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

SEPTEMBER 2004

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AMSA

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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). Since the publication of this document in 2001, state and tribal entities have been obligated to update their cadmium Ambient Water Quality Criteria (AWQC) accordingly. The purpose of this report is to summarize the status of Chadwick Ecological Consultants, Inc.'s (CEC) technical review of the freshwater cadmium AWQC on behalf of the Association of Metropolitan Sewerage Agencies (AMSA). This evaluation has been conducted in four phases.

The first phase of this process was a technical review of the existing U.S. EPA 2001 cadmium AWQC document, hereafter referred to as the 2001 Cadmium Update. The primary goal of this phase was to determine if U.S. EPA criteria development methods were followed for deriving the 2001 Cadmium Update and whether or not any errors were made in the development of the criteria.

The second phase of the evaluation was an extensive literature search to critically review available cadmium toxicity data in addition to those used in the derivation of the 2001 Cadmium Update. The purpose of this phase was to update the database from the 2001 Cadmium Update with all relevant information to date. Emphasis was placed on obtaining literature since the 2001 Cadmium Update. However, literature published prior to the document, but not cited, was reviewed as well to establish a criteria based on the most complete database available.

Following the compilation of literature and development of the revised database, the third phase was initiated to develop a potentially revised and updated AWQC for cadmium. Approximately 130 scientific papers and documents relating to the toxicity of cadmium to freshwater aquatic biota were critically reviewed for relevant content. Usable toxicity data points obtained from this review were allocated to the appropriate database (acute or chronic). Once the databases were assembled, acute and chronic AWQC were re-calculated using U.S. EPA's *Guidelines for Deriving Numerical Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* ([Guidelines] Stephan *et al*. 1985).

The fourth phase included the calculation of potential "use-specific" cadmium criteria for freshwater organisms. Specifically, acute and chronic cadmium AWQC were developed for cold and warmwater uses based on the expected distribution of the species in each database. These calculations could potentially supersede the general AWQC for cadmium when it can be demonstrated that a particular stream can be classified exclusively as either cold or warmwater.

REVIEW OF 2001 CADMIUM WATER QUALITY CRITERIA UPDATE

Phase 1 - Technical Review of 2001 Cadmium Update

Phase 1 of CEC's evaluation of the 2001 Cadmium Update consisted of a thorough investigation of the data used to calculate the most recent cadmium criteria. The document (U.S. EPA 2001) was critically reviewed for relevance of the toxicological data and adherence to U.S. EPA methodology (Stephan *et al*. 1985). The criteria presented in the 2001 Cadmium Update supersede previous 1995 AWQC update for cadmium (U.S. EPA 1996), which was built upon the 1984 criteria (U.S. EPA 1984) and principles set forth in the 1985 Guidelines (Stephan *et al*. 1985). Some general principles presented in the 1985 Guidelines include:

(1) Acute toxicity data must be available for species from a minimum of eight diverse families (the family Salmonidae, a second family in the class Osteichthyes, a third family in the phylum Chordata, a planktonic crustacean, a benthic crustacean, an insect, a family in a phylum other than Arthropoda or Chordata, and a family in any order of insect or any phylum not already represented).

(2) The final acute value (FAV) is derived by extrapolation or interpolation to a hypothetical genus more sensitive than 95 percent of all tested genera. The FAV is divided by two in order to obtain an acute criterion protective of nearly all individuals in the database.

(3) Chronic toxicity data must be available for at least three taxa. The chronic criterion is most often set by determining an appropriate acute-chronic ratio (the ratio of acutely toxic concentrations to the chronically toxic concentrations for the same species) and dividing the FAV by that ratio. However,

if sufficient data are available to meet the "eight-family rule," then the chronic value can be derived using the same procedure as used for FAV derivation.

(4) When necessary, the acute and/or chronic criterion may be lowered to protect recreationally or commercially important species.

Acute Toxicity

The 2001 Cadmium Update presents acute data for 55 genera of freshwater biota, including 39 species of invertebrates, 24 species of fish, one salamander, and one frog species. These 65 species satisfy the "eight-family rule" as specified in the 1985 Guidelines. However, we have determined four papers used in the 2001 Cadmium Update were unsuitable for acute criteria evaluation (Table 1).

TABLE 1: Summary of data from the 2001 Cadmium Update used by U.S. EPA in the cadmium criteria calculations, but deemed unsuitable and, therefore, deleted from the revised databases.

Species	Reference	Reason
Acute:		
Salvelinus fontinalis	Carroll *et al*. 1979	control had higher cadmium concentration than LC_{50}, but no response
Daphnia magna	Attar and Maly 1982	previous exposure of test organisms to cadmium
Xenopus laevis	Sunderman *et al*. 1991	pest species; not native to North America
Chronic:		
Daphnia magna	Chapman *et al*. manuscript	method of chronic calculations and underlying data not provided

Carroll *et al*. (1979) examined the toxicity of cadmium to brook trout (*Salvelinus fontinalis*) in response to various hardness constituents (i.e., $CaCO_3$, $MgCO_3$, etc.). The LC_{50} value used in the 2001 Cadmium Update came from the test in which the authors used reconstituted soft water. However, the LC_{50} (<1.5 µg/L) is lower than the measured cadmium concentration for the control (2.9 µg/L), in which they reported 100 percent survival. Therefore, we determined this set of data possessed inappropriate test conditions and methodology and was removed from the revised acute cadmium database.

Additionally, data was used from a study conducted by Attar and Maly (1982) that examined the toxicity of cadmium, zinc, and their mixtures to *Daphnia magna*. CEC determined these data unsuitable for use in AWQC derivations because of inappropriate treatment of test organisms. *D. magna* test organisms were cultured in a 430 L polyethylene tub containing a concentrated algae culture. Water quality analyses of the culture water showed that the water contained trace amounts of cadmium (1.0 µg/L) and iron (3 µg/L). This concentration of cadmium may seem insignificant, however the species mean chronic value for *D. magna* is < 0.3794 µg/L according to the 2001 Cadmium Update. Therefore, we determined these conditions constitute "previous exposure to cadmium," and data from this study were removed from the revised acute cadmium database.

Finally, data from Sunderman *et al*. (1991) for the African clawed frog (*Xenopus laevis*) were used in the acute criteria development in the 2001 Cadmium Update. CEC determined these data unsuitable because *X. laevis* is not native to North America. In fact, its distribution in North America is restricted to isolated regions in the southwestern U.S. where it was accidentally introduced and is considered a pest species.

After data from the aforementioned publications were removed from the acute database, the resultant acute database consists of 64 species occupying 54 genera. Only one species (*X. laevis*) constituting the entire data set for its genus was removed entirely from the revised acute database. The "eight-family rule" is still met by this database according to the 1985 Guidelines.

Chronic Toxicity

The 2001 Cadmium Update presents chronic data for 16 genera of freshwater organisms, including seven species of invertebrates and 14 species of fishes. These 21 species satisfy the "eight-family rule" as specified in the 1985 Guidelines. With regard to data review, only the chronic *D. magna* data from the unpublished Chapman *et al*. manuscript was determined to be unsuitable for use in cadmium AWQC derivation for two reasons (Table 1). First, the document we obtained through the U.S. EPA's document coordinator is a rough manuscript with very little details regarding the methodology. More specifically, the no-observed-effect-concentrations (NOEC) and lowest-observed-effect-concentrations (LOEC) that are typically used to calculate chronic values were not clearly defined, the methods used for calculating chronic values were not presented, and the underlying data were not reported. Additionally, the Chapman *et al*. data are roughly an order of magnitude lower than the other chronic Cladoceran data presented in the 2001 Cadmium Update making them outliers in the database. Therefore, all chronic data from the Chapman *et al*. manuscript were removed from the revised chronic cadmium database. Acute data from this document were retained in the acute database.

While a few *D. magna* data points were dropped, there were sufficient data from other studies to retain this species in the chronic cadmium database. The resultant revised chronic cadmium database is essentially the same as the 2001 Cadmium Update, in terms of the number and composition of genera and species, following the Phase 1 review.

Phase 2 - Literature Review

A comprehensive literature review of all cadmium documents not used in the 2001 Cadmium Update was conducted. This includes a review of all documents published since the 2001 Cadmium Update, as well as those published prior to 2001 that were not used in the criteria derivation. All relevant cadmium toxicity documents were obtained and reviewed for relevance of the toxicological data and adherence to U.S. EPA methodology (Stephan *et al*. 1985). Approximately 130 papers were reviewed, including unpublished toxicity data from recent studies conducted by Chadwick & Associates, Inc. (C&A) on behalf of Thompson Creek Mining Company (TCMC) (CEC 2003), as well as acute and chronic trout toxicity data from the Colorado Division of Wildlife (CDOW) published as "Federal Aid to Fisheries" (i.e., gray literature) reports.

<u>Acute Data</u>

Following review of these studies, we were able to add 14 acute data points from five studies to the revised acute cadmium database (Table 2). Of the six studies added to the database, four were published prior to the 2001 Cadmium Update. Two of these studies published prior to 2001 were not cited in either Table 1a (Acute toxicity of cadmium to freshwater animals) or Table 6a (Other data on effects of cadmium on freshwater organisms) of the 2001 Cadmium Update and apparently represent data unknown to U.S. EPA.

Suedel *et al*. (1997) tested the effects of exposure duration, test organism, and test endpoint on the toxicity of cadmium to a variety of freshwater species. Suitable acute 48- and 96-hour data points were reported in this study for *Ceriodaphnia dubia*, *D. magna*, *Pimephales promelas*, *Hyalella azteca*, and *Chironomus tentans* and were incorporated into the revised acute database. The other study not mentioned in the 2001 Cadmium Update is an internal report published by the CDOW in which brown trout (*Salmo trutta*) were exposed to various concentrations of cadmium sulfate in a static renewal toxicity test (Davies and Brinkman 1994). One acute value for *S. trutta* was utilized from this study.

TABLE 2: Acute cadmium toxicity data added to the acute database.

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	167.67	Suedel *et al*. 1997
Daphnia magna	S, M, T	$CdCl_2$	17	26.40	70.15	Suedel *et al*. 1997
Pimephales promelas	S, M, T	$CdCl_2$	17	4.80	12.75	Suedel *et al*. 1997
*Hyalella azteca**	S, M, T	$CdCl^2$	17	2.80	7.44	Suedel *et al*. 1997
*Chironomus tentans***	S, M, T	$CdCl_2$	17	2,956.00	7,854.85	Suedel *et al*. 1997
Salmo trutta	R, M, T	$CdSO_4$	37.6	2.37	3.07	Davies and Brinkman 1994
*Thymallus arcticus** (juvenile)	S, M, T	$CdCl_2$	41	4.00	4.79	Buhl and Hamilton 1991
Oncorhynchus mykiss	R, M, T	$CdCl_2$	420 (388-490)	7.40	1.08	Davies *et al*. 1993
Oncorhynchus mykiss	R, M, T	$CdCl_2$	427 (406-444)	5.92	0.85	Davies *et al*. 1993
Oncorhynchus mykiss	R, M, T	$CdCl_2$	217 (203-240)	4.20	1.11	Davies *et al*. 1993
Oncorhynchus mykiss	R, M, T	$CdCl_2$	227 (212-243)	6.57	1.67	Davies *et al*. 1993
Oncorhynchus mykiss	R, M, T	$CdCl_2$	46 (45-48)	2.64	2.85	Davies *et al*. 1993
Oncorhynchus mykiss	R, 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	8,296.43	Fargasova 2003

[a] S = static, R = renewal, M = measured, U = unmeasured, and T = total measured concentration.
[b] Value adjusted to hardness = 50 using the revised acute slope (0.9059) listed in Table 6.
* New genus.
** New species.

There are three studies listed in Table 6a ("Other Data") in the 2001 Cadmium Update that we believe provide useful data. One data point for the arctic grayling (*Thymallus arcticus*) from Buhl and Hamilton (1991) was added to the revised acute cadmium database. The data point is listed in Table 6a of the 2001

Cadmium Update because the U.S. EPA claims the toxicity test was conducted improperly due to low dissolved oxygen. Indeed, the authors stated there were dissolved oxygen problems in one of their selenite tests; yet, dissolved oxygen levels never fell below 40% saturation for their cadmium tests. We believe this cadmium datapoint is appropriate for use. Additional data listed in Table 6a of the 2001 Cadmium Update was for *Oncorhynchus mykiss* data from Davies *et al*. (1993), with no reason provided for the exclusion. Davies *et al*. (1993) tested acute and chronic toxicity of cadmium to *O. mykiss* at three different target hardness values (50, 200, and 400 mg/L). The acute values listed in Table 6a are inconsistent with values reported in the paper. Following our review of the publication, no reasons were found for not including data from this study. Therefore, these data were included in the revised acute cadmium database.

One study was found that was conducted since the publication of the 2001 Cadmium Update and contained data suitable for use in the revised acute cadmium database. Fargasova (2003) examined the acute toxicity of cadmium, copper, zinc, and their binary combinations to the midge, *Chironomus plumosus*. No previous cadmium toxicity data were available for this species. One data point from this study was added to the revised acute database.

Chronic Data

Twelve chronic data points from six studies were added by CEC to the revised chronic database (Table 3). Two of these studies was published prior to 2001, and were not cited in the 2001 Cadmium Update. Suedel *et al*. (1997) examined the long-term chronic effect of cadmium on several species, in addition to the acute effects previously mentioned. Long-term toxicity tests were conducted for the same five species *C. dubia*, *D. magna*, *P. promelas*, *H. azteca*, and *C. tentans*) as the acute toxicity tests; however, we only added the data for *C. dubia* to the revised chronic cadmium database because the test duration for the other species did not meet U.S. EPA chronic criteria development standards (Stephan *et al*. 1985). Additionally, Davies and Brinkman (1994) conducted a long-term toxicity test of cadmium on *S. trutta* in soft water that satisfies criteria development standards (Stephan *et al*. 1985). The reported chronic value from this study was added to the revised chronic database.

TABLE 3: Chronic cadmium toxicity data added to the chronic database.

Species	Method[a]	Chemical	Hardness (mg/L)	Chronic Value (µg/L)	Adjusted Chronic Value[b]	Reference
Ceriodaphnia dubia	LC	$CdCl_2$	17.0	2.00	4.59	Suedel *et al*. 1997
Salmo trutta	ELS	$CdSO_4$	39.8	1.33	1.58	Davies and Brinkman 1994
Daphnia magna	LC	$CdCl_2$	209.2	0.69	0.23	Canton and Slooff 1982
Oncorhynchus mykiss	LC	$CdCl_2$	46.2 (45-48)	1.47	1.56	Davies *et al*. 1993
Oncorhynchus mykiss	LC	$CdCl_2$	217.0 (203-240)	3.58	1.17	Davies *et al*. 1993
Oncorhynchus mykiss	LC	$CdCl_2$	413.8 (383-438)	3.64	0.73	Davies *et al*. 1993
Hyalella azteca	ELS	$CdCl_2$	280.0	1.40	0.38	Ingersoll and Kemble 2001
Daphnia magna	LC	$CdCl_2$	51.0	2.07	2.04	CEC 2003
Daphnia magna	LC	$CdCl_2$	99.0	2.23	1.32	CEC 2003
Daphnia pulex	LC	$CdCl_2$	52.0	2.17	2.17	CEC 2003
Hyalella azteca	ELS	$CdCl_2$	153.0	0.76	0.32	CEC 2003
Hyalella azteca	ELS	$CdCl_2$	126.0	0.50	0.25	CEC 2003

[a] ELS = early life stage and LC = life cycle or partial life cycle.
[b] Value adjusted to hardness = 50 using the revised chronic slope (0.7635) found in Table 8.

Two data sources (Canton and Slooff 1982 and Davies *et al*. 1993) were listed in Table 6a (Other Data) of the 2001 Cadmium Update as unused data for acute data points. However, both of these papers contain chronic data in addition to acute data. Chronic data from these papers are not mentioned in Table 2a (Chronic Toxicity of Cadmium to Freshwater Animals) or Table 6a. We determined three rainbow trout data points (Davies *et al*. 1993) and one *D. magna* data point (Canton and Slooff 1982) were suitable for use and added these data to the revised chronic database. Finally, chronic cadmium tests were conducted by C&A on behalf of TCMC using three freshwater species, including *D. pulex*, *D. magna*, and *H. azteca* (CEC 2003). Chronic values from these tests were added to the revised chronic database.

Phase 3 - Updated Cadmium Criteria Analysis

After excluding inappropriate data used in the 2001 Cadmium Update and adding data deemed suitable for inclusion from our literature review, revised acute (Table 4) and chronic (Table 5) databases were compiled. These databases are the basis for the subsequent cadmium AWQC recalculations reported in this document. For each species with at least one acute value, the species mean acute value (SMAV) was calculated as the geometric mean of the individual acute values (Stephan *et al*. 1985). Results from all flow-through tests and those in which the concentrations of the test material were measured took precedence over tests using static or renewal methods and unmeasured concentrations (Stephan *et al*. 1985). For each genus with more than one SMAV, the genus mean acute value (GMAV) was calculated as the geometric mean of all available SMAVs for the genus. Otherwise, the GMAV was equal to the SMAV if data for only one species was available (Stephan *et al*. 1985).

Acute Data

The revised acute cadmium AWQC database consists of 68 species (increased from 65) occupying 56 genera (increased from 55) of freshwater organisms (Table 4). Only one species and its corresponding genus (*X. laevis*) in the 2001 Cadmium Update database is not present in the revised acute database. Four species (*T. arcticus*, *H. azteca*, *C. tentans*, and *C. plumosus*) were added to the acute database, resulting in two additional genera (*Thymallus* and *Hyalella*). The revised acute database meets the "eight-family rule." Genus mean acute values range from the most sensitive at 1.91 µg/L for the genus *Salvelinus* to the least sensitive at 19,256 µg/L for the genus *Chironomus*. The top four most sensitive genera are all fish, and include *Salvelinus* (1.91 µg/L), *Salmo* (2.21 µg/L), *Morone* (3.18 µg/L), and *Oncorhynchus* (3.46 µg/L).

Chronic Data

Both the revised chronic cadmium AWQC database and the 2001 Cadmium Update database consist of 21 species occupying 16 genera and 12 families. No species or genera were entirely deleted from the 2001 cadmium document and none were added. Both the existing and revised chronic cadmium databases exactly meet the "eight-family rule." Genus mean chronic values (GMCV) range from the most sensitive at 0.28 µg/L for the genus *Hyalella* to the least sensitive at >23.07 µg/L for the genus *Oreochromis*. The top four most sensitive genera in terms of chronic toxicity to cadmium are *Hyalella* (0.28 µg/L), *Daphnia* (1.99 µg/L), *Oncorhynchus* (2.35 µg/L), and *Chironomus* (2.70 µg/L).

TABLE 4: Revised acute cadmium criteria database.

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family	Code
56	*Chironomus riparius*	19,256.25	109,568.59	Midge	Chironomidae	1, 2
	Chironomus tentans		7,854.85	Midge	Chironomidae	1, 2
	Chironomus plumosus		8,296.43	Midge	Chironomidae	1, 2
55	*Dendrocoelum lacteum*	14,956.11	14,956.11	Planaria	Planariidae	1, 2
54	*Orconectes virilis*	>11,193.54	11,030.68	Crayfish	Cambaridae	1, 2
	Orconectes immunis		>11,358.81	Crayfish	Cambaridae	1, 2
53	*Oreochromis mossambica*	10,015.83	10,015.83	Tilapia	Cichlidae	2
52	*Gasterosteus aculeatus*	5,940.39	5,940.39	Threespine stickleback	Gasterosteidae	2
51	*Gambusia affinis*	5,501.38	5,501.38	Mosquitofish	Poeciliidae	2
50	*Ictalurus punctatus*	4,988.97	4,988.97	Channel catfish	Ictaluridae	2
49	*Lepomis cyanellus*	4,869.13	3,659.42	Green sunfish	Centrarchidae	2
	Lepomis macrochirus		6,478.72	Bluegill	Centrarchidae	2
48	*Rhyacodrilus montana*	4,811.89	4,811.89	Tubificid worm	Tubificidae	1, 2
47	*Cyprinus carpio*	4,576.46	4,576.46	Common carp	Cyprinidae	2
46	*Stylodrilus heringianus*	4,200.86	4,200.86	Tubificid worm	Tubificidae	1, 2
45	*Notropis lutrensis*	4,071.80	4,071.80	Red shiner	Cyprinidae	2
44	*Spirosperma ferox*	3,031.21	2,673.27	Tubificid worm	Tubificidae	1, 2
	Spirosperma nikolskyi		3,437.07	Tubificid worm	Tubificidae	1, 2
43	*Varichaeta pacifica*	2,902.41	2,902.41	Tubificid worm	Tubificidae	1, 2
42	*Jordanella floridae*	2,806.94	2,806.94	Flagfish	Cyprinodontidae	1, 2
41	*Catostomus commersoni*	2,800.71	2,800.71	White sucker	Catostomidae	1, 2
40	*Poecilia reticulata*	2,579.10	2,579.10	Guppy	Poeciliidae	2
39	*Quistradilus multisetosus*	2,444.14	2,444.14	Tubificid worm	Tubificidae	1, 2
38	*Ephemerella grandis*	2,245.55	2,245.55	Mayfly	Ephemerellidae	1, 2
37	*Branchiura sowerbyi*	1,833.10	1,833.10	Tubificid worm	Tubificidae	1, 2
36	*Crangonyx pseudogracilis*	1,700.00	1,700.00	Amphipod	Crangonyctidae	1, 2
35	*Procambarus clarkii*	1,651.99	1,651.99	Crayfish	Cambaridae	1, 2

TABLE 4: Continued.

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family	Code
34	*Tubifex tubifex*	1,342.84	1,342.84	Tubificid worm	Tubificidae	1, 2
33	*Limnodrilus hoffmeisteri*	876.55	876.55	Tubificid worm	Tubificidae	1, 2
32	*Carassius auratus*	832.98	832.98	Goldfish	Cyprinidae	2
31	*Asellus bicrenata*	556.25	556.25	Isopod	Asellidae	1, 2
30	*Ambystoma gracile*	515.31	515.31	Salamander	Ambystomatidae	1, 2
29	*Plumatella emarginata*	303.60	303.60	Bryozoan	Plumatellidae	1, 2
28	*Alona affinis*	269.52	269.52	Cladoceran	Chydoridae	1, 2
27	*Cyclops varicans*	243.35	243.35	Copepod	Cyclopidae	1, 2
26	*Glossiphonia complanata*	212.68	212.68	Leech	Glossiphoniidae	1, 2
25	*Pectinatella magnifica*	194.97	194.97	Bryozoan	Pectinatellidae	1, 2
24	*Lumbriculus variegatus*	158.67	158.67	Worm	Lumbriculidae	1, 2
23	*Physa gyrina*	116.78	116.78	Snail	Physidae	1, 2
22	*Aplexa hypnorum*	102.63	102.63	Snail	Physidae	1, 2
21	*Gammarus pseudolimnaeus*	77.48	77.48	Amphipod	Gammaridae	1, 2
20	*Lirceus alabamae*	54.78	54.78	Isopod	Asellidae	1, 2
19	*Ceriodaphnia dubia*	48.45	49.97	Cladoceran	Daphnidae	1, 2
	Ceriodaphnia reticulata		47.02	Cladoceran	Daphnidae	1, 2
18	*Moina macrocopa*	45.52	45.52	Cladoceran	Moinidae	1, 2
17	*Gila elegans*	45.12	45.12	Bonytail	Cyprinidae	2
16	*Utterbackia imbecilis*	45.08	45.08	Mussel	Unionidae	1, 2
15	*Xyrauchen texanus*	42.67	42.67	Razorback sucker	Catostomidae	2
14	*Lophopodella carteri*	41.78	41.78	Bryozoan	Lophopodidae	1, 2
13	*Vilosa vibex*	37.37	37.37	Mussel	Unionidae	1, 2
12	*Actinonaia pectorosa*	35.75	35.75	Mussel	Unionidae	1, 2
11	*Lampsilis straminea claibornensis*	32.94	46.51	Mussel	Unionidae	1, 2
	Lampsilis teres		23.32	Mussel	Unionidae	1, 2
10	*Pimephales promelas*	28.52	28.52	Fathead minnow	Cyprinidae	2

TABLE 4: Continued.

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family	Code
9	*Daphnia magna*	27.62	15.49	Cladoceran	Daphnidae	1, 2
	Daphnia pulex		49.26	Cladoceran	Daphnidae	1, 2
8	*Simocephalus serrulatus*	27.58	27.58	Cladoceran	Daphnidae	1, 2
7	*Ptychocheilus lucius**	26.26	26.26	Colorado pikeminnow	Cyprinidae	2
	Ptychocheilus oregonensis		2,057.31	Northern pikeminnow	Cyprinidae	2
6	*Hyallela azteca*	7.44	7.44	Amphipod	Hyalellidae	1, 2
5	*Thymallus arcticus*	4.79	4.79	Arctic grayling	Salmonidae	1
4	*Oncorhynchus kisutch*	3.46	5.68	Coho salmon	Salmonidae	1
	Oncorhynchus tshawytscha		3.95	Chinook salmon	Salmonidae	1
	Oncorhynchus mykiss		1.85	Rainbow trout	Salmonidae	1
3	*Morone saxatilis*	3.18	3.18	Striped bass	Percichthyidae	2
2	*Salmo trutta*	2.21	2.21	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 .

TABLE 5: Updated chronic cadmium criteria database.

Rank	Species	GMCV (µg/L)	SMCV (µg/L)	Common Name	Family	Code
16	*Oreochromis aurea*	>23.07	>23.07	Blue tilapia	Cichlidae	2
15	*Aeolosoma headleyi*	20.62	20.62	Oligochaete	Aeolosomatidae	1, 2
14	*Lepomis macrochirus*	16.83	16.83	Bluegill	Centrarchidae	2
13	*Pimephales promelas*	15.87	15.87	Fathead minnow	Cyprinidae	2
12	*Ceriodaphnia dubia*	11.24	11.24	Cladoceran	Daphnidae	1, 2
11	*Micropterus dolomieui*	8.15	8.15	Smallmouth bass	Centrarchidae	2
10	*Esox lucius*	8.12	8.12	Northern pike	Esocidae	1, 2
9	*Catostomus commersoni*	7.83	7.83	White sucker	Catostomidae	1, 2
8	*Jordanella floridae*	5.33	5.33	Flagfish	Cyprinidontidae	2
7	*Aplexa hypnorum*	4.83	4.83	Snail	Physidae	1, 2
6	*Salmo salar*	4.72	8.06	Atlantic salmon	Salmonidae	1
	Salmo trutta		2.76	brown trout	Salmonidae	1
5	*Salvelinus fontinalis*	4.64	2.65	Brook trout	Salmonidae	1
	Salvelinus namaycush		8.11	Lake trout	Salmonidae	1
4	*Chironomus tentans*	2.70	2.70	Midge	Chironomidae	1, 2
3	*Oncorhynchus kisutch*	2.34	4.28	Coho salmon	Salmonidae	1
	Oncorhynchus mykiss		1.14	Rainbow trout	Salmonidae	1
	Oncorhynchus tshawytscha		2.65	Chinook salmon	Salmonidae	1
2	*Daphnia magna*	1.99	1.11	Cladoceran	Daphnidae	1, 2
	Daphnia pulex		3.59	Cladoceran	Daphnidae	1, 2
1	*Hyalella azteca*	0.28	0.28	Amphipod	Hyalellidae	1, 2

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

CADMIUM CRITERIA RECALCULATION

Once the revised databases were compiled, the genera were ranked by their corresponding GMAVs/GMCVs (Stephan *et al*. 1985). The four most sensitive genera were then selected and a series of calculations were conducted using the GMAVs/GMCVs for these genera to determine the final acute value (FAV) and final chronic value (FCV). Factors that significantly influence these final values include the number of genera in the database, and the magnitude and spread of the GMAVs/GMCVs for the four most sensitive genera.

Acute Cadmium Hardness Relationship

When enough data are available to show that the toxicity of a substance is related to a water quality characteristic for two or more species, the relationship is accounted for using analyses of covariance (Stephan *et al*. 1985). This appears to be the case for the relationship between cadmium toxicity and water hardness. The 2001 Cadmium Update normalized data and used analysis of covariance (Stephen *et al*. 1985) to obtain the acute hardness slope. Definitive acute values were available for 12 species over a range of hardness values such that the highest hardness was at least three times the lowest, and the highest was also at least 100 mg/L higher than the lowest. Only acute tests initiated with individuals less than 24-hour old neonates were used to estimate the hardness slope for *D. magna*. The individual species slopes ranged from 0.1086 (*D. magna*) to 2.03 (*P. promelas*), and the pooled slope was 1.17. However, the U.S. EPA decided that there was too much variability associated with the slopes for *D. magna* and *P. promelas.* Therefore, only the Chapman *et al*. manuscript data were used to compute the slope for *D. magna* (1.18) and only adult data were used to compute the slope for *P. promelas* (1.22). When the adjusted data set was used, the resultant pooled slope was 1.0166. This value was used by U.S. EPA to adjust all acute values to a common hardness (50 mg/L) and is also included in the final acute equation.

Reviewing data used to calculate the acute hardness slope in the 2001 Cadmium Update and adding data from the revised CEC acute database allowed development of a revised CEC acute hardness relationship (Table 6). One major conflict with data selection for the 2001 Cadmium Update acute hardness relationship is U.S. EPA's decision to limit fathead minnow data to adults, when only the toxicity data of the more sensitive age classes (juvenile and fry) were used in the SMAV calculations. U.S. EPA justified this decision because excluding juvenile and fry hardness related data decreased undesirable variability within the species and pooled slope. Yet in this situation, when data for multiple age classes are available, we believe data used to calculate the hardness relationship should be more consistent with data used to calculate the SMAV. This approach should be honored (even if data are more variable) as long as resulting slope is within the range of other species slopes. Therefore, instead of only adult data (slope = 1.220, R^2 = 0.70), juvenile data for fathead minnow (slope = 0.9210, R^2 = 0.29) were used in the revised pooled acute hardness slope. Additionally, Davies *et al*. (1993) provided 6 data points for *O. mykiss* that increased the range of water hardness tested for this species. These new data made it possible to add this previously unused species to the revised acute hardness slope calculations. Data points for *O. mykiss* from four other studies were then also added to the hardness relationship database. Analysis of covariance determined the individual species slopes of the revised database are not significantly different (p = 0.88). Overall, with a revised slope for *P. promelas* (1.5223) and the addition of *O. mykiss* (0.7679), the resultant pooled slope is 0.9059 (replacing the existing acute hardness pooled slope of 1.0166). This revised slope was used to adjust all values in the revised acute database to a common hardness (50 mg/L) and is placed in the revised final acute equation.

TABLE 6: Updated acute cadmium hardness slope. SMAS = species mean acute slope.

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		
Oncorhynchus tshawytscha	23.0		0.44	3.50		0.71	Chapman 1975, 1978	-0.819	-0.344		

TABLE 6: 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	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		
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		

TABLE 6: 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
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		
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
							Revised pooled acute slope =			**0.9059**	**0.69**

Acute Calculations

The recalculated FAV was then determined using the GMAVs for the four most sensitive genera in the revised acute database. Calculations followed the U.S. EPA methods for criteria derivation (Stephan *et al.* 1985), and are presented in Table 7. The revised FAV at a hardness of 50 mg/L is 2.886 µg/L, which results in a final acute equation of $e^{0.9059[\ln(hardness)]-3.1772}$ and criteria maximum concentration (CMC) of 1.443 µg/L for cadmium. The revised FAV is slightly higher than the FAV reported in the 2001 Cadmium Update (2.763 µg/L), and is higher than the SMAVs for many, but not all, commercially important trout. To further protect trout, the 2001 Cadmium Update replaced the calculated FAV with the SMAV of rainbow trout (2.014 µg/L) in the criterion calculation. This value was higher than the SMAV for the brook trout,

TABLE 7: Recalculation of the final acute values for cadmium using the updated acute database. N = 56 genera, R = sensitivity rank in database, P = rank / N+1.

Rank	Genus	GMAV	ln GMAV	(ln GMAV)^2	P = R/(N+1)	√P
4	*Oncorhynchus*	3.460	1.2412	1.5406	0.0702	0.2649
3	*Morone*	3.181	1.1572	1.3390	0.0526	0.2294
2	*Salmo*	2.207	0.7919	0.6270	0.0351	0.1873
1	*Salvelinus*	1.910	0.6472	0.4189	0.0175	0.1325
		sum	3.8375	3.9256	0.1754	0.8141

Calculations:
Acute Criterion

$$S^2 = \frac{\Sigma(\ln GMAV)^2 - (\Sigma \ln GMAV)^2/4}{\Sigma P - (\Sigma\sqrt{P})^2/4} = \frac{3.9256 - (3.8375)^2/4}{0.1754 - (0.8141)^2/4} = 25.0273$$

S = 5.0027

$L = [\Sigma \ln GMAV - S(\Sigma\sqrt{P})]/4 = [3.8375 - 5.0027\,(0.8141)]/4 = -0.0588$
$A = S\,(\sqrt{0.05}) + L = (5.0027)(0.2236) - 0.0588 = 1.0598$

Final Acute Value = FAV = e^A = 2.8859
CMC = ½ FAV = 1.4430
Pooled Slope = 0.9059

ln (Criterion Maximum Intercept)
= lnCMC - [pooled slope × ln (standardized hardness level)]
= ln (1.4430) - [0.9059 × ln (50)]
= -3.1772

Recalculated Acute Cadmium Criterion = $e^{0.9059\,[\ln(hardness)]\,-3.1772}$
@ Hardness 100 = 2.704 µg/L

Lowered to protect trout
FAV = 1.9102
CMC = 0.9551

= ln(0.9551)-[0.9059×ln(50)]
= -3.5898

Criterion to protect trout = $e^{0.9059[\ln(hardness)]-3.5898}$
@ Hardness 100 = 1.790 µg/L

yet lower than all other SMAVs in the 2001 Cadmium Update database. Following this approach, we lowered the revised FAV to the lowest GMAV (*Salvelinus*) of 1.910 µg/L to again further protect trout (Table 4). At a hardness of 100 mg/L, the revised CMC is 2.704 µg/L using the entire database or 1.790 µg/L using the lowered "trout" FAV

Chronic Hardness Relationship

The 2001 Cadmium Update also used the same procedures as the acute slope to obtain a slope that defines the chronic hardness relationship. The chronic hardness relationship was derived from three species, *D. magna*, *S. trutta*, and *P. promelas*. The individual species slopes ranged form 0.5212 (*S. trutta*) to 1.579 (*D. magna*), and the pooled slope was 0.9685. However, as with the acute slope, the *D. magna* data was determined too variable and, therefore, only data from the Chapman *et al*. manuscript was used. The resultant pooled slope with the reduced data set was 0.7409.

The revised CEC chronic hardness relationship was derived by reviewing data used to calculate the chronic hardness slope calculation in the 2001 Cadmium Update and adding data from the CEC revised chronic database (Table 8). The revised pooled chronic slope was derived from 9 individual data points that encompasses three species. Individual species slopes ranged from 0.4779 (*O. mykiss*) to 1.0034 (*P. promelas*). Since Chapman *et al*. manuscript data for *D. magna* were deleted from the revised chronic database, we also deleted these data from the chronic hardness slope database. This removes all *D. magna* data used in the final slope presented by the EPA and, therefore, removes *D. magna* from the chronic hardness slope calculation. However, the Davies *et al*. (1993) chronic toxicity tests for *O. mykiss* increased the range of hardness values tested. Target values ranged from 50 mg/L to 400 mg/L, enabling us to add this previously unused species to the chronic hardness slope database. Finally, the Davies and Brinkman (1994) data point for *S. trutta* was added to the database. Analysis of covariance determined the individual species slopes of the revised chronic slope database are not different ($p = 0.66$). Therefore, all data were grouped and the pooled slope of this revised database is 0.7635. This slope was used to standardize all chronic toxicity values to a common hardness and is in the final equation to compute the chronic AWQC at a given hardness.

TABLE 8: Updated chronic cadmium hardness slope. SMCS = species mean chronic slope.

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
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 =		**0.7635**	**0.68**

Chronic Calculations

The recalculated FCV was then determined using the GMCVs for the four most sensitive genera in the revised chronic database. Calculations followed the U.S. EPA methods for criteria derivation (Stephan *et al*. 1985) and are presented in Table 9. The recalculated FCV is 0.295 µg/L, whereas the FCV from the 2001 Cadmium Update was 0.162 µg/L. This results in a final chronic equation of $e^{0.7635\,[\ln(\text{hardness})]\,-4.2062}$ for cadmium. At a hardness of 100 mg/L, the revised chronic cadmium criteria based upon this equation is 0.502 µg/L. These calculations indicate that the revised chronic criteria (0.502 µg/L at a hardness of 100 mg/L) is roughly twice the criteria based on the 2001 cadmium document (0.271 µg/L at a hardness of 100 mg/L).

TABLE 9: Recalculation of the final chronic values for cadmium using the updated chronic database (N = 16 genera, R = sensitivity rank in database, P = rank / N+1).

Rank	Genus	GMCV	ln GMCV	(ln GMCV)^2	P = R/(N+1)	√P
4	*Chironomus*	2.697	0.9922	0.9845	0.2353	0.4851
3	*Oncorhynchus*	2.345	0.8523	0.7263	0.1765	0.4201
2	*Daphnia*	1.994	0.6903	0.4765	0.1176	0.343
1	*Hyalella*	0.276	-1.2861	1.6540	0.0588	0.2425
		sum	1.2487	3.8414	0.5882	1.4907

Calculations:
Chronic Criterion

$$S^2 = \frac{\Sigma(\ln GMCV)^2 - (\Sigma \ln GMCV)^2/4}{\Sigma P - (\Sigma\sqrt{P})^2/4} = \frac{3.8414 - (1.2487)^2/4}{0.5882 - (1.4907)^2/4} = 105.5595 \qquad S = 10.2742$$

$L = [\Sigma \ln GMCV - S(\Sigma\sqrt{P})]/4 = [1.2487 - 10.2742\,(1.4907)]/4 = -3.5167$
$A = S(\sqrt{0.05}) + L = (10.2742)(0.2236) + -3.5167 = -1.2194$
Final Chronic Value = FCV = e^A = 0.295
Pooled Slope = 0.7635

ln (Final Chronic Intercept) = ln FCV - [chronic slope × ln(standardized hardness level)]
= ln (0.295) - [0.7635 × ln (50)]
= -4.2062

Recalculated Chronic Cadmium Criterion = $e^{0.7635\,[\ln(\text{hardness})]\,-4.2062}$ @ Hardness 100 = 0.502 µg/L

Acute-Chronic Ratio

While the chronic toxicity database technically meets the "eight-family rule," it is still limited. Such a limited database can inadvertently affect chronic criteria calculations because of the "sample size" effect. The FCV can also be calculated by dividing the FAV by the acute-chronic ratio or ACR (Stephan *et al*. 1985). The acute-chronic ratio is an alternative means of deriving chronic criteria by relating acute toxicity values to chronic toxicity values. The ACR is calculated by dividing the acute value by the chronic value for a particular study in which these tests were conducted with the same dilution water and at the same hardness. For each species, a geometric mean of these ratios are calculated to obtain a species mean acute-chronic ratio (SMACR). Subsequently, the final acute-chronic ratio (FACR) is either calculated as the geometric mean of the SMACRs (if ratios are within a factor of 10) or the geometric mean of the SMACRs whose SMAVs are close to the final acute value (if SMAVs and SMACRs increase or decrease together). An ACR is usually calculated when the chronic database is lacking sufficient data for chronic AWQC derivation (e.g., when the chronic database does not meet the "eight-family rule").

A revised ACR database was compiled by deleting the previously mentioned unsuitable data used in the 2001 Cadmium Update and adding appropriate data from the revised acute and chronic databases. The revised ACR database includes 15 data points (increased from 10) representing eight species (increased from six). Comparing the SMACRs to the SMAVs of this database revealed a general positive relationship between the two values (Table 10) that was not observed with the 2001 Cadmium Update database. There are some outliers in this positive relationship; however, the trend is strong enough that the concept of calculating a FACR should not be completely disregarded. This is especially true since the chronic AWQC derivation is based on a limited database that barely meets the "eight-family" rule. The revised FACR was calculated from the three lowest SMACR values. This results in a revised FACR of 2.7632, which, in turn, results in an alternate FCV of 1.044, a final chronic equation of $e^{0.7635 [\ln(\text{hardness})] -2.9434}$, and a chronic AWQC of 1.773 µg/L at a hardness of 100 mg/L using the entire database. When only the lowest GMAV is used in place of the calculated FCV to protect trout, the final chronic equation is $e^{0.7635[(\ln(\text{hardness})]-3.3560}$, and the chronic AWQC is 1.174 µg/L at a hardness of 100 mg/L.

TABLE 10: Cadmium acute-chronic ratio. Only **bold** values were used in the final calculation.

Species	Reference	Hardness	Acute Value	Chronic Value	Ratio	SMAV	SMACR
Jordanella floridae	Spehar 1976	44.0	2,500.00	5.76	433.80	2,814.67	433.8018
Lepomis macrochirus	Eaton 1974	207.0	21,100.00	49.80	423.70	6,388.68	423.6948
Aplexa hypnorum	Holcombe *et al*. 1984	45.3	93.00	5.80	16.03	102.87	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	49.77	31.5500
Pimephales promelas	Pickering and Gast 1972	201.0	5,995.00	45.92	130.55	28.35	**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	15.49	44.7751
Oncorhynchus tshawytscha	Chapman 1975, 1982	25.0	1.41	1.56	0.90	4.02	**0.9021**
*Oncorhynchus mykiss**	Davies *et al*. 1993	400.0	7.40	3.64	2.03	1.86	**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.

USE-SPECIFIC CADMIUM CRITERIA

AWQC are based on protection of all species, as is appropriate for nationally based criteria. Such broad criteria may contain species not resident in particular water bodies. This discrepancy is generally addressed through the use of site-specific criteria. However, it is possible to address this concern through "use-specific" criteria.

As such, cadmium AWQC were also derived specific to warm and cold freshwater use classifications. These calculations were designed to include all species in the cadmium acute and chronic databases that could potentially occur in each of these use classifications. However, the minimum data requirements for the development of national AWQC are not met by these revised data sets, specifically the "eight-family rule" is not met for either database. For example, warmwater use-specific standards do not include the family Salmonidae, a requirement of the "eight-family rule," because salmonids do not occur in warmwater.

Including zooplankton in use-specific calculations is questionable, since we believe that zooplankton should be considered as a transient species in flowing water systems unless demonstrated otherwise. However, zooplankton were retained in both of these use-specific calculations. If we were to omit all zooplankton from the analyses, use-specific criteria values for cadmium would likely be higher for the warmwater acute criteria and both warmwater and coldwater chronic criteria. Coldwater acute criteria would not change significantly because zooplankton are not included in the four most sensitive species in the acute coldwater database.

Warmwater Acute

The GMAVs included in the warmwater acute recalculations are noted in Appendix Table A-1. The revised warmwater acute database consists of 61 species occupying 52 genera. Many more than eight families are represented in this revised database. Salmonidae is not present since the family does not occur in warmwater; yet, other bony fish remain within the database (e.g., *Morone saxatilis*, *Ptychocheilus* sp., and more) that can be used in place of Salmonidae. The four most sensitive genera in the warmwater database consist of *Morone* (3.18 µg/L), *Hyalella* (7.44 µg/L), *Ptychocheilus* (26.26 µg/L), and *Simacephalus* (27.58 µg/L). The recalculated warmwater FAV is 14.288 µ/L (Table 11), whereas the FAV from the 2001 Cadmium Update was 2.108 µg/L. The recalculations for all warmwater species results in a final acute equation of $e^{0.9059\ [\ln(\text{hardness})]\ -1.5776}$ for cadmium. At a hardness of 100 mg/L, the revised warmwater acute cadmium criteria based upon this equation is 13.386 µg/L. However, the striped bass (*M. saxatilis*) is potentially a recreationally important species whose GMAV (3.181) is lower than the recalculated warmwater FAV (as is the case with trout when the entire database is used). Lowering the FAV to 3.181 results in a final acute equation of $e^{0.9059[\ln(\text{hardness})]-3.0799}$, and a CMC of 2.980 µg/L at a hardness of 100 mg/L.

TABLE 11: Recalculation of the final acute values for cadmium using the revised warmwater acute database (N = 52 genera, R = sensitivity rank in database, P = rank / N+1).

Rank	Genus	GMAV	ln GMAV	(ln GMAV)^2	P = R/(N+1)	√P
4	*Simocephalus*	27.580	3.3171	11.0031	0.0755	0.2747
3	*Ptychocheilus*	26.262	3.2681	10.6806	0.0566	0.2379
2	*Hyallela*	7.440	2.0069	4.0277	0.0377	0.1943
1	*Morone*	3.181	1.1572	1.3390	0.0189	0.1374
		sum	9.7493	27.0504	0.1887	0.8443

Calculations:

Acute Criterion

$S^2 = \frac{\Sigma(\ln GMAV)^2 - (\Sigma \ln GMAV)^2/4}{\Sigma P - (\Sigma\sqrt{P})^2/4} = \frac{27.0504 - (9.7493)^2/4}{0.1887 - (0.8443)^2/4} = 313.5296$ S = 17.7068

L = [ΣlnGMAV - S(Σ√P)]/4 = [9.7493 - 17.7068 (0.8443)]/4 = 1.2999
A = S (√0.05) + L = (17.7068)(0.2236) - 1.2999 = 2.6594

Final Acute Value = FAV = e^A = 14.2880
CMC = ½ FAV = 7.1440
Pooled Slope = 0.9059

ln (Criterion Maximum Intercept)
= lnCMC - [pooled slope × ln (standardized hardness level)]
= ln (7.1440) - [0.9059 × ln (50)]
= -1.5776

Warmwater Acute Cadmium Criterion =
$e^{0.9059 [\ln (hardness)] -1.5776}$
@ Hardness 100 = 13.386 µg/L

Lowered to protect striped bass
FAV = 3.1809
CMC = 1.5905

= ln(1.5905)-[0.9059×ln(50)]
= -3.0799

Criterion to protect striped bass =
$e^{0.9059[\ln(hardness)]-3.0799}$
@ Hardness 100 = 2.980 µg/L

Chronic Criterion

Chronic Slope = 0.7635 (recalculated)
Final Acute-to-Chronic ratio (FACR) = 2.7632 (recalculated)

Final Chronic Value (FCV) = FAV ÷ ACR = 14.288 ÷ 2.7632 = 5.171 = 3.181 ÷ 2.7632 = 1.151

ln (Final Chronic Intercept) = ln FCV - [chronic slope × ln(standardized hardness level)]
= ln (5.171) - [0.7635 × ln (50)]
= -1.3438

Coldwater Chronic Cadmium Criterion =
$e^{0.7635 [\ln (hardness)] -1.3975}$
@ Hardness 100 = 8.778 µg/L

= ln(1.151)-[0.7635×ln(50)]
= -2.8461

Criterion to protect striped bass =
$e^{0.7635[\ln(hardness)]-2.8461}$
@ Hardness 100 = 1.954 µg/L

Warmwater Chronic

The GMCVs included in the chronic warmwater recalculations are noted in Appendix Table A-2. The revised warmwater chronic database consists of 14 species occupying 13 genera. This data base is a subset of the overall chronic database that only barely meets the "eight-family rule" for direct calculation of a FCV. Consequently, it would not be appropriate to directly calculate a warmwater FCV from the warmwater chronic database. However, a warmwater FCV can also be computed using the FACR (2.7632) (Table 11). Dividing the warmwater FAV of 14.288 µg/L using the entire database and 3.181 µg/L using the lowest GMAV by the FACR yields FCVs of 5.171 µg/L and 1.151 µg/L, respectively, for warmwater systems. These FCVs result in final chronic equations of $e^{0.7635\,[(\ln(\text{hardness})]\,-1.3438}$, and $e^{0.7635[\ln(\text{hardness})]-2.8461}$, respectively. At a hardness of 100 mg/L, the resultant AWQCS for cadmium from these equations are 8.778 µg/L and 1.954 µg/L, respectively.

Coldwater Acute

The GMAVs included in the acute coldwater recalculations are noted in Appendix Table A-3. The revised coldwater acute database consists of 52 species occupying 42 genera. Many more than the required eight families are represented in this revised coldwater acute database. The four most sensitive genera in the database consist of *Salvelinus* (1.91 µg/L), *Salmo* (2.21 µg/L), *Oncorhynchus* (3.46 µg/L), and *Thymallus* (4.79 µg/L). The recalculated coldwater FAV is 2.699 µg/L (Table 12), whereas the FAV from the 2001 Cadmium Update was 2.763 µg/L. This revised calculation results in a coldwater final acute equation of $e^{0.9059\,[(\ln(\text{hardness})]\,-3.2442}$ for cadmium. At a hardness of 100 mg/L, the updated acute cadmium criteria based upon this equation is 2.529 µg/L. As previously mentioned, the FAV could be lowered to the more protective value of 1.910 for trout. The coldwater final acute equation ($e^{0.9059\,[(\ln(\text{hardness})]\,-3.5898}$) and associated criteria at hardness = 100 (1.790 µg/L) would be identical to those calculated in Table 7 for the entire acute database to protect trout.

TABLE 12: Recalculation of the final acute values for cadmium using the revised coldwater acute database (N = 42 genera, R = sensitivity rank in database, P = rank / N+1).

Rank	Genus	GMAV	ln GMAV	(ln GMAV)^2	P = R/(N+1)	√P
4	*Thymallus*	4.788	1.5661	2.4526	0.0930	0.3050
3	*Oncorhynchus*	3.460	1.2412	1.5406	0.0698	0.2641
2	*Salmo*	2.207	0.7919	0.6270	0.0465	0.2157
1	*Salvelinus*	1.910	0.6472	0.4189	0.0233	0.1525
		sum	4.2464	5.0392	0.2326	0.9373

Calculations:
Acute Criterion

$$S^2 = \frac{\Sigma (\ln GMAV)^2 - (\Sigma \ln GMAV)^2/4}{\Sigma P - (\Sigma \sqrt{P})^2/4} = \frac{5.0392 - (4.2464)^2/4}{0.2326 - (0.9373)^2/4} = 41.0945$$

S = 6.4105

L = [ΣlnGMAV - S(Σ√P)]/4 = [4.2464 - 6.4105 (0.9373)]/4 = -0.4405
A = S (√0.05) + L = (6.4105)(0.2236) + -0.4405 = 0.9929

Final Acute Value = FAV = e^A = 2.6990
CMC = ½ FAV = 1.3495
Pooled Slope = 0.9059

Lowered to protect trout
FAV = 1.9102
CMC = 0.9551

ln (Criterion Maximum Intercept) = lnCMC - [pooled slope × ln (standardized hardness level)]
= ln (1.3495) - [0.9059 × ln (50)]
= -3.2442

= ln(0.955)-[0.9059×ln(50)]
= - 3.5898

Coldwater Acute Cadmium Criterion = $e^{0.9059 [\ln (hardness)] -3.2442}$
@ Hardness 100 = 2.529 µg/L

Criterion to protect trout = $e^{0.9059 [\ln (hardness)] -3.5898}$
@ Hardness 100 = 1.790 µg/L

Chronic Criterion
Chronic Slope = 0.7635 (recalculated)
Final Acute-to-Chronic ratio (FACR) = 2.7632 (recalculated)

Final Chronic Value (FCV) = FAV ÷ ACR = 2.6990 ÷ 2.7632 = 0.977 = 1.910 ÷ 2.7632 = 0.691

ln (Final Chronic Intercept) = ln FCV - [chronic slope × ln(standardized hardness level)]
= ln (0.977) - [0.7635 × ln (50)]
= -3.0103

= ln(0.691)-[0.7635×ln(50)]
= -3.3560

Coldwater Chronic Cadmium Criterion = $e^{0.7635 [\ln (hardness)] -3.0103}$
@ Hardness 100 = 1.658 µg/L

Criterion to protect trout = $e^{0.7635[\ln(hardness)]-3.3560}$
@ Hardness 100 = 1.174 µg/L

Coldwater Chronic

The GMCVs included in the chronic coldwater recalculations are noted in Appendix Table A-4. The revised coldwater chronic database consists of 16 species occupying 11 genera. Eight families are represented in this database, which only barely meets the minimum "eight-family rule" for AWQC derivation. Once again, it would not be appropriate to directly calculate the coldwater FCV. Therefore, the ACR method was used to determine the FCV for coldwater systems. The coldwater FCV was computed using the FACR (2.7632). Dividing the coldwater FAV (2.6990 µg/L) by the FACR yields an FCV of 0.977 µg/L for coldwater systems resulting in a final chronic equation of $e^{0.7635\ [(\ln(\text{hardness})]\ -3.0103}$. The resultant AWQC for cadmium from this equation is 1.658 µg/L at a hardness of 100 mg/L. Lowering the FAV to 1.910 to protect trout results in a final chronic equation of $e^{0.7635[\ln(\text{hardness})]-3.3560}$ and an AWQC of 1.174 µg/L at hardness = 100 µg/L.

SUMMARY

Chadwick Ecological Consultants, Inc. has completed its update of the cadmium AWQC. Methods for the update followed U.S. EPA guidelines (Stephan *et al*. 1985). First, a review of the 2001 Cadmium Update produced several data points from four studies that we believe were inappropriate for use in cadmium criteria derivations. These data points were excluded from the revised cadmium databases. Second, a thorough review of all the available literature on the toxicity of cadmium to freshwater organisms was carried out. This search produced 14 new acute data points from five sources and 12 new chronic data points from six sources. Four new species and two new genera were added to the revised acute database. Third, U.S. EPA methods for criteria derivation were followed to determine an updated FAV/FCV for cadmium and their corresponding equations. This produced a revised FAV (2.886 µg/L) that is higher than the FAV reported in the 2001 document (2.763 µg/L). The revised FCV (0.295 g/L) was also higher than the FCV from the 2001 document (0.162 µg/L). An alternative FCV (1.044 µg/L) was also determined by dividing the FAV by the FACR. Final acute and chronic equations for cadmium were derived using these values. The toxicity databases were also reviewed for determination of use-specific criteria for warm and cold waters. Table 13 summarizes the criterion maximum concentrations (CMC) and criterion continuous concentrations (CCC) for the different criteria equations.

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

	Hardness (mg/L)									
	25	50	75	100	150	200	250	300	350	400
2001 EPA Update										
CMC = $e^{1.0166[\ln(\text{hardness})]-3.924}$	0.521	1.054	1.592	2.133	3.221	4.316	5.415	6.517	7.623	8.731
CMC = $e^{0.7409[\ln(\text{hardness})]-4.719}$	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 = $e^{0.9059[\ln(\text{hardness})]-3.1772}$	0.770	1.443	2.083	2.704	3.904	5.066	6.201	7.314	8.411	9.492
CMC[a] = $e^{0.9059[\ln(\text{hardness})]-3.5898}$	0.510	0.955	1.379	1.790	2.584	3.353	4.105	4.842	5.567	6.283
CCC = $e^{0.7635[\ln(\text{hardness})]-4.2062}$	0.174	0.295	0.403	0.501	0.683	0.851	1.009	1.160	1.305	1.445
CCC[b] = $e^{0.7635[\ln(\text{hardness})]-2.9434}$	0.615	1.044	1.423	1.773	2.416	3.010	3.569	4.102	4.614	5.109
CCC[ab] = $e^{0.7635[\ln(\text{hardness})]-3.3560}$	0.407	0.691	0.942	1.174	1.599	1.992	2.362	2.715	3.054	3.382
CEC Revision (coldwater)										
CMC = $e^{0.9059[\ln(\text{hardness})]-3.2442}$	0.720	1.349	1.948	2.528	3.651	4.738	5.799	6.840	7.866	8.877
CCC[b] = $e^{0.7635[\ln(\text{hardness})]-3.0103}$	0.575	0.977	1.331	1.658	2.260	2.815	3.338	3.836	4.316	4.779
CEC Revision (warmwater)										
CMC = $e^{0.9059[\ln(\text{hardness})]-1.5776}$	3.813	7.144	10.315	13.386	19.328	25.082	30.701	36.214	41.642	46.996
CMC[a] = $e^{0.9059[\ln(\text{harndess})]-3.0799}$	0.849	1.590	2.296	2.980	4.303	5.584	6.835	8.062	9.270	10.462
CCC = $e^{0.7635[\ln(\text{hardness})]-4.5126}$	0.128	0.217	0.296	0.369	0.503	0.627	0.743	0.854	0.961	1.064
CCC[b] = $e^{0.7635[\ln(\text{hardness})]-1.3438}$	3.046	5.171	7.047	8.778	11.963	14.902	17.669	20.308	22.845	25.297
CCC[ab] = $e^{0.7635[\ln(\text{hardness})]-2.8461}$	0.678	1.151	1.569	1.954	2.663	3.317	3.934	4.521	5.086	5.632

Data Limitations and Caveats to Cadmium Criteria

The CEC revised FAVs and FCVs were derived from the best database presently available. Unfortunately, much of the data available for cadmium is limited, variable, and often dated. Additional testing of the acute and chronic cadmium toxicities for various key species is necessary to decrease data variability and more accurately define the toxicity of cadmium to sensitive species. For example, *Salvelinus* is the most sensitive genus in the acute database for cadmium. And yet, the acute value reported for one of the two species in this genus is based on an undefined value and, according to an unused data point (Holcombe *et al*. 1983), can vary by more than a factor of 5,000! Furthermore, *Salmo* is the second most sensitive genus in the acute database for cadmium, and is based on only 2 data points from two studies. Neither of these studies were conducted using the preferred flow-through methodology. Additional testing should be conducted to determine the acute toxicity of cadmium to these trout. Additionally, the data for the third most sensitive genus in the acute database, *Morone*, consists of only 2 data points from one study (Palawski *et al*. 1985). An obvious need exists to further examine the acute toxicity of cadmium to sensitive freshwater fish.

Additional chronic testing should be conducted to determine the appropriate toxicity of cadmium to the genus *Daphnia*. Chronic toxicity values for *D. magna* range from 0.23 µg/L to 3.06 µg/L at a hardness of 50 mg/L. Also, the chronic value for *D. pulex* contains substantial variation ranging from 2.11 µg/L to 6.13 µg/L at a hardness of 50 mg/L. Also, given the limited size of the chronic database, additional chronic cadmium toxicity testing should be conducted with taxa not presently represented.

Any further acute and chronic testing should also examine the hardness relationship for cadmium across a wider range of hardness values. Particular attention should be placed on *D. magna* and *P. promelas*. The acute hardness slope for *D. magna* was determined to be too variable, so the revised slope was restricted to data from one study (Chapman *et al*. manuscript) that showed a desirable relationship. Also, the revised acute hardness slope for *P. promelas* was restricted to data for fry and juveniles (slope = 0.9210), presumably because this produces a less variable estimate. However, data for all *P. promelas* produces an acute hardness slope of 2.1576, while the data for just adult *P. promelas* yields a slope of 1.2209. Simply put, the acute and chronic hardness slopes are based on few data points that show a generally weak relationship. Additional acute and chronic testing over a wide range of hardness is necessary to better define these relationships.

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APPENDIX A

Ranked Use-Specific Toxicity Databases

TABLE A-1: Warmwater acute species list.

Rank	Species	GMAV	SMAV	Common Name	Family
52	*Chironomus riparius*	19,256.25	109,568.59	Midge	Chironomidae
	Chironomus tentans		7,854.85	Midge	Chironomidae
	Chironomus plumosus		8,296.43	Midge	Chironomidae
51	*Dendrocoelum lacteum*	14,956.11	14,956.11	Planaria	Dendrocoelidae
50	*Orconectes virilis*	>11,193.54	11,030.68	Crayfish	Astacidae
	Orconectes immunis		>11,358.81	Crayfish	Astacidae
49	*Oreochromis mossambica*	10,015.83	10,015.83	Tilapia	Ciclidae
48	*Gasterosteus aculeatus*	5,940.39	5,940.39	Threespine stickleback	Gasterosteidae
47	*Gambusia affinis*	5,501.38	5,501.38	Mosquitofish	Poeciliidae
46	*Ictalurus punctatus*	4,988.97	4,988.97	Channel catfish	Ictaluridae
45	*Lepomis cyanellus*	4,869.13	3,659.42	Green sunfish	Centrarchidae
	Lepomis macrochirus		6,478.72	Bluegill	Centrarchidae
44	*Rhyacodrilus montana*	4,811.89	4,811.89	Tubificid worm	Tubificidae
43	*Cyprinus carpio*	4,576.46	4,576.46	Common carp	Cyprinidae
42	*Stylodrilus heringianus*	4,200.86	4,200.86	Tubificid worm	Tubificidae
41	*Notropis lutrensis*	4,071.80	4,071.80	Red shiner	Cyprinidae
40	*Spirosperma ferox*	3,031.21	2,673.27	Tubificid worm	Tubificidae
	Spirosperma nikolskyi		3,437.07	Tubificid worm	Tubificidae
39	*Varichaeta pacifica*	2,902.41	2,902.41	Tubificid worm	Tubificidae
38	*Jordanella floridae*	2,806.94	2,806.94	Flagfish	Cyprindontidae
37	*Catostomus commersoni*	2,800.71	2,800.71	White sucker	Castostomidae
36	*Poecilia reticulata*	2,579.10	2,579.10	Guppy	Poeciliidae
35	*Quistradilus multisetosus*	2,444.14	2,444.14	Tubificid worm	Tubificidae
34	*Ephemerella grandis*	2,245.55	2,245.55	Mayfly	Ephemerillidae
33	*Branchiura sowerbyi*	1,833.10	1,833.10	Tubificid worm	Tubificidae
32	*Crangonyx pseudogracilis*	1,700.00	1,700.00	Amphipod	Cragonyctidae
31	*Procambarus clarkii*	1,651.99	1,651.99	Crayfish	Cambaridae
30	*Tubifex tubifex*	1,342.84	1,342.84	Tubificid worm	Tubificidae
29	*Limnodrilus hoffmeisteri*	876.55	876.55	Tubificid worm	Tubificidae
28	*Carassius auratus*	832.98	832.98	Goldfish	Centrarchidae
27	*Asellus bicrenata*	556.25	556.25	Isopod	Asellidae
26	*Ambystoma gracile*	515.31	515.31	Salamander	Ambystomatidae
25	*Plumatella emarginata*	303.60	303.60	Bryozoan	Plumatellidae
24	*Alona affinis*	269.52	269.52	Cladoceran	Chydoridae
23	*Cyclops varicans*	243.35	243.35	Copepod	Cyclopidae
22	*Glossiponia complanta*	212.68	212.68	Leech	Glossiphoniidae
21	*Pectinatella magnifica*	194.97	194.97	Bryozoan	Pectinatelidae
20	*Lumbriculus variegatus*	158.67	158.67	Worm	Lumbriculidae

TABLE A-1: Continued.

Rank	Species	GMAV	SMAV	Common Name	Family
19	*Physa gyrina*	116.78	116.78	Snail	Physidae
18	*Aplexa hypnorum*	102.63	102.63	Snail	Physidae
17	*Gammarus pseudolimnaeus*	77.48	77.48	Amphipod	Gammaridae
16	*Lirceus amabamae*	54.78	54.78	Isopod	Asellidae
15	*Ceriodaphnia dubia*	48.45	49.92	Cladoceran	Daphnidae
	Ceriodaphnia reticulata		47.02	Cladoceran	Daphnidae
14	*Moina macrocopa*	45.52	45.52	Cladoceran	Daphnidae
13	*Gila elegans*	45.12	45.12	Bonytail	Cyprinidae
12	*Utterbackia imbecilis*	45.08	45.08	Mussel	Unionidae
11	*Xyrauchen texanus*	42.67	42.67	Razorback sucker	Castostomidae
10	*Lophopodella carteri*	41.78	41.78	Bryozoan	Lophopodidae
9	*Vilosa vibex*	37.37	37.37	Mussel	Unionidae
8	*Actinonaia pectorosa*	35.75	35.75	Mussel	Unionidae
7	*Lampsilis straminea claibornensis*	32.94	46.51	Mussel	Unionidae
	Lampsilis teres		23.32	Mussel	Unionidae
6	*Pimephales promelas*	28.52	28.52	Fathead minnow	Cyprinidae
5	*Daphnia pulex*	27.62	49.26	Cladoceran	Daphnidae
	Daphnia magna		15.49	Cladoceran	Daphnidae
4	*Simocephalus serrulatus*	27.58	27.58	Cladoceran	Daphnidae
3	*Ptychocheilus lucius*	26.26*	26.26	Colorado pikeminnow	Cyprinidae
	Ptychocheilus oregonensis		2057.31	Northern pikeminnow	Cyprinidae
2	*Hyallela azteca*	7.44	7.44	Amphipod	Hyalellidae
1	*Morone saxatilis*	3.18	3.18	Striped bass	Perichthyidae

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

TABLE A-2: Warmwater chronic species list.

Rank	Species	GMCV	SMCV	Common Name	Family
13	*Oreochromis aurea*	>23.07	>23.07	Blue tilapia	Cichlidae
12	*Aeolosoma headleyi*	20.62	20.62	Oligochaete	Aeolosomatidae
11	*Lepomis macrochirus*	16.83	16.83	Bluegill	Centrarchidae
10	*Pimephales promelas*	15.87	15.87	Fathead minnow	Cyprinidae
9	*Ceriodaphnia dubia*	11.24	11.24	Cladoceran	Daphnidae
8	*Micropterus dolomieui*	8.15	8.15	Smallmouth bass	Centrarchidae
7	*Esox lucius*	8.12	8.12	Northern pike	Esocidae
6	*Catostomus commersoni*	7.83	7.83	White sucker	Castostomidae
5	*Jordanella floridae*	5.33	5.33	Flagfish	Cyprinodontidae
4	*Aplexa hypnorum*	4.83	4.83	Snail	Physidae
3	*Chironomus tentans*	2.70	2.70	Midge	Chironomidae
2	*Daphnia magna*	1.99	1.11	Cladoceran	Daphnidae
	Daphnia pulex		3.59	Cladoceran	Daphnidae
1	*Hyalella azteca*	0.28	0.28	Amphipod	Hyalellidae

TABLE A-3: Coldwater acute species list.

Rank	Species	GMAV	SMAV	Common Name	Family
42	*Chironomus riparius*	19,256.25	109,568.59	Midge	Chironomidae
	Chironomus tentans		7,854.85	Midge	Chironomidae
	Chironomus plumosus		8,296.43	Midge	Chironomidae
41	*Dendrocoelum lacteum*	14,956.11	14,956.11	Planaria	Dendrocoelidae
40	*Orconectes virilis*	>11,193.54	11,030.68	Crayfish	Astacidae
	Orconectes immunis		>11,358.81	Crayfish	Astacidae
39	*Rhyacodrilus montana*	4,811.89	4,811.89	Tubificid worm	Tubificidae
38	*Stylodrilus heringianus*	4,200.86	4,200.86	Tubificid worm	Tubificidae
37	*Spirosperma ferox*	3,031.21	2,673.27	Tubificid worm	Tubificidae
	Spirosperma nikolskyi		3,437.07	Tubificid worm	Tubificidae
36	*Varichaeta pacifica*	2,902.41	2,902.41	Tubificid worm	Tubificidae
35	*Jordanella floridae*	2,806.94	2,806.94	Flagfish	Cyprinodontidae
34	*Catostomus commersoni*	2,800.71	2,800.71	White sucker	Castostomidae
33	*Quistradilus multisetosus*	2,444.14	2,444.14	Tubificid worm	Tubificidae
32	*Ephemerella grandis*	2,245.55	2,245.55	Mayfly	Ephemerillidae
31	*Branchiura sowerbyi*	1,833.10	1,833.10	Tubificid worm	Tubificidae
30	*Crangonyx pseudogracilis*	1,700.00	1,700.00	Amphipod	Cragonyctidae
29	*Procambarus clarkii*	1,651.99	1,651.99	Crayfish	Cambaridae
28	*Tubifex tubifex*	1,342.84	1,342.84	Tubificid worm	Tubificidae
27	*Limnodrilus hoffmeisteri*	876.55	876.55	Tubificid worm	Tubificidae
26	*Asellus bicrenata*	556.25	556.25	Isopod	Asellidae
25	*Ambystoma gracile*	515.31	515.31	Salamander	Salmonidae
24	*Plumatella emarginata*	303.60	303.60	Bryozoan	Plumatellidae
23	*Alona affinis*	269.52	269.52	Cladoceran	Chydoridae
22	*Cyclops varicans*	243.35	243.35	Copepod	Cyclopidae
21	*Glossiponia complanta*	212.68	212.68	Leech	Glossiphoniidae
20	*Pectinatella magnifica*	194.97	194.97	Bryozoan	Pectinatelidae
19	*Lumbriculus variegatus*	158.67	158.67	Worm	Lumbriculidae
18	*Physa gyrina*	116.78	116.78	Snail	Physidae
17	*Aplexa hypnorum*	102.63	102.63	Snail	Physidae
16	*Gammarus pseudolimnaeus*	77.48	77.48	Amphipod	Gammaridae
15	*Lirceus amabamae*	54.78	54.78	Isopod	Asellidae
14	*Ceriodaphnia dubia*	48.45	49.92	Cladoceran	Daphnidae
	Ceriodaphnia reticulata		47.02	Cladoceran	Daphnidae
13	*Moina macrocopa*	45.52	45.52	Cladoceran	Daphnidae
12	*Utterbackia imbecilis*	45.08	45.08	Mussel	Unionidae
11	*Lophopodella carteri*	41.78	41.78	Bryozoan	Lophopodidae
10	*Vilosa vibex*	37.37	37.37	Mussel	Unionidae

TABLE A-3: Continued.

Rank	Species	GMAV	SMAV	Common Name	Family
9	*Actinonaia pectorosa*	35.75	35.75	Mussel	Unionidae
8	*Lampsilis straminea claibornensis*	32.94	46.51	Mussel	Unionidae
	Lampsilis teres		23.32	Mussel	Unionidae
7	*Daphnia pulex*	27.62	49.26	Cladoceran	Daphnidae
	Daphnia magna		15.49	Cladoceran	Daphnidae
6	*Simocephalus serrulatus*	27.58	27.58	Cladoceran	Daphnidae
5	*Hyallela azteca*	7.44	7.44	Amphipod	Hyalellidae
4	*Thymallus arcticus*	4.79	4.79	Arctic grayling	Salmonidae
3	*Oncorhynchus kisutch*	3.46	5.68	Coho salmon	Salmonidae
	Oncorhynchus tshawytscha		3.95	Chinook salmon	Salmonidae
	Oncorhynchus mykiss		1.85	Rainbow trout	Salmonidae
2	*Salmo trutta*	2.21	2.21	Brown trout	Salmonidae
1	*Salvelinus fontinalis*	1.91	<1.76	Brook trout	Salmonidae
	Salvelinus confluentus		2.08	Bull trout	Salmonidae

TABLE A-4: Coldwater chronic species list.

Rank	Species	GMCV	SMCV	Common Name	Family
11	*Aeolosoma headleyi*	20.62	20.62	Oligochaete	Aeolosomatidae
10	*Ceriodaphnia dubia*	11.24	11.24	Cladoceran	Daphnidae
9	*Esox lucins*	8.12	8.12	Northern pike	Esocidae
8	*Catostomus commersoni*	7.83	7.83	White sucker	Castostomidae
7	*Aplexa hypnorum*	4.83	4.83	Snail	Physidae
6	*Salmo salar*	4.72	8.06	Atlantic salmon	Salmonidae
	Salmo trutta		2.76	brown trout	Salmonidae
5	*Salvelinus fontinalis*	4.64	2.65	Brook trout	Salmonidae
	Salvelinus namaycush		8.11	Lake trout	Salmonidae
4	*Chironomus tentans*	2.70	2.70	Midge	Chironomidae
3	*Oncorhynchus kisutch*	2.34	4.28	Coho salmon	Salmonidae
	Oncorhynchus mykiss		1.14	Rainbow trout	Salmonidae
	Oncorhynchus tshawytscha		2.65	Chinook salmon	Salmonidae
2	*Daphnia magna*	1.99	1.11	Cladoceran	Daphnidae
	Daphnia pulex		3.59	Cladoceran	Daphnidae
1	*Hyalella azteca*	0.28	0.28	Amphipod	Hyalellidae