APPENDIX A

INFORMATION USED IN THE SULFATE CORRECTION OF SELENATE ACUTE TOXICITY

Table A-1. Degrees of freedom (df), coefficients of determination (r^2), slopes and respective confidence intervals (CI) for regressions of the natural logarithm of selenate LC50% on the natural logarithm of sulfate concentration. The "Common regression" combines regression lines for individual species into a single model (Zar 1999), its slope is computed as in analysis of covariance. The "Total regression" estimates a linear function for all points, irrespective of taxa.

Species	df	r^2	Slope	95% CI
Fathead Minnow	14	0.83	0.48	[0.35, 0.60]
Chinook Salmon	3	0.87	0.49	[0.14, 0.83]
Gammarus pseudolimnaeus	5	0.61	0.86	[0.07, 1.66]
Hyalella azteca	4	0.39	0.19	[-0.14, 0.51]
Daphnia magna	4	0.92	0.87	[0.52, 1.22]
Ceriodaphnia dubia	11	0.84	0.70	[0.50, 0.91]
"Common regression"	46	0.65	0.58	[0.45, 0.71]
"Total regression"	51	0.36	0.76	[0.48, 1.04]

Table A-2. Data used in the regressions of the natural logarithm of selenate acute values on the natural logarithm of sulfate concentrations.

Species	Age/ Size	Data Source	[Sulfate] (µg/L)	LC50 or EC50 (µg/L)	Adjusted LC50
Hydra					
Hydra sp.	adult	Brooke et al. 1985	12000	7,300	25031.02
Leech					
Nephelopsis obscura	adult	Brooke et al. 1985	12000	442,000	1515577
Snail					
Aplexa hypnorum		Brooke et al. 1985	12000	193,000	661779.1
Cladoceran					
Ceriodaphnia dubia	<24 hr	Brix et al. 2001a,b	52000	1,969	2879.368
Ceriodaphnia dubia		Brix et al. 2001a,b	55000	1,864	2638.398
Ceriodaphnia dubia		GLEC 1999	25000	376	841.5682
Cladoceran					
Daphnia magna		Dunbar et al. 1983	163000	5,300	3989.863
Daphnia magna		Boyum 1984	22000	1,010	2434.939
Daphnia magna		Brooke et al. 1985	12000	570	1954.477
Daphnia magna		Ingersoll et al. 1990	41000	2,560	4298.133
Daphnia magna		Ingersoll et al. 1990	68000	4,070	5092.556
Daphnia magna		Maier et al. 1993	82000	2,840	3187.186
Daphnia pulex	<24 hr	Brix et al. 2001a,b	54000	10,123	14482.21
Daphnia pulex		Brix et al. 2001a,b	38000	8,111	14232.89
Daphnia pulex		GLEC 1999	25000	1,528	3419.99
Daphnia pulicaria		Boyum 1984	22000	246	593.0643
Amphipod					
Gammarus lacustris	8-12 mm	Brix et al. 2001a,b	120000	3,054	2746.951
Gammarus pseudolimnaeus	adult	Brooke et al. 1985	12000	75	257.168
Gammarus pseudolimnaeus		Brooke 1987	12000	57	195.4477
Gammarus pseudolimnaeus		GLEC 1998	25000	1,180	2641.092

Species	Age/ Size	Data Source	[Sulfate] (µg/L)	LC50 or EC50 (µg/L)	Adjusted LC50
Gammarus pseudolimnaeus		GLEC 1998	125000	2,870	2520.927
Gammarus pseudolimnaeus		GLEC 1998	367000	3,710	1742.628
Gammarus pseudolimnaeus		GLEC 1998	635000	3,270	1116.855
Gammarus pseudolimnaeus		GLEC 1999	25000	2,191	4903.925
Amphipod					
Hyalella azteca		Adams 1976	-	760	-
Hyalella azteca		Brasher and Ogle 1993	13000	1,031	3374.516
Hyalella azteca		Brix et al. 2001a,b	55000	1,428	2021.262
Hyalella azteca		GLEC 1998	40000	2,480	4224.001
Hyalella azteca		GLEC 1998	125000	1,350	1185.802
Hyalella azteca		GLEC 1998	367000	1,540	723.3552
Hyalella azteca		GLEC 1998	822000	3,580	1052.407
Midge					
Chironomus decorus	4th instar	Maier and Knight 1993	27000	23,700	50725.32
Midge					
Paratanytarsus parthenogeneticus	3rd instar	Brooke et al. 1985	12000	20,000	68578.14
Coho salmon					
Oncorhynchus kisutch	0.5 g	Hamilton and Buhl 1990b	185000	32,500	22730.56
Oncorhynchus kisutch	1.7 g	Hamilton and Buhl 1990b	291000	39,000	20963.42
Oncorhynchus kisutch	alevin	Buhl and Hamilton 1991	41000	158,422	265983.9
Oncorhynchus kisutch	juvenile	Buhl and Hamilton 1991	41000	30,932	51933.53
Oncorhynchus tshawytscha	(0.7 g	Hamilton and Buhl 1990b	185000	121,000	84627.63
Oncorhynchus tshawytscha	0.5 g	Hamilton and Buhl 1990b	185000	100,000	69940.19
Oncorhynchus tshawytscha	1.6 g	Hamilton and Buhl 1990b	291000	180,000	96754.25
Oncorhynchus tshawytscha		Hamilton and Buhl 1990b	291000	134,000	72028.17
Oncorhynchus tshawytscha	eyed egg	Hamilton and Buhl 1990b	47000>552,000		-
Oncorhynchus tshawytscha	alevin	Hamilton and Buhl 1990b	47000>176,640		-

Species	Age/ Size	Data Source	[Sulfate] (µg/L)	LC50 or EC50 (µg/L)	Adjusted LC50
Oncorhynchus tshawytscha	0.31 g	Hamilton and Buhl 1990b	47000	62,900	97548.09
Rainbow trout					
Oncorhynchus mykiss	juvenile	Brooke et al. 1985	12000	24,000	82293.77
Oncorhynchus mykiss	alevin	Buhl and Hamilton 1991	41000	196,460	329848.1
Oncorhynchus mykiss	juvenile	Buhl and Hamilton 1991	41000	13,501	22667.61
Oncorhynchus mykiss		Spehar 1986	12000	47,000	161158.6
Arctic grayling					
Thymallus arcticus	alevin	Buhl and Hamilton 1991	41000	41,800	70180.45
Thymallus arcticus	juvenile	Buhl and Hamilton 1991	41000	75,240	126324.8
Fathead minnow					
Pimephales promeles		Adams 1976	-	11,800	-
Pimephales promeles		Adams 1976	-	11,000	-
Pimephales promeles		Adams 1976	-	12,500	-
Pimephales promelas	juvenile	Brooke et al. 1985	12000	2,300	7886.486
Pimephales promelas		Spehar 1986	12000	5,500	18858.99
Pimephales promelas		GLEC 1998	24000	6,210	14233
Pimephales promelas		GLEC 1998	160000	10,800	8218.538
Pimephales promelas		GLEC 1998	474000	18,000	7286.649
Pimephales promelas		GLEC 1998	906000	42,100	11695.65
Colorado squawfish					
Ptychocheilus lucius	fry	Hamilton 1995	164000	27,588	20694.67
Ptychocheilus lucius	0.4-1.1 g juvenile	Hamilton 1995	164000	119,548	89676.92
Ptychocheilus lucius	1.7 g juvenile	Hamilton 1995	164000	138,358	103786.9
Ptychocheilus lucius	larva	Buhl and Hamilton 1996	174000	13,580	9842.351
Ptychocheilus lucius	juvenile	Buhl and Hamilton 1996	174000	42,780	31005.58
Ptychocheilus lucius	0.024-0.047 g	Hamilton and Buhl 1997a	97000	88,000	89571.65

Species	Age/ Size	Data Source	[Sulfate] (µg/L)	LC50 or EC50 (µg/L)	Adjusted LC50
Bonytail					
Gila elegans	fry	Hamilton 1995	164000	22,990	17245.56
Gila elegans	1.1 g juvenile	Hamilton 1995	164000	102,828	77134.7
Gila elegans	2.6 g juvenile	Hamilton 1995	164000	90,706	68041.58
Gila elegans	larva	Buhl and Hamilton 1996	174000	14,570	10559.87
Gila elegans	juvenile	Buhl and Hamilton 1996	174000	24,010	17401.68
Razorback sucker					
Xyrauchen texanus	fry	Hamilton 1995	164000	20,064	15050.67
Xyrauchen texanus	0.9 g juvenile	Hamilton 1995	164000	15,048	11288.00
Xyrauchen texanus	2.0 g juvenile	Hamilton 1995	164000	10,450	7838.892
Xyrauchen texanus	larva	Buhl and Hamilton 1996	174000	13,910	10081.52
Xyrauchen texanus	juvenile	Buhl and Hamilton 1996	174000	7,620	5522.733
Xyrauchen texanus	0.006-0.042 g	Hamilton and Buhl 1997a	97000	15,900	16183.97
Flannelmouth sucker					
Catostomus latipinnis	12-13 days	Hamilton and Buhl 1997b	97000	26,900	27380.43
Channel catfish					
Ictalurus punctatus	juvenile	Brooke et al. 1985	12000	66,000	226307.9
Bluegill					
Lepomis macrochirus	juvenile	Brooke et al. 1985	12000	63,000	216021.1

APPENDIX B

TOXICITY OF SELENIUM TO AQUATIC PLANTS

Toxicity to Aquatic Plants

Selenite

Data are available on the toxicity of selenite to 13 species of freshwater algae and plants (Table B-1). Results ranged from an LC_{50} of 70,000 µg/L for the green alga, *Chlorella ellipsoidea* (Shabana and El-Attar 1995) to 522 µg/L for incipient inhibition of the green alga, *Scenedesmus quadricauda* (Bringmann and Kuhn 1977a, 1978a,b, 1979, 1980b). Foe and Knight (Manuscript) found that 75 µg/L decreased the dry weight of *Selenastrum capricornutum* (Table F-1). Wehr and Brown (1985) reported that 320 µg/L increased the growth of the alga *Chrysochromulina breviturrita.* Thus, the sensitivities of freshwater algae to selenite cover about the same range as the acute and chronic sensitivities of freshwater animals.

The 96-hr EC_{50} for the saltwater diatom, *Skeletonema costatum*, is 7,930 µg/L, based on reduction in chlorophyll a (Table B-1). Growth of *Chlorella* sp., *Platymonas subcordiformis*, and *Fucus spiralis* increased at selenite concentrations from 2.6 to 10,000 µg/L (Table F-1). Other marine algae exposed to selenite from 14 to 60 days had no observed effect concentrations (NOAEC) that ranged from 1,076 to 107,606 µg/L. These data suggest that saltwater plants will not be adversely affected by concentrations of selenite that do not affect saltwater animals.

Selenate

Growth of several species of green algae were affected by concentrations ranging from 100 to 40,000 µg/L (Table B-1). Blue-green algae appear to be more tolerant to selenate with 1,866 µg/L being the lowest concentration reported to affect growth (Kiffney and Knight 1990). Kumar (1964) found that a blue-green alga developed and lost resistance to selenate. The difference in the sensitivities of green and blue-green algae to selenate might be of ecological significance, particularly in bodies of water susceptible to nuisance algal blooms. For example, Patrick et al. (1975) reported that a concentration of 1,000 µg/L caused a natural assemblage of algae to shift to a community dominated by blue-green algae.

The saltwater coccolithophore, *Cricosphaera elongata*, had reduced growth when exposed to 41,800 µg/L selenate for 14 days (Boisson et al. 1995). Seven other saltwater algal species investigated by Wong and

Oliveira (1991a) exhibited NOEC growth values that ranged from 1,043 to 104,328 µg/L. At 10,000 µg/L, selenate is lethal to four species of saltwater phytoplankton and lower concentrations increase or decrease growth (Table F-1). Wheeler et al. (1982) reported that concentrations as low as 10 µg/L reduced growth of *Porphyridium cruentum* (Table F-1).

Although selenite appears to be more acutely and chronically toxic than selenate to most aquatic animals, this does not seem to be true for aquatic plants. Selenite and selenate are about equally toxic to the freshwater algae *Anabaena cylindrica*, *Anabaena flos-aquae*, *Anabaena variabilis, Anacystis nidulans,* and *Scenedesmus dimorphus* (Kiffney and Knight 1990; Kumar and Prakash 1971; Moede et al. 1980) and the saltwater algae *Agemenellum quadroplicatum*, *Chaetoceros vixvisibilis* and *Amphidinium carterae* (Wong and Oliveira 1991a). The two oxidation states equally stimulated growth of *Chrysochromulina breviturrita* (Wehr and Brown 1985). On the other hand, selenate is more toxic than selenite to the freshwater *Selenastrum capricornutum* (Richter 1982; Ibrahim and Spacie 1990) and the saltwater *Chorella* sp., *Platymonas subcordiformis* and *Nannochloropsis oculata* (Wheeler et al. 1982; Wong and Oliveira 1991a). In addition, Fries (1982) found that growth of thalli of the brown macroalga, *Fucus spiralis,* was stimulated more by exposure to selenite at 2.605 µg/L than to the same concentration of selenate.

A Final Plant Value, as defined in the Guidelines, cannot be obtained because no test in which the concentrations of selenite or selenate were measured and the endpoint was biologically relevant has been conducted with an important aquatic plant species.

Table B-1. Toxicity of Selenium to Aquatic Plants

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
			FRESHWATER SPECIES			
			Selenium (IV)			
Green alga, *Chlorella vulgaris*	Sodium selenite	-	90-120	Reduced growth	5,480	De Jong 1965
Green alga, *Chlorella ellipsoidea*	Sodium selenite	-	7	EC50	70,000	Shabana and El-Attar 1995
Green alga, *Scenedesmus dimorphus*	Sodium selenite	-	14	Reduced growth	24,000	Moede et al. 1980
Green alga, *Scenedesmus quadricauda*	Sodium selenite	-	8	Incipient inhibition	522	Bringmann and Kuhn 1977a; 1978a,b; 1979; 1980b
Green alga, *Scenedesmus quadricauda*	Sodium selenite	-	8	Incipient inhibition	2,500	Bringmann and Kuhn 1959a
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	4	EC50	2,900	Richter 1982
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	6	EC50	65,000	Ibrahim and Spacie 1990
Blue-green alga, *Anabaena constricta*	Sodium selenite	-	7	EC50	67,000	Shabana and El-Attar 1995
Blue-green alga, *Anabaena cylindrica*	Sodium selenite	-	14	Reduced growth	24,000	Moede et al. 1980
Blue-green alga, *Anabaena flos-aquae*	Sodium selenite	-	10	Reduced chlorophyll a	1,866	Kiffney and Knight 1990
Blue-green alga, *Anabaena variabilis*	Sodium selenite	-	6-18	LC50	15,000[b]	Kumar and Prakash 1971
Blue-green alga, *Anacystis nidulans*	Sodium selenite	-	10-18	LC50	30,000[b]	Kumar and Prakash 1971
Blue-green alga, *Microcystis aeruginisa*	Sodium selenite	-	8	Incipient inhibition	9,400 (9,300)	Bringmann and Kuhn 1976; 1978a,b

Table B-1. Toxicity of Selenium to Aquatic Plants (cont.)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
Alga, *Euglena gracilis*	-	-	15	Reduced growth	5,920	Bariaud and Mestre 1984
Duckweed, *Lemna minor*	-	-	4	EC50	2,400	Wang 1986
Duckweed, *Lemna minor*	Sodium selenite	-	14	EC50 (mult. rate)	3,500	Jenner and Janssen-Mommen 1993
Duckweed, *Lemna minor*	Sodium selenite	-	14	NOEC (mult. rate)	800	Jenner and Janssen-Mommen 1993
			Selenium (VI)			
Green alga, *Ankistrodesmus falcatus*	Sodium selenate	-	14	Did not reduce growth	10	Vocke et al. 1980
Green alga, *Scenedesmus dimorphus*	Sodium selenate	-	14	Reduced growth	22,100	Moede et al. 1980
Green alga, *Scenedesmus obliquus*	Sodium selenate	-	14	Reduced growth	100	Vocke et al. 1980
Green alga, *Selenastrum capricornutum*	Sodium selenate	-	14	Reduced growth	300	Vocke et al. 1980
Green alga, *Selenastrum capricornutum*	Sodium selenate	-	4	EC50	199	Richter 1982
Green alga, *Selenastrum capricornutum*	Sodium selenate	-	6	EC50	<40,000	Ibrahim and Spacie 1990
Blue-green alga, *Anabaena cylindrica*	Sodium selenate	-	14	Reduced growth	22,100	Moede et al. 1980
Blue-green alga, *Anabaena flos-aquae*	Sodium selenate	-	10	Reduced chlorophyll a	1,866	Kiffney and Knight 1990
Blue-green alga, *Anacystis nidulans*	Sodium selenate	-	6-18	EC50	39,000[b]	Kumar and Prakash 1971

Table B-1. Toxicity of Selenium to Aquatic Plants (cont.)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
Blue-green alga, *Anabaena viriabilis*	Sodium selenate	-	10-18	EC50	17,000[b]	Kumar and Prakash 1971
Blue-green alga, *Microcoleus vaginatus*	Sodium selenate	-	14	Reduced growth	10,000	Vocke et al. 1980
Duckweed, *Lemna minor*	Sodium selenate	-	14	EC50 (mult. rate)	11,500	Jenner and Janssen-Mommen 1993
Duckweed, *Lemna minor*	Sodium selenate	-	14	NOEC (mult. Rate)	>2,400	Jenner and Janssen-Mommen 1993

Table B-1. Toxicity of Selenium to Aquatic Plants (cont.)

Species	Chemical	Salinity (g/kg)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
			SALTWATER SPECIES			
			Selenium (IV)			
Green alga, *Dunaliella tertiolecta*	Sodium selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a
Cyanophyceae alga, *Agemenellum quadruplicatum*	Sodium selenite	-	60	NOEC growth	10,761	Wong and Oliveira 1991a
Diatom, *Chaetoceros vixvisibilis*	Sodium selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a
Diatom, *Skeletonema costatum*	Selenious acid[c]	-	4	EC50 (reduction in chlorophyll a)	7,930	U.S. EPA 1978
Coccolithophore, *Cricosphaera elongata*	Sodium selenite	-	14	Reduced growth	4,570	Boisson et al. 1995
Dinoflagellate, *Amphidinium carterae*	Sodium selenite	-	60	NOEC growth	10,761	Wong and Oliveira 1991a
Dinoflagellate, *Peridinopsis borgei*	Selenium oxide	-	70-75	Maximum growth	0.01-0.05	Lindstrom 1985
Eustigmatophyceae alga, *Nannochloropsis oculata*	Sodium selenite	-	60	NOEC growth	107,606	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Isochrysis galbana*	Sodium selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Pavlova lutheri*	Sodiun selenite	-	60	NOEC growth	1,076	Wong and Oliveira 1991a

Table B-1. Toxicity of Selenium to Aquatic Plants (cont.)

Species	Chemical	Salinity (g/kg)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
			Selenium (VI)			
Green alga, *Dunaliella tertiolecta*	Sodium selenate	-	60	NOEC growth	104,328	Wong and Oliveira 1991a
Cyanophyceae alga, *Agemenellum quadruplicatum*	Sodium selenate	-	60	NOEC growth	10,433	Wong and Oliveira 1991a
Diatom, *Chaetoceros vixvisibilis*	Sodium selenate	-	60	NOEC growth	1,043	Wong and Oliveira 1991a
Coccolithophore, *Cricosphaera elongata*	Sodium selenate	-	14	Reduced growth	41,800	Boisson et al. 1995
Dinoflagellate, *Amphidinium carterae*	Sodium selenate	-	60	NOEC growth	10,433	Wong and Oliveira 1991a
Eustigmatophyceae alga, *Nannochloropsis oculata*	Sodium selenate	-	60	NOEC growth	10,433	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Isochrysis galbana*	Sodium selenate	-	60	NOEC growth	10,433	Wong and Oliveira 1991a
Pyrmnesiophyceae alga, *Pavlova lutheri*	Sodium selenate	-	60	NOEC growth	104,328	Wong and Oliveira 1991a

[a] Concentration of selenium, not the chemical.
[b] Estimated from published graph.
[c] Reported by Barrows et al. (1980) in work performed under the same contract.

APPENDIX C

BIOCONCENTRATION AND BIOACCUMUALTION OF SELENIUM

Bioconcentration and Bioaccumulation

Laboratory-Derived

Bioconcentration factors (BCFs) for selenium(IV) that have been obtained with freshwater species range from a low of 2 for the muscle of rainbow trout to 470 for the bluegill sunfish (Table C-1). Adams (1976) studied both uptake and elimination of selenium ^{75} by fathead minnows exposed to mean concentration of 12, 24, and 50 µg/L in the water. He found that concentrations in whole fish and in individual tissues increased at a rapid rate during the first 8 days and then at a slower rate for the next 88 days. Steady-state was approached, but not reached, after 96 days. The highest concentrations were found in viscera. Elimination of selenium was curvilinear and became asymptotic with the time axis after 96 days. Elimination was most rapid from the viscera with a half-life of 5.1 days, but the half-life of selenium in other tissues was greater than 50 days.

Adams (1976) also conducted uptake studies with rainbow trout exposed for 48 days to selenium(IV) at water concentrations ranging from 310 to 950 µg/L. Some of the trout died, and concentrations were somewhat higher in dead fish than in survivors. As with the fathead minnow, the viscera contained more selenium than gill or muscle. Based on his tests with the two fish species, Adams (1976) concluded that there was an inverse relationship between BCF and the concentration of selenium(IV) in water.

Gissel-Nielsen and Gissel-Nielsen (1978) exposed juvenile rainbow trout (*Oncorhynchus mykiss*) to waterborne selenium(IV) over a four week period. Exposure to selenium at 100 µg/L raised the selenium concentration in fish to 2.3 ± 0.02 µg/g dw, without increasing mortality, and steady-state conditions were shown to have been achieved.

Hodson et al. (1980) exposed rainbow trout to selenium(IV) from fertilization until 44 weeks post-hatch. At 53 µg/L selenium in the water, the BCF ranged from 8 L/kg for whole-body to 240 L/kg for liver. They concluded that selenium in tissues did not increase in proportion to selenium(IV) in water.

Hunn et al. (1987) exposed rainbow trout in a flow-through system to waterborne selenium(IV) for 90 days. The selenium concentration in the water where significant effects were not observed was 21 µg/L and the corresponding whole-body tissue level was 0.64 µg/g dw, the data yielding a BCF value of 30.5 L/kg.

Barrows et al. (1980) exposed bluegills to selenious acid for 28 days. They reported a maximum BCF in the whole fish of 20 L/kg and a half-life of between 1 and 7 days. If bluegills bioconcentrate selenium in the same manner as the rainbow trout used by Adams (1976), the 28-day exposure might not have been long enough to reach steady-state.

Lemly (1982) exposed bluegills and largemouth bass to 10 µg of selenium/L for 120 days to determine the effect of hardness and temperature on uptake and elimination. For bluegills, the geometric mean whole-body BCF at 20° and 30°C was 452 L/kg. For largemouth bass in similar tests, the BCF was 295 L/kg. For both species, the spleen, liver, kidney, and heart had higher concentrations than the whole-body. Neither water temperature nor hardness had a significant effect on the amount of selenium accumulated in the tissues after 90 days, although earlier values were influenced. After 30 days in clean water, selenium concentrations remained unchanged in spleen, liver, kidney, and white muscle, but the half-life for selenium in gills and erythrocytes was less than 15 days.

Besser et al. (1993) measured the aqueous bioaccumulation of both waterborne selenium(IV) and selenium(VI) by bluegill over a 30-day period. Selenium concentrations were monitored radiometrically with ^{75}Se- labeled compounds. Bluegills concentrated selenium about equally from both inorganic species and demonstrated similar aqueous selenium uptake rate constants (about 3 per day at 10 µg of selenium/L). A kinetic uptake-depuration model was used to estimate BCFs. Estimated BCFs for both selenium(IV) and selenium(VI) derived from the data were 56 L/kg.

Bertram and Brooks (1986) exposed adult fathead minnows to sodium selenate in water, in food, and in food and water together. The food was specially prepared by raising algae in a medium containing selenium(VI), feeding the algae to daphnids, mixing the exposed daphnids with unexposed daphnids, dewatering to form a "cake", and freezing for storage. Uptake of selenium(VI) from water (without the additional selenium in food) reached steady-state within 28 days. The whole-body BCFs ranged from 21 to 52 L/kg and decreased as the concentration in water increased (Table C-1). Uptake of selenium(VI) from food alone or from food and water together did not reach steady-state in 8 and 11 weeks, respectively. The uptake of selenium from food and water were additive.

Besser et al. (1993) also determined BCF values for algae and *Daphnia magna* exposed separately to waterborne selenium(IV) and selenium(VI). At 10 µg of selenium/L, the BCFs calculated for algae were

1440 L/kg for selenium(IV) and 428 L/kg for selenium(VI). In these laboratory simulated food web studies (waterborne selenium to algae; algae to *Daphnia*; and *Daphnia* to bluegills) concentration factors (CFs) for the transfer of selenium from algae to *Daphnia* and *Daphnia* to bluegill (0.61 and 0.51 L/kg, respectively) were also determined (Table C-2). Using the BCF and CF data, one can calculate an estimated BAF for bluegill for this laboratory food chain. An estimated BAF value of 550 L/kg was calculated for a waterborne exposure of 10 µg/L of 1:1 selenite:selenate to the algae- *Daphnia* - bluegill web.

A three-trophic level food chain experiment consisting of the alga, *Chlorella vulgaris*, the rotifer, *Brachionus calyciflorus*, and the fathead minnow, *Pimephales promelas* was conducted by Dobbs et al. (1996). The three species were exposed to selenium(VI) for 25 days in a three-trophic level system whereby the organisms were linked in a continuous flow-through system in separate vessels, with each organism feeding on the trophic level below it. These organisms were continuously exposed for 25 days to either 0, 110.3, 207.7 or 396.1 µg of total recoverable selenium/L from selenium(VI) in natural creek water supplemented with nutrients to sustain algal growth. Algal population growth, rotifer standing crop, and fathead minnow growth were reduced at 207.7, 110.3 and 110.3 µg/L, respectively, after the 25-day exposure. Bioconcentration factors were found to be dependent on the species, treatment level and length of exposure, and they ranged between 100 and 1,000 L/kg.

Hamilton et al. (2000) exposed, separately, swim-up larvae of razorback sucker (*Xyrauchen texanus*) and bonytail (*Gila elegans*) to waterborne selenium in a simulated Green River, Utah water formulation. The selenium was 6:1 selenate:selenite, and the measured ambient or base level was 76 µg/L in the razorback exposure and 73 µg/L in the bonytail exposure. A flow-through system was utilized, and a 90-day partial life-cycle chronic toxicity study monitoring growth, behavior and mortality was conducted. No chronic effects were observed in tests conducted at base level. Higher than ambient concentrations were studied also, but were not selected for use in the BCF derivation due to either observed chronic effects or abnormally high concentrations of selenium and other metals in the test waters. At 90 days, the whole-body tissue levels of selenium were 3.2 µg/g dw in the razorback and 2.2 µg/g dw in the boneytail, reflecting BCF values of 42 and 30 L/kg, respectively.

Field-Derived

Hermanutz et al. (1996) exposed bluegills to selenium(IV) over 221 days in outdoor experimental streams at Monticello, MN which contained a natural food web. At the end of the 221 days in waters maintained at a nominal selenium concentration of 2.5 µg/L, the average whole-body fish tissue level of selenium was 4.825 µg/g Se dw (based on a factor of 0.8 moisture content in fish tissue). The resulting BAF value was 1,930 L/kg.

Garcia-Hernandez et al. (2000) collected fish samples form October 1996 to March 1997 in a Sonora, Mexico wetland. Dissolved selenium concentrations in the water ranged from 5 to 19 µg/l (median of 11 µg/l). Median whole-body concentration of selenium was measured in *Tilapia* (3.0 µg/g dw), carp (3.3 µg/g dw), and largemouth bass (5.1 µg/g dw). Resulting BAF values were 273, 300, and 464 L/kg, respectively.

Kennedy et al. (2000) collected spawning age (3-6 years) cutthroat trout from the Fording River, British Columbia in 1998. The waters of the river had an average selenium level of 13.9 µg/L at the time of collection. The tissue (muscle) of the trout contained 12.5 ± 7.7 µg of selenium/g dw. Utilization of these values provides a field derived muscle BAF of 899 L/kg.

Mason et al. (2000) collected biota in two streams (Blacklick Run and Herrington Creek) in western Maryland in October 1997, April 1998, and July 1998. Water samples were collected for analysis monthly over the duration of the study. Numerous fish species, among other organisms, were collected during each of the sampling periods, and whole-body tissue levels of selenium were measured. In Herrington Creek, the average water concentration of selenium was found to be 0.33 µg/L, and the average tissue levels of selenium in the fish were: bullhead (1.35 µg/g dw); sucker (1.55 µg/g dw), trout (1.94 µg/g Se dw), and chub (1.50 µg/g Se dw). The resulting calculated BAF values were 4,091, 4,697, 5,879, and 4,545 L/kg, respectively. In Blacklick Creek the average water concentration was 0.39 µg/L, and the average tissue levels of selenium in fish were: dace (1.79 µg/g dw), trout (1.94 µg/g dw), and sculpin (2.55 µg/g dw). Resulting BAF values were 4,590, 4,974, and 6,538 L/kg, respectively. Dry weight values were obtained from the published wet weight data employing a 0.8 factor for fish moisture content.

Table C-1. Bioconcentration and Bioaccumulation of selenium by fish.

Fish Species	Selenium Species	Concentration in Water (µg/L)[a]	Duration (days)	Tissue (Concentration)	BCF[b] (L/kg)	BAF[b] (L/kg)	Reference
			LABORATORY DERIVED				
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	-	48	Muscle	2		Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	-	48	Whole-body	10[c]		Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	100	28	Whole-body (2.3 µg/g)	23		Gissel-Nielsen and Gissel-Nielsen 1978
Rainbow trout (embryo), *Oncorhynchus mykiss*	Sodium selenite	-	308 (post-hatch)	Whole-body (estimate)	42		Hodson et al. 1980
Rainbow trout *Oncorhorynchus mykiss*	Sodium selenite	21	90	Whole-body (0.64 µg/g)	30.5		Hunn et al. 1987
Fathead minnow, *Pimephales promelas*	Sodium selenite	-	96	Muscle	11.6		Adams 1976
Fathead minnow, *Pimephales promelas*	Sodium selenite	-	96	Whole-body	17.6		Adams 1976
Fathead minnow (6-9 mo.), *Pimephales promelas*	Sodium selenate	10.7	56	Whole-body	52[d]		Bertram and Brooks 1986
Fathead minnow (6-9 mo.), *Pimephales promelas*	Sodium selenate	21.5	56	Whole-body	26[d]		Bertram and Brooks 1986
Fathead minnow (6-9 mo.), *Pimephales promelas*	Sodium selenate	43.5	56	Whole-body	21[d]		Bertram and Brooks 1986
Bluegill, *Lepomis macrochirus*	Selenious acid	-	28	Whole-body	20		Barrows et al. 1980

Table C-1 continued.

Fish Species	Selenium Species	Concentration in Water (µg/L)[a]	Duration (days)	Tissue (Concentration)	BCF[b] (L/kg)	BAF[b] (L/kg)	Reference
Bluegill, *Lepomis macrochirus*	Sodium selenite	10 10 10 10	120 120 120 120	Whole-body Whole-body Whole-body Whole-body	450 470 430 460		Lemly 1982
Bluegill, *Lepomis macrochirus*	Selenate	10	30	Whole-body	56		Besser et al. 1993
Largemouth bass, *Micropterus salmoides*	Sodium selenite	10 10 10 10	120 120 120 120	Whole-body Whole-body Whole-body Whole-body	310 300 300 270		Lemly 1982
Bluegill, *Lepomis macrochirus*	Selenite	10	30	Whole-body	56		Besser et al. 1993
Bluegill, *Lepomis macrochirus*	selenite: selenate 1:1	10	30	Whole-body		550[e]	Besser et al. 1993
Razorback suker, *Xyrauchen texanus*	selenate/ selenite[f]	76	90	Whole-body (3.2 µg/g)	42		Hamilton et al. 2000
Bonytail, *Gila elegans*	selenate/ selenite[f]	73	90	Whole-body (2.2 µg/g)	30		Hamilton et al. 2000
			FIELD DERIVED				
Bluegill *Lepomis macrochirus*	Selenite	2.5	221	Whole-body (4.825 µg/g)		1,930	Hermanutz et al. 1996
Tilapia sp.	Natural[f]	11	Field	Whole-body (3.0 µg/g)		273	Garcia-Hernandez et al. 2000
Carp, *Cyprinus carpio*	Natural[f]	11	Field	Whole-body (3.3 µg/g)		300	Garcia-Hernandez et al. 2000
Largemouth bass, *Micropterus salmoides*	Natural[f]	11	Field	Whole-body (5.1 µg/g)		464	Garcia-Hernandez et al. 2000
Cutthroat trout, *Oncorhynchus clarki*	Natural[f]	13.9	Field	Muscle (12.5 µg/g)		899	Kennedy et al. 2000
Brown bullhead, *Ictalurus nebulosus*	Natural[f] (Herrington Creek, MD)	0.33	N/A[g] (10 month study)	Whole-body (1.35 µg/g)		4,091	Mason et al. 2000

Table C-1 continued.

Fish Species	Selenium Species	Concentration in Water (µg/L)[a]	Duration (days)	Tissue (Concentration)	BCF[b] (L/kg)	BAF[b] (L/kg)	Reference
White sucker, *Catostomus commersoni*	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 month study)	Whole-body (1.55 µg/g)		4,697	Mason et al. 2000
Brook Trout, *Salvelinus fonticnalis*	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 months study)	Whole-body (1.94 µg/g)		5,879	Mason et al. 2000
Creek Chub, *Semotilus arromaculatus*	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 months study)	Whole-body (1.50 µg/g)		4,545	Mason et al. 2000
Mottled Sculpin, *Cottus bairdi*	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 months study)	Whole-body (2.55 µg/g)		6,538	Mason et al. 2000
Blacknose Dace *Rhinchthus atratulus*	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 months study)	Whole-body (1.79 µg/g)		4,590	Mason et al. 2000
Brook Trout *Salvelins fortinalus*	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 months study)	Whole-body (1.94 µg/g)		4,974	Mason et al. 2000

[a] Measured concentration of selenium.
[b] Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of selenium in water and in tissue (dry weight).
[c] Estimated from graph.
[d] Calculated by dividing the reported equilibrium concentration in tissue (steady-state body burden) by the average measured concentration in water.
[e] Laboratory food chain: water–> algae –> daphnia –> bluegill.
[f] Not speciated.
[g] N/A not applicable.

Table C-2. Bioconcentration and Bioaccumulation of selenium by other aquatic organisms.

Other Species	Selenium Form	Concentration in Water (µg/L)[a]	Duration (days)	Tissue (Concentration)	BCF[b] (L/kg)	BAF[b] (L/kg)	Reference
			LABORATORY DERIVED				
Algae, *Chlamydomonas reinhardtii*	Selenite Selenate	10 10	4 4		1440 428		Besser et al. 1993
Cladoceran, *Daphnia magna*	Selenate: Selenite 1:1	156	21	Whole-body (14.7 µg/g)	94		Ingersoll et al. 1990
	Selenate: Selenite 1:1	348	21	Whole-body (31.7 µg/g)	91		
Cladoceran, *Daphnia magna*	Selenite Selenate	10 10	4 4		570[e] 293[e]		Besser et at. 1993
			FIELD DERIVED				
Ephemeroptera	Selenite	2.5	221	Whole-body (5.05 µg/g)		1,957	Hermanutz et al. 1996
Heptageniidae	Selenite	10	221	Whole-body (17.30 µg/g)		1,787	
Ephemeroptera	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 mo. study)	Whole-body (5.05 µg/g)		17,600	Mason et al. 2000
Heptageniidae	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 mo. study)	Whole-body (5.8 µg/g)		14,900	
Chironomidae	Natural[f]	14.5	N/A (3 yr. study)	Wholebody (24.7 µg/g)		1703	Zhang and Moore 1996
	Natural[f]	1.58	N/A (3 yr. study)	Wholebody (10.4 µg/g)		6582	
Chironomidae	Selenite	2.5	221	Wholebody (3.61 µg/g)		1399	Hermanutz et al. 1996
	Selenite	10	221	Wholebody (13.60 µg/g)		1405	
Hydropsychidae	Natural (ite/ate 9:1)	32	N/A	Wholebody (3.1 µg/g)		969	Reash et al. 1999

Table C-2 Continued.

Other Species	Selenium Form	Concentration in Water (µg/L)[a]	Duration (days)	Tissue (Concentration)	BCF[b] (L/kg)	BAF[b] (L/kg)	Reference
Hydropsychidae	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 mo. study)	Wholebody (10.5 µg/g)		31,800	Mason et al. 2000
	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 mo. study)	Wholebody (4.6 µg/g)		11,800	
Astacidae	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 mo. study)	Wholebody (1.275 µg/g)		3864	Mason et al. 2000
	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 mo. study)	Wholebody (0.405 µg/g)		1038	
Periphyton	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 mo. study)	Whole (2.860 µg/g)	8667		Mason et al. 2000
	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 mo. study)	Whole (0.245 µg/g)	628		
Bryophytes	Natural[f] (Herrington Creek, MD)	0.33	N/A (10 mo. study)	Whole (1.860 µg/g)	5636		Mason et al. 2000
	Natural[f] (Blacklick Run, MD)	0.39	N/A (10 mo. study)	Whole (0.780 µg/g)	2000		

[a] Measured concentration of selenium.
[b] Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of selenium in water and in tissue (dry weight).
[c] Estimated from graph.
[d] Calculated by dividing the reported equilibrium concentration in tissue (steady-state body burden) by the average measured concentration in water.
[e] Laboratory food chain: water–> algae –> daphnia –> bluegill.
[f] Not speciated.
[g] N/A not applicable.

APPENDIX D

ENVIRONMENTAL FACTORS AFFECTING SELENIUM TOXICITY AND BIOACCUMULATION

Environmental Factors Affecting Selenium Toxicity and Bioaccumulation

A variety of environmental factors have been shown to influence the toxicity/bioaccumulation of selenium. A brief summary of the influence of sulfate, hardness, heavy metals, pH, temperature and day length on selenium toxicity/bioaccumulation is presented below.

Sulfate

In acute toxicity tests and uptake experiments with selenium, sulfate has been shown to antagonize Se toxicity and Se uptake in plants and animals, frequently with a major effect on Se action. Where multiple Se forms are used in joint action experiments, Se(VI) is antagonized most by SO_4 with Se(IV) and Se(II) affected to a lesser extent. Sulfate has reduced Se mortality responses by 90 percent and Se uptake to 10 percent of controls or less. Thus, sulfate is a major co-factor in a number of Se toxicity and Se uptake experiments.

In four acute toxicity tests, sulfate antagonized selenate toxicity in three algae species and the cladoceran *Daphnia*. The LC_{50} values of two desmids (*Cosmerium* spp.) exposed to selenate plus sulfate were 4x and 8x the LC_{50} values of selenate only (Sarma and Jayaraman 1984). The growth of *Selenastrum capricornutum* increased by 50 percent when 11 or 107 µg/L Se(VI) were combined with 3.3 or 33 µg/L sulfate (Williams et al. 1994). The toxicity of 490 µg/L selenate to *D. magna* was reduced by 90 percent mortality by combining it with either 10 or 308 mg/L sulfate. Uptake studies, with one exception, document sulfate as antagonistic to uptake of selenium. In many cases, Se uptake rates are reduced to 40 to 50 percent of controls (Se alone or lowest SO_4 concentration), but there are examples of sulfate reducing uptake to 20 percent of controls. These examples include a rooted plant (six percent of control rate), an alga (7 percent), *Daphnia* (20 percent) and a midge (20 percent).

Of the two algal species investigated, *Chlamydomonas reinhardtii* responded less to sulfate and Se(VI) co-exposure (Williams et al. 1994) than *Selenastrum capricornutum* (7 percent low SO_4 rate) (Riedel and Sanders 1996). Widgeon grass (*Ruppia moritima*) uptake reductions (Se uptake, high or low sulfate) occurred most for Se(VI) (6 percent), then Se(IV) (44 percent) and Se(II) (56 percent) (Bailey et al. 1995).

Experiments with *Daphnia* show no interaction of Se and SO_4 in a microcosm experiment (Besser et al. 1989). However, other experiments with Se and SO_4 show a 43 percent reduction of Se uptake by sulfate (Hansen et al.1993) and uptake reductions ranging from 20 to 65 percent among three Se(VI) exposures and two sulfate levels (Ogle and Knight 1996). Se uptake by a midge, *Chironomus decorus*, was reduced to 20 to 65 percent of controls in a 48 hour exposure to 6 mg/L Se(VI) and 3 levels of SO_4 (Hansen et al. 1993).

Hardness

Acute toxicity tests of selenium forms with hardness as a variable were conducted with an invertebrate and three fish species. In all cases, water hardness variations did not cause major changes in the acute toxicity of selenium. LC_{50} value differences due to hardness were no less than half or more than double the LC_{50} of the standard of comparison.

D. magna were exposed to three forms of selenium and one Se mixture in acute toxicity tests (48h LC_{50}) to determine the effect of soft (46 mg/L $CaCO_3$) and hard (134 mg/L $CaCO_3$) water on selenium toxicity. Water hardness did not affect the toxicity of Se(VI) and Se(II), but Se(IV) was slightly more toxic in hard than soft water (LC_{50}, hard/soft = 0.5), as was the 1:1 mixture of Se(IV) and Se(VI) (LC_{50}, hard/soft = 0.6) (Ingersoll et al. 1990). *Mytilus edulis* were exposed to selenite in sea water with salinities of 15, 20, 27 and 30‰ (27‰ was close to the mussel's natural habitat). Se(IV) influx measured during 2 hours of exposure demonstrated an effect on uptake as follows: maximum influx at 20‰; greatest influx difference = 0.7 max (34‰) (Wang et al. 1996a).

Fry of chinook salmon and coho salmon were exposed for 96 hr to selenate, selenite and a 1:1 mixture in soft (42 mg/L $CaCO_3$) and hard (211 mg/L $CaCO_3$) water. Advanced fry of chinook salmon were exposed to Se(II) in brackish water (333 mg/L $CaCO_3$). In all cases, variable hardness had no effect on the toxicity of three forms of selenium or the mixture (Hamilton and Buhl 1990b).

Young striped bass (*Morone saxatilis*) exhibited some differential susceptibility to selenite in hard (285 mg/L $CaCO_3$) vs. soft (40 mg/L $CaCO_3$) water (LC_{50} hard/soft = 1.8) with Se(IV) in soft water being more toxic. The LC_{50} of Se(IV) in 1‰ saline (455 mg/L $CaCO_3$) was not significantly different than Se in soft or hard water (Palawski et al. 1985).

The Se BCF values for young salmon (*Onchorhynchus tsawytscha*) exposed for 90 days to a Se(VI):Se(IV) mixture (6:1) were no different in fresh water (371 mg/L $CaCO_3$) or well water (612 mg/L $CaCO_3$). Exposure for 60 days to Se in 1‰ saline reduced the Se BCF to approximately 50% of BCFs for well water and fresh water (Hamilton and Wiedmeyer 1990).

Heavy Metals

Joint action studies with selenium and metals were conducted with cadmium and mercury, which have been investigated frequently in this regard, and arsenic and molybdenum. The latter two chemicals were investigated in a chronic test (at least 3 broods) with *Ceriodaphnia dubia* at exposure concentrations of the three chemicals that alone caused chronic mortality and reproductive effects. As^{+5} or Mo^{+6}, combined with Se(VI) in a chronic test, reduced reproduction and increased cumulative mortality (Naddy et al. 1995).

Mercury uptake experiments with selenite had opposite results in two separate studies with the marine mussel, *Mytilus edulis*. In 30 - 50-day tests, Se(IV) uptake was doubled (Se alone = 0.8 ng/g/d) by joint exposure to Se (30 µg/L) and $HgCl_2$ (5 µg/L) (Pelletier 1986a). Uptake of Se in a 96-hr study (Se(IV), 2 µg/L; $HgCl_2$, 0.1- 1.0 mg/L) decreased as a function of Hg concentration (r^2 = - 0.93) (Micallef and Tyler 1987).

The toxicity of Se(IV) and Se(VI) to a fresh water snail (*Lymnaea*) was reduced by 55 to 66 percent mortality by 0.1 mg/L cadmium in an 11-day water exposure. Using growth to evaluate toxicity of selenium-cadmium pairs in two species of marine phytoplankton (*Crypthecodinium* sp., *Procentrum* sp.), Prevot and Sayer-Gobillard (1986) demonstrated in both species that the toxicity of the higher Se doses was reduced by cadmium. Cadmium slightly elevated Se(IV) uptake in gill tissues of *Carcinas maenas* (marine shore crabs) but Se levels in two other tissues and carapace were no different than Se exposure in a 29-day experiment.

In summary, cadmium mortality effects were consistent in antagonizing the toxicity of selenium, although the level of antagonism was low to moderate in these two cases. Mercury effects on Se uptake by *Mytilus* were not in agreement, i.e. in a 96-hour study, selenium uptake decreased as mercury increased, but in 30 - 50-day tests, mercury enhanced selenium uptake. Both metals are generally toxic which complicates Se-

metal investigations. For example, Se interaction with arsenic or molybdenum were conducted with metal concentrations that were toxic.

pH, Temperature and Day Length

Except for Se(IV) at acidic pH, pH changes in the range associated with natural waters do not have an appreciable effect on uptake of selenium. Temperature is a major modifying influence on the interaction of chemicals and aquatic organisms as shown by sediment storage and *Paramecium* experiments. Interaction by low temperature and day length dramatically enhanced the toxicity of Se in fish chronically exposed under laboratory conditions.

As presented in the chronic section, Lemly (1993b) investigated the effect of temperature and day-length effects with selenium on juvenile bluegills exposed for 180 days. Selenium exposures included 4.8 µg/L in water (SeVI:SeIV = 1:1) and Se(II) in food (5.1 µg/g) and simulation of summer conditions and winter conditions. Functions monitored during the study were percent lipid content of fish (energy reserve), cumulative mortality, body condition factor, Q_{O2} and gill pathology and blood abnormalities. All of these major functions were significantly affected by winter simulation plus selenium in experiments designed to chronically expose bluegills to a combination of selenium and environmental factors that would reflect actual exposure of natural fish populations to selenium during seasonal change.

APPENDIX E

SITE-SPECIFIC CONSIDERATIONS

Site-specific Considerations

Aquatic organism uptake of selenium by both water column exposure and dietary pathways has prompted a number of researchers to investigate the toxicity of selenium under site-specific conditions. Previous site-specific studies have addressed the water-based chronic criterion of 5 µg/L through examination of environmental variables that could potentially influence the availability and/or accumulation of selenium within the aquatic ecosystem under consideration, thereby either increasing or decreasing the toxic impact of selenium on the aquatic community (Adams et al. 1998; Canton and VanDerveer 1997; VanDerveer and Canton 1997).

Now that the recommended chronic criterion is tissue-based, site-specific factors that affect the bioaccumulation of selenium are not relevant in the modification of the criterion. Recent studies on the effects of selenium on bluegill in streams receiving wastewater from a coal ash effluent suggest fish exposed to Se-laden effluents may exhibit tolerance (Lohner et al. 2001a,b,c). The authors found the bluegill population receiving the coal ash effluent to have an age class structure and condition indices similar to reference locations despite having selenium concentration in the ovary and whole-body tissues twice the level of the FCV. Hematological and biochemical assays using samples from exposed bluegill have shown a reduced response relative to reference fish,but the authors contend that they are not always related to selenium. The authors hypothesize that selenium speciation, metabolism, bioavailability and antagonism are possible reasons for the decreased sensitivity of the resident bluegill population in the ash stream. To date, no experiments on the success on embryo-larval development have been conducted.

In an effort to determine if a proposed multiple-use water development project (Animas La Plata) would adversely affect aquatic biota in Colorado and New Mexico, Lemly (1997c) conducted a hazard assessment of selenium using the Protocol Method (Lemly 1995). Using existing environmental monitoring data, the hazard assessment indicated that selenium poses a siginificant toxic threat to aquatic biota in the Animas La Plata Project. Incorporating this information into the proposed water development will substantially reduce the chances of experiencing significant environmental problems similar to those encountered at Belews Lake and Kesterson National Wildlife Refuge. Once an aquatic system is impacted with selenium, it could take several to many years before the biological health of the system can be returned to the original condition prior to perturbation. The Grassland Water District in central California is an example of an

aquatic system that was contaminated with selenium as a result of subsurface agricultural drainwater used for wetland management since 1954 (Paveglio et al. 1997). Selenium contamination of aquatic bird food chains prompted the California State Water Resources Board to mandate the Grassland Water District to reduce selenium concentration starting in 1985 by essentially filling the wetlands with freshwater only. Selenium concentrations in a number of aquatic birds have gradually declined since 1985 (1985 to 1994), but selenium concentrations in some wintering birds still were above concentrations associated with impaired reproduction in laboratory and field studies. The authors estimated under the current management strategy, an additional 1 to 13 years from 1994 are needed for selected species to reach background selenium levels in liver. Thus, approximately 10 to 20 years are needed at this site to reduce the elevated levels of selenium in avian species and restore normal reproductive success.

APPENDIX F

OTHER DATA

Other Data

Selenite

Additional data on the lethal and sublethal effects of selenium on aquatic species are presented in Table F-1. Bringmann and Kuhn (1959a,b, 1976, 1977a, 1979, 1980b, 1981), Jakubczak et al. (1981), and Patrick et al. (1975) reported the concentrations of selenite that caused incipient inhibition (defined variously, such as the concentration resulting in a 3% reduction in growth) for algae, bacteria, and protozoans (Table F-1). Although incipient inhibition might be statistically significant, its ecological importance is unknown. Albertano and Pinto (1986) found the growth of three red algal species was inhibited at selenite concentrations that ranged from 790 to 3,958? g/L.

Selenate

Dunbar et al. (1983) exposed fed *D. magna* to selenate for seven days and obtained an LC_{50} of 1,870 ? g/L. This value is in the range of the 48-hr EC_{50}s in Table F-1.

Watenpaugh and Beitinger (1985a) found that fathead minnows did not avoid 11,200? g/L selenate during 30-minute exposures (Table F-1). These authors also reported (1985b) a 24-hr LC_{50} of 82,000 ? g/L for the same species and they found (1985c) that the thermal tolerance of the species was reduced by 22,200 ? g/L. Westerman and Birge (1978) exposed channel catfish embryos and newly hatched fry for 8.5 to 9 days to an unspecified concentration of selenate. Albinism was observed in 12.1 to 36.9% of the fry during the five years of such exposures. Pyron and Beitinger (1989) also investigated fathead minnows, and after a 24-hr exposure, no effect on reproductive behavior was found at 36,000? g/L, but when adults were exposed to 20,000 ? g/L selenate for 24-hr, edema was observed for their larvae.

The respiratory rate of the eastern oyster, *Crassostrea virginica*, was unaffected by exposure to selenate at 400 ? g/L for 14 days (Fowler et al. 1981). Embryos of the striped bass were quite tolerant to selenate in dilute salt water (Klauda 1985a, b). There was a 93% successful hatch of embryos at 200,000 ? g/L, but 50% of 72-day-old juveniles died after four days at 87,000 ? g/L. Exposure of juvenile fish for up to 65 days to concentrations of selenate between 39 and 1,360? g/L caused developmental anomalies and pathological lesions.

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
			FRESHWATER SPECIES			
			Selenium (IV)			
Green alga, *Scenedesmus quadricauda*	Sodium selenite	-	96 hr	Incipient inhibition (river water)	2,500	Bringmann and Kuhn 1959a,b
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	72 hr	Decreased dry weight and chlorophyll a	75	Foe and Knight, Manuscript
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	72 hr	BCF = 12-21[b]	10-100	Foe and Knight, Manuscript
Green alga, *Selenastrum capricornutum*	Sodium selenite	-	72 hr	BCF = 11,164[c]	150	Foe and Knight, Manuscript
Alga, *Chrysochromulina breviturrita*	Selenious acid	-	30 days	Increased growth	320	Wehr and Brown 1985
Red alga, *Cyanidium caldarium*	Selenious acid	-	20 days	Inhibited growth	3,958	Albertano and Pinto 1986
Red alga, *Cyanidioschyzon merolae*	Selenious acid	-	20 days	Inhibited growth	3,140	Albertano and Pinto 1986
Red alga, *Galdieria sulphuraria*	Selenious acid	-	20 days	Inhibited growth	790	Albertano and Pinto 1986
Algae (diatoms), Mixed population	Sodium selenite	-	18 days	Inhibited growth	11,000	Patrick et al. 1975
Bacterium, *Escherichia coli*	Sodium selenite	-	-	Incipient inhibition	90,000	Bringmann and Kuhn 1959a
Bacterium, *Pseudomonus putida*	Sodium selenite	-	16 hr	Incipient inhibition	11,400 (11,200)	Bringmann and Kuhn 1976; 1977a; 1979; 1980b
Protozoan, *Entosiphon sulcatum*	Sodium selenite	-	72 hr	Incipient inhibition	1.8 (1.9)	Bringmann 1978; Bringmann and Kuhn 1979; 1980b; 1981
Protozoan, *Microreqma heterostoma*	Sodium selenite	-	28 hr	Incipient inhibition	183,000	Bringmann and Kuhn 1959b

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Protozoan, *Chilomonas paramecium*	Sodium selenite	-	48 hr	Incipient inhibition	62	Bringmann and Kuhn 1981; Bringmann et al. 1980
Protozoan, *Uronema parduezi*	Sodium selenite	-	20 hr	Incipient inhibition	118	Bringmann and Kuhn 1980a; 1981
Snail, *Lymnaea stagnalis*	Sodium selenite	-	7.5 days	LT50	3,000	Van Puymbroeck et al. 1982
Cladoceran, *Daphnia magna*	Sodium selenite	-	48 hr	EC50 (river water)	2,500	Bringmann and Kuhn 1959a,b
Cladoceran, *Daphnia magna*	Sodium selenite	214	24 hr	LC50	16,000	Bringmann and Kuhn 1977a
Cladoceran, *Daphnia magna*	Sodium selenite	214	24 hr	EC50 (swimming)	9.9	Bringmann and Kuhn 1977b
Cladoceran, *Daphnia magna*	Sodium selenite	329	48 hr 96 hr 14 days	EC50 (fed)	710 430 430	Halter et al. 1980
Cladoceran (<24 hr), *Daphnia magna*	Sodium selenite	-	48 hr 21 days	EC50 (fed)	685 160	Adams and Heidolph 1985
Cladoceran (5th instar), *Daphnia magna*	Sodium selenite	-	48 hr	LC50 (fed)	680	Johnston 1987
Cladoceran, *Daphnia magna*	Selenious acid	220[d]	48 hr	LC50 (fed)	1,200	Kimball, Manuscript
Cladoceran (preadult), *Daphnia pulex*	Sodium selenite	42	24 hr	Did not reduce oxygen consumption or filtering rate	>498	Reading and Buikema 1980
Ostracod, *Cyclocypris* sp.	Sodium selenite	100.8	48 hr	LC50	130,000	Owsley 1984
Amphipod, *Hyalella azteca*	Sodium selenite	329	14 days	LC50 (fed)	70	Halter et al. 1980
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenite	133	48 hr	LC50	623	Brasher and Ogle 1993
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenite	133	10 days	LC50 (fed)	312	Brasher and Ogle 1993

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenite	133	24 days	LOEC reproduction (static-renewal)	200	Brasher and Ogle 1993
Midge (first instar), *Chironomus riparius*	Sodium selenite	134	48 h	LC50	7,950	Ingersoll et al. 1990
Midge (first instar), *Chironomus riparius*	Sodium selenite	40-48	48 h	LC50	14,600	Ingersoll et al. 1990
Coho salmon (fry), *Oncorhynchus kisutch*	Sodium selenite	325	43 days	LC50	160	Adams 1976
Rainbow trout (fry), *Oncorhynchus mykiss*	Sodium selenite	334	21 days	LC50	460	Adams 1976
Rainbow trout (fry), *Oncorhynchus mykiss*	Sodium selenite	334	21 days	Reduced growth	250	Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	330	5 days	LC50	2,700 2,750	Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	325	48 days	LC50	500	Adams 1976
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	325	96 days	LC50	280	Adams 1976
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	4 wk	MATC survival	200	Gissel-Nielsen and Gissel-Nielsen 1978
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	4 wk	MATC survival	4.7 µg/g dw (whole-body)	Gissel-Nielsen and Gissel-Nielsen 1978
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	4 wk	BCF = 23	100	Gissel-Nielsen and Gissel-Nielsen 1978
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	42 wk	MATC growth (dietary only exposure)	>9.96 µg Se/g dw (food)	Goettl and Davies 1978

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Sodium selenite	-	42 wk	MATC survival (dietary only exposure)	5.34 µg Se/g dw (food)	Goettl and Davies 1978
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	9 days	LC50	7,020	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	96 hr 9 days	LC50 (fed)	7,200 5,410	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	96 hr 9 days	LC50 (fed)	8,200 6,920	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	41 days	LOAEC (Reduced hatch of eyed embryos)	26	Hodson et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	135	50 wk	Decreased iron in blood and red cell volume	53	Hodson et al. 1980
Rainbow trout (fertilized egg), *Oncorhynchus mykiss*	Sodium selenite	135	44 wk	BCF = 33.2 BCF = 21.1	53	Hodson et al. 1980
Rainbow trout (embryo), *Oncorhynchus mykiss*	Sodium selenite	-	120 hr	Did not reduce survival or time to hatch	10,000	Klaverkamp et al. 1983b
Rainbow trout, *Oncorhynchus mykiss*	Sodium selenite	-	90 days	Chronic value for survival	14	Mayer et al. 1986
Rainbow trout (sac fry), *Oncorhynchus mykiss*	Sodium selenite	272	90 days	LC50	55.2[e]	Hunn et al. 1987
Rainbow trout (sac fry), *Oncorhynchus mykiss*	Sodium selenite	272	90 days	MATC survival	31.48	Hunn et al. 1987
Rainbow trout (egg), *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 17.5 BCF = 3.5	0.4 45.6	Hodson et al. 1986

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Rainbow trout (embryo), *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 3.1 BCF = 3.0	0.4 45.6	Hodson et al. 1986
Rainbow trout (sac-fry), *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 13.1 BCF = 1.6	0.4 45.6	Hodson et al. 1986
Rainbow trout (swim-up fry) *Oncorhynchus mykiss*	Sodium selenite	-	96 hr	BCF = 80.3 BCF = 20.2	0.4 45.6	Hodson et al. 1986
Northern pike, *Esox lucius*	Sodium selenite	10.2	76 hr	LC50	11,100	Klaverkamp et al. 1983a
Goldfish, *Carassius auratus*	Selenium dioxide	157	14 days	LC50	6,300	Cardwell et al. 1976a,b
Goldfish, *Carassius auratus*	Sodium selenite	-	10 days	Mortality	5,000	Ellis 1937; Ellis et al. 1937
Goldfish, *Carassius auratus*	Sodium selenite	-	46 days	Gradual anorexia and mortality	2,000	Ellis et al. 1937
Goldfish, *Carassius auratus*	Selenium dioxide	-	7 days	LC50	12,000	Weir and Hine 1970
Goldfish, *Carassius auratus*	Selenium dioxide	-	48 hr	Conditional avoidance	250	Weir and Hine 1970
Fathead minnow, *Pimephales promelas*	Selenium dioxide	157	9 days	LC50	2,100	Cardwell et al. 1976a,b
Fathead minnow, *Pimephales promelas*	Sodium selenite	329	96 hr	LC50 (fed)	1,000	Halter et al. 1980
Fathead minnow, *Pimephales promelas*	Sodium selenite	329	14 days	LC50 (fed)	600	Halter et al. 1980
Fathead minnow, *Pimephales promelas*	Selenious acid	220[d]	8 days	LC50 (fed)	420	Kimball, Manuscript
Creek chub, *Semotilus atromaculatus*	Selenium dioxide	-	48 hr	Mortality	?12,000	Kim et al. 1977

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Bluegill, *Lepomis macrochirus*	Sodium selenite	318	48 days	LC50	400	Adams 1976
Bluegill, *Lepomis macrochirus*	Selenium dioxide	157	14 days	LC50	12,500	Cardwell et al. 1976a,b
Bluegill (juvenile), *Lepomis macrochirus*	Sodium selenite	16	323 days	MATC larval survival (dietary only exposure)	19.75 µg Se/g dw (food)	Woock et al. 1987
Bluegill (juvenile), *Lepomis macrochirus*	Sodium selenite	25 and 200	120 days	No mortality	>10	Lemly 1982
Largemouth bass (juvenile), *Micropterus salmoides*	Sodium selenite	25 and 200	120 days	No mortality	10	Lemly 1982
Yellow perch, *Perca flavescens*	Sodium selenite	10.2	10 days	LC50	4,800	Klaverkamp et al. 1983a,b
African clawed frog, *Xenopus laevis*	Sodium selenite	-	7 days	LC50	1,520	Browne and Dumont 1980
African clawed frog, *Xenopus laevis*	Sodium selenite	-	1-7 days	Cellular damage	2,000	Browne and Dumont 1980
			Selenium (VI)			
Alga, *Chrysochromulina breviturrita*	-	-	30 days	Increased growth	50	Wehr and Brown 1985
Snail, *Lymnaea stagnalis*	Sodium selenate	-	6 days	LT50	15,000	Van Puymbroeck et al. 1982
Cladoceran, *Daphnia magna*	Sodium selenate	129.5	7 days	LC50 (fed)	1,870	Dunbar et al. 1983
Cladoceran (juvenile), *Daphnia magna*	Sodium selenate	-	48 hr	LC50 (fed)	550	Johnston 1987
Cladoceran (5th instar), *Daphnia magna*	Sodium selenate	-	48 hr	LC50 (fed)	750	Johnston 1987

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Cladoceran (5th instar), *Daphnia magna*	Sodium selenate	-	90 hr	42% of organ-isms had visible changes in gut morphology	250	Johnston 1989
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenate	133	48 hr	LC50	2378	Brasher and Ogle 1993
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenate	133	10 days	LC50 (fed)	627	Brasher and Ogle 1993
Amphipod (2 mm length), *Hyalella azteca*	Sodium selenate	133	24 days	LOEC reproduction (static renewal)	>700	Brasher and Ogle 1993
Midge (first instar), *Chironomus riparius*	Sodium selenate	134	48 h	LC50	16,200	Ingersoll et al. 1990
Midge (first instar), *Chironomus riparius*	Sodium selenate	40-48	48 h	LC50	10,500	Ingersoll et al. 1990
Rainbow trout (embryo, larva), *Oncorhynchus mykiss*	Sodium selenate	104 (92-110)	28 days	EC50 (death and deformity)	5,000 (4,180) (5,170)	Birge 1978; Birge and Black 1977; Birge et al. 1980
Goldfish (embryo, larva), *Carrassius auratus*	Sodium selenate	195	7 days	EC50 (death and deformity)	8,780	Birge 1978
Goldfish, *Carassius auratus*	Sodium selenate	-	24 hr	BCF = 1.42 BCF = 1.15 BCF = 1.47 BCF = 0.88 BCF = 1.54	0.45 0.9 1.35 2.25 4.5	Sharma and Davis 1980
Fathead minnow, *Pimephales promelas*	Sodium selenate	337.9	48 days	LC50	2,000	Adams 1976
Fathead minnow, *Pimephales promelas*	Sodium selenate	338	48 days	LC50	1,100	Adams 1976
Fathead minnow, *Pimephales promelas*	-	51	30 min	No avoidance	11,200	Watenpaugh and Beitinger 1985a
Fathead minnow, *Pimephales promelas*	-	-	24 hr	LC50	82,000	Watenpaugh and Beitinger 1985b

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Fathead minnow, *Pimephales promelas*	-	-	24 hr	Reduced thermal tolerance	22,200	Watenpaugh and Beitinger 1985c
Fathead minnow, *Pimephales promelas*	Sodium selenate	44-49	7 days	Chronic value - growth Chronic value-growth Chronic value-survival	1,739 561 2,000	Norberg-King 1989
Fathead minnow, *Pimephales promelas*	Sodium selenate	160-180	24 hr	No effect on reproductive behavior	36,000	Pyron and Beitinger 1989
Fathead minnow, *Pimephales promelas*	Sodium selenate	160-180	24 hr	Edema in larvae produced from adults exposed to Selenium VI	20,000	Pyron and Beitinger 1989
Channel catfish (embryo, fry), *Ictalurus punctatus*	Sodium selenate	90	8.5-9 days	Induced albinism	-	Westerman and Birge 1978
Narrow-mouthed toad (embryo, larva), *Gastrophryne carolinensis*	Sodium selenate	195	7 days	EC50 (death and deformity)	90	Birge 1978; Birge and Black 1977; Birge et al. 1979a
			Organo-selenium			
Bluegill (juvenile), *Lepomis macrochirus*	Seleno-L-methionine	16	323 days	MATC larval survival (dietary only exposure)	20.83 µg Se/g dw (food)	Woock et al. 1987
Bluegill (juvenile), *Lepomis macrochirus*	Seleno-L-methionine	283	90 days	EC20 survival (dietary only exposure)	>13.4 µg/g dw (food)	Cleveland et al. 1993
Bluegill (2 yr and adult), *Lepomis macrochirus*	Selenium	-	field	NOEC deformities	53.83 µg Se/g dw (liver)	Reash et al. 1999
Bluegill (2 yr and adult), *Lepomis macrochirus*	Selenium	-	field	NOEC deformities	23.38 µg Se/g dw (ovaries)	Reash et al. 1999

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration[a]	Reference
Redear sunfish (adult), *Lepomis microlophus*	Selenium	-	field	LOEC Adverse histopathological alterations	<38.15 µg Se/g dw	Sorensen 1988
			Selenium Mixtures			
Phytoplankton, Mixed population	Selenium	-	field	Reduced growth rates	18	Riedel et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	Selenite-Selenate mixture	138	21 days	MATC growth	115.2 µg Se/L	Ingersoll et al. 1990
Cladoceran (<24 hr), *Daphnia magna*	Selenite-Selenate mixture	138	21 days	MATC productivity	21.59 ? g/g dw (whole-body)	Ingersoll et al. 1990
Midge (<24-hr), *Chironomus riparius*	Selenite-Selenate mixture	138	30 days	MATC emergence	503.6	Ingersoll et al. 1990
Bluegill (juvenile), *Lepomis macrochirus*	Selenite-Selenate mixture	283	60 days	NOEC survival	340	Cleveland et al. 1993
Bluegill (juvenile), *Lepomis macrochirus*	Selenite-Selenate mixture	283	60 days	EC20 survival	4.07 µg/g dw (whole body)	Cleveland et al. 1993

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (ug/L)[a]	Reference
			SALTWATER SPECIES			
			Selenium (IV)			
Anaerobic bacterium, *Methanococcus vannielli*	Sodium selenite	-	110 hr	Stimulated growth	79.01	Jones and Stadtman 1977
Bacterium, *Vibrio fisheri*	Sodium selenite	-	5 min	50% decrease in light output (Microtox®)	68,420	Yu et al. 1997
Green alga, *Chlorella* sp.	Sodium selenite	32	14 days	5-12% increase in growth	10-10,000	Wheeler et al. 1982

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (ug/L)[a]	Reference
Green alga, *Platymonas subcordiformis*	Sodium selenite	32	14 days	23% increase in growth	100-10,000	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenite	32	20 days	Increased growth; induced glutathione peroxidase	4,600	Gennity et al. 1985a,b
Diatom, *Skeletonema costatum*	Selenium dioxide	-	5 days	BCF = 18,000 BCF = 16,000 BCF = 10,000	0.06 0.79 3.6	Zhang et al. 1990
Diatom, *Chaetoceros muelleri*	Selenium dioxide	-	6 days	BCF = 337,000 BCF = 65,000 BCF = 5,000	0.06 0.79 3.6	Zhang et al. 1990
Diatom, *Phaeodactylum tricornutum*	Selenium dioxide	-	8 days	BCF = 109,000 BCF = 27,000 BCF = 7,000	0.06 0.79 3.6	Zhang et al. 1990
Diatom, *Thallassiosira aestivalis*	Selenium oxide	29-30	72 hr	No effect on cell morphology	78.96	Thomas et al. 1980a
Brown alga, *Fucus spiralis*	Sodium selenite	-	60 days	1355% increase in growth of thalli	2.605	Fries 1982
Red alga, *Porphyridium cruentum*	Sodium selenite	32	27 days	Increase growth; induced glutathione peroxidase	4,600	Gennity et al. 1985a,b
			Selenium (VI)			
Bacterium, *Vibrio fisheri*	Sodium selenate	-	15 min	50% decrease in light output (Microtox®)	3,129,288	Yu et al. 1997
Green alga, *Chlorella* sp.	Sodium selenate	32	14 days	No effect on rate of cell	10-1,000	Wheeler et al. 1982
Green alga, *Chlorella* sp.	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenate	32	14 days	No effect on rate of cell population growth	10-100	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenate	32	14 days	71% reduction in rate of cell population growth	1,000	Wheeler et al. 1982
Green alga, *Dunaliella primolecta*	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982

Table F-1. Other Data on Effects of Selenium on Aquatic Organisms (continued)

Species	Chemical	Salinity (g/kg)	Duration	Effect	Concentration (ug/L)[a]	Reference
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	14 days	No effect on rate of cell population growth	10	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	14 days	16% decrease in rate of cell population growth	100	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	14 days	50% decrease in rate of cell population growth	1,000	Wheeler et al. 1982
Green alga, *Platymonas subcordiformis*	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982
Brown alga, *Fucus spiralis*	Sodium selenate	-	60 days	160% increase in growth rate of thalli	2.605	Fries 1982
Red alga, *Porphridium cruentum*	Sodium selenate	32	14 days	23-35% reduction in rate of cell population growth	10-1,000	Wheeler et al. 1982
Red alga, *Porphyridium cruentum*	Sodium selenate	32	4-5 days	100% mortality	10,000	Wheeler et al. 1982
Eastern oyster (adult), *Crassostrea virginica*	Sodium selenate	34	14 days	No significant effect on respiration rate of gill tissue	400	Fowler et al. 1981
Striped bass (embryo), *Morone saxatilis*	Sodium selenate	7.2-7.5	4 days	93% successful hatch and survive	200,000	Klauda 1985a,b
Striped bass (larva), *Morone saxatilis*	Sodium selenate	4.0-5.0	4 days	LC50 (control survival= 77%)	13,020	Klauda 1985a,b
Striped bass (juvenile), *Morone saxatilis*	Sodium selenate	3.5-5.5	9-65 days	Significant incidence of development anomalies of lower jaw	39-1,360	Klauda 1985a,b
Striped bass (juvenile), *Morone saxatilis*	Sodium selenate	3.5-5.5	45 days	Significant incidence of severe blood cytopathology	1,290	Klauda 1985a,b

[a] Concentration of selenium, not the chemical. Units are µg selenium/L of water unless noted otherwise.
[b] Converted from dry weight to wet weight basis (see Guidelines)
[c] Growth of algae was inhibited
[d] From Smith et al. (1976).
[e] Calculated from the published data using probit analysis and allowing for 8.9% spontaneous mortality.

Other Data - Endangered Species

Two similar studies were conducted in subsequent years, 1996 and 1997, to determine the effects of site water and site food contaminated with selenium on the endangered species, razorback sucker,*Xyrauchen texanus* (Hamilton et al. 2001a,b). Both studies show marked effects on the survival of razorback sucker larvae exposed to contaminated food and to a lesser extent, contaminated water. Although the data convincingly demonstrate effects to larval survival from exposure to contaminated food, it was not considered acceptable data for use in the derivation of the chronic criterion because of inconsistencies between levels of selenium in the food and larvae and degree and time to response. A summary of each of these two studies is presented below.

Evaluation of Contaminant Impacts on Razorback Sucker held in Flooded Bottomland Sites Near Grand Junction , Colorado - 1996 (Hamilton et al. 2001a)

This study was initiated with 5-day old razorback sucker larvae spawned from adults which were previously held (9 months) in three different location along the Colorado River that contained varying levels of selenium: Horsethief (the designated reference site which receives water pumped directly from the Colorado River near Fruita, CO), Adobe Creek (low level selenium contamination), and North Pond (high level selenium contamination). The selenium content in the eggs from three Horsethief females ranged from 5.8 to 6.6 µg Se/g dw, and the selenium content in adult muscle plugs at spawning was from 3.4 to 5.0 µg Se/g dw. The selenium content in the eggs from three Adobe Creek females ranged from 38.0 to 54.5 µg Se/g dw, and the selenium content in adult muscle plugs at spawning was from 11.5 to 12.9 µg Se/g dw. The selenium content in the eggs from three North Pond females ranged from 34.3 to 37.2 µg Se/g dw, and the selenium content in adult muscle plugs at spawning was from 14.1 to 17.3 µg Se/g dw. The selenium content in the eggs from a hatchery brood stock female was 7.1 µg Se/g dw, and the selenium content in adult muscle plugs at spawning ranged from 2.6 to 13.8 µg Se/g dw. The razorback sucker larvae spawned from fish hatchery brood stock and held in Colorado River (Horsethief) water were used as an additional reference group of test fish.

The experimental groups were subdivided into those receiving reference water (hatchery water; 24-Road Fish Hatchery) or site water. They were further subdivided into those receiving a daily ration of reference food (brine shrimp) or zooplankton collected from each site where their parents were exposed for the previous 9 months. A total of 60 larvae from each of the four adult sources (Horsethief, Adobe Creek, North Pond,

Brood Stock) were exposed to each treatment (2 replicates x 3 spawns x 10 fish/beaker). The larvae were held in beakers containing 800 mls of test water. Fifty percent of the test water was renewed daily.

Treatment conditions during the 30-day larval study:

Source of Larvae	**Treatments**	**Se in food (µg/g dw)**	**Se in water (µg/L)**
Horsethief Adults	Reference food: Reference water	2.7	< 1
	Reference food: Site water	2.7	0.9
	Site food: Reference water	5.6	< 1
	Site food: Site water	5.6	0.9
Adobe Creek Adults	Reference food: Reference water	2.7	< 1
	Reference food: Site water	2.7	5.5
	Site food: Reference water	20	< 1
	Site food: Site water	20	5.5
North Pond Adults	Reference food: Reference water	2.7	< 1
	Reference food: Site water	2.7	10.7
	Site food: Reference water	39	<1
	Site food: Site water	39	10.7
Hatchery raised Adults	Reference food: Reference water	2.7	< 1
	Reference food: Site water	2.7	0.9
	Site food: Reference water	5.6	< 1
	Site food: Site water	5.6	0.9

Growth, survival and development were evaluated amongst treatment groups for up to 30 days in the treatment conditions. Each treatment group was fed once daily after renewal. Test waters were collected every day from each site as grab samples for the renewal. A small portion of this water was retained at 3- and 7-day intervals for an analysis of total and dissolved selenium concentrations. At approximately 2-day intervals, aquatic invertebrates and brine shrimp not used for feeding were sieved from the media for selenium analysis. The number of live fish were recorded daily. After the 30-day exposure period, the surviving fish were

sacrificed and measured for total length. At this same time, approximately four fish from each treatment, when available, were collected as a composite sample and analyzed for selenium. Specific treatment conditions were as those described above.

After 30 days of exposure in the reference food-reference water treatment, survival of razorback sucker larvae from brood stock and Horsethief adults (89 and 87 percent, respectively) was slightly higher than those from Adobe Creek adults (84 percent) and North Pond adults (75 percent). Corresponding selenium concentrations in larval whole-body tissue were 3.6, 3.3, 7.7 and 9.7 µg Se/g dw, respectively. Survival was similar or slightly reduced in larvae from all four sources after 30 days of exposure in the reference food-site water treatments; corresponding selenium concentrations in larval whole-body tissue were 5.2, 5.1, 12.7 and 15.2 µg Se/g dw, respectively. In contrast, none of the larvae spawned from parents from Horsethief, Adobe Creek, or North Pond survived to 30 days when fed zooplankton collected from the three sites, irrespective of the water type they were exposed to (i.e., reference or site). Only the larvae from brood stock adults, which were fed zooplankton from the Horsethief site for this treatment, survived, and even these larvae suffered substantial mortality (40 and 60 percent respectively). The mean selenium concentrations in whole-body tissue of larvae from brood stock adults after the 30-day exposures were 5.4 µg Se/g dw (site food-reference water treatment) and 6.9 µg Se/g dw (site food-site water treatment).

Several inconsistencies were observed that suggest selenium may not be solely responsible for the effect on larval survival. Larval survival in the Adobe Creek treatment group exposed to reference water and reference food was 84 percent, similar to control survival (86-89 percent). The selenium concentration in the larvae from this Adobe Creek treatment group after 30 days was higher(7.7 µg/g dw) than brood stock fish (5.4 µg Se/g dw) which had a lower 30-day survival (62 percent). Also, the time to 50 percent mortality between the site food treatments, where most mortality occurred, was not related to selenium concentration in the diet or in the larvae.

Evaluation of Contaminant Impacts on Razorback Sucker held in Flooded Bottomland Sites Near Grand Junction , Colorado - 1997 (Hamilton et al. 2001b)

In a similar 30-day larval study conducted by the authors the in following year (1997), razorback sucker larvae from a single hatchery brood stock female (11 µg Se/g dw muscle) were subjected to one of the sixteen different combined water and dietary exposure conditions described in the earlier (1996) study. The female parent was held at Horsethief Canyon State Wildlife Area before spawning. The larvae were held in beakers containing 800 mls of test water as before, fifty percent of the test water was renewed daily. Specific treatment conditions for the 1997 30-day larval study were as follows:

Treatment conditions during the 30-day larval study:

Water Treatments	**Se in food (µg/g dw)**	**Se in water (µg/L)**
Reference food (brine shrimp): Reference water (24-Road Hatchery)	3.2	< 1
Reference food: Site water (Horsethief)	6.0	1.6
Reference food: Site water (Adobe Creek)	32.4	3.4
Reference food: Site water (North Pond)	52.5	13.3
Horsethief food: Reference water	3.2	< 1
Horsethief food: Site water (Horsethief)	6.0	1.6
Horsethief food: Site water (Adobe Creek)	32.4	3.4
Horsethief food: Site water (North Pond)	52.5	13.3
Adobe Creek food: Reference water	3.2	< 1
Adobe Creek food: Site water (Horsethief)	6.0	1.6
Adobe Creek food: Site water (Adobe Creek)	32.4	3.4
Adobe Creek food: Site water (North Pond)	52.5	13.3
North Pond food: Reference water	3.2	< 1
North Pond food: Site water (Horsethief)	6.0	1.6
North Pond food: Site water (Adobe Creek)	32.4	3.4
North Pond food: Site water (North Pond)	52.5	13.3

In this year's study, after 30 days of exposure, there was also good survival of razorback sucker larvae fed reference food (brine shrimp) and held in reference water or water from Horsethief (83 and 81 percent, respectively). The survival of these larvae was significantly greater than survival of larvae fed brine shrimp and held in water from North Pond (only 52 percent). Corresponding selenium concentrations in larval whole-body tissue after 10 days were 6.3, 6.7, and 11 µg Se/g dw, respectively. The average concentrations of selenium in the water for the three treatments were <1, 1.6, and 13.3 µg Se/L. After 30 days the mean selenium concentrations in these larvae were 5.2, 5.2, and 16 µg Se/g dw, respectively. Survival was markedly reduced (0 to 30 percent survival) in the remainder treatments where larvae were fed zooplankton from the various sites. Complete mortality was experienced by larvae exposed to Horsethief food and reference water treatment after 30 days.

Similar to the previous study, there are several inconsistencies in the results that suggested selenium may not be solely responsible for the effect on larval survival. The most notable inconsistency was that the greatest effect on larval survival (percent survival or time to 50 percent mortality) was from exposure to Horsethief food, the food with the lowest selenium contamination.

APPENDIX G

UNUSED DATA

Unused Data

Based on the requirements set forth in the guidelines (Stephen et al. 1985) the following studies are not acceptable for the following reasons and are classified as unused data.

Studies Were Conducted with Species That Are Not Resident in North America

Ahsanullah and Brand (1985)
Ahsanullah and Palmer (1980)
Baker and Davies (1997)
Barghigiani et al. (1993)
Chidambaram and Sastry (1991a,b)
Congiu et al. (1989)
Cuvin and Furness (1988)
Fowler and Benayoun (1976a,b)
Gaikwad (1989)
Gotsis (1982)
Hiraika et al. (1985)
Juhnke and Ludemann (1978)
Kitamura (1990)
Manoharan and Prabakaran (1994)
Minganti et al. (1994, 1995)
Niimi and LaHam (1975, 1976)
Regoli (1998)
Regoli and Principato (1995)
Rhodes et al. (1994)
Ringdal and Julshamn (1985)
Rouleau et al. (1992)
Sastry and Shukla (1994)
Savant and Nilkanth (1991)
Shultz and Ito (1979)
Srivastava and Tyagi (1985)
Takayanagi (2001)
Tomasik et al. (1995b)
Tian and Liu (1993)
Wrench (1978)

Deelstra et al. (1989), Forsythe and Klaine (1994), Okasako and Siegel (1980) and Petrucci et al. (1995) conducted tests with brine shrimp species that are too atypical to be used in derving national criteria.

These Reviews Only Contain Data That Have Been Published Elsewhere

Adams and Johnson (1981)
Biddinger and Gloss (1984)
Bowie et al. (1996)
Brandao et al. (1992)
Brooks (1984)
Burton and Stemmer (1988)
Chapman et al. (1986)
Davies (1978)
Devillers et al. (1988)
Eisler (1985)
Hall and Burton (1982)
Hodson and Hilton (1983)
Hodson et al. (1984)
Jenkins (1980)
Kaiser et al. (1997)
Kay (1984)
LeBlanc (1984)
Lemly (1993c, 1996ab, 1997d)
Lemly and Smith (1987)
McKee and Wolf (1963)
National Research Council (1976)
Neuhold (1987)
NCDNR&CD (1986)
Peterson and Nebeker (1992)
Phillips and Russo (1978)
Presser (1994)
Roux et al. (1996)
Thompson et al. (1972)
Versar (1975)

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Authors Did Not Specify the Oxidation State of Selenium Used in Study

Greenberg and Kopec (1986)
Hutchinson and Stokes (1975)
Kapu and Schaeffer (1991)
Kramer et al. (1989)
Mahan et al. (1989)
Rauscher (1988)
Snell et al. (1991b)

Selenium Was a Component of an Effluent, Fly Ash, Formulation, Mixture, Sediment or Sludge

Apte et al. (1987)
Baer et al. (1995)
Baker et al. (1991)
Berg et al. (1995)
Besser et al. (1989)
Biedlingmaier and Schmidt (1989)
Bjoernberg (1989)
Bjoernberg et al. (1988)
Blockmann et al. (1995)
Boisson et al. (1989)
Bondavalli et al. (1996)
Bowmer et al. (1994)
Brieger et al. (1992)
Burton and Pinkney (1984)
Burton et al. (1983, 1987)
Cherry et al. (1987)
Cieminski and Flake (1995)
Clark et al. (1989)
Cooke and Lee (1993)
Cossu et al. (1997)
Coyle et al. (1993)
Crane et al. (1992)
Crock et al. (1992)
Cushman et al. (1977)
Davies and Russell (1988)
de Peyster et al. (1993)
Dickman and Rygiel (1996)
Dierenfeld et al. (1993)
Drndarski et al. (1990)
Eriksson and Forsberg (1992)
Eriksson and Pedros-Alio (1990)
Fairbrother et al. (1994)
Fava et al. (1985a,b)
Feroci et al. (1997)
Finger and Bulak (1988)
Finley (1985)
Fisher and Wente (1993)
Fjeld and Rognerud (1993)
Fletcher et al. (1994)
Follett (1991)
Gerhardt (1990)
Gerhardt et al. (1991)
Gibbs and Miskiewicz (1995)
Graham et al. (1992)
Gunderson et al. (1997)
Hall (1988)
Hall et al. (1984, 1987, 1988,1992)
Hamilton et al. (1986, 2000)
Harrison et al. (1990)
Hartwell et al. (1987ab, 1988, 1997)
Hatcher et al. (1992)
Haynes et al. (1997)
Hayward et al. (1996)
Hellou et al. (1996)
Henebry and Ross (1989)
Henry et al. (1989, 1990, 1995)
Hildebrand et al. (1976)
Hjeltner and Julshman (1992)
Hockett and Mount (1996)
Hodson (1990)
Hoffman et al. (1988, 1991)
Homziak et al. (1993)
Hopkins et al. (2000)
Hothem and Welsh (1994a)
Jackson (1988)
Jackson et al. (1990)
Jacquez et al. (1987)
Jay and Muncy (1979)
Jayasekera (1994)
Jayasekera and Rossbach (1996)
Jenner and Bowmer (1990) (1992)
Jenner and Janssen-Mommen (1989)
Jin et al. (1997)
Jorgensen and Heisinger (1987)
Karlson and Frankenberger (1990)
Kemble et al. (1994)
Kenned (1986)
Kersten et al. (1991)
King and Cromartie (1986)
King et al. (1991, 1994)
Klusek et al. (1993)
Koh and Harper (1988)
Koike et al. (1993)
Krishnaja et al. (1987)
Kruuk and Conroy (1991)
Kuehl and Haebler (1995)
Kuehl et al. (1994)
Kuss et al. (1995)
Landau et al. (1985)
Livingstone et al. (1991)
Lobel et al. (1990)

Luoma and Phillips (1988)
Lundquist et al. (1994)
Lyle (1986)
MacFarlane et al. (1986)
Mann and Fyfe (1988)
Marcogliese et al. (1987)
Marvin et al. (1997)
Maurer et al (1999)
McCloskey and Newman (1995)
McCloskey et al. (1995)
McCrea and Fischer (1986)
McLean et al. (1991)
Mehrle et al. (1987)
Metcalf-Smith (1994)
Micallef and Tyler (1989)
Mikac et al. (1985)
Miles and Tome (1997)
Miller et al. (1996)
Misitano and Schiewe (1990)
Moore (1988)
Munawar and Legner (1993)
Muskett et al. (1985)
Naddy et al. (1995)
Nielsen and Bjerregaard (1991)
Norman et al. (1992)
Nuutinen & Kukkonen (1998)
Oberbach and Hartfield (1987, 1988)
Oberbach et al. (1989)
Ohlendorf et al. (1989, 1990, 1991)
Olsen and Welsh (1993)
Peters et al.(1999)
Phillips and Gregory (1980)
Pratt and Bowers (1990)
Presser and Ohlendorf (1987)
Prevot and Sayer-Gobillard (1986)
Pritchard (1997)
Pyleet al. (2001)
Reash et al. (1988, in press)
Rhodes and Burke (1996)
Ribeyre et al. (1995)
Rice et al. (1995)
Riggs and Esch (1987)
Riggs et al. (1987)
Robertson et al. (1991)
Roper et al. (1997)
Russell et al. (1994)
Ryther et al. (1979)
Saiki and Jenings (1992)
Saiki and Ogle (1995)
Saleh et al. (1988)
Seelye et al. (1982)
Sevareid and Ichikawa (1983)
Skinner (1985)
Somerville et al. (1987)
Sorenson and Bauer (1983)
Specht et al. (1984)
Steele et al. (1992)
Stemmer et al. (1990)
Summers et al. (1995)
Thomas et al. (1980b)
Timothy et al. (2001)
Trieff et al. (1995)
Turgeon and O'Conner (1991)
Twerdok et al. (1997)
Ursal (1987)
Van Metre and Gray (1992)
Wahl et al. (1994)
Wandan and Zabik (1996)
Wang et al. (1992, 1995)
Welsh (1992)
Weres et al. (1990)
White and Geitner (1996)
Wiemeyer et al. (1986)
Wildhaber and Schmitt (1996)
Williams et al. (1989)
Wolfe et al. (1996)
Wolfenberger (1987)
Wong and Chau (1988)
Wong et al. (1982)
Wu et al. (1997)
Yamaoka et al. (1994)
Zagatto et al. (1987)
Zaidi et al. (1995)
Zhang et al. (1996)

Exposed enzymes, excised tissue or tissue extractor

Tripathi and Pandey (1985) and Heinz (1993b) used test organisms that had been previously exposed to pollutants in food or water.

Albers et al. (1996)
Al-Sabti (1994, 1995)
Arvy et al. (1995)
Augier et al. (1993)
Avery et al. (1996)
Baatrup (1989)
Baatrup and Dansher (1987)
Baatrup et al. (1986)
Babich et al. (1986, 1989)

Barrington et al. (1997)
Becker et al. (1995a,b)
Bell et al. (1984, 1985, 1986a,b, 1987ab)
Berges and Harrison (1995)
Blondin et al. (1988)
Boisson et al. (1996)
Bottino et al. (1984)
Braddon (1982)
Braddon-Galloway and Balthrop (1985)
Bradford et al. (1994a,b)
Brandt et al. (1990)
Byl et al. (1994)
Chandy and Patel (1985)
Chen et al. (1997)
Cheng et al. (1993)
Christensen and Tucker (1976)
Dabbert and Powell (1993)
DeQuiroga et al. (1989)
Dierickx (1993)
Dietrich et al. (1987)
DiIlio et al. (1986)
Doyotte et al. (1997)
Drotar et al. (1987)
Dubois and Callard (1993)
Ebringer et al. (1996)
Engberg and Borsting (1994)
Engberg et al. (1993)
Eun et al. (1993)
Foltinova and Gajdosova (1993)
Foltinova et al. (1994)
Freeman and Sanglang (1977)
Grubor-Lajsic et al. (1995)
Hait and Sinha (1987)
Hanson (1997)
Heisinger and Scott (1985)
Heisinger and Wail (1989)
Henderson et al. (1987)
Henny and Bennett (1990)
Hoffman and Heinz (1988, 1998)
Hoffman et al. (1989, 1998)
Hontela et al. (1995)
Hoglund (1991)
Hsu et al. (1995)
Hsu and Goetz (1992)
Ishikawa et al. (1987)
James et al. (1993)
Jovanovic et al. (1995, 1997)
Kai et al. (1995)
Kedziroski et al. (1996)
Kelley et al. (1987)
Kralj and Stunja (1994)
Lalitha and Rani (1995)
Lan et al. (1995)
Lemaire et al. (1993)
Livingstone et al. (1992)
Low and Sin (1995, 1996)
Micallef and Tyler (1990)
Montagnese et al. (1993)
Murata et al. (1996)
Nakonieczny (1993)
Neuhierl and Boeck (1996)
Nigro et al (1992, 1994)
Norheim and Borch-Iohnsen (1990)
Norheim et al. (1991)
O'Brien et al. (1995)
Olson and Christensen (1980)
Overbaugh and Fall (1985)
Palmisano et al. (1995)
Patel et al. (1990)
Patel and Chandy (1987)
Perez et al. (1990)
Perez-Trigo et al. (1995)
Phadnis et al. (1988)
Price and Harrison (1988)
Rady et al. (1992)
Rani and Lalitha (1996)
Regoli et al. (1997)
Schmidt et al. (1985)
Schmitt et al. (1993)
Segner et al. (1994)
Sen et al. (1995)
Shigeoka et al. (1990, 1991)
Siwicki et al. (1994)
Srivastava and Srivastava (1995)
Sun et al. (1995)
Takeda et al. (1992a,b,(1993, 1997)
Treuhardt (1992)
Vazquez et al. (1994)
Veena et al. (1997)
Wise et al. (1993a,b)
Wong and Oliveira (1991)
Yokota et al. (1988)

Test procedures test material or results were not adequately described by Botsford (1997), Botsford et al. (1997, 1998), Bovee (1978), Gissel-Nielsen and Gissel-Nielsen (1973, 1978), Greenberg and Kopec (1986), Mauk (2001), and Nassos et al. (1980) or when the test media contained an excessive amount (>200 ? g/L) of EDTA (Riedel and Sanders (1996).

Some data obtained from tests conducted with just one exposure concentration to evaluate acute or chronic toxicity were not used (e.g., Bennett 1988; Heinz and Hoffman 1998; Munawar et al. 1987; Pagano et al. 1986; Wolfenberger 1986).

Kaiser (1980) calculated the toxicities of selenium(IV) and selenium(VI) to *Daphnia magna* based on physiochemical parameters. Kumar (1964) did not include a control treatment in the toxicity tests. The daphnids were probably stressed by crowding in the tests reported be Schultz et al. (1980). Siebers and Ehlers (1979) exposed too few test organisms as did Owsley (1984) in some tests.

Data Were Not Used When the Organisms Were Exposed to Selenium by Food or by Gavage or Injection

Frankenberger and Engberg (in press)
Hamilton (1999)
Hamilton and Lemly (1999)
Heinz and Sanderson (1990)
Heinz et al. (1990, 1996)
Hilton et al. (1982)
Hoffman and Heinz (1988)
Hoffman et al. (1991, 1992a,b,1996)
Huerkamp et al. (1988)
Julshamn et al. (1990)
Kleinow (1984)
Kleinow and Brooks (1986a,b)
Lemly (1996, 1997, 1999)
Lorentzen et al. (1994)
Maage and Waagboe (1990)
Malchow et al. (1995)
Paripatananontand Lovell(1997)
Sheline and Schmidt-Nielson (1977)
Stanley et al. (1994, 1996)
Wiemeyer and Hoffman (1996)
Wilson et al. (1997)

BCFs and BAFs from laboratory tests were not used when the tests were static or when the concentration of selenium in the test solution was not adequately measured or varied too much (Nassos et al. 1980; Ornes et al. 1991; Riedel et al. 1991; Sharma and Davis 1980; Vandermeulen and Foda 1988).

Selenium Concentrations Reported in Wild Aquatic Organisms Were Insufficient to Calculate BAF

Abdel-Moati and Atta (1991)
Adeloju and Young (1994)
Aguirre et al. (1994)
Akesson and Srikumar (1994)
Aksnes et al. (1983)
Allen and Wilson (1990)
Ambulkar et al. (1995)
Amiard et al. (1991, 1993)
Andersen and Depledge (1997)
Andreev and Simeonov (1992)
Angulo (1996)
Arrula et al. (1996)
Arway (1988)
Ashton (1991)
Augier et al. (1991, 1993, 1995a,b)
Augspurger et al. (1998)
Avery et al. (1996)
Badsha and Goldspink (1988)

Baines and Fisher (2001)
Baldwin and Maher (1997)
Baldwin et al. (1996)
Barghigiani (1993)
Barghigiani et al. (1991)
Baron et al. (1997)
Batley (1987)
Baumann and Gillespie (1986)
Baumann and May (1984)
Beal (1974)
Beck et al. (1997)
Beland et al. (1993)
Beliaeff et al. (1997)
Bell and Cowey (1989)
Benemariya et al. (1991)
Berry et al. (1997)
Bertram et al. (1986)
Besser et al. (1994, 1993)
Birkner (1978)
Boisson and Romeo (1996)
Bowerman et al. (1994)
Braune et a. (1991)
Brezina and Arnold (1977)
Brugmann and Hennings (1994)
Brugmann and Lange (1988)
Brumbaugh and Walther (1991)
Burger (1992, 1994, 1995, 1996, 1997a,b)
Burger and Gochfeld (1992a,b, 1993, 1995 ab, 1996, 1997)
Burger et al. (1992a,b,c,1993, 1994a,b)
Byrne and DeLeon (1986)
Byrne et al. (1985)
Cantillo et al. (1997)
Capar and Yess (1996)
Capelli et al. (1987, 1991)
Cappon (1984)
Cappon and Smith (1981)
(1982a,b)
Cardellicchio (1995)
Carell et al. (1987)
Carter and Porter (1997)
Caurant et al. (1994, 1996)
Chau and Riley (1965)
Chiang et al. (1994)
Chou and Uthe (1991)
Chvojka (1988)
Chvojka et al. (1990)
Clifford and Harrison (1988)
Collins (1992)
Combs et al. (1996)
Cosson et al. (1988)
Courtney et al. (1994)
Crowys et al. (1994)
Crutchfield (2000)
Cumbie and Van Horn (1978)
Currey et al. (1992)
Custer and Hohman (1994)
Custer and Mitchell (1991, 1993)
Custer et al. (1997)
Dabeka and McKenzie (1991)
Davoren (1986)
Deaker and Maher (1997)
Demon et al. (1988)
Dietz et al. (1995, 1996)
Doherty et al. (1993)
Elliott and Scheuhammer (1997)
Eriksson et al. (1989)
Evans et al. (1993)
Felton and Mathews (1990)
Felton et al. (1994)
Fitzsimmons et al. (1995)
Focardi et al. (1985, 1988)
Fowler (1986)
Fowler et al. (1975, 1985)
France (1987)
Friberg (1988)
Froslie et al. (1985, 1987)
Gabrashanske and Daskalova
(1985)
Gabrashanska and Nedeva (1994)
Galgan and Frank (1995)
Garcia - Hermandez et al. (2000)
Giardina et al. (1997)
Gillespie and Baumann (1986)
Gochfeld (1997)
Goede (1985, 1991, 1993a,b)
Goede et al. (1989, 1993)
Goede and DeBruin (1984, 1985)
Goede and Wolterbeek (1993, 1994a,b)
Gras et al. (1992)
Greig and Jones (1976)
Gutenmann et al. (1988)
Gutierrez-Galindo et al. (1994)
Guven et al. (1992)
Halbrook et al. (1996)
Hall and Fisher (1985)
Hamilton and Waddell (1994)
Hamilton and Wiedmeyer (1990)
Hansen et al. (1990)
Hardiman and Pearson (1995)
Hargrave et al. (1992)
Harrison and Klaverkamp (1990)
Hasunuma et al. (1993)
Haynes et al. (1995)
Hein et al. (1994)
Heiny and Tate (1997)
Heinz (1993a)
Heinz and Fitzgerald (1993a,b)
Heit (1985)
Heit and Klusek (1985)
Heit et al. (1980, 1989)

Hellou et al. (1992a,b) (1996a,b)
Henny and Herron (1989)
Hodge et al. (1996)
Hilton et al. (1982)
Honda et al. (1986)
Hothem and Ohlendorf (1989)
Hothem and Welsh (1994b)
Hothem and Zador (1995)
Hothem et al. (1995)
Houpt et al. (1988)
Hunter et al. (1995, 1997)
Ibrahim and Farrag (1992)
Ibrahim and Mat (1995)
Ishikawa et al. (1993)
Itano et al. (1984, 1985a,b)
Jarman et al. (1996)
Johns et al. (1988)
Johnson (1987)
Jop et al. (1997)
Jorhem et al. (1994)
Julshamn et al. (1987)
Kai et al. (1986a,b, 1988, 1992a,b, 1996)
Kaiser et al. (1979)
Kalas et al. (1995)
Kidwell et al. (1995)
Koeman et al. (1973)
Kovacs et al. (1984)
Krogh and Scanes (1997)
Krushevska et al. (1996)
Lakshmanan and Stephen (1994)
Lalitha et al. (1994)
LamLeung et al. (1991)
Lan et al. (1994a,b)
Langlois and Langis (1995)
Larsen and Stuerup (1994)
Larsen et al. (1997)
Lauchli (1993)
Law et al. (1996)
Lee and Fisher (1992a,b, 1993)
Leighton and Wobeser (1994)
Leland and Scudder (1990)
Lemly (1985a, 1994)
Leonzio et al. (1986, 1989, 1992)
Leskinen et al. (1986)
Li et al. (1996)
Lie et al. (1994)
Liu et al. (1987)
Lizama et al. (1989)
Lobel et al. (1989, 1991, 1992a,b)
Lonzarich et al. (1992)
Lourdes et al. (1990)
Lowe et al. (1985)
Lucas et al. (1970)
Lytle and Lytle (1982)
Mackey et al. (1996)
Maher (1987)
Maher et al. (1992, 1997)
Mann et al. (1988)
Mason et al. (2000)
Masuzawa et al. (1988)
Matsumoto (1991)
Maven et al. (1995)
May and McKinney (1981)
Mcdowell et al. (1995)
McKenzie-Parnell et al. (1988)
Meador et al. (1993)
Mehrle et al. (1982)
Meltzer et al. (1993)
Metcalfe-Smith et al. (1992, 1996)
Michot et al. (1994)
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APPENDIX H

DATA USED IN REGRESSION ANALYSIS OF SELENIUM IN WHOLE-BODY FISH TISSUE WITH SELENIUM IN MUSCLE, OVARY AND LIVER TISSUES

DATA USED IN REGRESSION ANALYSIS OF SELENIUM IN WHOLE-BODY FISH TISSUE WITH SELENIUM IN MUSCLE, OVARY AND LIVER TISSUES

Quantile regression was used to estimate median concentrations of selenium in the whole body as a function of selenium concentration in selected tissues (Tables H-2, H-3, H-4). Only data where organisms were exposed to selenium in water and in diet or in only diet were considered for analysis. Quantile regression fits a curve to the data such that a selected proportion t (the quantile) of observations are below and the complementary fraction 1- t is above it (Koenker and Basset 1978). Estimates of model parameters minimize the sum of weighted absolute deviations. In contrast, ordinary least squares minimize the sum of squared deviations. Least absolute deviation is less sensitive to outliers than least squares (Birkes and Dodge 1993). Other desired properties of quantile regression include: it is equivariant to scale changes, location shift, and monotonic transformations (Koenker and Basset 1978, Cade et al. 1999). Furthermore, with rank-score statistics it is possible to test hypotheses and build confidence intervals for parameters of linear models fit to data with heteroscedastic errors (Koenker 1994, Koenker and Machado 1999). The rank-score test does not have to assume homogeneous error distributions because the statistic is based on signs of residuals and not their size (Koenker and Machado 1999). For introductory presentations of quantile regression see Cade et al. (1999), Koenker and Hallock (2001), and Cade & Noon (2003). All quantile regressions reported here were performed using the R software (Ihaka & Gentleman 1996) version 1.8.0.

As the exact form of the relationship between selenium concentrations in the whole body ($[Se]_{WB}$) and in tissues ($[Se]_{Tissue}$) is not known, we considered three candidate models:

I) $[Se]_{WB} = a$.

II) $[Se]_{WB} = a + b\,[Se]_{Tissue}$ and

III) $[Se]_{WB} = \exp(a + b \ln([Se]_{Tissue}))$

where a and b are the model parameters we wish to estimate. Model (I) implicitly assumes that selenium concentrations in the whole body are independent of selenium concentrations in liver, muscle, or ovary tissues. Model (II) projects selenium concentrations in the whole body as a linear function of selenium concentrations in a tissue. Model (III) estimates selenium concentrations in the whole body as an exponential function of the logarithm of selenium concentrations in a tissue. This model is derived from the assumption of a linear relationship between the natural logarithms of $[Se]_{WB}$ and $[Se]_{Tissue}$.

Selection of the best model(s) considers both the fit and number of parameters. Models with greater number of parameters generally fit the data better, but such reduction in bias is invariably associated with an increase in variance of parameter estimates (Burnham and Anderson 2002). Model selection methods attempt to find a parsimonious model with the proper tradeoff between bias and variance. We apply the information theoretic approach for model selection (Burnham and Anderson 2002). It is based on the Kullback-Leibler information, $I(f,g)$, which expresses the information lost when model g is used to estimate the full reality f. Obviously, the full reality is never known, but an estimate of the relative distance from reality can be estimated by the Akaike Information Criterion (AIC, Akaike 1973)

$$AIC = -2 \ln(\mathcal{L}(\text{parameters}|\text{data})) + 2k$$

where k is the number of parameters in the model and $\mathcal{L}$(parameters|data) is the maximized likelihood of parameter estimates for the available data.. The AIC is a poor estimator of $I(f,g)$ when $n/k < 40$ (n is the sample size). In such instances, a second-order version of AIC, AIC_c, is recommended (Hurvich and Tsai 1989):

$$AIC_c = -2 \ln(\mathcal{L}(\text{parameters}|\text{data})) + 2k\left(\frac{n}{n-k-1}\right)$$

Hurvich and Tsai (1990) demonstrated that the modified version of AIC_c for least absolute deviation($L1AIC_c$) provides an unbiased estimator for the Kullback-Leibler information, but the small sample criterion for normal least squares regression, which is less computationally demanding, performs equally well

$$\mathbf{AIC} = n\ln(\sigma^2) + 2k\left(\frac{n}{n-k-1}\right)$$

where σ^2 is estimated as the sum of squared residuals divided by n. For the least absolute deviation regression, σ^2 is estimated as $(SWAD/n)^2$, thus AICc is computed by the expression

$$\mathbf{AIC} = 2n\ln(\mathbf{SWAD}/n) + 2k\left(\frac{n}{n-k-1}\right)$$

The AIC and AIC_c are used to rank candidate models. Comparisons among the M ranked candidates are based on the Akaike weight (w), which represents the likelihood of a model given the data

$$w_i = \frac{\exp\left(\frac{-\Delta_i}{2}\right)}{\sum_{i=1}^{M}\exp\left(\frac{-\Delta_i}{2}\right)}$$

where Δ_i is the difference in AIC (AIC_c) between model i and the model with the lowest AIC (AIC_c) value. Weights for all candidate models sum to 1. For each model, we computed the sum of weighted absolute deviations (SWAD), AIC_c and the Akaike weight (Table H-1).

The linear model (II) was selected the best among the three candidate functions for projecting concentrations of selenium in the whole body as a function of selenium concentrations in the liver (Table H-1). The exponential model (III) was selected the best for projections based on concentrations of selenium in muscles and ovaries. However, fits of models II and III to ovary data had similar weights. As the best model may not explain much of the observed variation in the data, we calculated coefficients of determination (R^1), defined as

$$R^1 = 1 - (SAF/SAR)$$

where SAF and SAR are the sum of weighted absolute deviations for the full and reduced models, respectively (Cade and Richards 1996). Coefficients of determination for models II and III were also very similar, suggesting that both models are equally effective in predicting concentrations of selenium in the whole body as a function of selenium concentrations in ovaries. With such knowledge, we opted to use the linear model (II) because it is easier to compute. The exponential model for muscle presented the highest coefficient of determination (0.77), indicating that samples of selenium concentrations from this tissue are more effective predictors than samples from liver and ovaries. The fitted quantile regression curves are shown in figure 5 of the selenium document.

TableH- 1. Number of parameters (k), sum of weighted absolute deviations (SWAD), second-order Akaike Information Criterion (AIC_c), differences between the model AIC_c and the lowest AIC_c of all candidate models (Delta), weight (*w*), rank (by weight), and coefficient of determination (R^1) for three candidate models to project selenium concentrations in the whole body as a function of selenium concentrations in a selected tissue.

Tissue: Muscle (*n* = 21)

Model	k	SWAD	AICc	Delta	Weight	Rank	R^1
$[Se]_{WB} = a$	2	66.00	52.76	59.20	1.27e-13	3	
$[Se]_{WB} = a + b\,[Se]_{Tissue}$	3	16.84	-1.85	4.59	9.17e-02	2	0.74
$[Se]_{WB} = \exp(a + b*\ln([Se]_{Tissue}))$	3	15.10	-6.43	0.00	9.08e-01	1	0.77

Tissue: Ovary (*n* = 23)

Model	k	SWAD	AICc	Delta	Weight	Rank	R^1
$[Se]_{WB} = a$	2	73.95	58.32	46.89	3.31e-11	3	
$[Se]_{WB} = a + b\,[Se]_{Tissue}$	3	25.20	11.46	0.03	4.97e-01	2	0.66
$[Se]_{WB} = \exp(a + b*\ln([Se]_{Tissue}))$	3	25.18	11.43	0.00	5.03e-01	1	0.66

Tissue: Liver (*n* = 26)

Model	k	SWAD	AICc	Delta	Weight	Rank	R^1
$[Se]_{WB} = a$	2	41.05	28.27	22.81	1.11e-05	3	
$[Se]_{WB} = a + b\,[Se]_{Tissue}$	3	25.20	5.46	0.00	9.99e-01	1	0.39
$[Se]_{WB} = \exp(a + b\ln([Se]_{Tissue}))$	3	40.83	30.56	25.10	3.54e-06	2	0.01

Table H-1. Whole body vs muscle

reference	species	site/treatment	Se in tissue, µg/g dw muscle	whole body
Hermanutz *et al*. 1996	bluegill	I control-down	2.05	1.95
	bluegill	I 10 µg/L-down	20.55	22.85
	bluegill	II control-up	1.9	2.45
	bluegill	II control-down	2.25	1.95
	bluegill	II 2.5 µg/L-up	3.5	3.5
	bluegill	II 2.5 µg/L-down	6.9	6.15
	bluegill	II 10 µg/L-up	17.55	15.45
	bluegill	II 10 µg/L-down	44.7	26.45
	bluegill	II rec 30-up	12.45	11.85
	bluegill	II rec 30-down	39.6	30.6
	bluegill	III control-up	3.35	3.35
	bluegill	III control-down	3.2	2.3
	bluegill	III rec 2.5-up	5.25	6.3
	bluegill	III rec 2.5-down	6.1	5.3
	bluegill	III rec 10-up	12.45	12
	bluegill	III rec 10-down	18.6	13
	bluegill	III rec 30-up	7.75	8.35
	bluegill	III rec 30-down	15.05	17.35
Garcia-Hernandez 2000	tilapia	Cienega de Santa Cl	3.5	3
	carp	Cienega de Santa Cl	4.6	3.3
	LM bass	Cienega de Santa Cl	5.4	5.1

Table H-2. Whole Body vs Ovary

reference	species	site/treatment	Se in tissue, µg/g dw ovary	whole body
Coyle 1993	bluegill	control	2.1	0.9
	bluegill	control + water Se	2.1	0.9
	bluegill	4.6 µg/g diet	8.3	2.9
	bluegill	8.4 µg/g diet	12.5	4.9
	bluegill	16.8 µg/g diet	25	7.2
	bluegill	33.3 µg/g diet	41	16
Hermanutz *et al*. 1996	bluegill	I control-down	0.35	1.95
	bluegill	I 10 µg/L-down	20.05	22.85
	bluegill	II control-up	5.25	2.45
	bluegill	II control-down	3.85	1.95
	bluegill	II 2.5 µg/L-up	10.1	3.5
	bluegill	II 2.5 µg/L-down	12.35	6.15
	bluegill	II 10 µg/L-up	34.8	15.45
	bluegill	II 10 µg/L-down	50.5	26.45
	bluegill	II rec 30-up	29.35	11.85
	bluegill	II rec 30-down	66	30.6
	bluegill	III control-down	5.3	2.3
	bluegill	III rec 2.5-up	8.4	6.3
	bluegill	III rec 2.5-down	9.5	5.3
	bluegill	III rec 10-up	31.15	12
	bluegill	III rec 10-down	19.55	13
	bluegill	III rec 30-up	17.85	8.35
	bluegill	III rec 30-down	19.1	17.35

Table H-3. Whole body vs liver

reference	species	site/treatment	Se in tissue, µg/g dw liver	whole body
Bryson 1985-84	bluegill	control	3.9	0.45
	bluegill	Se-plankton diet	9.1	2.35
	bluegill	Selenite diet	11	1.21
	bluegill	Se-cysteine diet	9.23	2.16
	bluegill	Se-cysteine 2X diet	16.33	3.74
	bluegill	Se-methionine diet	10.85	2.46
Hermanutz *et al*. 1996	bluegill	I control-down	5.4	1.95
	bluegill	I 10 µg/L-down	36.05	22.85
	bluegill	II control-up	13.2	2.45
	bluegill	II control-down	7.2	1.95
	bluegill	II 2.5 µg/L-up	29.2	3.5
	bluegill	II 2.5 µg/L-down	26.45	6.15
	bluegill	II 10 µg/L-up	119	15.45
	bluegill	II 10 µg/L-down	68.5	26.45
	bluegill	II rec 30-up	64	11.85
	bluegill	II rec 30-down	100.5	30.6
	bluegill	III control-up	9.95	3.35
	bluegill	III control-down	9.4	2.3
	bluegill	III rec 2.5-up	13.85	6.3
	bluegill	III rec 2.5-down	16.3	5.3
	bluegill	III rec 10-up	33.25	12
	bluegill	III rec 10-down	37.15	13
	bluegill	III rec 30-up	21	8.35
	bluegill	III rec 30-down	31.9	17.35
Garcia-Hernandez 2000	carp	Cienega de Santa Cl	8.2	3.3
	LM bass	Cienega de Santa Cl	4.7	5.1