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ADDENDUM TO *U.S. EPA CADMIUM WATER QUALITY CRITERIA DOCUMENT – TECHNICAL REVIEW AND CRITERIA UPDATE*

Introduction

The U.S. Environmental Protection Agency (U.S. EPA) revised its aquatic life criteria for cadmium on April 12, 2001, with the publication entitled *2001 Update of Ambient Water Quality Criteria for Cadmium* (U.S. EPA 2001). Chadwick Ecological Consultants, Inc. (CEC) conducted a technical review of the freshwater cadmium AWQC (CEC 2004) on behalf of the Association of Metropolitan Sewerage Agencies (AMSA).

This report included a technical review of the existing U.S. EPA 2001Cadmium Update, an extensive literature search to critically review available cadmium toxicity data in addition to those used in the derivation of the 2001 Cadmium Update, incorporation of new data not cited or available to U.S. EPA, and recalculation of updated acute and chronic cadmium criteria based on this analysis. This analysis culminated in a report entitled *U.S. EPA Cadmium Water Quality Criteria Document - Technical Review and Criteria Update* (CEC 2004) submitted to AMSA in September 2004. The results of this review were also presented to the Basic Standards Workgroup in September 2004. Since this presentation, we have received comments from the U.S. EPA, as well as comments and new data from the Colorado Division of Wildlife (CDOW). As a result of these comments and inclusion of the new data, our proposed acute and chronic criteria have changed slightly. These responses and the effect on criteria are summarized below.

Summary of Revision

Following response to the comments provided, there are slight changes to the acute and chronic hardness-based equations presented in our earlier report. These changes are summarized in the revised Table 13 from CEC 2004, presented below. Based on these changes, the general acute and chronic total cadmium equations are now as follows:

$$\text{Acute Cadmium} = e^{0.9151[(\text{hardness})]-3.6236}$$

$$\text{Chronic Cadmium} = e^{0.7998[(\text{hardness})]-4.4451}$$

Revised Table 13 from CEC 2004 report entitled "U.S. EPA Cadmium Water Quality Criteria Document –Technical Review and Criteria Update" prepared for AMSA.

TABLE 13 Revised: Summary of criterion maximum concentration (CMC) and criterion continuous concentration (CCC) at various hardness values for cadmium. All values are reported in µg/L (*revised December 2004*).

	Hardness (mg/L)									
	25	50	75	100	150	200	250	300	350	400
2001 EPA Update										
CMC = $e^{1.0166[\ln(hardness)]-3.924}$	0.521	1.054	1.592	2.133	3.221	4.316	5.415	6.517	7.623	8.731
CCC = $e^{0.7409[\ln(hardness)]-4.719}$	0.097	0.162	0.271	0.365	0.452	0.534	0.611	0.611	0.658	0.756
CEC Revision (all data)										
CMC = $e^{0.9151[\ln(hardness)]-3.1845}$	0.816	1.539	2.231	2.903	4.207	5.474	6.714	7.933	9.135	10.322
CMC[a] = $e^{0.9151[\ln(hardness)]-3.6236}$	0.508	0.957	1.387	1.805	2.616	3.404	4.175	4.933	5.68	6.419
CCC = $e^{0.7998[\ln(hardness)]-4.4451}$	0.154	0.268	0.371	0.467	0.646	0.813	0.971	1.124	1.271	1.415
CCC[b] = $e^{0.7998[\ln(hardness)]-3.0108}$	0.646	1.125	1.556	1.959	2.709	3.41	4.077	4.717	5.335	5.937
CCC[ab] = $e^{0.7998[\ln(hardness)]-3.4859}$	0.402	0.7	0.968	1.218	1.685	2.121	2.535	2.933	3.318	3.692
CEC Revision (coldwater)										
CMC = $e^{0.9151[\ln(hardness)]-3.1993}$	0.776	1.463	2.12	2.759	3.999	5.203	6.381	7.54	8.682	9.811
CCC[b] = $e^{0.7998[\ln(hardness)]-3.0616}$	0.614	1.07	1.479	1.862	2.575	3.241	3.875	4.483	5.071	5.643
CEC Revision (warmwater)										
CMC = $e^{0.9151[\ln(hardness)]-1.6141}$	3.787	7.141	10.348	13.465	19.514	25.391	31.143	36.798	42.372	47.88
CMC[a] = $e^{0.9151[\ln(harndess)]-3.1229}$	0.838	1.579	2.289	2.978	4.316	5.616	6.888	8.139	9.372	10.59
CCC = $e^{0.7998[\ln(hardness)]-4.8564}$	0.109	0.189	0.262	0.329	0.455	0.573	0.685	0.793	0.897	0.998
CCC[b] = $e^{0.7998[\ln(hardness)]-1.4765}$	2.998	5.219	7.218	9.086	12.566	15.817	18.908	21.876	24.746	27.535
CCC[ab] = $e^{0.7998[\ln(hardness)]-2.9852}$	0.663	1.154	1.597	2.01	2.78	3.499	4.182	4.839	5.474	6.091

[a] FAV lowered to protect a commercially important species.
[b] CCC values calculated from the ACR.

Additional Data and Database Revisions

Comments from the CDOW included reference to recently published data (Brinkman and Hansen 2004) on the toxicity of cadmium to the brown trout (*Salmo trutta*). Brinkman and Hansen (2004) presented both acute and chronic data. However, the reported chronic data were not suitable for use in criteria development due to insufficient test duration as required by Stephan *et al.* (1985) or Standard Methods (ASTM 2003). Nonetheless, three useable acute data points were added to the previously updated acute database and are presented in the revised Table 2 from CEC (2004). Inclusion of these new acute values influence the final acute value (FAV) by altering the acute hardness slope and genus mean acute value for *Salmo* (2nd most sensitive genus).

The CDOW also noted the availability of an additional data point (hardness = 39.8, LC_{50} = 1.87) generated by Davies and Brinkman (1994). We were aware of this data point when conducting the original literature review and determined acute data from this study were not suitable for use since data were generated from the first four days of a chronic test in which the organisms were fed. Test organisms are not generally fed during acute tests (Stephan *et al.* 1985). We had, however, found other useful acute data from another study ("Toxicity of Cadmium and Zinc to Wild Brown Trout") within the same publication (Davies and Brinkman 1994) that was already included in our updated database and listed in Table 2 of the original document (CEC 2004).

In comments from U.S. EPA, they reiterated their recommendations from the criteria document that chronic *Daphnia magna* data from an unpublished study by Chapman *et al.* be used in the calculations. The Chapman *et al.* manuscript chronic data for *D. magna* were eliminated from the updated chronic cadmium database in our original analysis (CEC 2004), not solely due to dissimilar values when compared to the remainder of the *Daphnia* data, but also due to insufficient information pertaining to chronic value calculations. Even though the Chapman *et al.* manuscript values remain substantially different and the results from additional testing concur with the other data presented for *D. magna*, we will add these data back into the database following U.S. EPA recommendations, as long as all other *Daphnia* data (including the recently added data for *D. magna* and data for *D. pulex*) are also included in the SMAV and GMAV calculations. We believe this is a reasonable solution for a genus with such highly divergent chronic values.

The addition of new acute data for *S. trutta* and re-inclusion of the chronic Chapman *et al.* data for *D. magna* results in a slightly steeper acute and chronic hardness slopes, respectively. The new data also increases the range of hardness concentrations tested for each organism such that *S. trutta* can be included in the acute hardness slope calculations and *D. magna* is re-included in the chronic hardness slope calculations. The new recalculated acute hardness slope of 0.9151 replaces the "updated slope" of 0.9059 presented by CEC (2004). Only the Chapman *et al.* manuscript and Canton and Sloof (1982) data are incorporated in the revised final pooled chronic slope of 0.7998, which replaces the "updated slope" of 0.7635 presented by CEC (2004). The revised ranked acute and chronic genus lists (Revised Tables 4 and 5) and the updated acute and chronic hardness slope calculation tables (Revised Tables 6 and 8 from CEC 2004) are as follows.

Revised Table 2 from CEC 2004 report entitled "U.S. EPA Cadmium Water Quality Criteria Document –Technical Review and Criteria Update" prepared for AMSA.

TABLE 2 - Revised: Acute cadmium toxicity data added to the acute database (*revised December 2004 with inclusion of brown trout data from Brinkman and Hansen 2004).*

Species	Method[a]	Chemical	Hardness (mg/L)	LC_{50} (µg/L)	Adjusted LC_{50}[b]	Reference
Ceriodaphnia dubia	S, M, T	$CdCl_2$	17	63.01	169.35	Suedel *et al*. 1997
Daphnia magna	S, M, T	$CdCl_2$	17	26.40	70.85	Suedel *et al*. 1997
Pimephales promelas	S, M, T	$CdCl_2$	17	4.80	12.88	Suedel *et al*. 1997
*Hyalella azteca**	S, M, T	$CdCl^2$	17	2.80	7.51	Suedel *et al*. 1997
*Chironomus tentans***	S, M, T	$CdCl_2$	17	2,956.00	7,933.19	Suedel *et al*. 1997
Salmo trutta	F, M, T	$CdSO_4$	37.6	2.37	3.08	Davies and Brinkman 1994
Salmo trutta	F, M, D	$CdSO_4$	151.4	3.66	3.66	Brinkman and Hansen 2004
Salmo trutta	F, M, D	$CdSO_4$	29.2	1.23	2.01	Brinkman and Hansen 2004
Salmo trutta	F, M, D	$CdSO_4$	67.6	3.9	2.96	Brinkman and Hansen 2004
*Thymallus arcticus** (juvenile)	S, M, T	$CdCl_2$	41	4.00	4.80	Buhl and Hamilton 1991
Oncorhynchus mykiss	R, M, T	$CdCl_2$	420 (388-490)	7.40	1.06	Davies *et al*. 1993
Oncorhynchus mykiss	F, M, T	$CdCl_2$	427 (406-444)	5.92	0.83	Davies *et al*. 1993
Oncorhynchus mykiss	F, M, T	$CdCl_2$	217 (203-240)	4.20	1.10	Davies *et al*. 1993
Oncorhynchus mykiss	F, M, T	$CdCl_2$	227 (212-243)	6.57	1.65	Davies *et al*. 1993
Oncorhynchus mykiss	F, M, T	$CdCl_2$	46 (45-48)	2.64	2.85	Davies *et al*. 1993
Oncorhynchus mykiss	F, M, T	$CdCl_2$	49 (48-50)	3.08	3.14	Davies *et al*. 1993
*Chironomus plumosus***	S, U	$CdCl_2$	80	12,700.00	8,260.64	Fargasova 2003

[a] S = static, R = renewal, M = measured, U = unmeasured, T = total measured concentration, F = flow-through, and D = dissolved measured concentration.
[b] Value adjusted to hardness = 50 using the revised acute slope (0.9151) listed in revised Table 6.
* New genus.
** New species.

Revised Table 4 from CEC 2004 report entitled "U.S. EPA Cadmium Water Quality Criteria Document –Technical Review and Criteria Update" prepared for AMSA.

TABLE 4 - Revised: Revised acute cadmium criteria database (*revised 2004 following inclusion of new data from Brinkman and Hansen 2004*).

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family	Code
56	*Chironomus riparius*	19,256.57	108,453.52	Midge	Chironomidae	1, 2
	Chironomus tentans		7,933.19	Midge	Chironomidae	1, 2
	Chironomus plumosus		8,260.64	Midge	Chironomidae	1, 2
55	*Dendrocoelum lacteum*	14,880.09	14,880.09	Planaria	Planariidae	1, 2
54	*Orconectes virilis*	<11,193.54	11,097.25	Crayfish	Cambaridae	1, 2
	Orconectes immunis		<11,371.23	Crayfish	Cambaridae	1, 2
53	*Oreochromis mossambica*	10,068.09	10,068.09	Tilapia	Cichlidae	2
52	*Gasterosteus aculeatus*	5,897.00	5,897.00	Threespine stickleback	Gasterosteidae	2
51	*Gambusia affinis*	5,578.08	5,578.08	Mosquitofish	Poeciliidae	2
50	*Ictalurus punctatus*	4,994.42	4,994.42	Channel catfish	Ictaluridae	2
49	*Lepomis cyanellus*	4,812.28	3,595.94	Green sunfish	Centrarchidae	2
	Lepomis macrochirus		6,440.04	Bluegill	Centrarchidae	2
48	*Rhyacodrilus montana*	4,912.28	4,912.28	Tubificid worm	Tubificidae	1, 2
47	*Cyprinus carpio*	4,547.36	4,547.36	Common carp	Cyprinidae	2
46	*Stylodrilus heringianus*	4,228.50	4,228.50	Tubificid worm	Tubificidae	1, 2
45	*Notropis lutrensis*	4,051.76	4,051.76	Red shiner	Cyprinidae	2
44	*Spirosperma ferox*	3,094.45	2,729.04	Tubificid worm	Tubificidae	1, 2
	Spirosperma nikolskyi		3,508.77	Tubificid worm	Tubificidae	1, 2
43	*Varichaeta pacifica*	2,962.96	2,962.96	Tubificid worm	Tubificidae	1, 2
42	*Jordanella floridae*	2,810.24	2,810.24	Flagfish	Cyprinodontidae	1, 2
41	*Catostomus commersoni*	2,827.16	2,827.16	White sucker	Catostomidae	1, 2
40	*Poecilia reticulata*	2,569.18	2,569.18	Guppy	Poeciliidae	2
39	*Quistradilus multisetosus*	2,495.13	2,495.13	Tubificid worm	Tubificidae	1, 2

TABLE 4 - Revised: Continued.

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family	Code
38	*Ephemerella grandis*	2,248.19	2,248.19	Mayfly	Ephemerellidae	1, 2
37	*Branchiura sowerbyi*	1,871.34	1,871.34	Tubificid worm	Tubificidae	1, 2
36	*Crangonyx pseudogracilis*	1,700.00	1,700.00	Amphipod	Crangonyctidae	1, 2
35	*Procambarus clarkii*	1,659.77	1,659.67	Crayfish	Cambaridae	1, 2
34	*Tubifex tubifex*	1,344.34	1,344.34	Tubificid worm	Tubificidae	1, 2
33	*Limnodrilus hoffmeisteri*	867.63	867.63	Tubificid worm	Tubificidae	1, 2
32	*Carassius auratus*	833.89	833.89	Goldfish	Cyprinidae	2
31	*Asellus bicrenata*	548.72	548.72	Isopod	Asellidae	1, 2
30	*Ambystoma gracile*	515.81	515.81	Salamander	Ambystomatidae	1, 2
29	*Plumatella emarginata*	299.69	299.69	Bryozoan	Plumatellidae	1, 2
28	*Alona affinis*	267.59	267.59	Cladoceran	Chydoridae	1, 2
27	*Cyclops varicans*	241.62	241.62	Copepod	Cyclopidae	1, 2
26	*Glossiphonia complanata*	210.93	210.93	Leech	Glossiphoniidae	1, 2
25	*Pectinatella magnifica*	192.46	192.46	Bryozoan	Pectinatellidae	1, 2
24	*Lumbriculus variegatus*	156.13	156.13	Worm	Lumbriculidae	1, 2
23	*Physa gyrina*	115.30	115.30	Snail	Physidae	1, 2
22	*Aplexa hypnorum*	102.73	102.73	Snail	Physidae	1, 2
21	*Gammarus pseudolimnaeus*	77.58	77.58	Amphipod	Gammaridae	1, 2
20	*Lirceus alabamae*	54.23	54.23	Isopod	Asellidae	1, 2
19	*Ceriodaphnia dubia*	48.15	49.86	Cladoceran	Daphnidae	1, 2
	Ceriodaphnia reticulata		46.50	Cladoceran	Daphnidae	1, 2
18	*Moina macrocopa*	45.31	45.31	Cladoceran	Moinidae	1, 2
17	*Gila elegans*	44.55	44.55	Bonytail	Cyprinidae	2
16	*Utterbackia imbecilis*	44.90	44.90	Mussel	Unionidae	1, 2

TABLE 4 - Revised: Continued.

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family	Code
15	*Xyrauchen texanus*	42.13	42.13	Razorback sucker	Catostomidae	2
14	*Lophopodella carteri*	41.24	41.24	Bryozoan	Lophopodidae	1, 2
13	*Vilosa vibex*	37.18	37.18	Mussel	Unionidae	1, 2
12	*Actinonaia pectorosa*	35.59	35.59	Mussel	Unionidae	1, 2
11	*Lampsilis straminea claibornensis*	33.00	46.61	Mussel	Unionidae	1, 2
	Lampsilis teres		23.37	Mussel	Unionidae	1, 2
10	*Pimephales promelas*	28.45	28.45	Fathead minnow	Cyprinidae	2
9	*Daphnia magna*	27.43	15.36	Cladoceran	Daphnidae	1, 2
	Daphnia pulex		48.98	Cladoceran	Daphnidae	1, 2
8	*Simocephalus serrulatus*	27.79	27.79	Cladoceran	Daphnidae	1, 2
7	*Ptychocheilus lucius**	25.93	25.93	Colorado pikeminnow	Cyprinidae	2
	Ptychocheilus oregonensis		2,070.47	Northern pikeminnow	Cyprinidae	2
6	*Hyallela azteca*	7.51	7.51	Amphipod	Hyalellidae	1, 2
5	*Thymallus arcticus*	4.80	4.80	Arctic grayling	Salmonidae	1
4	*Oncorhynchus kisutch*	3.47	5.72	Coho salmon	Salmonidae	1
	Oncorhynchus tshawytscha		3.98	Chinook salmon	Salmonidae	1
	Oncorhynchus mykiss		1.84	Rainbow trout	Salmonidae	1
3	*Morone saxatilis*	3.16	3.16	Striped bass	Percichthyidae	2
2	*Salmo trutta*	2.95	2.95	Brown trout	Salmonidae	1
1	*Salvelinus fontinalis*	1.91	<1.76	Brook trout	Salmonidae	1
	Salvelinus confluentus		2.08	Bull trout	Salmonidae	1

[1] Used in cold water calculations.

[2] Used in warm water calculations.

* Only the most sensitive species was used to calculate the GMAV .

Revised Table 5 from CEC 2004 report entitled "U.S. EPA Cadmium Water Quality Criteria Document –Technical Review and Criteria Update" prepared for AMSA.

TABLE 5 - Revised: Revised chronic cadmium criteria database (*revised December 2004 following re-inclusion of data from Chapman et al. manuscript*).

Rank	Species	GMCV (µg/L)	SMCV (µg/L)	Common Name	Family	Code
16	*Oreochromis aurea*	>22.1910	22.1910	Blue tilapia	Cichlidae	2
15	*Aeolosoma headleyi*	20.4219	20.4219	Oligochaete	Aeolosomatidae	1, 2
14	*Lepomis macrochirus*	15.9865	15.9865	Bluegill	Centrarchidae	2
13	*Pimephales promelas*	15.0918	15.0918	Fathead minnow	Cyprinidae	2
12	*Ceriodaphnia dubia*	11.6584	11.6584	Cladoceran	Daphnidae	1, 2
11	*Micropterus dolomieui*	8.1855	8.1855	Smallmouth bass	Centrarchidae	2
10	*Esox lucius*	8.1534	8.1534	Northern pike	Esocidae	1, 2
9	*Catostomus commersoni*	7.8632	7.8632	White sucker	Catostomidae	1, 2
8	*Jordanella floridae*	5.3420	5.3420	Flagfish	Cyprinidontidae	2
7	*Aplexa hypnorum*	4.8482	4.8482	Snail	Physidae	1, 2
6	*Salmo salar*	4.7250	8.2825	Atlantic salmon	Salmonidae	1
	Salmo trutta		2.6955	brown trout	Salmonidae	1
5	*Salvelinus fontinalis*	4.6582	2.6628	Brook trout	Salmonidae	1
	Salvelinus namaycush		8.1490	Lake trout	Salmonidae	1
4	*Chironomus tentans*	2.5338	2.5338	Midge	Chironomidae	1, 2
3	*Oncorhynchus kisutch*	2.3320	4.2968	Coho salmon	Salmonidae	1
	Oncorhynchus mykiss		1.0847	Rainbow trout	Salmonidae	1
	Oncorhynchus tshawytscha		2.7210	Chinook salmon	Salmonidae	1
2	*Daphnia magna*	1.3259	0.4920	Cladoceran	Daphnidae	1, 2
	Daphnia pulex		3.5735	Cladoceran	Daphnidae	1, 2
1	*Hyalella azteca*	0.2640	0.2640	Amphipod	Hyalellidae	1, 2

[1] Used in coldwater calculations.
[2] Used in warmwater calculations.

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Revised Table 6 from CEC 2004 report entitled "U.S. EPA Cadmium Water Quality Criteria Document –Technical Review and Criteria Update" prepared for AMSA.

TABLE 6 - Revised: Updated acute cadmium hardness slope. SMAS = species mean acute slope (*revised December 2004*).

Species	hardness (mg/L)	geomean (hardness)	normalized hardness	LC_{50}/EC_{50} (µg/L)	geomean (acute)	normalized acute	Reference	ln (norm hard)	ln (norm acute)	SMAS	R^2
Limnodrilus hoffmeisteri	5.3		0.19	170.00		0.27	Chapman *et al*. 1982	-1.678	-1.324		--
Limnodrilus hoffmeisteri	152.0	28.38	5.36	2,400.00	638.75	3.76	Williams *et al*. 1985	1.678	1.324	0.7888	--
Tubifex tubifex	128.0		2.89	3,200.00		2.66	Reynoldson *et al*. 1996	1.061	0.978		
Tubifex tubifex	128.0		2.89	1,700.00		1.41	Reynoldson *et al*. 1996	1.061	0.346		
Tubifex tubifex	5.3	44.28	0.12	320.00	1,202.96	0.27	Chapman *et al*. 1982	-2.123	-1.324	0.6238	0.93
Vilosa vibex	40.0		0.46	30.00		0.49	Keller as cited in U.S. EPA 2001	-0.768	-0.714		
Vilosa vibex	186.0	86.26	2.16	125.00	61.24	2.04	Keller as cited in U.S. EPA 2001	0.768	0.714	0.9286	--
Daphnia magna	51.0		0.43	9.90		0.31	Chapman *et al.* Manuscript	-0.839	-1.178		
Daphnia magna	104.0		0.88	33.00		1.03	Chapman *et al.* Manuscript	-0.127	0.026		
Daphnia magna	105.0		0.89	34.00		1.06	Chapman *et al.* Manuscript	-0.117	0.056		
Daphnia magna	197.0		1.67	63.00		1.96	Chapman *et al.* Manuscript	0.512	0.673		
Daphnia magna	209.0	118.05	1.77	49.00	32.14	1.52	Chapman *et al.* Manuscript	0.571	0.422	1.1824	0.91
Daphnia pulex	57.0		0.60	47.00		0.53	Bertram and Hart 1979	-0.508	-0.636		
Daphnia pulex	240.0		2.53	319.00		3.59	Elnabarawy *et al.* 1986	0.930	1.279		
Daphnia pulex	120.0		1.27	80.00		0.90	Hall *et al.* 1986	0.237	-0.104		
Daphnia pulex	120.0		1.27	100.00		1.13	Hall *et al*. 1986	0.237	0.119		
Daphnia pulex	53.5		0.56	70.10		0.79	Stackhouse and Benson 1988	-0.571	-0.236		
Daphnia pulex	85.0		0.90	66.00		0.74	Roux *et al*. 1993	-0.108	-0.296		
Daphnia pulex	85.0		0.90	99.00		1.12	Roux *et al*. 1993	-0.108	0.109		
Daphnia pulex	85.0	94.71	0.90	70.00	88.74	0.79	Roux *et al*. 1993	5.52	-0.237	1.0633	0.79
Oncorhynchus tshawytscha	211.0		4.05	26.00		5.27	Hamilton and Buhl 1990	1.398	1.661		
Oncorhynchus tshawytscha	343.0		6.58	57.00		11.55	Hamilton and Buhl 1990	1.884	2.446		
Oncorhynchus tshawytscha	23.0		0.44	1.80		0.36	Chapman 1975, 1978	-0.819	-1.009		

TABLE 6 - Revised: Continued.

Species	hardness (mg/L)	geomean (hardness)	normalized hardness	LC_{50}/EC_{50} (µg/L)	geomean (acute)	normalized acute	Reference	ln (norm hard)	ln (norm acute)	SMAS	R^2
Oncorhynchus tshawytscha	23.0		0.44	3.50		0.71	Chapman 1975, 1978	-0.819	-0.344		
Oncorhynchus tshawytscha	25.0		0.48	1.41		0.29	Chapman 1982	-0.735	-1.253		
Oncorhynchus tshawytscha	21.0	52.14	0.40	1.10	4.94	0.22	Finlayson and Verrue 1982	-0.909	-1.501	1.2576	0.95
Carassius auratus	20.0		0.50	2,340.00		0.64	Pickering and Henderson 1966	-0.686	-0.440		
Carassius auratus	20.0		0.50	2,130.00		0.59	McCarty *et al*. 1978	-0.686	-0.534		
Carassius auratus	140.0		3.53	46,800.00		12.88	McCarty *et al*. 1978	1.260	2.555		
Carassius auratus	44.4	39.71	1.12	748.00	3,634.43	0.21	Phipps and Holcombe 1985	0.112	-1.581	1.4608	0.57
Pimephales promelas (juvenile)	44.0		0.87	13.20		0.40	Spehar and Fiandt 1986	-0.138	-0.909		
Pimephales promelas (juvenile)	290.0		5.74	60.00		1.83	Schubauer-Berigan *et al.*1993	1.748	0.605		
Pimephales promelas (fry)	17.0		0.34	4.80		0.15	Suedel *et al.* 1997	-1.089	-1.920		
Pimephales promelas (fry)	60.0		1.19	210.00		6.41	Rifici *et al.* 1996	0.172	1.858		
Pimephales promelas (fry)	60.0		1.19	180.00		5.50	Rifici *et al.* 1996	0.172	1.704		
Pimephales promelas (fry)	40.0		0.79	21.50		0.66	Spehar 1982	-0.233	-0.421		
Pimephales promelas (fry)	48.0		0.95	11.70		0.36	Spehar 1982	-0.051	-1.029		
Pimephales promelas (fry)	39.0		0.77	19.30		0.59	Spehar 1982	-0.258	-0.529		
Pimephales promelas (fry)	45.0		0.89	42.40		1.29	Spehar 1982	-0.115	0.258		
Pimephales promelas (fry)	47.0		0.93	54.20		1.65	Spehar 1982	-0.072	0.504		
Pimephales promelas (fry)	44.0		0.87	29.00	32.75	0.89	Spehar 1982	-0.138	-0.122	0.9210	0.29
Pimephales promelas (fry)	20.0	50.49	0.26	1,270.00		0.34	Pickering and Henderson 1966	-1.335	-1.088		
Poecilia reticulata	105.0		1.38	3,800.00		1.01	Canton and Slooff 1982	0.323	0.008		
Poecilia reticulata	209.2	76.02	2.75	11,100.00	3,769.67	2.94	Canton and Slooff 1982	1.012	1.080	0.8752	0.95
Poecilia reticulata	34.5		0.57	1.00		0.33	Hughes 1973	-0.565	-1.096		
Morone saxatilis	34.5		0.57	2.00		0.67	Hughes 1973	-0.565	-0.402		

TABLE 6 - Revised: Continued.

Species	hardness (mg/L)	geomean (hardness)	normalized hardness	LC_{50}/EC_{50} (µg/L)	geomean (acute)	normalized acute	Reference	ln (norm hard)	ln (norm acute)	SMAS	R^2
Morone saxatilis	40.0		0.66	4.00		1.34	Palawski *et al*. 1985	-0.417	0.291		
Morone saxatilis	285.0	60.69	4.70	10.00	2.99	3.34	Palawski *et al*. 1985	1.547	1.207	0.8089	0.72
Morone saxatilis	20.0		0.17	2,840.00		0.20	Pickering and Henderson 1966	-1.790	-1.631		
Lepomis cyanellus	360.0		3.00	66,000.00		4.55	Pickering and Henderson 1966	1.100	1.515		
Lepomis cyanellus	85.5		0.71	11,520.00		0.79	Carrier and Beitinger 1988b	-0.338	-0.230		
Lepomis cyanellus	335.0	119.84	2.80	20,500.00	14,504.98	1.41	Jude 1973	1.028	0.346	0.8986	0.88
Lepomis macrochirus	20.0		0.56	1,940.00		0.46	Pickering and Henderson 1966	-0.585	-0.786		
Lepomis macrochirus	18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
Lepomis macrochirus	18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
Lepomis macrochirus	207.0		5.77	21,100.00		4.95	Eaton 1980	1.752	1.600		
Lepomis macrochirus	44.4	35.89	1.24	6,470.00	4,258.80	1.52	Phipps and Holcombe 1985	0.213	0.418	0.9531	0.95
Oncorhynchus mykiss	420.0		6.93	7.40		4.04	Davies *et al*. 1993	1.935	1.397		
Oncorhynchus mykiss	427.0		7.04	5.92		3.23	Davies *et al*. 1993	1.952	1.174		
Oncorhynchus mykiss	217.0		3.58	4.20		2.29	Davies *et al*. 1993	1.275	0.830		
Oncorhynchus mykiss	227.0		3.74	6.57		3.59	Davies *et al*. 1993	1.320	1.278		
Oncorhynchus mykiss	46.0		0.76	2.64		1.44	Davies *et al*. 1993	-0.276	0.366		
Oncorhynchus mykiss	49.0		0.81	3.08		1.68	Davies *et al*. 1993	-0.213	0.520		
Oncorhynchus mykiss	23.0		0.38	1.30		0.71	Chapman 1975, 1978	-0.969	-0.342		
Oncorhynchus mykiss	23.0		0.38	1.00		0.55	Chapman 1978	-0.969	-0.605		
Oncorhynchus mykiss	31.0		0.51	1.75		0.96	Davies 1976	-0.671	-0.045		
Oncorhynchus mykiss	44.4		0.73	3.00		1.64	Phipps and Holcombe 1985	-0.312	0.494		
Oncorhynchus mykiss	30.7		0.51	0.71		0.39	Stratus Consulting 1999	-0.681	-0.947		
Oncorhynchus mykiss	29.3		0.48	0.47		0.26	Stratus Consulting 1999	-0.727	-1.360		
Oncorhynchus mykiss	31.7		0.52	0.51		0.28	Stratus Consulting 1999	-0.649	-1.278		
Oncorhynchus mykiss	30.2		0.50	0.38		0.21	Stratus Consulting 1999	-0.697	-1.572		

TABLE 6 - Revised: Continued.

Species	hardness (mg/L)	geomean (hardness)	normalized hardness	LC_{50}/EC_{50} (µg/L)	geomean (acute)	normalized acute	Reference	ln (norm hard)	ln (norm acute)	SMAS	R^2
Oncorhynchus mykiss	30.0		0.49	1.29		0.70	Stratus Consulting 1999	-0.704	-0.350		
Oncorhynchus mykiss	89.3	60.64	1.47	2.85	1.83	1.56	Stratus Consulting 1999	0.387	0.442	0.7679	0.68
Salmo trutta	43.5		0.80	1.40		0.51	Spehar and Carlson 1984	-0.229	-0.680		
Salmo trutta	37.6		0.69	2.37		0.86	Davies and Brinkman 1994	-0.374	-0.153		
Salmo trutta	29.2		0.53	1.23		0.45	Brinkman and Hansen 2004	-0.627	-0.809		
Salmo trutta	67.6		1.24	3.90		1.41	Brinkman and Hansen 2004	0.212	0.345		
Salmo trutta	151.4	54.68	2.77	10.10	2.76	3.66	Brinkman and Hansen 2004	1.018	1.297	1.2671	0.91
								Revised pooled acute		**slope = 0.9151**	**0.69**

Revised Table 8 from CEC 2004 report entitled "U.S. EPA Cadmium Water Quality Criteria Document –Technical Review and Criteria Update" prepared for AMSA.

TABLE 8 Revised: Updated chronic cadmium hardness slope. SMCS = species mean chronic slope (*revised December 2004*).

Species	hardness (mg/L)	geomean (hard)	normalized hardness	chronic value (µg/L)	geomean (chronic)	normalized chronic	Reference	ln (norm hard)	ln (norm acute)	SMCS	R^2
Daphnia magna	209.2		1.68	0.67		2.15	Canton and Slooff 1982	0.5206	0.7654		
Daphnia magna	53.0		0.43	1.52		0.49	Chapman *et al*. manuscript	-0.8524	-0.7180		
Daphnia magna	103.0		0.83	0.21		0.68	Chapman *et al*. manuscript	-0.1879	-0.3853		
Daphnia magna	209.0	124.30	1.68	0.44	0.31	1.40	Chapman *et al*. manuscript	0.5197	0.3380	0.9659	0.89
Salmo trutta	39.8		0.52	1.33		0.25	Davies and Brinkman 1994	-0.65	-1.38		
Salmo trutta	44.0		0.58	6.67		1.27	Eaton *et al*. 1978	-0.55	-0.24		
Salmo trutta	250.0	75.93	3.29	16.49	5.27	3.13	Brown *et al*. 1994	1.19	1.14	0.9931	0.65
Pimephales promelas	201.0		2.14	45.92		2.14	Pickering and Gast 1972	0.76	0.76		
Pimephales promelas	44.0	94.04	0.47	10.00	21.43	0.47	Spehar and Fiandt 1986	-0.76	-0.76	1.0034	--
Oncorhynchus mykiss	46.2		0.26	1.47		0.49	Davies *et al*. 1993	-1.36	-0.72		
Oncorhynchus mykiss	217.0		1.21	3.58		1.19	Davies *et al*. 1993	0.19	0.17		
Oncorhynchus mykiss	413.8		2.31	3.64		1.21	Davies *et al*. 1993	0.84	0.19		
Oncorhynchus mykiss	250.0	179.46	1.39	4.31	3.01	1.43	Brown *et al*. 1994	0.33	0.36	0.4779	0.86
							Revised pooled chronic slope =			**0.7998**	**0.72**

Acute-Chronic Ratio Calculations

The final acute-chronic ratio (FACR) can be calculated a number of different ways depending on the distribution of acute-chronic ratios (ACR) and the relationship between the ACRs and SMAVs (Stephan *et al*. 1985). On the surface, we believe the suggestion by the commentors to incorporate *D. magna* into the FACR seems reasonable, given the similarity between the SMAV for *D. magna* and the warmwater final acute value (FAV). Yet we decided not to include this since the SMACR from *D. magna* appears to be an outlier in the positive relationship between the SMAV and SMACR (Fig. 1 and revised Table 10). This now becomes even more apparent with the inclusion of the chronic Chapman *et al*. manuscript data for *D. magna*.

Additionally, we do not agree with the suggestion by the U.S. EPA that the genus mean acute-chronic ratios (GMACRs) should be used in place of the species mean acute-chronic ratios (SMACRs) for the FACR calculations. Standard methods to derive FACR specifically state to use the SMACRs (Stephan *et al.* 1985) and no U.S. EPA published documents since have suggested using the GMACRs. Therefore, we stand by an initial calculation from the three lowest SMACRs (2.7362), which includes a species with a SMAV greater than the warmwater FAV. [Note: Although an ACR < 1 is unrealistic (see revised Table 10), these values are still acceptable for use in the calculations since the FACR will be corrected to 2.0 if the calculated FACR is < 2.0.]

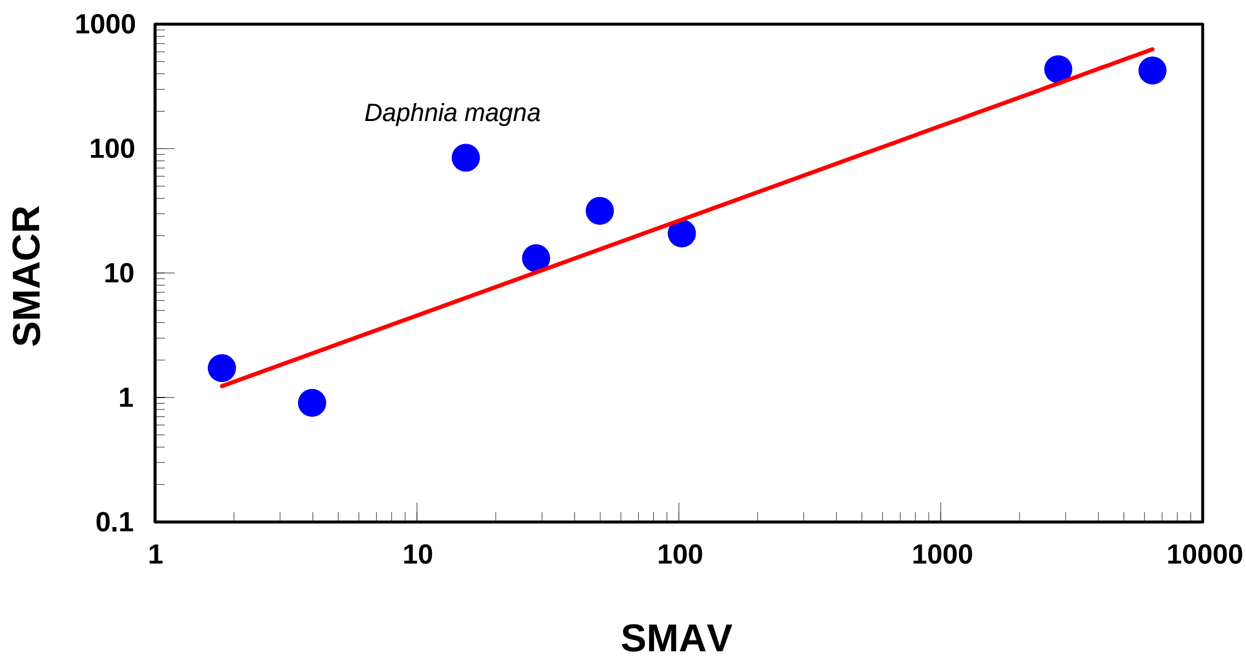

FIGURE 1: The relationship between the species mean acute values (SMAV) and species mean acute-chronic ratios (SMACR) (log-log scale).

Revised Table 10 from CEC 2004 report entitled "U.S. EPA Cadmium Water Quality Criteria Document –Technical Review and Criteria Update" prepared for AMSA.

TABLE 10 - Revised: Cadmium acute-chronic ratio. Only **bold** values were used in the final calculation (*revised December 2004*).

Species	Reference	Hardness	Acute Value	Chronic Value	Ratio	SMAV	SMACR
Jordanella floridae	Spehar 1976	44.0	2,500.00	5.76	433.80	2,810.24	433.8018
Lepomis macrochirus	Eaton 1974	207.0	21,100.00	49.80	423.70	6,440.04	423.6948
Aplexa hypnorum	Holcombe *et al*. 1984	45.3	93.00	5.80	16.03	102.73	20.7584
Aplexa hypnorum	Holcombe *et al*. 1984	45.3	93.00	3.46	26.88		
Ceriodaphnia dubia	Suedel *et al*. 1997	17.0	63.10	2.00	31.55	49.86	31.5500
Pimephales promelas	Pickering and Gast 1972	201.0	5,995.00	45.92	130.55	28.45	**13.1275**
Pimephales promelas	Spehar and Fiandt 1986	44.0	13.20	10.00	1.32		
Daphnia magna	Canton and Sloof 1982	209.2	30.00	0.67	44.78	15.36	44.7751
Oncorhynchus tshawytscha	Chapman 1975, 1982	25.0	1.41	1.56	0.90	3.98	**0.9021**
*Oncorhynchus mykiss**	Davies *et al*. 1993	400.0	7.40	3.64	2.03	1.84	**1.7298**
*Oncorhynchus mykiss**	Davies *et al*. 1993	400.0	5.92	3.64	1.63		
*Oncorhynchus mykiss**	Davies *et al*. 1993	200.0	4.20	3.58	1.17		
*Oncorhynchus mykiss**	Davies *et al*. 1993	200.0	6.57	3.58	1.84		
*Oncorhynchus mykiss**	Davies *et al*. 1993	50.0	2.64	1.47	1.80		
*Oncorhynchus mykiss**	Davies *et al*. 1993	50.0	3.08	1.47	2.10		
				Final acute-chronic ratio =			**2.7362**

* Acute values were grouped with chronic values of like target hardness values.

Other Changes/Comments Addressed in the Revision

- As noted by CDOW, methods for the Davies and Brinkman tests (1994) were corrected from renewal to flow-through. This allowed inclusion of the data in the revised calculations.

- In response to the CDOW request for clarification, we should note the U.S. EPA criteria guidance (Stephan *et al*. 1985) states that results from flow tests are to be preferentially used for SMAV calculations when flow-through, static, and/or renewal tests are available for a given species. Additionally, only results from tests in which cadmium was measured were used to calculate SMAVs if both measured and unmeasured data were available for a given species, again following U.S. EPA criteria guidelines.

- It is important to now note that since our initial review contained incorrect test condition information pertaining to the methods used in the *S. trutta* data (Davies and Brinkman 1994), the existing data point derived from a static, measured test in the 2001 Cadmium Update (U.S. EPA 2001) will not be used in the SMAV calculation, yet will remain in the hardness slope calculations to be consistent with the previously described priority rule.

- As requested by U.S. EPA, tables similar to Tables 1 and 2 of U.S. EPA criteria documents are provided in the accompanying Appendix. The only difference from standard U.S. EPA tables is that data contained in these tables are restricted to data used to derive the SMAVs (e.g., no outlier data deemed suitable, but left out of the SMAV calculations, are included in the tables).

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APPENDIX A

Acute and Chronic Toxicity Databases

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Dendrocoelum lacteum	Planarian	R, M, T	Cadmium chloride	87	24702	14880.09	14880.09	Ham et al. 1995
Lumbriculus variegatus	Worm (adult)	S, M, T	Cadmium nitrate	290 (280-300)	780	156.13	156.13	Schubauer-Berigan et al. 1993
Branchiura sowerbyi	Tubificid worm	S, M	Cadmium sulfate	5.3	240	1871.34	1871.34	Chapman et al. 1982
Limnodrilus hoffmeisteri	Tubificid worm (30-40 mm)	F, M, T	--	152	2400	867.63	867.63	Williams et al. 1985
Quistadrilus multisetosus	Tubificid worm	S, M	Cadmium sulfate	5.3	320	2495.13	2495.13	Chapman et al. 1982
Rhyacodrilus montana	Tubificid worm	S, M	Cadmium sulfate	5.3	630	4912.28	4912.28	Chapman et al. 1982
Spirosperma ferox	Tubificid worm	S, M	Cadmium sulfate	5.3	350	2729.04	2729.04	Chapman et al. 1982
Spirosperma nikolskyi	Tubificid worm	S, M	Cadmium sulfate	5.3	450	3508.77	3508.77	Chapman et al. 1982
Stylodrilus heringlianus	Tubificid worm	S, M	Cadmium sulfate	5.3	550	4288.50	4288.50	Chapman et al. 1982
Tubifex tubifex	Tubificid worm	S, M, T	Cadmium chloride	128 (119-137)	3200	1353.85	1344.34	Reynoldson et al. 1996
Tubifex tubifex	Tubificid worm	S, M, T	Cadmium chloride	128 (119-137)	1700	719.23		Reyonldson et al. 1996
Tubifex tubifex	Tubificid worm	S, U	Cadmium chloride	5.3	320	2495.13		Chapman et al. 1982
Varichaeta pacifica	Tubificid worm	S, M	Cadmium sulfate	5.3	380	2962.96	2962.96	Chapman et al. 1982
Glossiponia complanta	Leech	R, M, T	Cadmium chloride	122.8	480	210.93	210.93	Brown and Pascoe 1988
Alpexa Hypnorum	Snail	F, M	Cadmium chloride	45.3	93	101.79	102.73	Holcombe et al. 1984
Alpexa Hypnorum	Snail (adult)	F, M, T	Cadmium chloride	44.4	93	103.68		Phipps and Holcombe 1985
Physa gyrina	Snail (immature)	S, M	--	200.0	410	115.30	115.30	Wier and Walter 1976
Actinonaia pectorosa	Mussel (juvenile)	S, M, T	--	82	46.4	29.51	35.59	Keller unpublished
Actinonaia pectorosa	Mussel (juvenile)	S, M, T	--	84	69	42.92		Keller unpublished

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Lampsilis straminea claibornensis	Mussel (juvenile)	S, M, T	--	40	38	46.61	46.61	Keller unpublished
Lampsilis teres	Mussel	S, M, T	--	40	11	13.49	23.37	Keller unpublished
Lampsilis teres	Mussel (juvenile)	S, M, T	--	40	33	40.48		Keller unpublished
Utterbackia imbecilis	Mussel (juvenile)	S, M, T	Cadmium chloride	90.0	114.7	66.98	44.90	Keller unpublished
Utterbackia imbecilis	Mussel (juvenile)	S, M, T	Cadmium chloride	90.0	111.8	65.29		Keller unpublished
Utterbackia imbecilis	Mussel (juvenile)	S, M, T	Cadmium chloride	92.0	81.9	46.88		Keller unpublished
Utterbackia imbecilis	Mussel (juvenile)	S, M, T	Cadmium chloride	86.0	93	56.62		Keller unpublished
Utterbackia imbecilis	Mussel (juvenile)	S, M, T	Cadmium chloride	39.0	9	11.30		Keller and Zam 1991
Utterbackia imbecilis	Mussel (juvenile)	S, M, T	Cadmium chloride	90.0	107	62.49		Keller and Zam 1991
Vilosa vibex	Mussel	S, M, T	--	40.0	30	36.80	37.18	Keller unpublished
Vilosa vibex	Mussel	S, M, T	--	186.0	125	37.57		Keller unpublished
Alona affinis	Cladoceran	S, U	Cadmium nitrate	109	546	267.59	267.59	Ghosh et al. 1990
Ceriodaphnia dubia	Cladoceran (<24 hr)	S, U	Cadmium chloride	90 (80-100)	54	31.54	49.86	Bitton et al. 1996
Ceriodaphnia dubia	Cladoceran (<24 hr)	R, M, T	Cadmium chloride	80 (70-90)	54.5	35.45		Diamond et al. 1997
Ceriodaphnia dubia	Cladoceran (<24 hr)	S, U	Cadmium chloride	90 (80-100)	55.9	32.64		Lee et al. 1997
Ceriodaphnia dubia	Cladoceran	S, M, T	Cadmium chloride	17	63.1	169.35		Suedel et al. 1997
Ceriodaphnia reticulata	Cladoceran (<24 hr)	S, U	Cadmium chloride	240	184	43.79	46.50	Elnabarawy et al. 1986
Ceriodaphnia reticulata	Cladoceran (<6 hr)	S, U	Cadmium chloride	120	110	49.37		Hall et al. 1986
Daphnia magna	Cladoceran	S, U	Cadmium chloride	45	65	71.58	15.36	Biesinger and Christensen 1972

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Daphnia magna	Cladoceran (<24 hr)	R, M	Cadmium chloride	105	30	15.21		Canton and Sloof 1982
Daphnia magna	Cladoceran (<24 hr)	R, M	Cadmium chloride	209.2	30	8.10		Canton and Sloof 1982
Daphnia magna	Cladoceran	S, U	Cadmium chloride	120	20	8.98		Hall et al 1986
Daphnia magna	Cladoceran	S, U	Cadmium chloride	120	40	17.95		Hall et al 1986
Daphnia magna	Cladoceran (<24 hr)	S, U	Cadmium chloride	240	178	42.37		Elnabarawy et al. 1986
Daphnia magna	Cladoceran	S, M, T	Cadmium chloride	170 (160-180)	3.6 (genotype A)	1.17		Baird et al 1991
Daphnia magna	Cladoceran	S, M, T	Cadmium chloride	170 (160-180)	9 (genotype A-1)	2.94		Baird et al 1991
Daphnia magna	Cladoceran	S, M, T	Cadmium chloride	170 (160-180)	9 (genotype A-2)	2.94		Baird et al 1991
Daphnia magna	Cladoceran	S, M, T	Cadmium chloride	170 (160-180)	4.5 (genotype B)	1.47		Baird et al 1991
Daphnia magna	Cladoceran	S, M, T	Cadmium chloride	170 (160-180)	27.1 (genotype E)	8.84		Baird et al 1991
Daphnia magna	Cladoceran	S, M, T	Cadmium chloride	170 (160-180)	115.9 (genotype S-1)	37.82		Baird et al 1991
Daphnia magna	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	170 (160-180)	24.5 (Clone F)	7.99		Stuhlbacher et al. 1992
Daphnia magna	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	170 (160-180)	129.4 (Clone S-1)	42.23		Stuhlbacher et al. 1992
Daphnia magna	Cladoceran	S, U	Cadmium sulfate	250	280	64.20		Crisinel et al. 1994
Daphnia magna	Cladoceran (<24 hr)	S, U	Cadmium chloride	170 (160-180)	9.5	3.10		Guilhermino et al. 1996
Daphnia magna	Cladoceran	S, M, T	Cadmium sulfate	46.1	112 (clone S-1)	120.64		Barata et al. 1998
Daphnia magna	Cladoceran	S, M, T	Cadmium sulfate	90.7	106 (clone S-1)	61.46		Barata et al. 1998

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Daphnia magna	Cladoceran	S, M, T	Cadmium sulfate	179	233 (clone S-1)	72.53		Barata et al. 1998
Daphnia magna	Cladoceran	S, M, T	Cadmium sulfate	46.1	30.1 (clone A)	32.42		Barata et al. 1998
Daphnia magna	Cladoceran	S, M, T	Cadmium sulfate	90.7	23.4 (clone A)	13.57		Barata et al. 1998
Daphnia magna	Cladoceran	S, M, T	Cadmium sulfate	179	23.6	7.35		Barata et al. 1998
Daphnia magna	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	51	9.9	9.72		Chapman et al. manuscript
Daphnia magna	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	104	33	16.88		Chapman et al. manuscript
Daphnia magna	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	105	34	17.24		Chapman et al. manuscript
Daphnia magna	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	197	63	17.96		Chapman et al. manuscript
Daphnia magna	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	209	49	13.24		Chapman et al. manuscript
Daphnia magna	Cladoceran	S, M, T	Cadmium chloride	17	26.4	70.85		Suedel et al. 1997
Daphnia pulex	Cladoceran	S, U	Cadmium chloride	57	47	41.69	48.98	Bertram and Hart 1979
Daphnia pulex	Cladoceran (<24 hr)	S, U	Cadmium chloride	240	319	75.93		Elnabarawy et al 1986
Daphnia pulex	Cladoceran (<24 hr)	S, U	Cadmium chloride	120	80	35.91		Hall et al 1986
Daphnia pulex	Cladoceran (<24 hr)	S, U	Cadmium chloride	120	100	44.88		Hall et al 1986
Daphnia pulex	Cladoceran (<24 hr)	S, M, T	Cadmium chloride	53.5	70.1	65.89		Stackhouse and Benson 1988
Daphnia pulex	Cladoceran	S, U	Cadmium chloride	85 (80-90)	66	40.61		Roux et al. 1993
Daphnia pulex	Cladoceran	S, U	Cadmium chloride	85 (80-90)	99	60.92		Roux et al. 1993
Daphnia pulex	Cladoceran	S, U	Cadmium chloride	85 (80-90)	70	43.07		Roux et al. 1993
Daphnia pulex	Cladoceran	S, U	Cadmium chloride	82	71.25	45.31		Hatakeyama and Yasuno

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Moina macrocopa	Cladoceran	S, U	Cadmium *	82	71.25	45.31	45.31	Hatakeyama and Yasuno1981
Simocephalus serrulatus	Cladoceran	S, M	Cadmium chloride	11.1	7	27.75	27.79	Giesy et al. 1977
Simocephalus serrulatus	Cladoceran	S, M	Cadmium chloride	43.5 (39-48)	24.5	27.83		Spehar and Carlson 1984
Cyclops varicans	Copepod	S, U	Cadmium nitrate	109	493	241.62	241.62	Gosh et al. 1990
Asellus bicrenata	Isopod	F, M	Cadmium chloride	220	2129	548.72	548.72	Bosnak and Morgan 1981
Lirceus alabamae	Isopod	F, M	Cadmium chloride	152	150	54.23	54.23	Bosnak and Morgan 1981
Crangonyx pseudogracilis	Amphipod (4 mm)	R, U	Cadmium chloride	50	1700	1700.00	1700.00	Martin and Holdich
Gammarus pseudolimnaeus	Amphipod	S, M	Cadmium chloride	43.5 (39-48)	68.3	77.58	77.58	Spear and Carlson 1984
Hyallela azteca	Amphipod	S, M, T	Cadmium chloride	17	2.8	7.51	7.51	Suedel et al. 1997
Orconectes immunis	Crayfish (1.8 g)	F, M, T	Cadmium chloride	44.4	10200	11371.23	11371.23	Phipps and Holcombe 1985
Orconectes virilis	Crayfish	F, M, T	Cadmium chloride	26.0	6100	11097.25	11097.25	Mirenda 1986
Procambarus clarkii	Crayfish (juvenile)	S, M	Cadmium chloride	30.0	1040	1659.77	1659.77	Naqvi and Howell 1993
Ephemerella grandis	Mayfly	S, U	Cadmium sulfate	44	2000	2248.19	2248.19	Warnick and Bell 1969
Chironomus plumosus	Midge	S, U	Cadmium chloride	80	12700	8260.64	8260.64	Fargasova 2003
Chironomus riparius	Midge (10-12 mm)	F, M, T	--	152	300000	108453.52	108453.52	Williams et al. 1985
Chironomus tentans	Midge	S, M, T	Cadmium chloride	17	2956	7933.19	7933.19	Suedel et al. 1997
Pectinatella magnifica	Bryozoan	S, U	--	205 (190-220)	700	192.46	192.46	Pardue and Wood 1980
Lophopodella carteri	Bryozoan	S, U	--	205 (190-220)	150	41.24	41.24	Pardue and Wood 1980

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Plumatella emarginata	Bryozoan	S, U	--	205 (190-220)	1090	299.69	299.69	Pardue and Wood 1980
Oncorhynchus kisutch	Coho salmon (parr)	F, M	Cadmium chloride	22	2.7	5.72	5.72	Chapman 1975
Oncorhynchus tshawytscha	Chinook salmon (swim-up)	F, M	Cadmium chloride	23	1.8	3.66	3.98	Chapman 1975, 1978
Oncorhynchus tshawytscha	Chinook salmon *	F, M	Cadmium*	23	3.5	7.12		Chapman 1975, 1978
Oncorhynchus tshawytscha	Chinook salmon (smolt)	F, M	Cadmium chloride	23	2.9	5.90		Chapman 1975, 1978
Oncorhynchus tshawytscha	Chinook salmon (juvenile)	F, M	Cadmium chloride	25	1.41	2.66		Chapman 1982
Oncorhynchus tshawytscha	Chinook salmon (juvenile)	F, M	Cadmium sulfate	21 (20-22)	1.1	2.43		Finlayson and Verrue 1982
Oncorhynchus mykiss	Rainbow trout (swim-up)	F, M	Cadmium chloride	23	1.3	2.65	1.84	Chapman 1975, 1978
Oncorhynchus mykiss	Rainbow trout (parr)	F, M	Cadmium chloride	23	1	2.04		Chapman 1978
Oncorhynchus mykiss	Rainbow trout (smolt)	F, M	Cadmium chloride	23	4.1	8.34		Chapman 1975
Oncorhynchus mykiss	Rainbow trout (smolt)	F, M	Cadmium chloride	23	2.9	5.90		Chapman 1975
Oncorhynchus mykiss	Rainbow trout	F, M	Cadmium sulfate	31	1.75	2.71		Davies 1976
Oncorhynchus mykiss	Rainbow trout (8.8 g)	F, M, T	Cadmium chloride	44.4	3	3.34		Phipps and Holcombe 1985
Oncorhynchus mykiss	Rainbow trout (fry)	F, M, T	Cadmium chloride	9.2	0.5	2.35		Cusimano et al. 1986
Oncorhynchus mykiss	Rainbow trout (263 g)	F, M, T	Cadmium chloride	30.7 (pH=7.5 @ 8˚C)	0.71	1.11		Stratus Consulting 1999
Oncorhynchus mykiss	Rainbow trout (259 g)	F, M, T	Cadmium chloride	29.3 (pH=7.5 @ 8˚C)	0.47	0.77		Stratus Consulting 1999

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Oncorhynchus mykiss	Rainbow trout (1150 g)	F, M, T	Cadmium chloride	31.7 (pH=7.5 @ 8˚C)	0.51	0.77		Stratus Consulting 1999
Oncorhynchus mykiss	Rainbow trout (1130 g)	F, M, T	Cadmium chloride	30.2 (pH=7.5 @ 12˚C)	0.38	0.60		Stratus Consulting 1999
Oncorhynchus mykiss	Rainbow trout (299 g)	F, M, T	Cadmium chloride	30 (pH=7.5 @ 8˚C)	1.29	2.06		Stratus Consulting 1999
Oncorhynchus mykiss	Rainbow trout (289 g)	F, M, T	Cadmium chloride	89.3 (pH=7.5 @ 8˚C)	2.85	1.68		Stratus Consulting 1999
Oncorhynchus mykiss	Rainbow trout (36 g)	R, M, T	Cadmium chloride	420.0	7.400	1.06		Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout (50-mm TL)	R, M, T	Cadmium chloride	427.0	5.920	0.83		Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout (36 g)	R, M, T	Cadmium chloride	217.0	4.200	1.10		Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout (50-mm TL)	R, M, T	Cadmium chloride	227.0	6.570	1.65		Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout (36 g)	R, M, T	Cadmium chloride	46.0	2.640	2.85		Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout (50-mm TL)	R, M, T	Cadmium chloride	49.0	3.080	3.14		Davies et al. 1993
Salmo trutta	Brown trout	S, M	Cadmium chloride	43.5 (39-48)	1.4	1.59	2.61	Spehar and Carlson 1984
Salmo trutta	Brown trout (juvenile)	R, M, T	Cadmium sulfate	37.6	2.37	3.08		Davies and Brinkman 1994
Salmo trutta	Brown trout (fry)	F, M, D	Cadmium sulfate	29.2	1.24**	2.02		Brinkman and Hansen 2004
Salmo trutta	Brown trout (fry)	F, M, D	Cadmium sulfate	67.6	4.06**	3.08		Brinkman and Hansen 2004
Salmo trutta	Brown trout (fry)	F, M, D	Cadmium sulfate	151.4	10.90**	3.95		Brinkman and Hansen 2004
Salvelinus fontinalis	Brook trout	F, M	Cadmium chloride	42	1.5	1.76	1.76	Holcombe et al. 1979
Salvelinus confluentus	Bull trout (76.1 mg)	F, M, T	Cadmium chloride	30.7	0.91	1.42	2.08	Stratus Consulting 1999

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Salvelinus confluentus	Bull trout (200 mg)	F, M, T	Cadmium	29.3	0.99	1.61		Stratus Consulting 1999
Salvelinus confluentus	Bull trout (221 mg)	F, M, T	Cadmium chloride	31.7	1	1.52		Stratus Consulting 1999
Salvelinus confluentus	Bull trout (218 mg)	F, M, T	Cadmium chloride	30.2	0.9	1.43		Stratus Consulting 1999
Salvelinus confluentus	Bull trout (84.2 mg)	F, M, T	Cadmium chloride	30	2.89	4.61		Stratus Consulting 1999
Salvelinus confluentus	Bull trout (72.7 mg)	F, M, T	Cadmium chloride	89.3	6.06	3.56		Stratus Consulting 1999
Carssius auratus	Goldfish (8.8 g)	F, M, T	Cadmium chloride	44.4	748	833.89	833.89	Phipps and Holcombe 1985
Cyprinus carpio	Common carp (fry)	S, U	Cadmium nitrate	100	4300	2280.32	4547.36	Suresh et al. 1993
Cyprinus carpio	Common carp (fingerling)	S, U	Cadmium nitrate	100	17100	9068.25		Suresh et al. 1993
Notropis lutrensis	Red shiner	S, M, T	Cadmium *	85.5	6620	4051.76	4051.76	Carrier and Beitinger 1988
Pimephales promelas	Fathead minnow (fry)	S, M	Cadmium chloride	40.0	21.5	26.37	28.45	Spehar 1982
Pimephales promelas	Fathead minnow (fry)	S, M	Cadmium chloride	48.0	11.7	12.15		Spehar 1982
Pimephales promelas	Fathead minnow (fry)	S, M	Cadmium chloride	39.0	19.3	24.23		Spehar 1982
Pimephales promelas	Fathead minnow (fry)	S, M	Cadmium chloride	45.0	42.4	46.69		Spehar 1982
Pimephales promelas	Fathead minnow (fry)	S, M	Cadmium chloride	47.0	54.2	57.36		Spehar 1982
Pimephales promelas	Fathead minnow (fry)	S, M	Cadmium chloride	44.0	29	32.60		Spehar 1982
Pimephales promelas	Fathead minnow (<24 hr)	S, U	Cadmium nitrate	60.0	210	177.73		Rifici et al. 1996
Pimephales promelas	Fathead minnow (1-2 d)	S, U	Cadmium nitrate	60.0	180	152.34		Rifici et al. 1996
Pimephales promelas	Fathead minnow (<24 hr)	S, M, T	Cadmium nitrate	290.0	73	14.61		Schubauer-Berigan et al. 1993

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Pimephales promelas	Fathead minnow (<24 hr)	S, M, T	Cadmium nitrate	290.0	60	12.01		Schubauer-Berigan et al. 1993
Pimephales promelas	Fathead minnow (<24 hr)	S, M, T	Cadmium nitrate	290.0	65	13.01		Schubauer-Berigan et al. 1993
Pimephales promelas	Fathead minnow	F, M, T	Cadmium *	44.0	13.2	14.84		Spehar and Fiandt 1986
Pimephales promelas	Fathead minnow	S, M, T	Cadmium chloride	17.0	4.8	12.88		Suedel et al. 1997
Ptychocheilus lucius	Colorado squawfish (larva)	S, U	Cadmium chloride	199	78	22.04	25.93	Buhl 1997
Ptychocheilus lucius	Colorado squawfish (juvenile)	S, U	Cadmium chloride	199	108	30.51		Buhl 1997
Ptychocheilus oregonensis	Northern pike minnow (juvenile)	F, M	Cadmium chloride	25	1092	2059.18	2070.47	Andros and Garton 1980
Ptychocheilus oregonensis	Northern pike minnow (juvenile)	F, M	Cadmium chloride	25	1104	2081.81		Andros and Garton 1980
Gila elegans	Bonytail (larva)	S, U	Cadmium chloride	199	148	41.81	44.55	Buhl 1997
Gila elegans	Bonytail (juvenile)	S, U	Cadmium chloride	199	168	47.46		Buhl 1997
Catostomus commersoni	White sucker	F, M	Cadmium chloride	18	1110	2827.16	2827.16	Duncan and Klaverkamp 1983
Xyrauchen texanus	Razorback sucker (larva)	S, U	Cadmium chloride	199.0	139	39.27	42.13	Buhl 1997
Xyrauchen texanus	Razorback sucker (juvenile)	S, U	Cadmium chloride	199.0	160	45.20		Buhl 1997
Ictalurus punctatus	Channel catfish (7.4 g)	F, M, T	Cadmium chloride	44.4	4480	4994.42	4994.42	Phipps and Holcombe 1985
Jordanella floridae	Flagfish	F, M	Cadmium chloride	44	2500	2810.24	2810.24	Spehar 1976
Gambusia affinis	Mosiquitofish	F, M	Cadmium chloride	11.1	900	3567.75	5578.08	Giesy et al. 1977
Gambusia affinis	Mosiquitofish	F, M	Cadmium *	11.1	2200	8721.18		Giesy et al. 1977

Species	Common Name	Method	Chemical	Hardness (mg/L) as $CaCO_3$	LC_{50}, total ug/L	LC_{50} adj to hardness=50	SMAV*	Ref
Poecilia reticulata	Guppy	S, U	Cadmium chloride	20.0	1270	2937.37	2569.18	Pickering and Henderson 1966
Poecilia reticulata	Guppy (3-4 wk)	R, M, T	Cadmium chloride	105.0	3800	1927.17		Canton and Sloof 1982
Poecilia reticulata	Guppy (3-4 wk)	R, M, T	Cadmium chloride	209.2	11100	2995.74		Canton and Sloof 1982
Gasterosteus aculeatus	Threespine stickleback	S, U	Cadmium chloride	115	6500	3033.17	5897.00	Pascoe and Cram 1977
Gasterosteus aculeatus	Threespine stickleback	R, M	Cadmium chloride	107	23000	11464.79		Pascoe and Mattey 1977
Morone saxatilis	Striped bass (63 d)	S, U	Cadmium chloride	40	4	4.91	3.16	Palawski 1973
Morone saxatilis	Striped bass (63 d)	S, U	Cadmium chloride	285	10	2.03		Palawski 1973
Lepomis cyanellus	Green sunfish	F, M	Cadmium *	335	20500	3595.94	3595.94	Jude 1973
Lepomis macrochirus	Bluegill	F, M	Cadmium chloride	207	21100	5749.97	6440.04	Eaton 1980
Lepomis macrochirus	Bluegill (1.0 g)	F, M, T	Cadmium chloride	44.4	6470	7212.93		Phipps an dHolcombe1985
Oreochromis mossambica	Tilapia	R, U	Cadmium chloride	28.4	6000	10068.09	10068.09	Gaikwad 1989
Ambystoma gracile	Salamander	F, M, T	Cadmium chloride	45	468.4	515.81	515.81	Nebeker et al. 1995
Thymallus arcticus	Arctic grayling (juvenile)	S, M, T	Cadmium chloride	41.0	4	4.80	4.80	Buhl and Hamilton 1991

*value taken from 1984 document

** values estimated from dissolved Cd before updated in study

Species	**Common Name**	**Test**	**Chemical**	**Hardness (mg/L as $CaCO_3$)**	**Chronic limits, total (µg/L)**	**Chronic value total (µg/L)**	**Chronic value/EC_{20}s hardness=50**	**SMCV**	**GMCV**	**Ref**
Aeolosoma headleyi	Oligochaete	LC	--	65	--	25.19	20.422	20.4219	20.4219	Niederlehner 1984
Aplexa hypnorum	Snail	LC	Cadmium chloride	45.3	4.41-7.63	3.46	3.744	4.8482	4.8482	Holcombe et al. 1984
Aplexa hypnorum	Snail	LC	Cadmium chloride	45.3	2.5-4.79	5.801	6.278			Holcombe et al. 1984
Ceriodaphnia dubia	Cladoceran	LC	--	20	10-19	13.78	28.676	11.6584	11.6584	Jop et al. 1984
Ceriodaphnia dubia	Cladoceran	LC	Cadmium chloride	17		2	4.740			Suedel et al. 1997
Daphnia magna	Cladoceran	LC	Cadmium chloride	51.0	--	2.070	2.037	0.4920	1.3259	CEC 2003
Daphnia magna	Cladoceran	LC	Cadmium chloride	99.0	--	2.230	1.291			CEC 2003
Daphnia magna	Cladoceran	LC	Cadmium chloride	209.2		0.670	0.213			Canton and Slooff 1982
Daphnia magna	Cladoceran	LC	Cadmium chloride	150.0	5.0-10.0	7.070	2.936			Bodar et al. 1988b
Daphnia magna	Cladoceran	LC	Cadmium chloride	130.0	<1.86-1.86	1.860	0.866			Borgmann et al. 1989
Daphnia magna	Cladoceran	LC	Cadmium chloride	53.0	0.08-0.29	0.152	0.145			Chapman et al manuscript
Daphnia magna	Cladoceran	LC	Cadmium chloride	103.0	0.16-0.28	0.212	0.119			Chapman et al manuscript
Daphnia magna	Cladoceran	LC	Cadmium chloride	209.0	0.21-0.91	0.437	0.139			Chapman et al manuscript
Daphnia pulex	Cladoceran	LC	Cadmium chloride	52.0	--	2.170	2.103	3.5735		CEC 2003
Daphnia pulex	Cladoceran	LC	--	65.0	--	7.490	6.072			Niederlehner 1984
Hyalella azteca	Amphipod	LC	Cadmium chloride	280.0	5.8-17.4	0.984	0.248	0.2640	0.2640	Ingersoll and Kemble 2001
Hyalella azteca	Amphipod	ELS	Cadmium chloride	153.0	--	0.760	0.311			CEC 2003
Hyalella azteca	Amphipod	ELS	Cadmium chloride	126.0	--	0.500	0.239			CEC 2003

Species	**Common Name**	**Test**	**Chemical**	**Hardness(mg/L as$CaCO_3$)**	**Chronic limits, total (µg/L)**	**Chronicvalue total (µg/L)**	**Chronic value/EC_{20}s hardness=50**	**SMCV**	**GMCV**	**Ref**
Chironomus tentans	Midge	LC	Cadmium chloride	280	5.8-17.4	10.05	2.534	2.5338	2.5338	Ingersoll and Kemble Unpublished
Pimephales promelas	Fathead minnow	LC	Cadmium sulfate	201	37-57	45.92	15.092	15.0918	15.0918	Pickering and Gast 1972
Catostomus commersoni	White sucker	ELS	Cadmium chloride	44	4.2-12.0	7.099	7.863	7.8632	7.8632	Eaton et al. 1978
Jordanella floridae	Flagfish	LC	Cadmium chloride	44	4.1-8.1	5.763	6.383	5.3420	5.3420	Spehar 1976
Jordanella floridae	Flagfish	LC	Cadmium chloride	47.5	3.0-6.5	4.416	4.601			Carlson et al. 1982
Jordanella floridae	Flagfish	LC	Cadmium chloride	47.5	3.4-7.3	4.982	5.191			Carlson et al. 1982
Lepomis macrochirus	Bluegill	LC	Cadmium sulfate	207	31-80	49.8	15.986	15.9865	15.9865	Eaton et al. 1978
Micropterus dolomieui	Smallmouth bass	ELS	Cadmium chloride	44	4.3-12.7	7.39	8.186	8.1855	8.1855	Eaton et al. 1978
Oreochromis aurea	Blu tilapia	LC	Cadmium nitrate	145	>52	52	22.191	22.1910	22.1910	Papoutsoglou and Abel 1988
Oncorhynchus kisutch	Coho salmon	ELS	Cadmium chloride	44	1.3-3.4	2.102	2.328	4.2968	2.3320	Eaton et al. 1978
Oncorhynchus kisutch	Coho salmon	ELS	Cadmium chloride	44	4.1-12.5	7.159	7.930			Eaton et al. 1978
Oncorhynchus tshawytscha	Chinook salmon	ELS	Cadmium chloride	25	1.3-1.88	1.563	2.721	2.7210		Chapman 1975
Oncorhynchus mykiss	Rainbow trout	LC	Cadmium chloride	46.2		1.47	1.566	1.0847		Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout	LC	Cadmium chloride	217		3.58	1.107			Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout	LC	Cadmium chloride	413.8		3.64	0.671			Davies et al. 1993
Oncorhynchus mykiss	Rainbow trout (270 d)	LC	Cadmium sulfate	250	3.39-5.48	4.31	1.190			Brown et al. 1994

Species	**Common Name**	**Test**	**Chemical**	**Hardness (mg/L as $CaCO_3$)**	**Chronic limits, total (µg/L)**	**Chronic value total (µg/L)**	**Chronic value/EC_{20}s hardness=50**	**SMCV**	**GMCV**	**Ref**
Salmo salar	Atlantic salmon	ELS	Cadmium chloride	23.5	90-270	155.9	285.169			Rombough and Garside 1982
				(19-28)	(5 °C)					
					2.5-8.2	4.528	8.283	8.2825	8.2825	
					(9.6 °C)					
Salmo trutta	Brown trout	LC	Cadmium sulfate	250	9.34-29.1	16.49	4.552	4.5518	2.69552217	Brown et al. 1994
Salmo trutta	Brown trout	ELS	Cadmium sulfate	39.8		1.33	1.596	1.5963		Davies and Brinkman 1994
Salvelinus fontinalis	Brook trout	ELS	Cadmium chloride	44	1.7-3.4	2.404	2.663	2.6628	4.6582	Benoit et al 1976
Salvelinus namaycush	Lake trout	ELS	Cadmium chloride	44	4.4-12.3	7.357	8.149	8.1490		Eaton et al. 1978
Esox lucius	Northern pike	ELS	Cadmium chloride	44.0	4.2-12.9	7.361	8.153	8.1534	8.1534	Eaton et al. 1978