COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF CLEAN WATER

RATIONALE FOR THE DEVELOPMENT OF AMBIENT WATER QUALITY CRITERIA FOR PROTECTION OF AQUATIC LIFE USE

Cadmium

May 2022

Executive Summary

Section 303 of the federal Clean Water Act (CWA) requires states to periodically, but at least once every three years, review and revise as necessary their water quality standards. The federal water quality standards regulation at 40 CFR 131.11(b)(1) requires states to adopt numeric water quality criteria that are based on section 304(a) criteria recommendations developed by the United States Environmental Protection Agency (USEPA), section 304(a) criteria recommendations modified to reflect site-specific conditions, or other scientifically-defensible methods. Additionally, the CWA directs states to adopt criteria for toxic pollutants "the presence of which in the affected waters could reasonably be expected to interfere with a state's designated uses." 33 U.S.C. § 303(c)(2)(B).

USEPA published nationally recommended ambient water quality criteria for cadmium to protect aquatic life in March 2016 (USEPA 2016). USEPA's 2016 recommendation for cadmium replaces its recommended water quality criteria published in 2001. Pennsylvania's water quality standards currently include water quality criteria for protection of aquatic life that are based on USEPA's 2001 recommendations. The 2016 USEPA recommendation for cadmium was developed through its authority under section 304(a) of the CWA. Under the CWA, states and authorized tribes must adopt water quality criteria into their water quality standards to protect designated uses.

The Pennsylvania Department of Environmental Protection (Department) has reviewed USEPA's 2016 cadmium aquatic life criteria recommendations and has determined that they will provide an appropriate level of aquatic life protection to surface waters of this Commonwealth. Therefore, the Department is recommending the Environmental Quality Board (Board) adopt an equation-based criterion maximum concentration (CMC) of $\{1.136672 – [(\ln[H]) \times (0.041838)]\} \times Exp(0.9789 \times \ln[H] - 3.866)$ to protect freshwater aquatic life criteria from acute exposures to cadmium and an equation-based criterion continuous concentration (CCC) of $\{1.101672 – [(\ln[H]) \times (0.041838)]\} \times Exp(0.7977 \times \ln[H] - 3.909)$ to protect freshwater aquatic life from chronic exposures to cadmium.

History of Regulation

In 1980, the Department established a toxics management strategy following USEPA's publication of water quality criteria for the protection of human health and aquatic life for 104 of 126 priority pollutants. The Department's toxics management strategy contained ambient water quality criteria for cadmium based on USEPA's 1980 freshwater aquatic life criteria recommendations, which were updated in 1984. While USEPA's equation-based criteria recommendations did not change between 1980 and 1984, the expression of cadmium changed from total recoverable to acid-soluble.

In 1989, the Department published its toxics management strategy as a statement of policy in the *Pennsylvania Bulletin* on March 11, 1989 (19 Pa.B. 1059). This publication established 25 Pa. Code Chapter 16 (relating to water quality toxics management strategy – statement of policy). The Department's strategy contained ambient water quality criteria for cadmium based on USEPA's 1984 freshwater aquatic life criteria recommendations. As part of its 6^{th} triennial review of water quality standards in 2005, the Department evaluated USEPA's 2001 cadmium water quality criteria recommendations for the protection of freshwater aquatic life and determined they were appropriate for the protection of Pennsylvania's surface waters. At that time, water quality criteria for toxic substances were still located in Chapter 16 (Appendix A - Table 1). The Department published final amendments to Chapter 16, which included updated aquatic life water quality criteria for cadmium based on USEPA's 2001 recommendations, in the *Pennsylvania Bulletin* on February 12, 2005 (35 Pa. B. 1223). In 2008, the Department moved the statewide water quality criteria from Appendix A-Table 1 to the newly-created Table 5 in 25 Pa. Code Chapter 93 (relating to water quality standards).

Background

Cadmium is a relatively rare, naturally occurring metal found in mineral deposits that is widely distributed at low concentrations in the environment. Cadmium has two oxidation states. The metallic state is insoluble and rarely present in water. The divalent state typically occurs as one of several salts that freely dissolve in water. Divalent cadmium is the form most likely to be found in well-oxygenated freshwaters with low levels of organic carbon (USEPA 2016).

Pennsylvania is rich in mineral resources such as coal. The concentration of cadmium in coal is dependent upon the type of coal. Bituminous coal has a higher average concentration of cadmium than anthracite coal (USEPA 2016). Cadmium is primarily used in manufacturing batteries, pigments, plastic stabilizers, metal coatings, alloys and electronics, but it is also found as an impurity in zinc, lead and copper ore mine wastes; fossil fuels; iron and steel; cement; and fertilizers. In addition, it is often present as a natural or introduced constituent in inorganic phosphate fertilizers. Currently, over 80%

of the cadmium consumed globally is used for nickel-cadmium batteries and the demand for cadmium has increased to support this market (USEPA 2016).

Cadmium enters the environment through both anthropogenic and natural pathways. The anthropogenic sources and pathways include mining, agriculture, urban activities, industrial waste, manufacturing, coal ash, use of fossil fuels, incineration, and municipal effluent. The natural sources and pathways include weathering and erosion of rocks and soils and natural combustion from volcanoes and forest fires. Anthropogenic sources account for more than 90% of the total cadmium present in surface waters (USEPA 2016).

Cadmium readily and strongly adsorbs to clays, muds, some hydrous oxides, humic materials and organic matter. This property greatly reduces cadmium bioavailability and results in its removal from the water column. It is estimated that up to 93% of cadmium entering surface waters will be removed from the water column through adsorption to sediments. Thus, the concentration of cadmium in unpolluted freshwaters is usually very low and often non-detectable. However, it should be noted that the solubility of cadmium compounds in water depends upon both the specific compound and on abiotic factors including pH, alkalinity, hardness and organic matter. USEPA's 2016 criteria recommendations for cadmium are hardness-based equations. Hardness is a measure of the dissolved minerals (mainly calcium and magnesium) in surface water. Increased hardness has been shown to ameliorate the toxic effects of cadmium in freshwater animals (USEPA 2016).

The Department reviewed water quality sample data for cadmium in the national Water Quality Portal. The Water Quality Portal is a cooperative service provided by the United States Geological Survey (USGS), USEPA and the National Water Quality Monitoring Council (NWQMC). A search of the database generated approximately 23,800 sample results for cadmium in Pennsylvania surface waters that were collected between 1967 and 2021 by USGS, the National Park Service and the Department. Approximately 5,700 of the 23,800 samples were collected during the past ten years (2012-2022). Most samples were analyzed for dissolved cadmium, but a small number of samples were analyzed for total recoverable. Over 99% of the samples had non-detectable levels of cadmium. Of the 0.7% of samples that had detectable amounts, the results ranged from 0.006 ug/L to 1.9 ug/L.

A search of National Pollutant Discharge Elimination System (NPDES) permits issued under the Department's Clean Water Program generated 169 permits with discharge effluent limitations or monitor and report requirements for cadmium. Cadmium effluent limitations in these NPDES permits may be affected by the Department's updated water quality criteria for cadmium upon renewal of the permit.

Cadmium and Aquatic Life Toxicity

Cadmium is a non-essential metal that has no biological function in animals, and it is acutely toxic to aquatic animals. Cadmium is a known teratogen, carcinogen and a probable mutagen. It is known to induce various short- and long-term adverse physiological effects in fish including effects on growth, reproduction, immune and endocrine function, development and behavior. Other toxic effects include histopathological effects of the gill, liver, and kidney in fish, renal tubular damage, alterations of free radical production and the antioxidant defense system, immunosuppression, and structural effects on invertebrate gills (USEPA 2016).

The free ionic form of cadmium is the suspected cause of acute and chronic toxicity in aquatic organisms. Exposure to free cadmium ions disrupts calcium homeostasis and causes oxidative damage. In freshwater fish, cadmium competes with calcium at high affinity binding sites in the gill membrane and blocks the uptake of calcium ions which results in acute hypocalcemia. Cadmium also disrupts sodium balance and enzymatic function within the cell (USEPA 2016).

As previous discussed in the background section, the toxicity of cadmium is dependent upon other water quality parameters such as hardness, pH, salinity, alkalinity, some metals and organic carbon.

Acute toxicity tests generally determine the amount of a substance it takes to kill 50% of the test organisms, but tests may also include determination of the amount of substance it takes to negatively affect or inhibit an organism. These values are often referred to as a lethal concentration (LC50), an effective concentration (EC50), or an inhibitory concentration (IC50). Depending upon the organism, acute toxicity tests are most often conducted over a 48- or 96-hour period. During USEPA's review of cadmium, acceptable toxicity test data were available for 101 freshwater species representing 75 genera, which represents a significant increase in data available since 2001. USEPA's 2016 freshwater acute criterion recommendation incorporates data for 36 new species and 20 new genera. The four most sensitive genus mean acute values (GMAVs) included the following: (1) trout (*Salvelinus confluentus* and *Salvelinus fontinalis*); (2) sculpin (*Cottus bairdii* and *Cottus confusus*); (3) Brown Trout (*Salmo trutta*); and (4) Striped Bass (*Morone saxatilis*).

Chronic toxicity tests measure longer-term effects associated with exposures to lower concentrations of a pollutant over an extended period of time. Chronic toxicity tests measure lethal and sublethal effects, which include growth, development, behavior, and reproduction. The typical endpoint for chronic exposure is the EC20, which is the concentration that it takes to affect 20% of the test organisms, but endpoints may include a no-observed-effect-concentration (NOEC) or a lowest-observed-effect-concentration (LOEC). Cadmium has been shown to negatively affect the survival, growth and/or reproduction of 20 genera of aquatic animals, including 11 species of invertebrates and 16 species of fish. The four most sensitive genus mean chronic values (GMCVs) included the following: (1) amphipod (*Hyalella azteca*), (2) cladocerans (*Ceriodaphnia dubia* and *Ceriodaphnia reticulata*), (3) Mottled Sculpin (*Cottus bairdii),* and (4) midge (*Chironomus dilutus*).

Data on bioaccumulation of cadmium in freshwater aquatic organisms was available from approximately 30 different peer-reviewed publications for 29 species including aquatic plants, invertebrates, frogs and fish. The available data indicate that bioaccumulation of cadmium is low-to-moderate in freshwater organisms with values ranging from 3 to 65,600.

Guidelines for Cadmium

Current USEPA 304(a) Water Quality Criteria Recommendations for Cadmium

The current federal recommendations are designed to protect aquatic life from the acute and chronic effects of cadmium (USEPA 2016). The following equations give the magnitude for the CMC, or acute criterion, and the CCC, or chronic criterion, where H represents hardness.

$$CMC = \{1.136672 - [(\ln[H]) \times (0.041838)]\} \times Exp(0.9789 \times \ln[H] - 3.866)$$

$$CCC = \{1.101672 - [(\ln[H]) \times (0.041838)]\} \times Exp(0.7977 \times \ln[H] - 3.909)$$

The average duration periods for the CMC[1] and the CCC are one-hour and four-days, respectively. USEPA typically recommends average durations of one hour for the CMC and four days for the CCC for aquatic life criteria based on standard laboratory toxicity tests. These recommendations can be found in USEPA's Water Quality Standards Handbook (USEPA 2017). The current 304(a) cadmium criteria recommendations also state that the criterion magnitudes for cadmium are not to be exceeded at a frequency of more than once every three years on average.

Complete details regarding the specific derivation for both the acute and chronic components of the cadmium aquatic life criteria are described in USEPA's 2016 recommendation for cadmium (USEPA 2016).

The criteria recommendations were derived using the peer-reviewed procedures defined in USEPA's *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (the 1985 guidelines, Stephan et al. 1985). Therefore, comprehension of these guidelines will be necessary to understand the process used by USEPA to derive this aquatic life criterion recommendation. When these guidelines are followed, ambient water quality criteria are designed to be protective of the aquatic organisms and aquatic life uses specified by states in their water quality standards regulations.

[1] The duration of the 2016 criteria was changed from 1-day to 1-hour to reflect the 1985 guidelines-based recommended acute duration.

The 1985 guidelines require that a minimum of eight phylogenetically different families are represented in the toxicity data set that is used to derive criteria values for aquatic life and describe which eight phylogenetically different families are required to be in the dataset. The CMC was developed by first assembling available acute test data and it was determined that the minimum data requirements prescribed in the 1985 guidelines were met.

During USEPA's review of cadmium, acceptable toxicity test data were available for 101 freshwater species representing 75 genera (see Table A-1 in the Appendix). Although the freshwater acute dataset met the minimum data requirements in the guidelines, USEPA derived the CMC to be protective of the commercially and recreationally important Rainbow Trout (*Oncorhynchus mykiss*) as is consistent with procedures described in the 1985 guidelines. By accounting for the commercial and recreational importance of the Rainbow Trout, the CMC value is lower. This lower value is protective of the other salmonid species for which toxicity data are available, including some Federally-listed threatened and endangered species. Rainbow Trout are present in Pennsylvania surface waters.

The acceptable data for the chronic calculation included 27 species representing 20 genera, compared to 21 species and 16 genera in the 2001 criteria (see Table A2 in the Appendix).

USEPA also updated the acute and chronic hardness slopes with data for several new species. The 2016 updated acute cadmium hardness slope incorporates data for 13 species, where eight species were used in the 2001 criteria. The 2016 updated chronic slope incorporates data for four species, where two species were used in the 2001. The new chronic slope uses EC20 estimates for three of the four species, instead of only Maximum Acceptable Toxicant Concentrations (MATCs), as used for the 2001 chronic slope. USEPA explains the MATCs were used only for *Daphnia magna* in the 2016 slope in order to retain the invertebrate species.

Table 1 comes from USEPA's *2016 Ambient Aquatic Life Water Quality Criteria for Cadmium* (USEPA 2016). It provides a comparison between the freshwater CMC and CCC values calculated based on USEPA's 2016 recommendations (USEPA 2016) and the 2001 recommendations (USEPA 2001). The columns labeled "2016 criteria" contain the magnitude values that were calculated based on the equations given above for varying hardness concentrations. The columns labeled "2001 criteria" contain the magnitude values that were calculated based on the equations in USEPA's 2001 recommendations (USEPA 2001). The magnitude values for 2016 supersede the 2001 values.

Table 1. Freshwater CMC and CCC at Various Water Hardness.

Hardness (mg/L as CaCO3)	CMC (µg/L Cd dissolved)		CCC (µg/L Cd dissolved)	
	2001 Criteria (superseded)	2016 Criteria	2001 Criteria (superseded)	2016 Criteria
25	0.52	0.49	0.09	0.25
50	1.0	0.94	0.15	0.43
75	1.5	1.4	0.20	0.58
100	2.0	1.8	0.25	0.72
150	3.0	2.6	0.33	1.0
200	3.9	3.4	0.40	1.2
250	4.9	4.2	0.46	1.4
300	5.9	5.0	0.53	1.6
350	6.8	5.8	0.59	1.8
400	7.7	6.5	0.64	2.0

Calculated CMC values at all hardness concentrations based on the 2016 recommendation are all slightly lower or more stringent than the CMC values based on the previous recommendation published in 2001. Alternately, the calculated CCC values are all slightly less stringent as the calculated magnitudes have all increased. These minor differences can be attributed mainly to the inclusion of new toxicity studies in the derivation of the most recent national recommendation (Table 1).

USEPA 304(a) national criteria recommendations developed using the 1985 guidelines are based on the premise that toxicological data for the species used to derive the national criteria recommendations are representative of the sensitivities of appropriate untested species (USEPA 2013). Based on this premise, the national criteria recommendations are designed to protect the various freshwater and saltwater aquatic communities found across the United States.

Development of Cadmium Water Quality Criteria

The Department evaluated USEPA's 304(a) recommendations for acute and chronic freshwater cadmium criteria to determine if the recommendations are appropriate for this Commonwealth. The Department's evaluation included consideration of the toxicological studies and the aquatic organisms used in these studies along with the methodology used to derive the national recommendation (i.e. the guidelines). These 304(a) criteria recommendations are consistent with the Department's regulations and policies for developing aquatic life criteria found at §§ 93.8a, 93.8c, 16.21 – 16.24.

The following equations give the magnitude for the CMC, or acute criterion, and the CCC, or chronic criterion, where H represents hardness.

$$CMC = \{1.136672 - [(\ln[H]) \times (0.041838)]\} \times Exp(0.9789 \times \ln[H] - 3.866)$$

$$CCC = \{1.101672 - [(\ln[H]) \times (0.041838)]\} \times Exp(0.7977 \times \ln[H] - 3.909)$$

Table 2 provides a comparison between the freshwater CMC and CCC values calculated based on the Department's current 2022 recommendations and its previous recommendations which were published as final-form rulemaking in 2005.

Table 2. Freshwater CMC and CCC at Various Water Hardness.

Hardness (mg/L as CaCO3)	CMC (µg/L Cd dissolved)		CCC (µg/L Cd dissolved)	
	2005 Criteria (superseded)	2022 Criteria	2005 Criteria (superseded)	2022 Criteria
25	0.52	0.49	0.09	0.25
50	1.0	0.94	0.15	0.43
75	1.5	1.4	0.20	0.58
100	2.0	1.8	0.25	0.72
150	3.0	2.6	0.33	1.0
200	3.9	3.4	0.40	1.2
250	4.9	4.2	0.46	1.4
300	5.9	5.0	0.53	1.6
350	6.8	5.8	0.59	1.8
400	7.7	6.5	0.64	2.0

Conclusion

The Department recommends the Board adopt USEPA's 304(a) ambient water quality criteria recommendations for cadmium as described in this rationale document. Statewide application of these nationally-recommended water quality criteria will provide an appropriate level of protection for freshwater aquatic organisms from the toxic effects of cadmium.

Literature Cited

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Appendix A

Table A-1. This table was taken from USEPA 2016 and shows the freshwater GMAVs comparing species lists used in the 2001 and 2016 national recommendations for aquatic life for cadmium. All data are adjusted to a hardness of 100 mg/L as CaCO3. The values in bold are either new or revised for the 2016 recommendation.

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
49,052	195,967	Midge, *Chironomus plumosus*	-	**15,798**	New species added to GMAV calculation
-	-	Midge, *Chironomus riparius*	195,967	**>152,301**	Revised the effect concentration from Williams et al. 1985
30,781	8,573	Common carp, *Cyprinus carpio*	8,573	**30,781**	New data for existing species
26,837	21,569	Nile tilapia, *Oreochromis niloticus*	-	**66,720**	New species added to GMAV calculation
-	-	Mozambique tilapia, *Oreochromis mossambica*	21,569	**10,795**	New data for existing species
26,607	28,454	Planarian, *Dendrocoelum lacteum*	28,454	**26,607**	Acute value edited from re-review of Ham et al. 1995
22,138	-	Mayfly, *Rhithrogena hageni*	-	**22,138**	New genus
>20,132	-	Little green stonefly, *Sweltsa sp.*	-	**>20,132**	New genus
12,100	13,146	Mosquitofish, *Gambusia affinis*	13,146	12,100	-
11,627	4,754	Oligochaete, *Branchiura sowerbyi*	4,754	**11,627**	New data for existing species
11,171	12,479	Oligochaete, *Rhyacodrilus montana*	12,479	11,171	-
11,045	11,002	Threespine stickleback, *Gasterosteus aculeatus*	11,002	11,045	-
9,917	10,225	Channel catfish, *Ictalurus punctatus*	10,225	9,917	-
9,752	10,894	Oligochaete, *Stylodrilus heringianus*	10,894	9,752	-
7,798	-	Mayfly, *Hexagenia rigida*	-	**7,798**	New genus
7,752	8,551	Green sunfish, *Lepomis cyanellus*	5,997	6,276	-
-	-	Bluegill, *Lepomis macrochirus*	12,194	9,574	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
7,716	7,762	Red shiner, *Cyprinella lutrensis*	7,762	7,716	-
7,037	7,861	Oligochaete, *Spirosperma ferox*	6,933	6,206	-
-	-	Oligochaete, *Spirosperma nikolskyi*	8,913	7,979	-
6,808	-	Yellow perch, *Perca flavescens*	-	**6,808**	New genus
6,738	7,527	Earthworm, *Varichaetadrilus pacificus*	7,527	6,738	(formerly, *Varichaeta pacifica*)
5,947	6,344	White sucker, *Catostomus commersonii*	6,344	5,947	-
5,674	6,338	Oligochaete, *Quistadrilus multisetosus*	6,338	5,674	-
5,583	5,759	Flagfish, *Jordanella floridae*	5,759	5,583	-
4,929	4,981	Guppy, *Poecilia reticulata*	4,981	4,929	-
4,467	4,607	Mayfly, *Empherella subvaria*	4,607	4,467	-
4,193	2,753	Tubificid worm, *Tubifex tubifex*	2,753	**4,193**	New data for existing species
3,350	3,439	Amphipod, *Crangonyx pseudogracilis*	3,439	3,350	-
3,121	-	Copepod, *Diaptomus forbesi*	-	**3,121**	New genus
2,967	-	Zebrafish, *Danio rerio*	-	**2,967**	New genus
2,231	3,093	African clawed frog, *Xenopus laevis*	3,093	**2,231**	New data for existing species
1,983	3,536	Crayfish, *Procambarus acutus*	-	**812.8**	New species added to GMAV calculation
-	-	Crayfish, *Procambarus alleni*	-	**6,592**	New species added to GMAV calculation
-	-	Red swamp crayfish, *Procambarus clarkii*	3,536	**1,455**	New data for existing species
1,656	1,707	Goldfish, *Carassius auratus*	1,707	1,656	-
>1,637	-	Caddisfly, *Arctopsyche sp.*	-	**>1,637**	New genus

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
1,593	1,568	Oligochaete, *Limnodrilus hoffmeisteri*	1,568	1,593	-
1,582	59.08	Fathead minnow, *Pimephales promelas*	59.08	**1,582**	Same studies but only used F,M tests to calculate GMAV
1,023	1,055	Northwestern salamander, *Ambystoma gracile*	1,055	1,023	-
983.8	955.0	Isopod, *Caecidotea bicrenata*	955.0	983.8	(formerly, *Asellus bicrenata*)
>808.4	-	Snail, *Gyraulus sp.*	-	**>808.4**	New genus
651.3	-	Lake whitefish, *Coregonus clupeaformis*	-	**651.3**	New genus
539.7	525.3	Bryozoa, *Plumatella emarginata*	525.3	539.7	-
501.7	500.1	Cladoceran, *Alona affinis*	500.1	501.7	-
453.0	451.6	Cyclopoid copepod, *Cyclops varicans*	451.6	453.0	-
427.9	-	Pond snail, *Lymnaea stagnalis*	-	**427.9**	New genus
410.4	-	Planarian, *Dugesia dorotocephala*	-	**410.4**	New genus
392.5	389.5	Leech, *Glossiphonia complanata*	389.5	392.5	-
350.4	-	Mayfly, *Baetis tricaudatus*	-	**350.4**	New genus
346.6	337.4	Bryozoa, *Pectinatella magnifica*	337.4	346.6	-
275.0	264.2	Worm, *Lumbriculus variegatus*	264.2	275.0	-
208.0	202.6	Snail, *Physa acuta*	-	**2,152[b]**	New species for existing genus, but ten- fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-	-	Pouch snail, *Physa gyrina*	202.6	208.0	-
204.1	210.3	Snail, *Aplexa hypnorum*	210.3	204.1	-
154.3	159.2	Amphipod, *Gammarus pseudolimnaeus*	159.2	154.3	-
145.5	-	Worm, *Nais elinguis*	-	**145.5**	New genus

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
120.1	-	Hydra, *Hydra circumcincta*	-	**184.8**	New genus (formerly, *Hydra attenuata*)
-	-	Hydra *Hydra oligactis*	-	**154.8**	New genus
-	-	Green hydra, *Hydra viridissima*	-	**38.85**	New genus
-	-	Hydra, *Hydra vulgaris*	-	**187.1**	New genus
103.1	-	Cladoceran, *Diaphanosoma brachyurum*	-	**103.1**	New genus
99.54	97.98	Isopod, *Lirceus alabamae*	97.98	99.54	-
94.67	>23,632	Crayfish, *Orconectes immunis*	>23,281	>22,579[b]	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-	-	Crayfish, *Orconectes juvenilis*	-	**134.0**	New species added to GMAV calculation
-	-	Crayfish, *Orconectes placidus*	-	**66.89**	New species added to GMAV calculation
-	-	Crayfish, *Orconectes virilis*	23,988	22,800[b]	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
86.51	87.16	Cladoceran, *Moina macrocopa*	87.16	86.51	-
80.38	78.32	Bonytail, *Gila elegans*	78.32	80.38	-
76.02	74.08	Razorback sucker, *Xyrauchen texanus*	74.08	76.02	-
74.28	72.29	Bryozoa, *Lophopodella carteri*	72.29	74.28	-
73.67	72.61	Cladoceran, *Ceriodaphnia dubia*	63.46	**64.03**	New data for existing species
-	-	Cladoceran, *Ceriodaphnia reticulata*	83.08	84.76	-
71.76	86.82	Mussel, *Utterbackia imbecillis*	86.82	**71.76**	New data for existing species
70.76	71.16	Southern rainbow mussel, *Villosa vibex*	71.16	70.76	-
68.51	-	Mussel, *Lasmigona subviridis*	-	**68.51**	New genus
67.90	68.38	Mussel, *Actinonaias pectorosa*	68.38	67.90	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
61.42	50.44	Cladoceran, *Daphnia ambigua*	-	**24.81**	New species added to GMAV calculation
-	-	Cladoceran, *Daphnia magna*	27.14	**40.62**	New data for existing species and Attar and Maly (1982) was not used to calculate SMAV, see Unused data (Appendix J)
-	-	Cladoceran, *Daphnia pulex*	93.77	**109.2**	New data for existing species
-	-	Cladoceran, *Daphnia similis*	-	**129.3**	New species added to GMAV calculation
57.71	61.10	Cladoceran, *Simocephalus serrulatus*	61.10	57.71	-
51.34	68.29	Neosho mucket, *Lampsilis rafinesqueana*	-	**44.67**	New species added to GMAV calculation
-	-	Fatmucket, *Lampsilis siliquoidea*	-	**35.73**	New species added to GMAV calculation
-	-	Southern fatmucket, *Lampsilis straminea claibornensis*	96.44	93.17	-
-	-	Yellow sandshell, *Lampsilis teres*	48.35	46.71	-
46.79	452.6	Colorado pikeminnow, *Ptychocheilus lucius*	45.59	46.79	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-		Northern pike minnow, *Ptychocheilus oregonensis*	4,493	4,265[b]	-
<33.78	*Acipens e r*	White sturgeon, *Acipenser transmontanus*	-	**<33.78**	New genus
23.00	-	Amphipod, *Hyalella azteca*	-	**23.00**	New genus
>15.72	-	Mountain whitefish, *Prosopium williamsoni*	-	**>15.72**	New genus
6.141	7.760	Cutthroat trout, *Oncorhynchus clarkii*	-	**5.401**	New species added to GMAV calculation
-	-	Coho salmon, *Oncorhynchus kisutch*	12.58	11.88	-
-	-	Rainbow trout, *Oncorhynchus mykiss*	4.265	**3.727**	New data for existing species
-	-	Chinook salmon, *Oncorhynchus tshawytscha*	8.708	**5.949**	No new data, but only the most sensitive life stage used for SMAV calculation
5.931	5.916	Striped bass, *Morone saxatilis*	5.916	5.931	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
5.642	3.263	Brown trout, *Salmo trutta*	3.263	**5.642**	New data for existing species
4.411	-	Mottled sculpin, *Cottus bairdii*	-	**4.418**	New genus
-	-	Shorthead sculpin, *Cottus confusus*	-	**4.404**	New genus
4.190	<3.971	Bull trout, *Salvelinus confluentus*	4.353	4.190	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
-	-	Brook trout, *Salvelinus fontinalis*	<3.623	**3,055[b]**	Carroll et al. 1979 was not used to calculate SMAV, see Unused data (Appendix J)

[a] Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
[b] There is a 10x difference in SMAVs for the genus, only most sensitive SMAV is used in the GMAV calculation.
[The following species were not included in the Ranked GMAV Table because hardness test conditions were not reported and therefore toxicity values could not be normalized: Leech, *Nephelopsis obscura*; Crayfish, *Orconectes limosus*; Prawn, *Macrobrachium rosenbergii*; Mayfly, *Drunella grandis grandis*; Stonefly, *Pteronarcella badia*; Midge, *Culicoides furens*; Grass carp, *Ctenopharyngodon idellus*.]

Table A-2. This table was taken from USEPA 2016 and shows the freshwater GMCVs comparing species lists used in the 2001 and 2016 national recommendations for aquatic life for cadmium. All data are adjusted to a hardness of 100 mg/L as CaCO3. The values in bold are either new or revised for the 2016 recommendation.

2016 GMCV[a] (µg/L)	2001 GMCV (µg/L)	Species	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Comment
>38.66	>39.48	Blue tilapia, *Oreochromis aureus*	>39.48	>38.66[c]	(formerly, *Oreochromis aurea*)
36.70	34.66	Oligochaete, *Aeolosoma headleyi*	34.66	**36.70**	Different values used from Niederlehner et al. 1984 that was a more appropriate duration
16.43	29.05	Bluegill, Lepomis *macrochirus*	29.05	16.43	-
15.16	-	Oligochaete, *Lumbriculus variegatus*	-	**15.16**	New genus
14.22	13.58	Smallmouth bass, *Micropterus dolomieu*	13.58	14.22[c]	-
14.17	13.52	Northern pike, *Esox lucius*	13.52	14.17[c]	-
14.16	27.37	Fathead minnow, *Pimephales promelas*	27.37	14.16	-
13.66	13.04	White sucker, *Catostomus commersonii*	13.04	13.66[c]	-
11.29	-	Fatmucket, *Lampsilis siliquoidea*	-	**11.29**	New genus
9.887	-	Pond snail, *Lymnaea stagnalis*	-	**9.887**	New genus
8.723	8.886	Flagfish, *Jordanella floridae*	8.886	8.723	-
3.516	8.055	Snail, *Aplexa hypnorum*	8.055	3.516	-
3.360	10.52	Atlantic salmon, *Salmo salar*	13.24	2.389	-
-	-	Brown trout, *Salmo trutta*	8.360	**4.725**	New data for existing species, and more sensitive exposure scenario used
3.251	4.082	Rio Grande cutthroat trout, *Oncorhynchus clarkii virginalis*	-	**3.543**	New species added to GMCV calculation
-	-	Coho salmon, *Oncorhynchus kisutch*	7.127	**NA[b]**	See footnote

2016 GMCV[a] (µg/L)	**2001 GMCV (µg/L)**	**Species**	**2001 SMCV (µg/L)**	**2016 SMCV (µg/L)**	**Comment**
-	-	Rainbow trout, *Oncorhynchus mykiss*	2.186	**2.192**	New data for existing species
-	-	Chinook salmon, *Oncorhynchus tshawytscha*	4.366	4.426	-
2.356	7.726	Brook trout, *Salvelinus fontinalis*	4.416	2.356	-
-	-	Lake trout, *Salvelinus namaycush*	13.51	**NA[b]**	See footnote
2.024	<0.6340	Cladoceran, *Daphnia magna*	<0.6340	**0.9150**	New data for existing species
-	-	Cladoceran, *Daphnia pulex*	10.30[b]	**4.478**	New data for existing species
2.000	4.686	Midge, *Chironomus dilutus*	4.686	2.000	(formerly, *Chironomus tentans*)
1.470	-	Mottled sculpin, *Cottus bairdii*	-	**1.470**	New genus
1.293	45.40	Cladoceran, Ceriodaphnia dubia	45.40	**1.293**	New data for existing species
-	-	Cladoceran, Ceriodaphnia reticulata	-	**NA[b]**	See footnote
0.7453	0.4590	Amphipod, Hyalella azteca	0.4590	0.7453	-

[a] Ranked from most resistant to most sensitive based on Genus Mean Chronic Value.
[b] Not included in the GMCV calculation because normalized EC_{20} data are available for the genus.
[c] Calculated from the MATC and not EC_{20} but retained to avoid losing a GMCV.
[d] Not used in GMCV calculation because species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.
[The following species were not included in the Ranked GMCV Table because hardness test conditions were not reported and therefore toxicity values could not be normalized: Mudsnail, *Potamopyrgus antipodarum*.]