Table A-1: Chemical description; degradation rates, products, and pathways; bioaccumulation ratings; and advantages and disadvantages of imazapyr and glyphosate herbicides for estuarine use

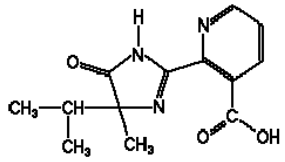
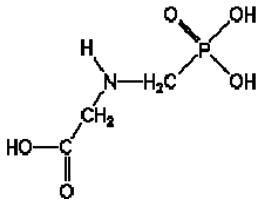
	Imazapyr	Glyphosate
Trade Name (Company)	Habitat® (Bayer Corporation)	Rodeo® (Dow Chemical Company) Aquamaster® (Monsanto Corporation)
Registration No.	81334-34-1	1071-83-6
Formulation	Aqueous solution of isopropylamine salt of imazapyr plus acidifier; active ingredient: 28.7% isopropylamine salt of imazapyr; equivalent to 22.6% imazapyr	Aqueous solution of isopropylamine salt of glyphosate; technical formulation contains 2,4-nitrosoglyphosate ("NNG") impurity; active ingredient: 53.8% glyphosate isopropylamine salt; equivalent to 48.0% glyphosate
Chemical name	IUPAC: (*RS*)-2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)nicotinic acid CAS: 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid	IUPAC: *N*-(phosphonomethyl)glycine CAS: *N*-(phosphonomethyl)glycine
Chemical formula		
Formula	$C_{13}H_{15}N_3O_3$	$C_3H_8NO_5P$
Herbicide family	Imidazolinone	Organophosphorus
Mode of action	Systemic, broad-spectrum (non-selective); amino acid synthesis inhibitor, specifically, inhibits acetohydroxyacid synthase ("AHAS") aka acetolactase synthase ("ALS"), the first enzyme in the synthesis of branched-chain aliphatic amino acids (valine, leucine, and isoleucine) and as a result inhibits protein synthesis and cell growth	Systemic, broad-spectrum (non-selective); amino acid synthesis inhibitor; inhibits 5-enolpyruvylshikimate-3-phosphate synthase, needed by plants to synthesize chorismate, an intermediate metabolic product in the synthesis of aromatic amino acids
Molecular weight	261.28 g/mole imazapyr 320.42 g/mole imazapyr isopropylamine salt	169.08 g/mole glyphosate 228.22 g/mole glyphosate isopropylamine salt

Table A-1 contd.: Chemical description; degradation rates, products, and pathways; bioaccumulation ratings; and advantages and disadvantages of imazapyr and glyphosate herbicides for estuarine use

	Imazapyr	Glyphosate
Specific gravity	1.04–1.07	0.5
Minimum drying time	1 hour	6 hours
Highest proposed application rate	1.5 lb a.e./acre	10.8 lb/acre
Rate of kill	Very slow	Relatively slow
Volatility	Vapor pressure = 1.8×10^{-11} mm Hg Henry's Law constant of 7.1×10^{-17} atm m^3/mole No volatilization from dry soil surfaces; low volatilization of imazapyr from water or moist soil surfaces.	Extremely low vapor pressure, thus, negligible risk of movement through volatility
Solubility	Water: 11,272 mg/L	Water: ~12,000 mg/L
Soil organic carbon adsorption coefficient	K_{oc} = 8.81 Very low K_{oc} indicates low sorption potential.	K_{oc} = 24,000 Very high K_{oc} indicates tight sorption to most soils, suspended solids, and sediments in the environment.
Octanol/water partition coefficient	K_{ow} = 0.22, 1.3	K_{ow} = 0.0003
Degradation pathways	Slow anaerobic microbial degradation. No degradation under anaerobic conditions. Rapid photolysis in water.	Primarily degraded by microbes and fungi in soil or water, under both aerobic and anaerobic conditions. Photodegradation in water and soil are not expected to contribute significantly to glyphosate degradation.
Degradation products	Quinolinic acid	Aminomethylphosphonic acid ("AMPA"); further degraded to carbon dioxide and phosphate.
Half-life in soil	$t_{½}$ = 25–141 days	Average $t_{½}$ = 32 days, based on 47 agricultural and forestry studies. In most cases, >90% degraded within six months after application.
Half-life in benthic sediment	$t_{½}$ = <2 to 7 days	$t_{½}$ = >3 to 12 months

Table A-1 contd.: Chemical description; degradation rates, products, and pathways; bioaccumulation ratings; and advantages and disadvantages of imazapyr and glyphosate herbicides for estuarine use

	Imazapyr	Glyphosate
Half-life in water	No detectable degradation due to hydrolysis up to 30 days, pH 5-7 Average $t_{½}$ = 1-4 days (photolysis)	$t_{½}$ = 7–14 days
Bioaccumulation	BCF = 3; Low potential for bioaccumulation	BCF in fish after 10-14 day exposure period = 0.2 to 0.3 Low potential for bioaccumulation in aquatic animals; poorly absorbed when ingested by terrestrial mammals; any absorbed glyphosate is rapidly eliminated resulting in minimal tissue retention.
Advantages for estuarine use	— Rapid photolysis in water — Shorter minimum drying time than glyphosate — No adsorption to particles — Formulation can be mixed with salt water — Aerial applications require an order of magnitude lower spray volumes than glyphosate — Application is more cost-effective than application of glyphosate — Does not require use of non-ionic surfactants	— Low leaching potential due to strong sorption to soil/sediment particles
Disadvantages for estuarine use	— Increased adverse effects to non-target emerged vegetation due to higher efficacy on vascular plants	— Efficacy hindered by minimum drying time — Inactivated by adsorption to sediment particles — Formulation requires mixing with freshwater, which is not readily available — Aerial applications require large spray volumes, which require frequent refilling of helicopter tanks — Application is expensive — Requires use of non-ionic surfactants

Table A-2: Chemical properties, environmental fate, general toxicity rating, and toxicity of adjuvants

Adjuvant (Manufacturer)	Ingredients[1]	Chemical Properties	Degradation Pathways	General Toxicity Rating	Toxicity (lowest reported)
Non-ionic Surfactants ("NIS")					
R-11® (surface activator) (Wilbur-Ellis Company)	80% octylphenoxy polyethoxyethanol, 20% butanol and compounded silicone	– soluble in lipid and water – flammable – specific gravity = 1.0	Slowly biodegraded by progressive shortening of ethoxylate chain; intermediate breakdown products of polyethylene glycol (anti-freeze) and short-chain ethoxylates	Mammals: practically non-toxic orally, mild skin irritation possible Fish: Moderately toxic Other aquatic biota: slightly toxic	96-hr LC_{50}, rainbow trout 3.8 ppm[2] 96-hr LC_{50}, bluegill sunfish 4.2 ppm[2] 96-hr LC_{50}, juvenile rainbow trout 6 ppm[5] 48-hr LC_{50}, *Daphnia* spp. 19 ppm[3] LD_{50} oral, rabbit >5,840 mg/kg[2] LD_{50} dermal, rabbit >5,000 mg/kg[2]
X-77® (spreader activator) (Valent Corp.)	Alkylarylpoly (oxy-ethylene) glycols, free fatty acids, isopropyl alcohol	– soluble in lipid and water – flammable	Slowly biodegraded by progressive shortening of ethoxylate chain; intermediate breakdown products of polyethylene glycol (anti-freeze) and short-chain ethoxylates	Mammals: practically non-toxic orally Fish and other aquatic biota: moderately toxic	96-hr LC_{50}, rainbow trout 4.2 ppm[2] 96-hr LC_{50}, bluegill sunfish 4.3 ppm[2] 48-hr LC_{50}, *Daphnia* spp. 2 ppm[2] LD_{50} oral, rabbit >5,000 mg/kg[2] LD_{50} dermal, rabbit >5,000 mg/kg[2]
Liberate® (penetrating surfactant, deposition and drift control agent) (Loveland Industries, Inc.)	Phosphatidylcholine (lecithin), methyl esters of fatty acids, alcohol ethoxylate	– emulsifiable – specific gravity = 0.976	Biodegradation presumed rapid due to natural lecithin ingredients	Mammals: practically non-toxic orally, moderate skin irritation possible	96-hr LC_{50}, rainbow trout 17.6 ppm[1] NOEC, rainbow trout 12.5 ppm[1] 48-hr LC_{50}, *Daphnia magna* 9.3 ppm[1] NOEC, *Daphnia magna* 7.5 ppm[1] LD_{50} oral, rat >5,000 mg/kg[1] LD_{50} dermal, rat >5,000 mg/kg[1]
LI-700® (wetting and penetrating surfactant) (Loveland Industries, Inc.)	Phosphatidylcholine (lecithin), methylacetic acid, alkyl polyoxyethylene ether	– emulsifiable – not flammable – specific gravity = 1.03	Biodegradation presumed rapid due to natural lecithin ingredients	Mammals: practically non-toxic orally, causes skin and eye irritation Fish and other aquatic biota: practically non-toxic	96-hr LC_{50}, rainbow trout 17 ppm[2] 24-hr LC_{50}, rainbow trout 22 ppm[2] 96-hr LC_{50}, juv. rainbow trout 700 ppm[5] 96-hr LC_{50}, bluegill sunfish 210 ppm[2] 48-hr LC_{50}, *Daphnia* spp. 170 ppm[3] LD_{50} oral, rat >5,000 mg/kg[2] LD_{50} dermal, rat >5,000 mg/kg[2]
Cygnet Plus (Cygnet Enterprises)	75% d-limonene and related isomers, 15% methylated vegetable oil, 10% alkyl hydroxypoly oxyethylene; manufactured from natural limonene	– flammable – specific gravity = 0.87		Mammals: causes skin and eye irritation; Fish: slightly toxic Other aquatic biota: moderately toxic	NOEC, Ceriodaphnia dubia 3.0 ppm[4] 96-hr LC50 Ceriodaphnia dubia 6.6 ppm[4] NOEC, rainbow trout 30 ppm[4] 96-hr LC50, rainbow trout 45 ppm[4] NOEC, fathead minnow 15 ppm[4] 96-hr LC50, fathead minnow ppm[4]
Esterified Seed Oils ("ESOs") or Mehylated Seed Oils ("MSOs")					
Competitor® Wilbur-Ellis Company)	Ethyl oleate, sorbitan alkyl polyethoxylate ester, dialkyl polyoxy-ethylene glycol	– soluble in water – combustible – specific gravity = 0.9		Fish: slightly toxic Other aquatic biota: practically non-toxic	96-hr LC_{50}, rainbow trout 95 ppm[3] 48-hr LC_{50}, *Daphnia* spp. >100 ppm[3]

Table A-2 contd.: Chemical properties, environmental fate, general toxicity rating, and toxicity of adjuvants

Adjuvant (Manufacturer)	Ingredients[1]	Chemical Properties	Degradation Pathways	General Toxicity Rating	Toxicity (lowest reported)
Crop Oil Concentrates ("COC")					
Agri-Dex® (wetting and penetrating agent) (Helena Chemical Company)	Proprietary; heavy range paraffin-based petroleum oil with polyol fatty acid esters and polyethoxylyated derivatives	– dispersible in water as micelles – moderately flammable	Biodegradation presumed rapid	Mammals: practically non-toxic through oral ingestion, mild skin and eye irritant; Fish and other aquatic biota: practically non-toxic	96-hr LC_{50}, rainbow trout 271 ppm[2] 24-hr LC_{50}, rainbow trout 386 ppm[2] 96-hr LC_{50}, juv. rainbow trout 271 ppm[5] 48-hr LC_{50}, *Daphnia* spp. >1,000 ppm[3] LD_{50} oral, rat 5,010 mg/kg[2] LD_{50} dermal, rabbit >2,020 mg/kg[2]
Silicone-based Surfactants					
Dyne-Amic® (activator, spreader-sticker, wetting and penetrating agent, buffer) (Helena Chemical Company)	Organosilicone , methylated vegetable oil			Fish and other aquatic biota: slightly toxic	96-hr LC_{50}, rainbow trout 23.2 ppm[3] 48-hr LC_{50}, *Daphnia* spp. 60 ppm[3]
Kinetic® (spreader-sticker, wetting agent) (Helena Chemical Company)	Organosilicone , polyoxypropylene-polyoxyethylene copolymer			Fish and other aquatic biota: slightly toxic	96-hr LC_{50}, rainbow trout 13.9 ppm[3] 48-hr LC_{50}, *Daphnia* spp. 60.7 ppm[3]
Colorants					
Blazon® Spray Pattern Indicator "Blue" (Milliken Chemical)	Proprietary; 30% non-ionic polymeric colorant, 70% water	– pH = 7.0 – completely soluble in water – specific gravity = 1.07 – mildly acidic		Mammals: practically non-toxic orally; mild skin irritant; not mutagenic	LD_{50} rat >5,000 mg/kg[1]

[1] Manufacturer specimen labels
[2] Referenced in Entrix 10/03.
[3] Erik Johansen, Washington State Department of Agriculture, Memorandum Re: Summary of Acute Toxicity Data for Five Spray Adjuvants, February 4, 2004.
[4] Pacific Ecorisk, An Evaluation of the Acute Toxicity of "CYGNET PLUS" to *Ceriodaphnia dubia* (water flea), *Oncorhynchus mykiss* (rainbow trout), and *Pimephales promelas* (fathead minnow), December 10, 2004.
[5] King *et al.* 2004.

Table A-3a: Imazapyr herbicide mixture component concentrations and application rates for treatment of non-native *Spartina* in San Francisco Estuary

Application Method	Spray Volume	Formulation	Active Ingredient[1]	Surfactant[2]	Colorant
High volume handheld sprayer	100 gal/acre	0.52-0.75% solution 4-6 pints/100 gal	1-1.5 lb a.e./acre	0.25% v/v NIS with ≥70% a.i.; ~1% v/v MSO, ESO, or VOC; SBS according to label	3 qt/100 gal
Low-volume directed sprayer	20 gal/acre	0.75-1.5% solution 1.2-2.4 pints/20 gal	0.3-0.6 lb a.e./acre	0.25% v/v NIS with ≥70% a.i.; ~1% v/v MSO, ESO, or VOC; SBS according to label	3 qt/100 gal
Broadcast sprayer/ Aerial application	10-30 gal/acre	2.5-7.5% solution 6 pints/10-30 gal	0.5-1.5 lb a.e./acre	0.25% v/v NIS with ≥70% a.i.; ~1% v/v MSO, ESO, or VOC; SBS according to label	0.5-1.5 qt/acre

[1] Active ingredient in Habitat® is imazapyr isopropylamine salt; values expressed as imazapyr acid equivalent
[2] NIS = non-ionic surfactant; MSO = methylated seed oil; ESO = esterified seed oil; VOC = vegetable oil concentrate, SBS = silicone-based surfactant, %v/v = percentage based on volume by volume

Table A-3b: Glyphosate herbicide mixture component concentrations and application rates for treatment of non-native *Spartina* in San Francisco Estuary

Application Method	Spray Volume	Formulation	Active Ingredient[1]	Surfactant[2]*	Colorant
High volume handheld sprayer	100 gal/acre	1-2% solution 1-2 gal/100 gal	4-8 lb a.e./acre	≥0.5% v/v NIS with ≥50% a.i.	3 qt/100 gal
Low-volume directed sprayer	25-200 gal/acre	1-8% solution 1-8 gal/100 gal	1.35-10.8 lbs a.e./acre	≥0.5% v/v NIS with ≥50% a.i.	3 qt/100 gal
Broadcast sprayer/ Aerial application	7-40 gal/acre/ 7-20 gal/acre	4.5-7.5 pints/acre	2.25-3.75 lb a.e./acre	≥0.5% v/v NIS with ≥50% a.i.	0.5-1.5 qt/acre

[1] The active ingredient in Rodeo® and Aquamaster® is glyphosate isopropylamine salt; values are expressed as glyphosate acid equivalent
[2] NIS = non-ionic surfactant, %v/v = percentage based on volume by volume

Table A-4: Worst-case concentration of imazapyr herbicide dissolved in leading edge of incoming tide

Assumptions

Worst-case occurs on the leading edge of lateral flow from overtopped channel through an herbicide-treated marsh
Herbicide was uniformly sprayed across the entire marsh surface (but not in channels) at an application rate r = 15.6 mg a.e./sqft
The herbicide applied on a unit area (1 sqft) is therefore mass m = 15.6 mg a.e.
The herbicide dissolves completely in the incoming water
A percentage, p, of the herbicide sticks to the vegetation canopy, and does not dissolve in the first one foot of flow depth
Incoming tidal water overbanks channel and flows laterally across the surface of the marsh to a maximum distance D
Water flow across marsh (after it leaves channel) has a uniform depth d = 1ft
A percentage, s, of the active herbicide that was deposited onto the sediment surface dissolves into the water column
The dissolved herbicide is instantly fully dissolved in the first unit volume that flows through
No evaporation
No rain or other input of fresh water

Application rate

Habitat® label application rate: 4-6 pints per acre — Label indicates 2 pounds imazapyr acid equivalents per gallon Habitat®

6 pints/acre = 0.75 gal/acre — 1.5 lb a.e./acre = 15.61 mg a.e./ft^2

Variables (p, D, and s can be varied):

r =	15.61	mg a.e./ft^2	Herbicide application rate
m =	15.61	mg a.e.	Initial mass of herbicide per unit area (per 1 ft^2)
p =	0%		Percentage of applied herbicide that is absorbed into vegetation canopy
d =	1	ft	Depth of water flow across marsh (1 ft allows unit volume calculations)
D =	100	ft	Distance of lateral flow across the marsh surface[a]
s =	60%		Percentage of herbicide reaching the sediment that resuspends into water column
C =	?		Concentration of herbicide in water column (mg a.e./ft^3)

Equation[b]

C = m × (1-p) × D × s = (mass per unit area) × (1-percent absorbed by plant canopy) × (percent dissolved in water column) × (number of units through which water flows)

Computed Concentration

C =	m	1-p	D	s	=	
	15.61	100%	100	60%		937 mg/ft^3
						33.1 mg/liter

Notes

a) Most *Spartina* infested marshes in the San Francisco Estuary that will become inundated by tidal water in the days following imazapyr application have a multitude of channels throughout the marsh that will transport water directly from the San Francisco Bay before overbanking and causing lateral flow across the marsh. In these marshes there would be a maximum of 100 feet of lateral flow through sprayed marsh before meeting with another flow.

b) Calculation does not take into account potential decay during period of time between spraying and water inundation nor any decay that might occur in water column once the herbicide is resuspended from sediment.

Table A-5: Ecotoxicity categories for acute toxicity of pesticides to wildlife[1]

Toxicity Category	Mammals		Birds	
	Acute Oral or Dermal LD_{50} (mg/kg)	Acute Inhalation LC_{50} (ppm)	Acute Oral LD_{50} (mg/kg)	Acute Inhalation LC_{50} (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

Table A-6: Ecotoxicity categories for acute toxicity of pesticides to aquatic organisms[1]

Toxicity 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

Table A-7: Ecotoxicity categories for acute toxicity of pesticides to insects[1]

Toxicity Category	Concentration (µg/bee)
Highly toxic	<2
Moderately toxic	2 - 11
Practically non-toxic	>11

[1] U.S. EPA, Technical Overview of Ecological Risk Assessment, Analysis Phase: Ecological Effects Characterization, September 28, 2004.

Table A-8: Toxicity of imazapyr to mammals

Test Substance	Animal Species	Administration Route	Gender	LD_{50} or ED_{50}	Effect[3]	Testing Facility (Reporting Year)
Imazapyr technical	Rat	oral	♂	>5,000 mg/kg b.w.	NOEL	American Cyanamid Company (1983)[1]
			♀	>5,000 mg/kg b.w.	NOEL	
	Rabbit	dermal	♂	>2,000 mg/kg b.w.	NOEL	
			♀	>2,000 mg/kg b.w.	NOEL	
	Rat	inhalatory	♂	>1 ppm	ND	Food and Drug Research Laboratories (1983)[1]
			♀	>1 ppm (analytical)	ND	
AC 243,997 (93% pure)	Rat	inhalation	♂+♀	>1.3 ppm	L	Voss *et al.* (1983)[2]
Imazapyr isopropylamine technical (49.3% a.i.)	Rat	oral	♂	>10,000 ppm diet	DA	Medical Scientific Research, Laboratory (1983)[1]
			♀	>10,000 ppm diet	DA	
		intraperitoneal	♂	4,200 mg/kg b.w.	DA, B, A, S, CY, C, DBW	
			♀	3,700 mg/kg b.w.	DA, B, A, S, CY, C, DBW	
		subcutaneous	♂	>5,000 mg/kg b.w.	DA	
			♀	>5,000 mg/kg b.w.	DA	
		dermal	♂	>2,000 mg/kg b.w.	NOEL	
			♀	>2,000 mg/kg b.w.	NOEL	
	Mouse	oral	♂	>10,000 mg/kg b.w.	DA	
			♀	>10,000 mg/kg b.w.	DA	
		intraperitoneal	♂	3,450 mg/kg b.w.	DA, B, A, S, CY, C, DBW	
			♀	3,000 mg/kg b.w.	DA, B, A, S, CY, C, DBW	
		subcutaneous	♂	>5,000 mg/kg b.w.	DA, B, S	
			♀	>5,000 mg/kg b.w.	DA, B, S	

Table A-8 contd.: Toxicity of imazapyr to mammals

Test Substance	Animal Species	Administration Route	Gender	LD_{50} or ED_{50}	Effect[3]	Testing Facility (Reporting Year)
Imazapyr isopropylamine (25% a.i.)	Rat	oral	♂	>5,000 mg/kg b.w.	DA	American Cyanamid Company (1983)[1]
			♀	>5,000 mg/kg b.w.	DA	
	Mouse	oral	♂	>5,000 mg/kg b.w.	DA	American Cyanamid Company (1986)[1]
			♀	>5,000 mg/kg b.w.	DA	
	Rabbit	dermal	♂	>2,148 mg/kg b.w.	NOEL	American Cyanamid Company (1983)[1]
			♀	>2,148 mg/kg b.w.	NOEL	
	Rat	inhalatory	♂	>0.2	NOEL	Food and Drug Research Laboratories (1983)[1]
			♀	>0.2 (analytical)	NOEL	
Arsenal® 4-AS	Rat	inhalatory	♂+♀	>4.62 ppm	L	Hershman & Moore (1986)[2]
Chopper®RTU (NOS)	Rat	inhalatory	♂+♀	>3.34 ppm	L	Werley (1987)[2]

[1] cited in Entrix 10/03.
[2] cited in SERA 12/04, Appendix 1
[3] Acronyms: A = ataxia (loss of ability to coordinate muscular movement); B = blepharoptosis (drooping of upper eyelid); b.w. = body weight; C = convulsion; CY = cyanosis (bluish discoloration of skin and mucous membranes resulting from inadequate oxygenation of blood); DA = decreased activity; DBW = decreased body weight; ED_{50} = dose causing 50% inhibition of a process; L = lethality; LD_{50} = lethal dose, 50% kill; ND = nasal discharge; NOEL = no-observable-effect level (no toxic signs); NOS = not otherwise specified; S = sedation

Table A-9: Toxicity of imazapyr to birds

Test Substance	Species	Test (Observed Effect)	Result*
Arsenal® (identical with Habitat®)	Northern bobwhite quail	LD_{50}, 18-weeks dietary	>1890 mg/kg diet ~200 mg/kg b.w.
		NOEL, 18-weeks dietary	1890 mg/kg HDT ~200 mg/kg b.w.
		LD_{50}, 5-day acute dietary	>5000 mg/kg diet ~674 mg/kg b.w.
		NOEL, 5-day acute dietary	5000 mg/kg HDT ~674 mg/kg b.w.
	Mallard duck	LD_{50}, 18-weeks dietary	>1890 mg/kg diet ~200 mg/kg b.w.
		NOEL, 18-weeks dietary	1890 mg/kg diet ~200 mg/kg b.w.
		LD_{50}, 5-day acute dietary	>5000 mg/kg diet ~674 mg/kg b.w.
		NOEL, 5-day acute dietary	5000 mg/kg HDT ~674 mg/kg b.w.

* Fletcher 1983a, 1983b, Fletcher *et al.* 1984a, 1984b, 1984c, 1984d, 1995a, 1995b; all in SERA 12/04, Appendix 3

Table A-10: Toxicity of imazapyr and imazapyr herbicide/surfactant mixtures to fish

Test Substance + Surfactant	Animal Species	Test	Result	Reference
Arsenal® Herbicide (28.7% imazapyr) + Hasten	Rainbow trout, juvenile (*Oncorhynchus mykiss*)	96-hr LC_{50}	113 ppm surfactant	Smith *et al.* 2002[1]
Arsenal® Herbicide (28.7% imazapyr) + Agri-Dex®		96-hr LC_{50}	479 ppm surfactant	
Arsenal® Herbicide (28.7% imazapyr)		96-hr LC_{50}	77,716 ppm of concentrate 22,305 mg imazapyr a.e./L	Grue 2003[1] King *et al.* 2004
Arsenal® Concentrate (53.1 a.i. imazapyr)		96-hr LC_{50}	43,947 ppm of concentrate 23,336 mg imazapyr a.e./L	Grue 2003[1]
AC 243,997 with isopropylamine in water	Bluegill sunfish (*Lepomis macrochirus*)	96-hr LC_{50}	>1000 mg/L	Cohle & McAllister 1984a[2]
Arsenal® Herbicide (22.6% purity)		96-hr LC_{50}	180 mg/L	Cohle & McAllister 1984b[2]
AC 243,997 (99.5% purity)		96-hr LC_{50}	>100 mg/L	Kintner & Forbis 1983a[2]
Imazapyr NOS	Rainbow trout (*Salmo gairdneri*) Channel catfish (*Ictaluras punctatis*) Bluegill sunfish (*Lepomis macrochirus*)	96-hr LC_{50}	>100 mg/L	Peoples 1984[2] Gagne *et al.* 1994[2]
Arsenal® Herbicide (22.6% purity)	Rainbow trout (*Salmo gairdneri*)	96-hr LC_{50}	110 mg/L	Cohle & McAllister 1984c[2]
Arsenal® Herbicide (21.5% purity)		96-hr LC_{50}	>110 mg a.e./L	Drotter *et al.* 1995[2]

Table A-10 contd.: Toxicity of imazapyr and imazapyr herbicide/surfactant mixtures to fish

Test Substance + Surfactant	Animal Species	Test	Result	Reference
AC 342,997 (purity NOS)	Fathead minnow (*Pimephales promelas*)	NOEC LOEC MATC	120 mg a.i./L >120 mg/L >120 mg/L	Drotter *et al.* 1998[2]
AC 342,997 (99.6% purity)		28-day NOEC LOEC MATC	>118 mg a.i./L >118 mg a.i./L >118 mg a.i./L	Drotter *et al.* 1999[2]
AC 243,997 (99.5% purity)	Atlantic silverside (marine) (*Menidia menidia*)	96-hr LC_{50}	184 mg/L	Manning 1989a[2]
Imazapyr NOS	Nile tilapia (*Tilapia nilotica*)	24-hr LC_{50} 48-hr LC_{50} 72-hr LC_{50} 96-hr LC_{50}	4,670 µg/L 4,630 µg/L 4,610 µg/L 4,360 µg/L	Supamataya *et al.* 1981[2]
	Silver barb (*Barbus genionotus*)	24-hr LC_{50} 96-hr LC_{50}	2,706 µg/L 2,706 µg/L	

[1] cited in Entrix 10/03
[2] cited in SERA 12/04

Abbreviations: LC_{50} = lethal concentration, 50% kill; LOEC = lowest-observable-effect concentration; MATC = maximum allowable toxicant concentration; NOEC = no-observable-effect concentration (no toxic signs); NOS = not otherwise specified

Table A-11: Toxicity of imazapyr and imazapyr/surfactant mixtures to aquatic invertebrates

Test Substance	Species	Test (observed effect)	Result	Reference
Arsenal® Applicator's Concentrate (479 g imazapyr a.e./L)	Freshwater benthic macroinvertebrates	In-situ microcosm NOEC, (D, BM)	>18.4 mg/L (HDT)	Fowlkes *et al.* 2003
Arsenal®Herbicide (22.6% purity)	Freshwater water flea (*Daphnia magna*)	NOEC 48-hr LC_{50}	180 mg/L 350 mg/L	Forbis *et al.* 1984[2]
Arsenal® + unidentified surfactant		48-hr LC_{50}	79.1 mg imazapyr a.e./L	Cyanamid 1997[1]
Arsenal®		NOEC	40.7 mg imazapyr a.e./L	
		48-hr EC_{50} (?)	373 mg imazapyr a.e./L	
	Eastern oyster (*Crassostrea virginica*)	EC_{50} (G) NOEC	>132 mg imazapyr/L >132 mg imazapyr/L (HDT)	Mangels & Ritter 2000[1]
	Pink shrimp (*Penaeus duorarum*)	EC_{50} (S)	>132 mg imazapyr/L >132 mg imazapyr/L (HDT)	
AC 243,997 (technical)	Freshwater water flea (*Daphnia magna*) (<24 hours old)	24-hr LC_{50} 48-hr LC_{50}	>100 mg imazapyr a.e./L >100 mg imazapyr a.e./L	Kintner & Forbis 1983[2]
AC 243,997 (99.5% a.i.)	Freshwater water flea (*Daphnia magna*)	7, 14, 21-day NOEC (S/R/G)	97.1 mg/L (HDT, MATC)	Manning 1989[2]
AC 243,997 (purity NOS)	Grass shrimp (*Paleomonetes pugio)*	BCF	<1 (not calculable)	Drotter *et al.* 1996[2]
	Eastern oyster (*Crassosstrea virginica*)	BCF	<1 (not calculable)	Drotter *et al.* 1996[2]
AC 243,997 (99.6% purity)		EC_{50} (G)	>132 mg/L	Drotter *et al.* 1997[2]
AC 243,997 (99.5% purity)		96-hr EC_{50} (G)	>173 mg/L	Ward 1989[2]

[1] cited in Entrix 10/03
[2] cited in SERA 12/04, Appendix 4

Abbreviations: BM = biomass, D = deformity, S = survival; R = reproduction; G = growth; HDT = highest dose tested; MATC = maximum allowable toxicant concentration

Table A-12: Toxicity of imazapyr and imazapyr/surfactant mixtures to non-target aquatic vegetation

Test Substance	Species	Test (Observed Effect)	Result	Reference
Technical grade imazapyr	Green algae (*Selenastrum capricornutum*)	EC_{50} (G) EC_{25} (G)	71 mg/L 78 mg/L	Hughes 1987[2] Mangels & Ritter 2000[1]
	Freshwater diatom *(Navicula pelliculosa)*	EC_{50} (G) EC_{25} (G)	>59 mg/L >59 mg/L	Mangels & Ritter 2000[1]
	Saltwater diatom (*Skeletonema costatum*)	EC_{50} (G) EC_{25} (G)	85 mg/L 42.2 mg/L	Hughes 1987[2]
	Blue-green algae (*Anabaena flos-aquae*)	EC_{50} (G) EC_{25} (G)	117 mg/L 7.3 mg/L	Mangels & Ritter 2000[1]
	Green algae (*Chlorella emersonii*)	EC_{50} (G)	0.2 mg/L	Landstein *et al.* 1993[2]
	Duckweed (*Lemna gibba*)	EC_{50} (G) EC_{25} (G)	0.024 mg/L 0.013 mg/L	Hughes 1987[2]
Arsenal®+ unidentified surfactant	Common water milfoil (*Myriophyllum sibiricum*)	EC_{25} (G shoots) EC_{50} (G shoots) EC_{25} (# roots) EC_{50} (# roots) EC_{25} (G roots) EC_{50} (G roots)	0.013 mg/L 0.032 mg/L 0.022 mg/L 0.029 mg/L 0.0079 mg/L 0.0099 mg/L	Roshon *et al.* 1999[2]
	Green algae (*Selenastrum capricornutum*)	EC_{50} (G) EC_{25} (G)	14.1 mg/L 8.36 mg/L	Mangels & Ritter 2000[1]
	Duckweed (*Lemna gibba*)	LC_{50} EC_{50} (G) EC_{25} (G)	24 ppb 0.0216 mg/L 0.0132 mg/L	Mangels & Ritter 2000 Mangels & Ritter 2000[1]

[1] cited in Entrix 10/03.
[2] cited in SERA 12/04, Appendix 4.

Abbreviations: S = survival; R = reproduction; G = growth; HDT = highest dose tested; MATC = maximum allowable toxicant concentration

Table A-13: Toxicity endpoints for risk quotient calculation and levels of concern for interpretation of risk quotients

	Aquatic animals	Mammals	Birds	Aquatic vascular plants and algae	Non-endangered plants	Endangered plants
Assessment						
Acute	EC_{50} or LC_{50} acute toxicity	LD_{50} oral	LD_{50} oral	EC_{50}	EC_{25} seedling emergence and vegetative vigor	EC_{25} seedling emergence and vegetative vigor or NOEC
Chronic	NOEC early-life stage or full life-cycle tests	NOEC 2-generation reproduction	NOEC 21-week reproduction			
Levels of concern (risk quotient greater than)						
Acute risk	0.5	0.5	0.5	1.0	1.0	1.0
Acute restricted use	0.1	0.2	0.2			
Acute risk endangered species	0.05	0.1	0.1			
Chronic risk	1.0	1.0	1.0			

U.S. Environmental Protection Agency, Technical Overview of Ecological Risk Assessment, Analysis Phase: Ecological Effects Characterization and Risk Characterization, September 28th, 2004.