BERNICLA*	a	o	c	c
_____ Canada Goose*	*BRANTA CANADENSIS*	a	c	a	a
_____ Wood Duck*	*AIX SPONSA*	u	u	u	-
_____ Green-winged Teal	*ANAS CRECCA*	c	r	c	c
_____ Mallard*	*ANAS PLATYRHYNCHOS*	c	c	c	c
_____ Northern Pintail	*ANAS ACUTA*	u	r	a	c
_____ Blue-winged Teal	*ANAS DISCORS*	u	r	u	-
_____ Cinnamon Teal*	*ANAS CYANOPTERA*	u	u	u	-
_____ Northern Shoveler	*ANAS CLYPEATA*	u	r	u	o
_____ Gadwall	*ANAS STREPERA*	u	r	u	u
_____ Eurasian Wigeon	*ANAS PENELOPE*	-	-	o	o
_____ American Wigeon	*ANAS AMERICANA*	c	r	a	c
_____ Canvasback	*AYTHYA VALISINERIA*	u	-	u	u
_____ Ring-necked Duck	*AYTHYA COLLARIS*	u	-	u	u
_____ Tufted Duck	*AYTHYA FULIGULA*	-	-	-	r
_____ Greater Scaup	*AYTHYA MARILA*	u	-	u	u
_____ Lesser Scaup	*AYTHYA AFFINIS*	c	-	c	c
_____ Harlequin Duck	*HISTRIONICUS HISTRIONICUS*	r	-	r	r
_____ Oldsquaw	*CLANGULA HYEMALIS*	o	-	r	o
_____ Black Scoter	*MELANITTA NIGRA*	u	-	u	u
_____ Surf Scoter	*MELANITTA PERSPICILLATA*	c	o	c	c"
_____ White-winged Scoter	*MELANITTA FUSCA*	c	o	c	c
_____ Common Goldeneye	*BUCEPHALA CLANGULA*	u	-	u	c
_____ Barrow's Goldeneye	*BUCEPHALA ISLANDICA*	r	-	-	r

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	Species	Scientific Name	Abundance by season			
_____	Bufflehead	*BUCEPHALA ALBEOLA*	c	-	c	c
_____	Hooded Merganser*	*LOPHODYTES CUCULLATUS*	u	o	u	u
_____	Common Merganser*	*MERGUS MERGANSER*	c	u	u	u
_____	Red-breasted Merganser		r	c	c"	
_____	Ruddy Duck	*OXYURA JAMAICENSIS*	o	-	u	u"
VULTURES			Spring	Summer	Fall	Winter
_____	Turkey Vulture	*CATHARTES AURA*	u	u	u	r
OSPREY, KITES, EAGLES AND HAWKS			Spring	Summer	Fall	Winter
_____	Osprey*	*PANDION HALIAETUS*	u	u	u	r
_____	White-tailed Kite	*ELANUS LEUCURUS*	o	u	o	o
_____	Bald Eagle*	*HALIAEETUS LEUCOCEPHALUS*	u	u	u	u
_____	Northern Harrier*	*CIRCUS CYANEUS*	c	c	c	c
_____	Sharp-shinned Hawk	*ACCIPITER STRIATUS*	u	r	u	u
_____	Cooper's Hawk	*ACCIPITER COOPERII*	u	r	u	u
_____	Northern Goshawk	*ACCIPITER GENTILIS*	r	-	r	r
_____	Red-tailed Hawk*	*BUTEO JAMAICENSIS*	c	c	c	c
_____	Rough-legged Hawk	*BUTEO LAGOPUS*	u	-	u	u
FALCONS			Spring	Summer	Fall	Winter
_____	American Kestrel	*FALCO SPARVERIUS*	u	r	u	u
_____	Merlin	*FALCO COLUMBARIUS*	u	-	u	u
_____	Peregrine Falcon	*FALCO PEREGRINUS*	u	-	u	u
_____	Gyrfalcon	*FALCO RUSTICOLUS*	-	-	r	r
GALLINACEOUS BIRDS			Spring	Summer	Fall	Winter
_____	Ring-necked Pheasant*	*PHASIANUS COLCHICUS*	u	u	u	u
_____	Blue Grouse*	*DENDRAGAPUS OBSCURUS*	u	u	u	r
_____	Ruffed Grouse*	*BONASA UMBELLUS*	u	u	u	u
_____	Wild Turkey	*MELEAGRIS GALLOPAVO*	r	r	r	r
_____	Northern Bobwhite*	*COLINUS VIRGINIANUS*	u	u	o	o

APPENDIX C:
Avian Species in Willapa Bay

Species	Scientific Name	Abundance by season			
RAILS		Spring	Summer	Fall	Winter
_____ Virginia Rail*	*RALLUS LIMICOLA*	u	u	u	r
_____ Sora	*PORZANA CAROLINA*	r	-	r	-
_____ American Coot	*FULICA AMERICANA*	u	-	u	c
PLOVERS		Spring	Summer	Fall	Winter
_____ Black-bellied Plover	*PLUVIALIS SQUATAROLA*	c	u	a	c
_____ American Golden Plover	*PLUVIALIS DOMINICA*	r	r	u	r
_____ Snowy Plover*	*CHARADRIUS ALEXANDRINUS*	u	u	u	r
_____ Semipalmated Plover	*CHARADRIUS SEMIPALMATUS*	c	c	c	r
_____ Killdeer*	*CHARADRIUS VOCIFERUS*	u	u	c	u
OYSTERCATCHERS		Spring	Summer	Fall	Winter
_____ American Oystercatcher*	*HAEMATOPUS PALLIATUS*	u	u	u	-
SHOREBIRDS		Spring	Summer	Fall	Winter
_____ Greater Yellowlegs	*TRINGA MELANOLEUCA*	c	u	c	c
_____ Lesser Yellowlegs	*TRINGA FLAVIPES*	-	-	r	-
_____ Willet	*CATOPTROPHORUS SEMIPALMATUS*	r	-	o	o
_____ Wandering Tattler	*HETEROSCELUS INCANUS*	u	o	u	-
_____ Spotted Sandpiper	*ACTITIS MACULARIA*	u	o	u	-
_____ Whimbrel	*NUMENIUS PHAEOPUS*	c	o	c	-
_____ Long-billed Curlew	*NUMENIUS AMERICANUS*	u	-	u	o
_____ Bar-tailed Godwit	*LIMOSA LAPPONICA*	-	-	o	-
_____ Marbled Godwit	*LIMOSA FEDOA*	u	o	u	r
_____ Ruddy Turnstone	*ARENARIA INTERPRES*	c	o	c	r
_____ Black Turnstone	*ARENARIA MELANOCEPHALA*	u	u	u	u
_____ Surfbird	*APHRIZA VIRGATA*	c	r	c	r
_____ Red Knot	*CALIDRIS CANUTUS*	c	-	u	-
_____ Sanderling	*CALIDRIS ALBA*	a	c	a	c
_____ Semipalmated Sandpiper	*CALIDRIS PUSILLA*	o	r	-	-

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Avian Species in Willapa Bay

	Species	Scientific Name	Abundance by season			
_____	Western Sandpiper	*CALIDRIS MAURI*	a	a	a	c
_____	Least Sandpiper	*CALIDRIS MINUTILLA*	c	c	a	u
_____	Pectoral Sandpiper	*CALIDRIS MELANOTOS*	-	-	c	-
_____	Sharp-tailed Sandpiper	*CALIDRIS ACUMINATA*	r	-	u	-
_____	Dunlin	*CALIDRIS ALPINA*	a	u	a	a
_____	Stilt Sandpiper	*CALIDRIS HIMANTOPUS*	-	-	r	-
_____	Ruff	*PHILOMACHUS PUGNAX*	-	-	r	-
_____	Short-billed Dowitcher	*LIMNODROMUS GRISEUS*	a	a	c	-
_____	Long-billed Dowitcher	*LIMNODROMUS SCOLOPACEUS*	u	r	c	u
SNIPE			Spring	Summer	Fall	Winter
_____	Common Snipe	*GALLINAGO GALLINAGO*	c	r	c	u
PHALAROPES			Spring	Summer	Fall	Winter
_____	Wilson's Phalarope	*PHALAROPUS TRICOLOR*	-	-	r	-
_____	Red-necked Phalarope	*PHALAROPUS LOBATUS*	u	o	u	-
_____	Red Phalarope	*PHALAROPUS FULICARIA*	r	r	o	-
JAEGERS			Spring	Summer	Fall	Winter
_____	Parasitic Jaeger	*STERCORARIUS PARASITICUS*	r	r	u	-
GULLS AND TERNS			Spring	Summer	Fall	Winter
_____	Bonaparte's Gull	*LARUS PHILADELPHIA*	c	u	c	r
_____	Heermann's Gull	*LARUS HEERMANNI*	o	c	c	-
_____	Mew Gull	*LARUS CANUS*	c	r	c	c
_____	Ring-billed Gull	*LARUS DELAWARENSIS*	c	u	c	u
_____	California Gull	*LARUS CALIFORNICUS*	c	u	a	u
_____	Herring Gull	*LARUS ARGENTATUS*	-	-	-	r
_____	Thayer's Gull	*LARUS THAYERI*	-	-	-	r
_____	Western Gull*	*LARUS OCCIDENTALIS*	c	c	c	c
_____	Glaucous-winged Gull*	*LARUS GLAUCESCENS*	c	c	c	c
_____	Black-legged Kittiwake	*RISSA TRIDACTYLA*	u	r	u	u

APPENDIX C:
Avian Species in Willapa Bay

	Species	Scientific Name	Abundance by season			
_____	Sabine's Gull	*XEMA SABINI*	r	r	r	-
_____	Caspian Tern*	*STERNA CASPIA*	c	c	c	-
_____	Common Tern	*STERNA HIRUNDO*	u	r	u	-
_____	Arctic Tern	*STERNA PARADISAEA*	r	-	r	-
SEABIRDS			Spring	Summer	Fall	Winter
_____	Common Murre	*URIA AALGE*	u	c	c	u
_____	Pigeon Guillemot*	*CEPPHUS COLUMBA*	c	c	u	r
_____	Marbled Murrelet*		u	u	u"	
_____	Ancient Murrelet	*SYNTHLIBORAMPHUS ANTIQUUS*	-	-	r	r
_____	Cassin's Auklet	*PTYCHORAMPHUS ALEUTICUS*	-	-	r	r
_____	Rhinoceros Auklet	*CERORHINCA MONOCERATA*	o	u	o	o
_____	Tufted Puffin	*FRATERCULA CIRRHATA*	o	u	o	o
_____	Horned Puffin	*FRATERCULA CORNICULATA*	-	-	-	o
DOVES			Spring	Summer	Fall	Winter
_____	Rock Dove*	*COLUMBA LIVIA*	u	u	u	u
_____	Band-tailed Pigeon*	*COLUMBA FASCIATA*	c	c	c	-
_____	Mourning Dove	*ZENAIDA MACROURA*	r	r	r	-
OWLS			Spring	Summer	Fall	Winter
_____	Barn Owl*	*TYTO ALBA*	u	u	u	u
_____	Western Screech-Owl*	*OTUS KENNICOTTII*	u	u	u	u
_____	Great Horned Owl*	*BUBO VIRGINIANUS*	u	u	u	u
_____	Snowy Owl	*NYCTEA SCANDIACA*	-	-	-	r
_____	Northern Pygmy-Owl*	*GLAUCIDIUM GNOMA*	u	u	u	u
_____	Burrowing Owl		-	r	r"	
_____	Barred Owl*	*STRIX VARIA*	u	u	u	u
_____	Long-eared Owl	*ASIO OTUS*	r	-	r	r
_____	Short-eared Owl	*ASIO FLAMMEUS*	u	o	u	u
_____	Northern Saw-whet Owl*	*AEGOLIUS ACADICUS*	u	u	u	u

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Avian Species in Willapa Bay

Species	Scientific Name	Abundance by season			
GOATSUCKERS		Spring	Summer	Fall	Winter
_____ Common Nighthawk*	*CHORDEILES MINOR*	r	u	u	-
SWIFTS		Spring	Summer	Fall	Winter
_____ Vaux's Swift*	*CHAETURA VAUXI*	c	c	c	-
HUMMINGBIRDS		Spring	Summer	Fall	Winter
_____ Anna's Hummingbird	*CALYPTE ANNA*	-	-	-	r
_____ Rufous Hummingbird*	*SELASPHORUS RUFUS*	a	a	o	r
KINGFISHERS		Spring	Summer	Fall	Winter
_____ Belted Kingfisher*	*CERYLE ALCYON*	u	u	u	o
WOODPECKERS		Spring	Summer	Fall	Winter
_____ Red-breasted Sapsucker	*SPHYRAPICUS RUBER*	u	-	u	u
_____ Downy Woodpecker*	*PICOIDES PUBESCENS*	u	u	u	u
_____ Hairy Woodpecker*	*PICOIDES VILLOSUS*	u	u	u	u
_____ Northern Flicker*	*COLAPTES AURATUS*	c	c	c	c
_____ Pileated Woodpecker*	*DRYOCOPUS PILEATUS*	u	u	u	u
FLYCATCHERS		Spring	Summer	Fall	Winter
_____ Olive-sided Flycatcher*	*CONTOPUS BOREALIS*	c	c	o	-
_____ Western Wood-Pewee*	*CONTOPUS SORDIDULUS*	u	u	o	-
_____ Willow Flycatcher*	*EMPIDONAX TRAILLII*	u	u	o	-
_____ Pacific-slope Flycatcher*	*EMPIDONAX DIFFICILIS*	c	c	u	-
_____ Western Kingbird	*TYRANNUS VERTICALIS*	r	-	-	-
LARKS		Spring	Summer	Fall	Winter
_____ Horned Lark*	*EREMOPHILA ALPESTRIS*	u	u	u	o
SWALLOWS		Spring	Summer	Fall	Winter
_____ Purple Martin*		o	r	-"	

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	Species	Scientific Name	Abundance by season			
_____	Tree Swallow*	*TACHYCINETA BICOLOR*	c	c	u	o
_____	Violet-green Swallow*	*TACHYCINETA THALASSINA*	c	c	u	o
_____	Northern Rough-winged Swallo	*STELGIDOPTERYX SERRIPENNIS*	u	u	o	-
_____	Cliff Swallow*	*HIRUNDO PYRRHONOTA*	c	c	o	-
_____	Barn Swallow*	*HIRUNDO RUSTICA*	c	a	o	-
JAYS, MAGPIES AND CROWS			Spring	Summer	Fall	Winter
_____	Gray Jay	*PERISOREUS CANADENSIS*	o	o	o	o
_____	Steller's Jay*	*CYANOCITTA STELLERI*	u	u	c	u
_____	Scrub Jay	*APHELOCOMA COERULESCENS*	o	o	o	o"
_____	American Crow*	*CORVUS BRACHYRHYNCHOS*	c	c	c	c
_____	Common Raven*	*CORVUS CORAX*	u	u	u	u
CHICKADEES AND TITMICE			Spring	Summer	Fall	Winter
_____	Black-capped Chickadee*	*POECILE ATRICAPILLUS*	c	c	c	c
_____	Chestnut-backed Chickadee*	*POECILE RUFESCENS*	c	c	c	c
BUSHTITS			Spring	Summer	Fall	Winter
_____	Bushtit*	*PSALTRIPARUS MINIMUS*	o	r	o	o
NUTHATCHES			Spring	Summer	Fall	Winter
_____	Red-breasted Nuthatch	*SITTA CANADENSIS*	u	r	u	u
CREEPERS			Spring	Summer	Fall	Winter
_____	Brown Creeper*	*CERTHIA AMERICANA*	u	u	u	u"
WRENS			Spring	Summer	Fall	Winter
_____	Bewick's Wren*	*THRYOMANES BEWICKII*	u	u	u	u
_____	Winter Wren*	*TROGLODYTES TROGLODYTES*	c	c	c	c
_____	Marsh Wren*	*CISTOTHORUS PALUSTRIS*	c	c	c	u

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Avian Species in Willapa Bay

Species	Scientific Name	Abundance by season			
KINGLETS, BLUEBIRDS AND THRUSHES		Spring	Summer	Fall	Winter
_____ Golden-crowned Kinglet*	*REGULUS SATRAPA*	c	c	c	c
_____ Ruby-crowned Kinglet	*REGULUS CALENDULA*	c	r	c	u
_____ Western Bluebird	*SIALIA MEXICANA*	r	-	r	-
_____ Mountain Bluebird	*SIALIA CURRUCOIDES*	r	-	r	-
_____ Townsend's Solitaire	*MYADESTES TOWNSENDI*	o	r	r	-
_____ Swainson's Thrush*	*CATHARUS USTULATUS*	c	c	u	-
_____ Hermit Thrush	*CATHARUS GUTTATUS*	u	-	u	u
_____ American Robin*	*TURDUS MIGRATORIUS*	c	c	c	u
_____ Varied Thrush*	*IXOREUS NAEVIUS*	c	u	c	c
WAGTAILS AND PIPITS		Spring	Summer	Fall	Winter
_____ American Pipit	*ANTHUS RUBESCENS*	-	-	o	-
WAXWINGS		Spring	Summer	Fall	Winter
_____ Cedar Waxwing*	*BOMBYCILLA CEDRORUM*	u	c	u	r
SHRIKES		Spring	Summer	Fall	Winter
_____ Northern Shrike	*LANIUS EXCUBITOR*	o	-	u	u
STARLINGS AND MYNAS		Spring	Summer	Fall	Winter
_____ European Starling*	*STURNUS VULGARIS*	c	c	c	c
VIREOS		Spring	Summer	Fall	Winter
_____ Solitary Vireo*	*VIREO SOLITARIUS*	r	-	r	-
_____ Hutton's Vireo*	*VIREO HUTTONI*	u	u	u	u
_____ Warbling Vireo*	*VIREO GILVUS*	u	u	o	-
WARBLERS		Spring	Summer	Fall	Winter
_____ Orange-crowned Warbler*	*VERMIVORA CELATA*	c	c	u	-
_____ Yellow Warbler*	*DENDROICA PETECHIA*	u	u	r	-
_____ Yellow-rumped Warbler*	*DENDROICA CORONATA*	c	u	u	c

APPENDIX C:
Avian Species in Willapa Bay

	Species	Scientific Name	Abundance by season			
_____	Black-throated Gray Warbler*	*DENDROICA NIGRESCENS*	c	c	u	-
_____	Townsend Warbler	*DENDROICA TOWNSENDI*	c	-	u	u
_____	Hermit Warbler	*DENDROICA OCCIDENTALIS*	r	r	-	-"
_____	Palm Warbler	*DENDROICA PALMARUM*	-	-	r	r
_____	MacGillivray's Warbler	*OPORORNIS TOLMIEI*	r	r	-	-"
_____	Common Yellowthroat*	*GEOTHLYPIS TRICHAS*	c	c	u	-
_____	Wilson's Warbler*	*WILSONIA PUSILLA*	c	c	u	-
TANAGERS			Spring	Summer	Fall	Winter
_____	Western Tanager*	*PIRANGA LUDOVICIANA*	u	u	o	-
GROSBEAKS AND BUNTINGS			Spring	Summer	Fall	Winter
_____	Black-headed Grosbeak*	*PHEUCTICUS MELANOCEPHALUS*	u	u	r	-
TOWHEES AND SPARROWS			Spring	Summer	Fall	Winter
_____	Rufous-sided Towhee*	*PIPILO ERYTHROPHTHALMUS*	u	u	c	c
_____	Chipping Sparrow	*SPIZELLA PASSERINA*	r	-	r	-
_____	Savannah Sparrow*	*PASSERCULUS SANDWICHENSIS*	c	c	u	-
_____	Fox Sparrow	*PASSERELLA ILIACA*	u	-	u	u
_____	Song Sparrow*	*MELOSPIZA MELODIA*	c	c	c	c
_____	Lincoln's Sparrow	*MELOSPIZA LINCOLNII*	r	-	r	-
_____	White-throated Sparrow	*ZONOTRICHIA ALBICOLLIS*	o	o	-	-
_____	Golden-crowned Sparrow	*ZONOTRICHIA ATRICAPILLA*	c	-	c	c
_____	White-crowned Sparrow*	*ZONOTRICHIA LEUCOPHRYS*	c	c	c	u
_____	Dark-eyed Junco*	*JUNCO HYEMALIS*	c	c	c	c
_____	Lapland Longspur	*CALCARIUS LAPPONICUS*	r	-	c	r
_____	Snow Bunting	*PLECTROPHENAX NIVALIS*	-	-	o	o
BLACKBIRDS, MEADOWLARKS AND ORIOLES			Spring	Summer	Fall	Winter
_____	Red-winged Blackbird*	*AGELAIUS PHOENICEUS*	c	c	c	c
_____	Western Meadowlark*	*STURNELLA NEGLECTA*	u	u	u	u
_____	Yellow-headed Blackbird	*XANTHOCEPHALUS XANTHOCEPHALUS*	r	-	-	-

APPENDIX C:
Avian Species in Willapa Bay

	Species	Scientific Name	Abundance by season			
_____	Brewer's Blackbird*	*EUPHAGUS CYANOCEPHALUS*	c	c	u	u
_____	Brown-headed Cowbird*	*MOLOTHRUS ATER*	c	c	u	r
_____	Bullock's Oriole*	*ICTERUS BULLOCKII*	o	o	r	-"
FINCHES			Spring	Summer	Fall	Winter
_____	Purple Finch*	*CARPODACUS PURPUREUS*	c	c	u	u
_____	House Finch*	*CARPODACUS MEXICANUS*	c	c	c	c
_____	Red Crossbill*	*LOXIA CURVIROSTRA*	u	c	u	u
_____	Common Redpoll	*CARDUELIS FLAMMEA*	-	-	-	r
_____	Pine Siskin*	*CARDUELIS PINUS*	c	o	c	c
_____	American Goldfinch*	*CARDUELIS TRISTIS*	u	c	c	r
WEAVER FINCHES			Spring	Summer	Fall	Winter
_____	House Sparrow*	*PASSER DOMESTICUS*	c	c	c	c"

Notes: a = abundant, c = common, u = uncommon, o = occasional, r = rare, * = known to nest in the area"

Appendix D

Terrestrial and Amphibious Wildlife in the Wallapa Bay Watershed

APPENDIX D:
Terrestrial and Amphibious Wildlife in the Wallapa Bay Watershed

MARSUPIALS		
_____	Virginia opossum	*DIDELPHIS VIRGINIANA*
INSECTIVORES		
_____	Vagrant Shrew	*SOREX VAGRANS*
_____	Dusky Shrew	*SOREX MONTICOLUS*
_____	Marsh Shrew	*NEOSOREX PALUSTRIS*
_____	Trowbridge's Shrew	*SOREX TROWBRIDGII*
_____	Shrew-Mole	*NEUROTRICHUS GIBBSII*
_____	Townsend's Mole	*SCAPANUS TOWNSENDII*
_____	Coast Mole	*SCAPANUS ORARIUS*
BATS		
_____	Little Brown Myotis	*MYOTIS LUCIFUGUS*
_____	Yuma Myotis	*MYOTIS YUMANENSIS*
_____	Long-eared Myotis	*MYOTIS EVOTIS*
_____	Long-legged Myotis	*MYOTIS VOLANS*
_____	California Myotis	*MYOTIS CALIFORNICUS*
_____	Silver-haired Bat	*LASIONYCTERIS NOCTIVAGANS*
_____	Big Brown Bat	*EPTESICUS FUSCUS*
_____	Hoary Bat	*LASIURUS CINEREUS*
RABBITS AND HARES		
_____	Snowshoe Hare	*LEPUS AMERICANUS*
RODENTS		
_____	Mountain Beaver	*APLODONTIA RUFA*
_____	Townsend's Chipmunk	*TAMIAS TOWNSENDII*
_____	Douglas Squirrel	*TAMIASCIURUS DOUGLASII*
_____	Northern Flying Squirrel	*GLAUCOMYS SABRINUS*
_____	Beaver	*CASTOR CANADENSIS*
_____	Deer Mouse	*PEROMYSCUS MANICULATUS*
_____	Forest Deer Mouse	*PEROMYSCUS MANICULATUS GRACILIS*
_____	Bushy-tailed Woodrat	*NEOTOMA CINEREA*
_____	Southern Red-backed Vole	*CLETHRIONOMYS GAPPERI*
_____	Townsend's Vole	*MICROTUS TOWNSENDII*
_____	Long-tailed Vole	*MICROTUS LONGICAUDUS*
_____	Oregon Vole	*MICROTUS OREGONI*
_____	Muskrat	*ONDATRA ZIBETHICUS*
_____	Norway Rat	*RATTUS NORVEGICUS*
_____	Pacific Jumping Mouse	*ZAPUS TRINOTATUS*
_____	Porcupine	*ERETHIZON DORSATUM*
_____	Nutria	*MYOCASTOR COYPUS*
CARNIVORES		
_____	Coyote	*CANIS LATRANS*
_____	Black Bear	*URSUS AMERICANUS*
_____	Raccoon	*PROCYON LOTOR*
_____	Pine Marten	*MARTES AMERICANA*
_____	Long-tailed Weasel	*MUSTELA FRENATA*

APPENDIX D:
Terrestrial and Amphibious Wildlife in the Wallapa Bay Watershed

_____	Mink	*MUSTELA VISON*
_____	Striped Skunk	*MEPHITIS MEPHITIS*
_____	River Otter	*LUTRA CANADENSIS*
_____	Bobcat	*LYNX RUFUS*
_____	Cougar	*FELIS CONCOLOR*

WHALES, DOLPHINS, AND PORPOISES

_____	Gray Whale	*ESCHRICHTIUS ROBUSTUS*
_____	Harbor Porpoise	*PHOCOENA PHOCOENA*

SEALS AND SEA LIONS

_____	Stellar Sea Lion	*EUMETOPIAS JUBATUS*
_____	California Sea Lion	*ZALOPHUS CALIFORNIANUS*
_____	Harbor Seal	*PHOCA VITULINA*
_____	Northern Fur Seal	*CALLORHINUS URSINUS*

DEER

_____	Roosevelt Elk	*CERVUS ELAPHUS ROOSEVELTI*
_____	Black-tailed Deer	*ODOCOILEUS HEMIONUS COLUMBIANUS*
_____	Columbian White-tailed Deer	*ODOCOILEUS VIRGINIANUS LEUCURUS*

AMPHIBIANS

BULLFROG	*RANA CATESBEIANA*
CASCADE TORRENT SALAMANDER	*RHYACOTRITON CASCADAE*
CASCADES FROG	*RANA CASCADAE*
COLUMBIA SPOTTED FROG	*RANA LUTEIVENTRIS*
COLUMBIA TORRENT SALAMANDER	*RHYACOTRITON KEZERI*
COPE'S GIANT SALAMANDER	*DICAMPTODON COPEI*
DUNN'S SALAMANDER	*PLETHODON DUNNI*
ENSATINA	*ENSATINA ESCHSCHOLTZII*
GREAT BASIN SPADEFOOT	*SPEA INTERMONTANA*
GREEN FROG	*RANA CLAMITANS*
LARCH MOUNTAIN SALAMANDER	*PLETHODON LARSELLI*
LONG-TOED SALAMANDER	*AMBYSTOMA MACRODACTYLUM*
NORTHERN LEOPARD FROG	*RANA PIPIENS*
NORTHWESTERN SALAMANDER	*AMBYSTOMA GRACILE*
OLYMPIC TORRENT SALAMANDER	*RHYACOTRITON OLYMPICUS*
OREGON SPOTTED FROG	*RANA PRETIOSA*
PACIFIC GIANT SALAMANDER	*DICAMPTODON TENEBROSUS*
PACIFIC TREEFROG	*HYLA REGILLA*
RED-LEGGED FROG	*RANA AURORA*
ROCKY MOUNTAIN TAILED FROG	*ASCAPHUS MONTANUS*
ROUGHSKIN NEWT	*TARICHA GRANULOSA*
TAILED FROG	*ASCAPHUS TRUEI*
TIGER SALAMANDER	*AMBYSTOMA TIGRINUM*
VAN DYKE'S SALAMANDER	*PLETHODON VANDYKEI*
WESTERN REDBACK SALAMANDER	*PLETHODON VEHICULUM*
WESTERN TOAD	*BUFO BOREAS*
WOOD FROG	*RANA SYLVATICA*
WOODHOUSE'S TOAD	*BUFO WOODHOUSII*

APPENDIX D:
Terrestrial and Amphibious Wildlife in the Wallapa Bay Watershed

REPTILES

CALIFORNIA MOUNTAIN KINGSNAKE	*LAMPROPELTIS ZONATA*
COMMON GARTER SNAKE	*THAMNOPHIS SIRTALIS*
GOPHER SNAKE	*PITUOPHIS CATENIFER*
GREEN SEA TURTLE	*CHELONIA MYDAS*
LEATHERBACK SEA TURTLE	*DERMOCHELYS CORIACEA*
LOGGERHEAD SEA TURTLE	*CARETTA CARETTA*
NIGHT SNAKE	*HYPSIGLENA TORQUATA*
NORTHERN ALLIGATOR LIZARD	*ELGARIA COERULEA*
NORTHWESTERN GARTER SNAKE	*THAMNOPHIS ORDINOIDES*
PACIFIC GOPHER SNAKE	*PITUOPHIS CATENIFER CATENIFER*
PAINTED TURTLE	*CHRYSEMYS PICTA*
POND SLIDER	*PSEUDEMYS SCRIPTA*
RACER	*COLUBER CONSTRICTOR*
RINGNECK SNAKE	*DIADOPHIS PUNCTATUS*
RUBBER BOA	*CHARINA BOTTAE*
SAGEBRUSH LIZARD	*SCELOPORUS GRACIOSUS*
SHARPTAIL SNAKE	*CONTIA TENUIS*
SHORT-HORNED LIZARD	*PHRYNOSOMA DOUGLASSI*
SIDE-BLOTCHED LIZARD	*UTA STANSBURIANA*
SNAPPING TURTLE	*CHELYDRA SERPENTINA*
SOUTHERN ALLIGATOR LIZARD	*ELGARIA MULTICARINATA*
STRIPED WHIPSNAKE	*MASTICOPHIS TAENIATUS*
WESTERN FENCE LIZARD	*SCELOPORUS OCCIDENTALIS*
WESTERN POND TURTLE	*CLEMMYS MARMORATA*
WESTERN RATTLESNAKE	*CROTALUS VIRIDIS*
WESTERN SKINK	*EUMECES SKILTONIANUS*
WESTERN TERRESTRIAL GARTER SNAKE	*THAMNOPHIS ELEGANS*

Appendix E

Threatened and Endangered Species and Species of Concern within Washington State, and the Potential for Imazapyr Exposure from *Spartina* Treatment

APPENDIX E:
Threatened and Endangered Species and Species of Concern within Wahsington State, and the Potential for Imazapyr Exposure from *Spartina* Treatment

Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
Cascades Frog	*Rana cascadae*	Amphibian	FCo	SM	N	Mountain meadows, streams, ponds, and lakes above 3,000' (900 m), in the water and vegetation around it.
Columbia Spotted Frog	*Rana luteiventris*	Amphibian	FCo	SC	P	Mountainous areas near cold streams and lakes, wetlands. Reported to move overland in spring and summer.
Columbia Torrent Salamander	*Rhyacotriton kezeri*	Amphibian	FCo	SC	N	Live on the edges of cold, clear mountain streams. Can be found under gravel or in waterfall spray zones. Sometimes found away from streams during rainy season.
Larch Mountain Salamander	*Plethodon larselli*	Amphibian	FCo	SS	N	Prefers lava talus slopes and outcrops in dense Douglas fir stands; 100-3,900' (30-1,189 m).
Northern Leopard Frog	*Rana pipiens*	Amphibian	FCo	SE	N	From freshwater sites with profuse vegetation to brackish marshes and moist fields; from desert to mountain meadow. Not found on West Coast.
Olympic Torrent Salamander	*Rhyacotriton olympicus*	Amphibian	FCo	SM	N	Live on the edges of cold, clear mountain streams. Can be found under gravel or in waterfall spray zones. Sometimes found away from streams during rainy season.
Oregon Spotted Frog	*Rana pretiosa*	Amphibian	FC	SE	N	Mountainous areas near cold streams and lakes, wetlands. Reported to move overland in spring and summer.
Red-legged Frog	*Rana aurora*	Amphibian	FCo	none	P	Usually found near ponds or other permanent water with extensive vegetation. Also likes damp woods.
Tailed Frog	*Ascaphus truei*	Amphibian	FCo	SM	N	Usually clear, cold swift-flowing mountain streams; sometimes found near water in damp forests or in more open areas in cold, wet weather.
Van Dyke's Salamander	*Plethodon vandykei*	Amphibian	FCo	SC	N	Streams, mountain seeps, waterfall splash zones, and talus slopes at 1,500-5,000' (457-1,524 m).
Western Toad	*Bufo boreas*	Amphibian	FCo	SC	P	Near springs, streams, meadows, woodlands on Pacific Coast.
Beller's Ground Beetle	*Agonum belleri*	Beetle	FCo	SC	N	A terrestrial species, not found in estuary habitats
Hatch's Click Beetle	*Eanus hatchii*	Beetle	FCo	SC	N	A terrestrial species, not found in estuary habitats
Aleutian Canada Goose	*Branta canadensis leucopareia*	Bird	FCo	ST	P	An uncommon visitor to coastal

APPENDIX E:
Threatened and Endangered Species and Species of Concern within Wahsington State, and the Potential for Imazapyr Exposure from *Spartina* Treatment

Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
American Peregrine Falcon	*Falco peregrinus anatum*	Bird	FCo	SS	P	Open country, especially along rivers; also near lakes, along coasts, and in cities. Migrates chiefly along coasts. Breeds from Alaska and Canadian Arctic south locally through mountainous West, and sparingly in East. Winters coastal, north to British Columbia and Massachusetts. Several Subspecies also represented by the WDFW as species of concern; these include the Peale's Peregrine.
Bald Eagle	*Haliaeetus leucocephalus*	Bird	FT	ST	Y	Common resident to Puget Sound and Coastal WA
Black Tern	*Childonias niger*	Bird	FCo	SM	P	Freshwater marshes and marshy lakes in summer; sandy coasts on migration and in winter. No sightings recorded in Willapa, but suitable habitat.
Brown Pelican	*Pelecanus occidentalis*	Bird	FE	SE	P	Resident of Pacific Coast from southern California south to Chile, dispersing northward as far as southern British Columbia after nesting season. Also on Atlantic Coast from North Carolina south to Venezuela.
Burrowing Owl	*Athene cunicularia*	Bird	FCo	SC	N	Plains, deserts, fields, and airports
Cassin's Auklet	*Ptychoramphus aleuticus*	Bird	FCo	SC	N	Open ocean. Nests on sea cliffs and isolated headlands.
Ferruginous Hawk	*Buteo regalis*	Bird	FCo	ST	N	Prairies, brushy open country, badlands.
Harlequin Duck	*Histrionicus histrionicus*	Bird	FCo	none	P	Swift-moving streams in summer; rocky, wave-lashed coasts and jetties in winter.
Loggerhead Shrike	*Lanius ludovicianus*	Bird	FCo	SC	P	Grasslands, orchards, and open areas with scattered trees; open grassy woodlands; deserts in the West.
Marbled Murrelet	*Brachyramphus marmoratus*	Bird	FT	ST	Y	Breeds in coastal rain forests; inshore waters at other times.
Northern Goshawk	*Accipiter gentilis*	Bird	FCo	SC	P	Breeds in coniferous forests; winters in farmlands, woodland edges, and open country. Rarely recorded from Willapa.
Olive-sided Flycatcher	*Contopus borealis*	Bird	FCo	none*	Y	Boreal spruce and fir forests, usually near openings, burns, ponds, and bogs.

APPENDIX E:
Threatened and Endangered Species and Species of Concern within Wahsington State, and the Potential for Imazapyr Exposure from *Spartina* Treatment

Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
Oregon Vesper Sparrow	*Pooecetes gramineus affinis*	Bird	FCo	SC	P	Prefers relatively dry and sparsely vegetated areas with scattered tall structures used for song perches.
Sage-grouse	*Centrocercus urophasianus*	Bird	FC	ST	N	A rare shrub-steppe species of the Columbia Plateau in areas where disturbance factors have disrupted mature shrub-steppe habitat
Sharp-tailed Grouse	*Tympanuchus phasianellus*	Bird	FCo	ST	N	Found in the North Central Cascades at altitude. Not coastal
Short-tailed Albatross	*Phoebastria albatrus*	Bird	FE	SC	N	An open ocean piscivore. Does not frequent coastal areas along Washington's Coast. An extremely rare bird.
Slender-billed White-breasted Nuthatch	*Sitta carolinensis aculeata*	Bird	FCo	SC	Y	Large trees in deciduous and mixed forests.
Snowy Plover	*Charadrius alexandrinus*	Bird	FT	SE	Y	Sandy coastal beaches and shore of salt ponds and alkaline lakes, from Washington to Baha, California
Spotted Owl	*Strix occidentalis*	Bird	FT	SE	P	Wet, coniferous, old-growth forests; innermost tidal denditricchannels along the Willapa Bay coast retain some adjacent old growth habitat potentially supportable for spotted owl
Streaked Horned Lark	*Eremophila alpestris strigata*	Bird	FC	SC	P	Grasslands and lowland prairies.
Tufted Puffin	*Fratercula cirrhata*	Bird	FCo	SC	P	Nests on vertical sea cliffs, in colonies or singly. Feeds at sea.
Willow Flycatcher	*Empidonax traillii*	Bird	FCo	none*	P	Dense streamside thickets, swampy thickets, wooded lakeshores and streams.
Yellow-billed Cuckoo	*Coccyzus americanus*	Bird	FC	SC $B,RI	P	Moist thickets, willows, overgrown pastures, and orchards
Island Marble	*Euchloe ausonides insulanus*	Butterfly	FCo	SC	P	Grasslands and Garry oak woodlands.
Makah (Queen Charlotte) Copper	*Lycaena mariposa charlottensis*	Butterfly	FCo	SC	P	Sedge dominated fens (prairie terrain) containing swamp gentian within the coastal rainforests of the Olympic Peninsula.
Mardon Skipper	*Polites mardon*	Butterfly	FC	SE	P	Fescue-dominated native prairie grasslands.
Oregon Silverspot Butterfly	*Speyeria zerene hippolyta*	Butterfly	FT	SE	P	Coastal meadows in salt spray zone. Spartina meadows have displaced some habitats where its forage, Viola adunca, might otherwise grow.

APPENDIX E:
Threatened and Endangered Species and Species of Concern within Wahsington State, and the Potential for Imazapyr Exposure from *Spartina* Treatment

Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
Taylor's (Whulge) Checkerspot	*Euphydras editha taylori*	Butterfly	FC	SC	P	Native grasslands, prairies, and oak woodlands of Vancouver Island, the Puget Sound basin, and the Willamette Valley.
Valley Silverspot	*Speyeria zerene bremnerii*	Butterfly	FCo	SC	P	Moist Garry Oak ecosystems.
Bull Trout (Coastal/Puget Sound)	*Salvelinus confluentus*	Fish	FT	SC	Y	Coastal and mountain streams; deep pool of large, cold rives; deep cold lakes; rarely brackish and salt water.
Bull Trout	*Salvelinus confluentus*	Fish	FT	SC	Y	Coastal and mountain streams; deep pool of large, cold rives; deep cold lakes; rarely brackish and salt water.
Bull Trout (Columbia Basin)	*Salvelinus confluentus*	Fish	FT	SC	Y	Coastal and mountain streams; deep pool of large, cold rives; deep cold lakes; rarely brackish and salt water.
Chinook Salmon (Upper Columbia SP)	*Oncorhynchus tshawytscha*	Fish	FE	SC	N	Coastal streams and rivers, intertidal areas , and open ocean.
Chinook Salmon (Snake R. Fall)	*Oncorhynchus tshawytscha*	Fish	FT	SC	Y	Coastal streams and rivers, intertidal areas , and open ocean.
Chinook Salmon (Puget Sound)	*Oncorhynchus tshawytscha*	Fish	FT	SC	Y	Coastal streams and rivers, intertidal areas , and open ocean.
Chinook Salmon (Lower Columbia)	*Oncorhynchus tshawytscha*	Fish	FT	SC	Y	Coastal streams and rivers, intertidal areas , and open ocean.
Chinook Salmon (Snake R. SP/SU)	*Oncorhynchus tshawytscha*	Fish	FT	SC	N	Coastal streams and rivers, intertidal areas , and open ocean.
Chum Salmon (Hood Canal SU)	*Oncorhynchus keta*	Fish	FT	SC	Y	Coastal waters; enters streams to spawn. Naturally spawned populations in the Columbia drainage and naturally spawned summer-run populations in the Hood Canal and its tributaries in Olympic Peninsula rivers between Hood Canal and Dungeness Bay are classified as threatened in Oregon and Washington.
Chum Salmon (Lower Columbia)	*Oncorhynchus keta*	Fish	FT	SC	Y	Coastal streams and rivers, intertidal areas , and open ocean.
Coastal Cutthroat	*Oncorhynchus clarki clarki*	Fish	FCo	none	Y	Small, cool headwater streams and larger rivers; ponds and lakes; sea-run form in intertidal areas and inshore marine waters.

APPENDIX E:
Threatened and Endangered Species and Species of Concern within Wahsington State, and the Potential for Imazapyr Exposure from *Spartina* Treatment

Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
Packific Hake (C. Puget Sound)	*Merluccius productus*	Fish	FC	SC	Y	Coastal Waters as juveniles: Open waters as adults.
Pacific Herring (Discovery Bay)	*Clupea pallasi*	Fish	FC	SC	P	Frequently offshore, but usually inshore in harbors and large estuaries during spawning.
Pacific Herring (Cherry Point)	*Clupea pallasi*	Fish	FC	SC	P	Frequently offshore, but usually inshore in harbors and large estuaries during spawning.
Pacific Lamprey	*Lampetra tridentata*	Fish	FCo	none	P	Migrate as adults to ocean. Widespread and often well offshore. Found in shallow waters to 820 ft.
River Lamprey	*Lampetra ayresi*	Fish	FCo	SC	P	Migrate as adults to ocean. Widespread and often well offshore. Found in shallow waters to 820 ft.
Rock Bass	*Ambloplites rupestris*	Fish	none	none	N	Vegetated and brushy stream margins of lakes. Most common in clear, silt free rocky streams
Salish Sucker	*Catostromus SP.*	Fish	none	SM	N	Pools and runs of small cool headwaters and creeks.
Sand Roller	*Percopsis transmontana*	Fish	none	SM	N	Quiet backwater and pool margins of small to large rivers.
Sockeye Salmon (Snake R.)	*Oncorhynchus nerka*	Fish	FE	SC	N	Streams and rivers; lakes; intertidal areas and open ocean
Sockeye Salmon (Ozette Lake)	*Oncorhynchus nerka*	Fish	FT	SC	N	Streams and rivers; lakes; intertidal areas and open ocean
Steelhead (Upper Columbia)	*Oncorhynchus mykiss*	Fish	FE	SC	P	Clear, cool streams and rivers; lakes; intertidal areas and open ocean
Steelhead (Snake River)	*Oncorhynchus mykiss*	Fish	FT	SC	P	Clear, cool streams and rivers; lakes; intertidal areas and open ocean
Steelhead (Middle Columbia)	*Oncorhynchus mykiss*	Fish	FT	SC	P	Clear, cool streams and rivers; lakes; intertidal areas and open ocean
Steelhead (Lower Columbia)	*Oncorhynchus mykiss*	Fish	FT	SC	Y	Clear, cool streams and rivers; lakes; intertidal areas and open ocean
Westslope Cutthroat	*Oncorhynchus clarki lewisi*	Fish	FCo	none	N	Small, cool streams and rivers; lakes

APPENDIX E:
Threatened and Endangered Species and Species of Concern within Wahsington State, and the Potential for Imazapyr Exposure from *Spartina* Treatment

Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
Black Right Whale	*Balaena glacialis*	Mammal	FE	SE	N	A marine pelagic species.
Blue Whale	*Balaenoptera musculus*	Mammal	FE	SE	N	A marine pelagic species.
California Bighorn Sheep	*Ovis canadensis Californiana*	Mammal	FCo	none	N	Semi-open, precipitous terrain with rocky slopes, ridges, and cliffs or canyons; from alpine meadow to hot desert.
Cathlamet Pocket Gopher	*Thomomys mazama louiei*	Mammal	FC	SC	N	Prairies to mountain meadows. Known only from the type locality in Wahkiakum County. It may now be extinct.
Columbian White-tailed Deer	*Odocoileus virginianus leucurus*	Mammal	FE	SE	P	Coastal and inland floodplains, in woodlands and scrub. Some habitat along Willapa Bay may be suitable for this species, if it expands from its current range.
Destruction Island Shrew	*Sorex trowbridgii destrructioni*	Mammal	FCo	none	N	Numerous habitats; most common in moist fields, bogs, marshes, and moist woods.
Fin Whale	*Balaenoptera physalus*	Mammal	FE	SE	N	A marine pelagic species.
Fisher	*Martes pennanti*	Mammal	FCo	SE	N	Not coastal--a species of mature, dense forested habitat.
Fringed Myotis	*Myotis thysanodes*	Mammal	FCo	SM	N	Oak, pinyon, and juniper forests; desert scrub. Roosts in caves, mines, buildings, and other protected locations
Gray Wolf	*Canis lupus*	Mammal	FT	SE	N	Open tundra and forests
Grizzly Bear	*Ursus arctos*	Mammal	FT	SE	N	Only an occasional visitor to Washington wilderness habitat in the North Cascades; not coastal
Humpback Whale	*Megaptera novaeangliae*	Mammal	FE	SE	N	A marine pelagic species.
Kincaid's Meadow Vole	*Microtus pennsylvanicus*	Mammal	FCo	SM	P	Lush, grassy fields; also marshes, swamps, woodland glades, and mountaintops.
Least Chipmunk	*Tamias minimus*	Mammal	none	none*	P	Pastures, piney woods, rocky cliffs, and sagebrush deserts; often abundant in open coniferous forests.
Long-eared Myotis	*Myotis evotis*	Mammal	FCo	SM	Y	Variety of habitats, from sage to high-altitude coniferous forests; mostly found in forested regions. Sometimes roosts in buildings

APPENDIX E:
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Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
Long-legged Myotis	*Myotis volans*	Mammal	FCo	SM	Y	Mainly coniferous forests. In summer, roosts in trees, crevices, or buildings
Lynx	*Lynx canadensis*	Mammal	FT	ST	N	Deep, coniferous forest interspersed with rocky areas, bogs, swamps, or thickets
Mazama (Western) Pocket Gopher	*Thomomys mazama*	Mammal	FC	SC	N	Prairies to mountain meadows
Olympic Pocket Gopher	*Thomomys mazama melanops*	Mammal	FC	SC	N	Prairies to mountain meadows
Pacific Townsend's Big-eared Bat	*Coryhorhinus townsendii*	Mammal	FCo	SC	P	occur in a variety of habitats from desert shrub to deciduous and coniferous forests at a wide range of elevations
Pallid Townsend's Big-eared Bat	*Coryhorhinus Townsendii*	Mammal	FCo	SC	P	occur in a variety of habitats from desert shrub to deciduous and coniferous forests at a wide range of elevations
Preble's Shrew	*Sorex preblei*	Mammal	FCo	SM	P	Open areas, woodlands, forests
Pygmy Rabbit	*Brachylagus idahoensis*	Mammal	FE	SE	N	It is patchily distributed in the sagebrush-dominated areas of the Great Basin
Sea Otter	*Enhydra lutris*	Mammal	FCo	SE	N	Coastal waters within a mile (1.5 km) of shore; especially rocky shallows with kelp beds and abundant shellfish
Sei Whale	*Balaenoptera borealis*	Mammal	FE	SE	N	A marine pelagic species.
Shelton Pocket Gopher	*Thomomys mazama couchi*	Mammal	FC	SC	P	Native grasslands, prairies and oak woodlands of Mason County, Washington.
Small-footed Myotis	*Myotis ciliolabrum*	Mammal	FCo	SM	P	Usually lives in arid, rocky habitats including forests and woodlands.
Sperm Whale	*Physeter macrocephalus*	Mammal	FE	SE	N	A marine pelagic species.
Steller Sea Lion	*Eumetopias jubatus*	Mammal	FT	ST	N	Stellers are found throughout the North Pacific Rim from Japan to central California. Unlike California sea lions, Stellers tend to remain off shore or haul out in unpopulated areas.
Townsend's Big-eared Bat	*Coryhorhinus tonsendii*	Mammal	FCo	SC	P	Western deserts and dry pine forests.

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Common Name	Scientific Name	Animal Type	Federal Status	State Status	Potential Estuary Presence?	Habitat and Range
Washington Ground Squirrel	*Spermophilus washingtoni*	Mammal	FC	SC	P	Sagebrush and grassland habitats in Southeastern Washington and small area of Oregon in Gilliam, Morrow, and Umatilla Counties.
Western Gray Squirrel	*Sciurus griseus*	Mammal	FCo	ST	P	Woodlands and coniferous forests, particularly Quercus garryana woodlands.
Wolverine	*Gulo gulo*	Mammal	FCo	SC	N	A wide range of habitats with circumpolar distribution, North American primarily montane coniferous habitats.
Woodland Caribou	*Rangifer tarandus*	Mammal	FE	SE	N	Usually found in small herds in boreal forests from British Columbia to Newfoundland
Yelm Pocket Gopher	*Thomomys mazama yelmensis*	Mammal	FC	SC	P	Native grasslands, prairies and oak woodlands of western Washington.
Yuma Myotis	*Myotis yumanensis*	Mammal	FCo	none*	P	Yuma myotis occur in a variety of habitats including riparian, and scrublands and deserts, and forests.
California Floater	*Anodonta californiensis*	Mollusk	FCo	SC	N	Shallow areas of clean, clear lakes, ponds and large rivers. They prefer lower elevations and a soft, silty substrate to burrow into.
Giant Columbia Spire Snail	*Fluminicola columbiana*	Mollusk	FCo	SC	N	Relatively pristine colder, clear streams of the Snake-Columbia River system with a high dissolved oxygen content.
Newcomb's Littorine Snail	*Algamorda subrotundata*	45	FCo	SC	P	Rocky shores in the upper intertidal zone of marine coastal environments.
Fender's Soliperlan Stonefly	*Soliperla fenderi*	Other insect	FCo	none	N	Fender's soliperlan stonefly nymphs are exclusively found in seeps in the headwaters of small streams. As adults, stoneflies are poor fliers and live along the shores of the streams.
Lynn's Clubtail	*Gomphus lynnae*	Other insect	FCo	none	N	Clear streams that have relatively open canopies. In Washington, sightings of Columbia clubtail have only been confirmed along the Yakima River in Benton County, Washington.
Green Sea Turtle	*Chelonia mydas*	Reptile	FT	ST	N	Open-ocean species; no breeding colonies in WA
Leatherback Sea Turtle	*Dermochelys coreacea*	Reptile	FE	SE	N	Open-ocean species; no breeding colonies in WA
Loggerhead Sea Turtle	*Caretta caretta*	Reptile	FT	ST	N	Open-ocean species; no breeding colonies in WA

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Sagebrush Lizard	*Sceloporus graciosus*	Reptile	FCo	SC	N	Primarily areas of sagebrush and gravelly soils or fine-sand dunes. Never far from shelter such as stony piles, crevices, animal burrows. Preferred habitat not supported in estuarine conditions.
Western Pond Turtle	*Clemmys Marmorata*	Reptile	FCo	SE	P	Ponds and small lakes with abundant vegetation. Also seen in marshes, slow-moving streams, reservoirs, and occasionally in brackish water.

Note: Fco = federal species of concern; FT = federally listed as threatened; FE = federally endangered;
FC = Federal Candidate Species
SE = State endangered; ST = state threatened; SC = state species of concern
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