Center for Biological Diversity

Please accept the attached comments filed on behalf of the Center for Biological Diversity. The Center's comments will be provided through three submissions to relay all relevant attachments. This is submission 1 of 3.

CENTER *for* BIOLOGICAL DIVERSITY Because life is good.

Submitted Via State Public Comment Portal

May 7, 2024

Casey Sixkiller
Regional Administrator
Environmental Protection Agency, Region 10
1200 6th Avenue
Seattle, WA 98101

Marla Koberstein
Department of Ecology
Water Quality Program
P.O. Box 47696
Olympia, WA 98504

Re: Comments on Washington's Proposed Updates to Aquatic Life Toxics Criteria, WAC 173-201A-240 (CR-102)

Dear Ms. Koberstein and Regional Administrator Sixkiller,

Please accepted the following public comments submitted on behalf of the Center for Biological Diversity (Center) and its 1.7 million members and supporters to the Washington Department of Ecology's (Ecology) proposal to revise Washington's aquatic life toxics criteria, WAC 173-201A-240.

The Center is concerned that the proposed criteria provide insufficient protections for federally listed endangered and threatened species and, in consideration of prior national, Oregon, and Idaho Section 7 consultation findings, likely violates the Endangered Species Act's prohibition on the take of listed species. The Center, therefore, urges Ecology to revisit its proposed criteria for the benefit of endangered and threatened species and revise downward those criteria to levels that meet the obligations of the Clean Water Act to support the most sensitive aquatic life uses[1] and the Endangered Species Act's requirement that "endangered species [] be afforded the highest of priorities." *Tennessee Valley Authority v. Hill*, 437 U.S. 153, 174 (1978).

I. The Methodologies Used by Ecology and EPA for Deriving Water Quality Criteria Are Legally Deficient and Under-Protective of Endangered Species and Critical Habitats

The presence of toxic pollutants in waterways has a significant impact on aquatic and aquatic-dependent species' survival. According to the National Marine Fisheries Service (NMFS), "degraded water quality has been one of the contributing factors for the decline of almost all of

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[1] *See* 40 C.F.R. § 131.11(a) (criteria must support the most sensitive use).

the anadromous fish species NMFS has listed since the mid-1980s."[2] Cyanide, cadmium, and mercury are three toxic pollutants that present significant threats to endangered and threatened aquatic species and their critical habitats.[3]

Over the last two decades, a series of lawsuits and consultations regarding EPA's national criteria and its approval of state standards and criteria for various pollutants—including cyanide, cadmium, and mercury—have raised profound concerns regarding the overall approaches that EPA utilizes in reviewing and approving water quality criteria; these cases also raise concerns about the inadequate and antiquated methodologies EPA used to establish national water quality criteria. *See, e.g., Center for Biological Diversity v. EPA*, Case No. 22-138, 2023 U.S. Dist. LEXIS 145674 (D. Ariz. Aug. 18, 2023) (finding that EPA acted unlawfully when it failed to engage in Endangered Species Act Section 7 consultation prior to issuing nationwide water quality criteria for cadmium and vacating EPA's 2016 chronic freshwater cadmium criterion); *Northwest Environmental Advocates v. National Marine Fisheries Service et al.*, Case No. 10-907-BR (2010) (dealing with the Oregon's Endangered Species Act consultation history and failures); *Northwest Environmental Advocates v. The National Marine Fisheries Service et al.*, Case No. 13-00263-DCN (2013) (dealing with the Idaho's Endangered Species Act consultation history and failures).

The Center hereby attaches and incorporates into these comments past biological opinions and draft biological opinions and request they be made part of the record for this rulemaking as well as incorporated into EPA's review of Ecology's ultimate submission. The biological opinions describe severe methodological flaws and inadequate approaches that have inevitably yielded legally insufficient and under protective criteria. Each document included provides information that can guide Ecology's development of its criteria. More recent science, however, suggests the need for even more protective standards to fully comply with the Endangered Species Act.

Even further, because Washington is downstream of a number of states with known aquatic toxic pollution issues, including Idaho, Oregon, and even small portions of Wyoming and Montana, some of its waters are already receiving significant pollutants from upstream states, which raises concerns about cumulative impacts, and suggests even more stringent criteria are required to address pollution in a legally sufficient manner.[4] While in theory, Clean Water Act section 303(d)

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[2] NATIONAL MARINE FISHERIES SERVICE, DRAFT ENDANGERED SPECIES ACT SECTION 7 CONSULTATION BIOLOGICAL OPINION & CONFERENCE OPINION ON THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S APPROVAL OF STATE OR TRIBAL, OR FEDERAL NUMERIC WATER QUALITY STANDARDS FOR CYANIDE BASED ON EPA'S RECOMMENDED 304(A) AQUATIC LIFE CRITERIA, 270 (2010) [hereinafter NMFS National Cyanide Draft BiOp].

[3] While these comments focus on the cyanide, cadmium, and mercury pollution and Washington's associated criteria, several additional pollutants are of concern to the Center. We request that Washington finalize toxics criteria across the board that are adequately protective of endangered and threatened species and their critical habitats.

[4] *See* EPA, Downstream Protection Guidance, Goal: Illustrate Considerations and Procedures Associated with Incorporating Downstream Protection into Development of Numeric Criteria, at 7 (2014) (describing that to develop downstream protections, the state should "establish numeric criteria in the receiving waterbody and build upstream")*; see also* 40 C.F.R. § 131.10(b) (a state "shall ensure that its water quality standards provide for the attainment and maintenance of water quality standards of downstream waters").

total maximum daily loads (TMDLs) are the mechanism to address total pollutant loading, Washington's TMDL program is largely moribund, it issues very few TMDLs for toxic pollutants, and its TMDLs do not take into consideration the cumulative effects of multiple toxic pollutants. For these reasons, Washington's water quality criteria for toxic pollutants must address the need to provide full protection of these downstream waters.

While the Center is generally supportive of Ecology's proposal to establish more stringent criteria, the proposed criteria still raise concerns regarding their effects on Washington's threatened and endangered species, including salmonids, southern resident orcas, and amphibians. Illustratively, for example, Washington's proposed chronic cyanide criteria is significantly higher than the level recommended in Fish and Wildlife Service's (FWS) biological opinion on EPA's national 304(a) cyanide criteria for bull trout. The proposal also does not appear to account for or address amphibian sensitivity to these toxics—another issue identified in FWS's biological opinion on EPA's national 304(a) criteria for cyanide.

II. Washington's Proposed Cyanide Water Quality Criteria are Not Adequately Protective of Listed Species or Critical Habitats

Cyanide, Freshwater	**Proposed Acute (µg/L)**	**Proposed Chronic (µg/L)**	**ESA Consultation History, if Applicable**
Idaho	22	5.2	Both received a jeopardy determination[5]
EPA	22	5.2	Both received a draft jeopardy determination[6]
FWS Draft BiOp	13.77	0.68	Recommended level for bull trout[7]
NMFS Draft BiOp	None Provided	None Provided	
WA Ecology	12	2.7	Yet to be fulfilled.

a. Salmonids

Past consultations by FWS and NMFS on toxics criteria nationally and standards in several Pacific Northwest states indicate that the presence of cyanide threatens a number of federally listed salmonids species found in Washington, including bull trout, Chinook salmon, chum salmon, coho salmon, sockeye salmon, and steelhead.[8]

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[5] NATIONAL MARINE FISHERIES SERVICE, ENDANGERED SPECIES ACT SECTION 7(A)(2) BIOLOGICAL OPINION AND MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT ESSENTIAL FISH HABITAT (EFH) CONSULTATION, 299 (2014) [hereinafter NMFS Idaho Toxics BiOp].

[6] FISH AND WILDLIFE SERVICE, DRAFT BIOLOGICAL OPINION ON EPA'S PROPOSED PROGRAM OF CONTINUING APPROVAL OR PROMULGATION OF NEW CYANIDE CRITERIA IN STATE AND TRIBAL WATER QUALITY STANDARDS, 298 (2010) [hereinafter FWS National Cyanide Draft BiOp].

[7] *Id.* at 304.

[8] NMFS National Cyanide Draft BiOp at 270.

On the basis of these past actions, the bull trout appears to be the most sensitive of Washington's federally endangered and threatened species that is threatened by presence of cyanide. As detailed in the above chart, Ecology's proposed criteria for cyanide are higher than levels established through past biological opinions as necessary to adequately protect bull trout as required by the Endangered Species Act.[9]

Cyanide has been shown to cause reduced growth rates, reproductive performance, and survival in bull trout.[10] High chronic levels of cyanide can reduce the number of eggs spawned by females, reduce the number of eggs that hatch, and drastically reduce the survivorship of young fish. In the biological opinion for EPA's national 304(a) cyanide criteria, FWS found that exposure to bull trout at the chronic criterion proposed by EPA would likely "substantially reduce their reproduction" and that exposure at the proposed acute criterion would likely cause "substantial reductions in survival."[11] Based on this "magnitude of adverse effects," FWS found that the species was likely to be extirpated from the waters where they are exposed to cyanide toxicity at either criterion amount and suggested a chronic freshwater criterion of 0.68 µg/L—significantly lower than the chronic freshwater criterion of 2.7µg/L for cyanide the Ecology proposes here.

Washington should, therefore, revisit its proposed criteria and revise downward to a proposed chronic freshwater criterion for cyanide of no more than 0.68 µg/L, more so if updated science shows that a more stringent standard is necessary to protect bull trout and other salmonid populations; the Center does not take immediate issue with Washington's proposed acute freshwater criteria but request that it be revised as necessary subject to the outcome of further Washington-specific Endangered Species Act consultation activities.

b. Oregon Spotted Frog

In its 2010 consultation with EPA regarding national 304(a) water quality criteria for cyanide, FWS noted a lack of data for effects of cyanide on amphibian species but concluded that because amphibians are among the most sensitive species for a significant number of the pollutants examined, it is likely that amphibian species are highly sensitive to cyanide.[12] There, FWS used data for relative sensitivity of amphibians to rainbow trout, since rainbow trout is a species often used for criteria development.[13] Based on this analysis, FWS concluded that amphibian species are estimated to be as or more sensitive to cyanide than rainbow trout and thus likely to be adversely affected by exposure to cyanide at EPA's suggested chronic criterion of 5.2µg/L.

Since that consultation was completed, the Oregon spotted frog was listed as a threatened species in 2014 and has two critically imperiled populations in Washington.[14] The Oregon spotted frog is considered "the most aquatic native frog species in the Pacific Northwest (PNW)."[15] In making

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[9] FWS National Cyanide Draft BiOp at 304.

[10] FWS National Cyanide Draft BiOp at 221.

[11] *Id.*

[12] *Id.* at 250.

[13] *Id.*

[14] 79 Fed. Reg. 51,658 (Aug. 29, 2014).

[15] *Id*. at 51,661.

its listing determination, the FWS determined that toxic chemicals pose a hazard to the Oregon spotted frog.[16] Yet, Ecology does not even appear to have included the Oregon spotted frog on its list of relevant Endangered Species Act listed species.[17] Cyanide criteria must therefore be adjusted accordingly following Endangered Species Act consultation.

c. Orcas

Southern Resident Orcas could also be indirectly affected by Ecology's proposed cyanide criteria due to the possible reduction in salmonid populations.[18] Salmon, particularly Chinook salmon, are a key food source for the southern resident orcas and if proposed criteria harm salmonids, it is likely that the orcas will suffer as well. In NMFS consultation for EPA's national 304(a) cyanide criteria, the agency found that EPA's criteria would "reduce freshwater production of all listed salmon species, as well as non-listed salmon species where cyanide concentrations are allowed to reach EPA's recommended aquatic life criteria concentrations."[19]

III. Washington's Cadmium Water Quality Criteria are Not Adequately Protective of Listed Species and Critical Habitats

Cadmium is one of the most toxic metals to fish and can have various effects on aquatic organisms, including spinal deformities, inhibited respiration, immobility, and population alterations.[20] It can also cause neurotoxic effects in fish, manifesting as altered behavior, reduced growth, reproductive failure, and death.[21] Salmonids are particularly sensitive to cadmium pollution.[22] The principal acute effect of cadmium is gill toxicity, which causes an inability to breathe in aquatic organisms. Cadmium toxicity increases with water temperature.[23]

a. Freshwater Cadmium

Cadmium, Freshwater	**Proposed Acute (µg/L)**	**Proposed Chronic (µg/L)**	**ESA Consultation History, if Applicable**
Oregon	2.0	0.25	Acute standard received jeopardy determination.[24] Both standards likely to adversely affect listed species.

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[16] *Id*. at 51,689-90.

[17] *See* Washington Dep't. of Ecology, Proposed Updates to Aquatic Life Toxics Criteria, WAC 173-201A-240 Technical Support Document, 31-32 (2024) [hereinafter Ecology Technical Support Doc].

[18] NMFS National Cyanide Draft BiOp at 271.

[19] *Id.* at 256.

[20] NATIONAL MARINE FISHERIES SERVICE, JEOPARDY AND DESTRUCTION OR ADVERSE MODIFICATION OF CRITICAL HABITAT ENDANGERED SPECIES ACT BIOLOGICAL OPINION FOR ENVIRONMENTAL PROTECTION AGENCY'S PROPOSED APPROVAL OF CERTAIN OREGON ADMINISTRATIVE RULES RELATED TO REVISED WATER QUALITY CRITERIA FOR TOXIC POLLUTANTS, 270 (2012) [hereinafter NMFS OR Toxics BiOp].

[21] *Id.* at 271.

[22] *Id.* at 270.

[23] *Id.* at 271.

[24] *Id.* at 547

Idaho	1.3	0.6	NMFS independent analysis: standards not likely to adversely affect ESA listed Chinook salmon, sockeye salmon, or steelhead in the state, but noted that determination was location specific[25]
EPA 2016	1.8	[0.72]	No consultation.[26] Chronic criterion vacated to 2001 value; acute criterion levels remain in place but have been remanded back to EPA by court order[27]
EPA 2001	[2.0]	0.25	No consultation.
WA Ecology	1.3	0.41	Yet to be fulfilled.

For cadmium, Ecology proposes a freshwater acute criterion of 1.3µg/L and a chronic freshwater criterion of 0.41 µg/L. Since EPA's nationwide 304(a) freshwater cadmium criterion was vacated by court order, the maximum concentration reverted back to the 2001 criterion of 0.25 µg/L; at a minimum, Washington must do the same.

However, based on the outcome of Endangered Species Act consultation, these criteria must be set at a level that is protective of federally listed species in Washington. Comparatively, the FWS biological opinion for Oregon toxics stated that "chronic exposure to cadmium at the proposed chronic level [of 0.25µg/L] is considered to have adverse effects to all bull trout potentially exposed by reducing their fitness through a reduction in growth."[28] The NMFS biological opinion for Oregon similarly found that "listed species exposed to waters equal to the acute or chronic [cadmium] criteria concentrations will suffer acute and chronic toxic effects."[29]

a. Saltwater Cadmium

Cadmium, Saltwater	**Proposed Acute (µg/L)**	**Proposed Chronic (µg/L)**	**ESA Consultation History, if Applicable**
Oregon	40	8.8	Listed species will suffer acute or chronic toxic effects including mortality (moderate intensity) and sublethal effects (moderate intensity)[30]
EPA 2016[31]	33	7.9	
WA Ecology 2024	33	7.9	Yet to be fulfilled.

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[25] National Marine Fisheries Service, Comments on Environmental Protection Agency's Draft Aquatic Life Ambient Water Quality Criteria for Cadmium, 2 (Jan. 26, 2016).

[26] Center for Biological Diversity, EPA Approves Dangerous Water Quality Standards for Cadmium (April 1, 2016), https://www.biologicaldiversity.org/news/press_releases/2016/cadmium-04-01-2016.html.

[27] *Ctr. For Biological Diversity v. United States Env't Prot. Admin*, No. CV-22-00138-TUC-JCH, 2023 U.S. Dist. LEXIS 145674, at *44 (D. Ariz. Aug. 18, 2023).

[28] NMFS Oregon Toxics BiOp at 193.

[29] *Id.* at 270.

[30] *Id.* at 367.

[31] ENVIRONMENTAL PROTECTION AGENCY, AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA CADMIUM – 2016, XV (2016).

Ecology's proposed change to saltwater cadmium criteria is also likely to put threatened and endangered species at risk. Ecology proposes to set saltwater cadmium criteria at EPA's 304(a) chronic criterion of 33µg/L and acute criterion of 7.9µg/L. During the peer review of EPA's 304(a) criteria, it was pointed out that the development of these criteria was based on insufficient toxicity data for effects on anadromous salmon and that "only one study evaluated Cd toxicity in coho salmon smolts in saltwater conditions, and this was at nearly full seawater strength."[32] This was a concern because anadromous salmonids encounter cadmium at lower salinities. It is important to better understand the impact of varying levels of salinity on cadmium toxicity of anadromous fish species and incorporate those findings into Washington's criteria.

The same peer review also noted that sea level rise associated with climate change is likely to cause saltwater intrusion into salmonid spawning habitat making it particularly important to understand how salinity affects cadmium toxicity.[33] Comparatively, in NMFS's biological opinion for Oregon's cadmium criteria, the agency pointed out various issues with EPA's criteria derivation methods, including for saltwater cadmium.[34] Therefore, relying on the EPA's 304(a) will not necessarily result in adequate protection for threatened and endangered species and their critical habitats in Washington waters.

IV. Washington's Existing Mercury Water Quality Criteria are Not Adequately Protective of Listed Species or Critical Habitats and Must be Updated

Washington should learn from Idaho's mistakes and move forward with updating its water quality criteria for mercury.[35] In Idaho, which Ecology cites as a reason for not proceeding with amended mercury criteria at this time, EPA recently issued a proposed rule providing for both tissue and water column criteria for mercury.[36] The proposed chronic total mercury criteria are 0.225 µg/kg wet weight for muscle fish tissue, 0.162 µg/kg wet weight for whole body fish tissue, and 0.0021 µg/L for water column values.[37] In so doing, EPA asserted that these results were consistent with reasonable and prudent alternatives in the Services' biological opinions, and explained that it is important to include both a tissue and water column value in mercury and methylmercury criteria.[38]

In contrast, Washington is not only proposing to neglect updating its mercury criteria through this rulemaking but, in doing so, it is continuing to rely on an outdated freshwater chronic criterion which measures the proposed water column value at 0.012 µg/L. That is insufficient. First, "[b]ecause tissue measurements provide a more direct measure of toxicity for bioaccumulative pollutants such as mercury, . . . it appropriate to establish tissue criteria for these pollutants. However, criteria expressed as organism tissue concentrations can prove challenging

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[32] ENVIRONMENTAL PROTECTION AGENCY, EPA RESPONSE TO EXTERNAL PEER REVIEW COMMENTS ON THE DRAFT AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA FOR CADMIUM, 39 (2015).
[33] *Id.*
[34] NMFS OR Toxics BiOp at 366-367.
[35] *See, e.g., Northwest Environmental Advocates et al. v. United States Environmental Protection Agency*, Case No. 13-00263-DCN (Memorandum Decision and Order, ECF No. 103, July 19, 2021).
[36] *See* EPA, *Mercury Criterion to Protect Aquatic Life in Idaho*, 89 Fed. Reg. 24,758 (April 9, 2024).
[37] *Id.* at 24,774.
[38] *Id.* at 24,762, 24,768.

to implement in CWA programs such as NPDES permitting and Total Maximum Daily Loads (TMDLs) because these programs typically demonstrate that water quality standards are met by using a water column concentration to calculate a load-based effluent limit or daily load, respectively."[39] Both are needed.

Second, per Idaho's earlier FWS biological opinion, which Ecology quotes in its TSD at 82, "[b]ased on the above information, implementation of the proposed chronic criterion for mercury is likely to adversely affect growth, reproduction, and behavior in the bull trout throughout its distribution in Idaho." Idaho's proposed freshwater chronic criterion was 0.012 µg/L or the same as Washington's current criterion. This means that Washingtons mercury criteria are, a minimum, likely not to be sufficiently protective of bull trout.

V. EPA Methodologies for Derivation of Water Quality Criteria Do Not Prevent Adverse Effects to Listed Species and Critical Habitats

To the extent that Ecology based its proposed criteria on EPA's methodology, its analysis will suffer from the same issues as EPA's methodology—issues that are detailed in the NMFS biological opinions for EPA's national 304(a) cyanide criteria and Oregon's toxics criteria. The Center appreciates Ecology's attempts to account for some shortcomings in EPA's methodology by utilizing alternative derivation methods for some toxics and by using the 1st percentile of the genus toxicity data distribution rather than the 5th percentile. However, considering the extensive flaws underlying the toxicity data developed by EPA, using the 1st percentile of that data is not sufficient to protect endangered and threatened species.

For the freshwater acute cadmium criterion, for example, Ecology appears to be using the same derivation methods as EPA's recommendation;[40] for its chronic cadmium criterion, it used an EPA dataset and the 1st percentile of the toxicity distribution.[41] Although using the 1st percentile is more protective of species than the 5th, it is possible that issues in the underlying data still would not allow for a sufficiently protective calculation. Additionally, as discussed above, the proposed chronic cadmium criterion is in excess of the EPA criteria of 0.25µg/L, which is the current nationwide criteria following vacatur of EPA's 2016 criteria.

For cyanide, Ecology used new science in developing its proposed acute criterion, and an "acute to chronic" (ACR) ratio to develop its proposed chronic criterion because it lacked the toxicity data needed to calculate a chronic criterion using other methods.[42] The ACR is the ratio of the mean LC_{50} (concentration causing 50% lethality following acute exposure) for the species to the concentration following chronic exposure that causes a level of adverse effect that is the threshold of unacceptability.[43] Since the ACR was calculated by EPA and is based on underlying values that could suffer from the flaws in EPA's methodology highlighted by NMFS in its national 304(a) cyanide and Oregon toxics biological opinions, it is possible that the values proposed by Ecology reflect some of those issues as well.

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[39] *Id*. at 24,762.

[40] Ecology Technical Support Doc. at 60.

[41] *Id*. at 62.

[42] *Id*. at 127–128.

[43] NMFS National Cyanide Draft BiOp at 245.

Importantly, EPA's methodology for calculating toxicity values at which adverse effects occur *does not* adequately account for compounding stressors such as temperature, dissolved oxygen, and others on the responses of aquatic life to toxics.[44] In its biological opinion for Idaho's toxics standards, FWS recommended that any new standards be calculated "using a temperature/toxicity correlation"[45] to account for the inverse relationship between cyanide toxicity and temperature.[46] Dissolved oxygen is also important to account for because in environments with less than optimal dissolved oxygen, fish compensate by increasing gill movement and ventilation volume to maintain adequate oxygen volumes. Since cyanide is a powerful asphyxiant, additional cyanide in waters with low dissolved oxygen further stresses fish and reduces the lethal concentration at which survival is expected.[47] In the NMFS biological opinion for the national 304(a) cyanide criteria, the agency pointed out that EPA's attempts to "avoid confounding factors" in their analysis that prevents them from replicating realistic conditions in the wild.[48]

It is not clear whether or to what extent Ecology accounted for the increased toxicity of cyanide at low temperatures. This is an important consideration, particularly for salmonids that spawn in cold waters and could face serious consequences from increased toxicity of cyanide at these low temperatures. It is also unclear whether the proposed criteria accounted for the impact of low dissolved oxygen or concurrent exposures with other contaminants and stressors.

VI. Conclusion

Cyanide, cadmium, and mercury pollution threatens Washington's many endangered and threatened aquatic species. The Center urges Ecology to propose criteria that are sufficiently protective of Washington's federally protected endangered and threatened species, including by taking into consideration toxic pollution from upstream states and accounting for EPA's methodological limitations.

Please contact Hannah Connor at hconnor@biologicaldiversity.org with any questions.

Sincerely,

Hannah Connor
Environmental Health Deputy Director
Center for Biological Diversity
hconnor@biologicaldiversity.org

Trisha Sharma

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[44] *Id.* at 266.

[45] FISH AND WILDLIFE SERVICE, BIOLOGICAL OPINION FOR THE WATER QUALITY STANDARDS FOR NUMERIC WATER QUALITY CRITERIA FOR TOXIC POLLUTANTS (2015) at 277 [hereinafter FWS Idaho Toxics BiOp].

[46] *Id.* at 143.

[47] NMFS National Cyanide Draft BiOp at 221.

[48] *Id.* at 266.

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Ctr. for Biological Diversity v. United States Env't Prot. Admin.

United States District Court for the District of Arizona

August 18, 2023, Decided; August 18, 2023, Filed

No. CV-22-00138-TUC-JCH

Reporter
2023 U.S. Dist. LEXIS 145674 *

Center for Biological Diversity, Plaintiff, v. United States Environmental Protection Administration, et al., Defendants.

Core Terms

consultation, species, cadmium, nationwide, effects, water-quality, recommendations, stringent, revised, criterion, waters, biological, chronic, agency's action, vacatur, freshwater, habitat, regulations, departure, environmental, reasonable probability, cumulative, guidelines, pollutant, agencies, turtles, sea, water quality standards, water quality, indirectly

Counsel: **[*1]** For Center for Biological Diversity, a non-profit organization, Plaintiff: Claire Tonry, LEAD ATTORNEY, PRO HAC VICE, Law Office of Claire Tonry, Seattle, WA; Hannah Mary Margaret Connor, LEAD ATTORNEY, PRO HAC VICE, Center for Biological Diversity - Washington, DC, Washington, DC; Richard Adam Smith, LEAD ATTORNEY, PRO HAC VICE, Smith & Lowney PLLC, Seattle, WA.

For United States Environmental Protection Administration, Michael S Regan, in his official capacity, Defendants: Clifford Eugene Stevens, Jr., LEAD ATTORNEY, US Dept of Justice - Environment & Natural Resources Div., Washington, DC.

Judges: John C. Hinderaker, United States District Judge.

Opinion by: John C. Hinderaker

Opinion

ORDER

In this case, Plaintiff Center for Biological Diversity (the "Center") asserts the Endangered Species Act ("ESA") requires Defendant Environmental Protection Agency ("EPA") to consult with expert agencies before issuing recommended water-quality criteria. *E.g.*, Doc. 29 at 16-17.[1] EPA responds that the ESA only requires EPA to consult later, when states apply to adopt or modify EPA's recommended criteria. *E.g.*, Doc. 31 at 12-13. The issues are fully briefed, *see* Docs. 32, 37, and the Court heard oral argument on July 18, 2023. Doc. 38 ("Hr'g Tr.").

Although **[*2]** EPA's position is defensible, the Court agrees with the Center that issuing water-quality criteria recommendations is an "action" under the ESA that requires consultation. The Court therefore will grant in part summary judgment for the Center, deny summary judgment for EPA, vacate EPA's 2016 chronic freshwater 304(a) cadmium criterion, and remand EPA's 2016 304(a) cadmium criteria for proceedings consistent with this Order.

I. Background

This case arises from the intersection of the ESA and the Clean Water Act ("CWA"). The ESA is "the most comprehensive legislation for the preservation of endangered species ever enacted by any nation." *Tenn. Valley Auth. v. Hill, 437 U.S. 153, 180 (1978)*. Its heart is section 7(a)(2). *W. Watersheds Project v. Kraayenbrink, 632 F.3d 472, 495 (9th Cir. 2011)*. Section 7(a)(2) provides:

> Each Federal agency shall, in consultation with and with the assistance of the Secretary, insure that any action authorized, funded, or carried out by such agency (hereinafter in this section referred to as an "agency action") is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of [critical] habitat of such

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[1] All page citations are to the ECF document page number unless otherwise specified.

> species....

16 U.S.C. § 1536(a)(2). The Department of the Interior, through the United States Fish and Wildlife Service ("FWS"), and the Department **[*3]** of Commerce, through the National Marine Fisheries Service ("NMFS" and together with FWS "the Services"), promulgated regulations interpreting and implementing ESA Section 7(a)-(d). 51 Fed. Reg. 19926-01; 50 C.F.R. § 402.01. These regulations provide:

> Each Federal agency shall review its actions at the earliest possible time to determine whether any action may affect listed species or critical habitat. If such a determination is made, formal consultation is required....

50 C.F.R. § 402.14(a). By contrast, if an agency determines its action will have "no effect," then consultation is not required. *See* San Luisa & Delta-Mendota Water Auth. v. Jewell, 747 F.3d 581, 596 (9th Cir. 2014) (citing 50 C.F.R. § 402.14).

The CWA exists to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" by reducing, and eventually eliminating, the discharge of pollutants into these waters. 33 U.S.C. § 1251(a). To that end, the CWA requires each state to adopt water quality standards for all the waters of that state and to review them at least every three years. *Id.* §§ 1313(a), (b), (c)(1) (2000). EPA administers the CWA. 33 U.S.C. § 1251(d). As the CWA's administrator, EPA must develop and publish recommendations for states' water quality criteria, called "304(a) criteria." *Id.* §§ 1313(a)-(d), 1314(a). As of 2015, states must either adopt EPA's 304(a) criteria or explain their decision not to, justifying any departure based on "sound scientific **[*4]** rationale" and "scientifically defensible methods." *See* 40 C.F.R. §§ 131.11, 131.20(a). Specifically,

> States must adopt those water quality criteria that protect the designated use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use.
>
> ....

In establishing criteria, States should:

> (1) Establish numerical values based on:
>
> > (i) 304(a) Guidance; or
> >
> > (ii) 304(a) Guidance modified to reflect site-specific conditions; or
> >
> > (iii) Other scientifically defensible methods;
>
> (2) Establish narrative criteria or criteria based upon biomonitoring methods where numerical criteria cannot be established or to supplement numerical criteria.

40 C.F.R. § 131.11. Likewise,

> [I]f a State does not adopt new or revised criteria for parameters for which EPA has published new or updated CWA section 304(a) criteria recommendations, then the State shall provide an explanation when it submits the results of its triennial review to the Regional Administrator consistent with CWA section 303(c)(1) and the requirements of paragraph (c) of this section.

40 C.F.R. § 131.20. Whatever course states choose to take, they must seek EPA's permission before revising their **[*5]** water-quality standards. 33 U.S.C. § 1313(c). If a state fails to maintain CWA standards, EPA is also required to promulgate water quality standards for that state directly. 33 U.S.C § 1313(c)(4).

The Center and EPA agree on the material facts. *Compare* Doc. 29 at 11-17, *with* Doc. 31 at 10-15. In 2001, EPA and the Services signed a Memorandum of Agreement (MOA) "to enhance coordination between [the] agencies so [they could] best carry out [their] responsibilities under the CWA and ESA." 66 Fed. Reg. 11202; AR 4768-83. For its part, EPA agreed it would consult with the Services at the national level. AR 4778. The MOA stated:

> National 304(a) consultations will ensure a consistent approach to evaluating the effects of pollutants on species .... National consultations will also ensure better consideration of effects on species whose ranges cross State boundaries.

66 Fed. Reg. 11202, 11212; AR 4778. In 2007, EPA began its first national consultation under the MOA for cyanide. AR 4790. In 2010, the Services issued draft Biological Opinions finding that EPA's proposed cyanide criteria likely would jeopardize more than 200 species. *See* AR 5089-901; AR 5392. FWS noted:

> [T]his biological opinion does not include incidental take exemptions [(permitting incidental harms to protected species in **[*6]** certain circumstances)] .... Therefore, it will be necessary for EPA to conduct subsequent, step-down ESA section 7 consultations ... on individual State and Tribal water quality standards .... [FWS] anticipate[s] much of the [nationwide] analysis will carry over, so that the [state-level] consultation ... need only focus on

> potential effects of elements that were not fully considered here.

AR 4788; *accord* AR 5395 (NMFS's draft biological opinion). The parties disagree to some extent what happened next. EPA cites its own letter to the Services to assert EPA and the Services agreed to end the cyanide national consultation for a variety of reasons. *See* AR 4766-67. The Center asserts "[t]here are no contemporaneous documents in the record ... confirming this decision was made." Doc. 29 at 15-16 (citing Docs. 21-2, 26-2, 28-2). In any event, the parties agree nothing further came of the 2001 MOA after the Services' issued their draft biological opinions.

In 2016, EPA revised its 304(a) criteria for cadmium. *See* Doc. 29 at 12; Doc. 31 at 10. Cadmium is a metal pollutant that can harm aquatic species, particularly in freshwater species and long-lived species. *See* Doc. 29 at 11; Doc. 31 at 10. Harmful exposure **[*7]** to cadmium may be either acute or chronic. *See* Doc. 29 at 11; Doc. 31 at 11. Acute exposure causes increased mortality in organisms, and chronic exposure affects their growth, reproduction, immune and endocrine systems, development, and behavior. AR 725. Cadmium pollution in water predominantly results from human sources, such as mining or industrial waste. *See* Doc. 29 at 11; Doc. 31 at 10. The Services have noted that increased cadmium levels would risk harm to many listed species, including salmon, steelhead, sturgeon, sea turtles, corals, and mussels. *See* AR 1628-29, 1656, 5463. Of the four categories of allowable cadmium concentration—acute and chronic for freshwater, and acute and chronic for marine/estuarine waters—EPA increased only the chronic freshwater criterion; EPA decreased the criteria for the other three categories. *See* Doc. 29 at 13; Doc. 31 at 11. Before revising the criteria, EPA followed its own process for major criteria revisions, which included data review, public notice, a call for additional data, peer review, public input, and publication of the final criteria in the Federal Register. *See* *63 Fed. Reg. 67548, 67549*; AR 722-883.

EPA did not consult with NMFS and FWS when it revised and **[*8]** published the new cadmium criteria. *See* Doc. 29 at 12-13; Doc. 31 at 16. Instead, EPA performed state-level consultations for each state that has revised its cadmium criteria since the 2016 revision. *See* Doc. 31 at 13; Hr'g Tr. at 65:19-25. EPA justified its state-by-state approach in a response to the Center's public comment on its 2016 criteria. *See* AR 871. EPA noted that national consultations are inefficient because "any gains in consistency from an initial national consultation are likely to be undone by inconsistencies among the follow-up consultations at the field office level." AR 871. EPA also noted that even if it conducted nationwide consultations, they would not "obviate the need for further consultation" at the lower level. AR 871. EPA also acknowledged that nationwide consultation would "tend to produce" more stringent 304(a) criteria. *See* AR 871; *see also* Doc. 31 at 12.

II. Legal Standards

A. Summary Judgment Standard

Summary judgment is required if "the pleadings, depositions, answers to interrogatories, and admissions on file, together with the affidavits, if any, show that there is no genuine issue as to any material fact and that the moving party is entitled to judgment **[*9]** as a matter of law." *Fed. R. Civ. P. 56(c)*. Summary judgment is a particularly appropriate tool for resolving claims challenging agency action. *See* *Occidental Eng'g Co. v. INS, 753 F.2d 766, 770 (9th Cir. 1985)*.

B. Review Standard

The Court reviews de novo an agency's interpretation of a statute outside its administration. *Karuk Tribe of Cal. v. U.S. Forest Serv., 681 F.3d 1006, 1017 (9th Cir. 2012)* (en banc) (citations omitted). The Court may set aside an agency's action if the action was "arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law." *5 U.S.C. § 706(2)(A)*.

III. Analysis

A. Standing

The parties first dispute whether the Center has standing to bring its case. Article III standing requires "(1) a concrete and particularized injury that is 'actual or imminent, not conjectural or hypothetical'; (2) a causal connection between the injury and the defendant's challenged conduct; and (3) a likelihood that a favorable decision will redress that injury." *Pyramid Lake Paiute Tribe of Indians v. Nev. Dep't of Wildlife, 724 F.3d 1181, 1187 (9th Cir. 2013)* (quoting *Lujan v. Defs. of Wildlife, 504 U.S. 555, 560, 112 S. Ct. 2130 (1992)*). When a plaintiff is an organization, plaintiff's members must set forth their "reasonable concerns about the effects of [the challenged activity]" and how that activity "directly affected those [members'] recreational, aesthetic, and economic interests." *Friends of the Earth v. Laidlaw Envtl. Servs., 528 U.S. 167, 183-84 (2000)*. "[T]he desire to use or observe an animal species, even for purely [a]esthetic purposes, is undeniably a cognizable interest **[*10]** for purposes of standing." *Lujan, 504 U.S. at 562-63*.

a. The Center establishes injury-in-fact.

Injury-in-fact from a procedural injury is established by showing "the procedures in question are designed to protect some threatened concrete interest ... that is the ultimate basis of [a plaintiff's] standing.' *Nat. Res. Def. Council v. U.S. Env't Prot. Agency, 38 F.4th 34, 54 (9th Cir. 2022)* ("NRDC (2022)") (citing *Salmon Spawning & Recovery All. v. Gutierrez, 545 F.3d 1220, 1225 (9th Cir. 2008)*). EPA somewhat ambivalently disputes that the Center has established injury-in-fact. Doc. 31 at 16 (challenging "at least" the second and third prongs); *see also* Doc. 37 at 9-10 (emphasizing aspects of EPA's MSJ challenging imminent injury). Either way, the Court must resolve the question to its satisfaction. *See Lance v. Coffman, 549 U.S. 437, 439 (2007)* ("A federal court has an obligation to assure itself of jurisdiction before proceeding to the merits[.]").

First, the Center alleges a procedural injury because it claims EPA violated the ESA when EPA issued revised 304(a) criteria without consulting the Services. Doc. 29 at 18. Failure to conduct a required consultation is a procedural injury for standing purposes. *Citizens for Better Forestry v. U.S. Dep't of Agric., 341 F.3d 961, 969 (9th Cir. 2003)*. Second, the Center's members assert that cadmium threatens their educational, professional, and recreational activities associated with protected species. Doc. 29 at 18; *see also, e.g.*, Doc. 29-1 (declarant **[*11]** Burdette describing personal and professional interests extending to South Atlantic and Gulf Regions (more than 20 states), Kemp's ridley sea turtles that range between Nova Scotia, North Carolina, Texas, and Mexico, and Atlantic sturgeon that range between New York, North Carolina, and Georgia). Mr. Burdette's interests, like the other declarants, indicate a "tangible, continuing connection" to states and species impacted by EPA's decision not to conduct nationwide consultation. *See Ecological Rts. Found. v. Pac. Lumber Co., 230 F.3d 1141, 1148 (9th Cir. 2000)*. Third, the ESA consultation requirement was designed to "advance the ESA's overall goal" of protecting endangered species, *see Salmon Spawning & Recovery All., 545 F.3d at 1225-26*, including the Kemp's ridley sea turtles and Atlantic sturgeon the Center's members have a concrete interest in. Finally, the Center's members adequately allege their interest is threatened by EPA's state-by-state approach to water-quality consultation, which the Center says insufficiently provides for cumulative and inter-state effects compared with nationwide consultation. Doc. 29 at 18. More generally, and as discussed in more detail below, *see* §§ III(A)(b), (B), the Court finds that the Center's alleged injury is actual and imminent because EPA's current approach is deficient in ways that **[*12]** tend to produce less stringent criteria and have been adopted or likely will be adopted by most states soon.

b. The Center establishes causation.

Given an alleged procedural injury, "[t]he causation requirement is satisfied by showing a 'reasonable probability of the challenged action's threat to [plaintiffs'] concrete interest.'" *NRDC (2022), 38 F.4th at 54-55* (citing *Nat'l Fam. Farm Coal. v. EPA, 966 F.3d 893, 910 (9th Cir. 2020)*). The challenged action here is EPA's decision not to conduct nationwide consultation. The Center alleges EPA's decision threatens the Center's interests by inadequately considering cumulative and inter-state effects. This threat either has materialized or will materialize imminently. For example, Mr. Burdette describes his ongoing interest and plans to observe Kemp's ridley sea turtles and Atlantic sturgeon, which are found near his home in North Carolina but range far outside state waters. Doc 29-1 ¶ 22. North Carolina has adopted EPA's 2016 criteria. AR 4641-87. Similarly, declarant Miller describes an ongoing interest in and plans to observe chinook salmon and green sturgeon, which are found near his home in Oregon but range between Washington and California. Doc 29-4 ¶¶ 7, 13. Oregon and California currently use the EPA's 2001 304(a) criterion **[*13]** for chronic freshwater cadmium and are overdue to review and update it. *See* Doc. 29 at 37, 40; *40 C.F.R. § 131.20(a)*. Washington currently uses EPA's 1985 304(a) criteria together with EPA's National Toxics Rule and is overdue to review and update them. *See* Doc. 29 at 21; *40 C.F.R. §§ 131.20(a)*, 131.36. If, as the Center alleges, EPA's current state-by-state approach to Section 7 consultation is inadequate, Mr. Burdette and Mr. Miller's interests, like the other declarants, are threatened to a reasonable probability. In that case, the threat materialized for Mr. Burdette and the other declarants whose states adopted EPA's 2016 criteria. And the threat currently hangs over Mr. Miller and those declarants whose states are overdue to review and revise their water quality standards.[2] The Court thus turns to the question of whether EPA's current approach creates a reasonable probability of harm and thereby threatens the Center's concrete interests.

First, EPA's current approach creates a reasonable probability of harm because it likely results in less stringent criteria than nationwide consultation would produce. EPA acknowledges that nationwide consultation likely would "tend to produce" more stringent criteria. Doc. 31 at 12; AR 871 (response **[*14]** to the Center's public comment on EPA's 2016 criteria).[3] That result is intuitive because EPA's criteria would then have to account for those states with the highest risk and exposure to cadmium. EPA argues that more stringent criteria are inefficient because more states would have to depart from them, causing greater expense overall. *See* Doc. 31 at 36 (defining the purpose of 304(a) criteria as to alleviate states' "burden"). But the ESA instructs agencies to give endangered species "first priority," "whatever the cost." *Tenn. Valley Auth., 437 U.S. at 184-85, 194*. Agencies must review their actions "at the earliest possible time," *50 C.F.R. § 402.14*, "to avoid piecemeal chipping away of habitat ... [that] eviscerate[s] Congress' intent to give the benefit of the doubt to [threatened] species." *See* *Conner v. Burford, 848 F.2d 1441, 1454 (9th Cir. 1988)* (citation omitted). EPA's argument essentially turns that mandate on its head. *See* Doc. 31 at 12 ("allowing the most sensitive location-specific potential concerns" for protected species "to drive national recommendations would inappropriately distort those recommendations."); AR 871 ("EPA believes that it is more efficient [for states to modify 304(a) criteria to make them more stringent than to modify 304(a) criteria to make them less stringent]."). **[*15]** The ESA requires primary consideration of protected species, not efficiency or cost-effectiveness. EPA's contrary emphasis drives the point home. EPA emphasizes again and again that nationwide consultation would be cumbersome and that more states would have to seek site-specific variances. But that is the point. Nationwide consultation would produce more stringent criteria, which gives the "benefit of the doubt" to protected species. The Center and its members seek a result consistent with the ESA's policy. To the extent that result is inconsistent with EPA's policy, EPA's policy must yield.

Second, EPA's approach creates a reasonable probability of harm because NMFS believes EPA's approach is inadequate. NMFS is one of the two agencies entrusted with promulgating and administering ESA's enacting regulations. NMFS is also a subject-matter expert, responsible for understanding and quantifying risks to protected species. NMFS's interpretations of ESA's enacting regulations are therefore highly relevant. In 2016, NMFS commented on EPA's 2016 304(a) criteria when EPA sought public comment. *See* AR 1628-29. NMFS asserted EPA's decision to consult "only when [EPA] approves state proposed **[*16]** water quality criteria results in a piecemeal approach when considering implications of such guidelines for broadly ranging species." AR 1629. NMFS urged EPA to "implement an assessment strategy that takes into account the aggregate effects of EPA's authorizations of state proposed water quality criteria such that EPA can ensure that these authorizations taken together do not jeopardize the continued existence of ESA listed species[.]" AR 1629. NMFS specifically identified concerns with sturgeon and sea turtles. *See* AR 1628. For sea turtles, NMFS wrote:

> The Oregon consultation concluded that ESA listed sea turtles would be unlikely to accumulate a significant amount of cadmium specifically from state waters. However, EPAs cadmium guidelines apply to all waters of the US so exposures would occur throughout the US portion of sea turtle ranges. Further cadmium accumulates in tissue with age and sea turtles are understood to be very long lived species. For example, green turtles reach sexual maturity between 20 and 50 years of age. For such long lived species we would need to consider whether cadmium accumulation from US waters over a lifespan would reach tissue concentrations directly **[*17]** resulting in or contributing to adverse effects.

AR 1628. NMFS's concerns mirror the Center's and its

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[2] The Court assumes states will comply with the law. Here, that means the Court assumes states overdue to review and revise their water-quality standards will do so immediately. The alternative—permitting hypothetical failure to comply with the law to defeat standing—would set the standing threshold impossibly high.

[3] In its Reply, EPA tries to distance itself from this admission. *See* Doc. 37 at 11. EPA emphasizes that nationwide consultation would "'tend to produce' recommended criteria 'that states would need to modify to make less stringent,'' not that more stringent criteria "would in fact occur." *Id.* That distinction is irrelevant because a tendency to produce something is also a reasonable probability that it will occur.

declarants'. *See* Doc. 29 at 29; Doc. 29-4 ¶ 23. NMFS uniquely understands the strengths and weaknesses of its consultations with EPA. If, as the record shows, NMFS believes its state-by-state consultations with EPA inadequately consider cumulative and inter-state effects, then they likely do. At the very least, NMFS's concerns create a reasonable probability of harm from EPA's decision not to conduct nationwide consultation.

Third, EPA's approach creates a reasonable probability of harm because the record shows that formal consultations do not completely consider cumulative and inter-state effects. North Carolina, for example, sought to adopt EPA's 2016 criteria, and EPA accordingly consulted formally with NMFS. *See* AR 11699-995. NMFS's biological opinion focused almost entirely on North Carolina, not species' lifecycle or migratory path. *See id.* EPA insists that biological opinions consider cumulative and inter-state effects through the definition of the "environmental baseline" and "action area." Doc. 31 at 34-35. EPA's argument is not supported by the record. Cumulative effects are **[*18]** limited to those within "the action area." AR 11804; 50 C.F.R. § 402.02 (same). Similarly, the "environmental baseline" is "the condition of the listed species or its designated critical habitat *in the action area*, without the consequences to the listed species or designated critical habitat caused by the proposed action." AR 11751 (emphasis added); 50 C.F.R. § 402.02 (same). The "action area" includes "all waters the criteria will be applied to within the state ... and any waters in other states affected by [that state's] water quality[.]" AR 11733; 50 C.F.R. § 402.02. Essentially, a biological opinion considers 304(a) criteria impacts to species within the state and within waters downstream of the state. It does not, as EPA contends, thereby focus on the lifecycle of long-lived and migratory species who range both upstream and downstream of a state. EPA's citation to the Services' 2019 revision of Section 7 regulations is misplaced. *See* Doc. 31 at 34-35 (citing 84 Fed. Reg. 44,976, 44,994-95 (Aug. 27, 2019)). The Services' discussion of the "effects of climate change both 'within and outside the action area'" does not suggest the Services analyze species' life history outside the action area. Climate change appears to be a unique aspect of biological opinions. *See, e.g.*, AR 11804-05 **[*19]** (setting apart climate change in a subsection of cumulative effects within the action area). The other state consultations show similar shortcomings. The record of formal state-by-state consultations thus shows that EPA's approach creates a reasonable probability of harm by failing to consider cumulative and interstate effects completely.

Finally, EPA's approach creates a reasonable probability of harm even if formal consultations are not deficient because EPA can conduct informal consultations. Informal consultations do not require a biological opinion from the Services. *See* 50 C.F.R. § 402.13. Instead, EPA typically produces a biological assessment or evaluation, which avoids a formal consultation if the Services concur with its conclusions. *See* 50 C.F.R. §§ 402.13, 402.14(b)(1). Most of EPA's consultations are informal. Hr'g Tr. at 66:2-5. EPA concedes that these informal consultations do not use the "environmental baseline" term, but insists they still consider cumulative effects. Doc. 31 at 35 (citing, *e.g.*, AR 3289-90 (Mississippi), 3667 (Northern Mariana Islands)). EPA's citations do not support its claim. The Mississippi Biological Evaluation, for example, mentions bioaccumulation but does not consider inter-state effects. **[*20]** AR 3289-90. Similarly, the Northern Mariana Islands consultation mentions "bioaccumulation" but only in contrast with "direct effects." AR 3667. The other informal consultations have similar shortcomings. Thus, even if formal consultations sufficiently considered cumulative and interstate effects, EPA's state-by-state approach would still create a reasonable probability of harm through its use of informal consultations.

c. The Center establishes redressability.

Given a procedural violation, the redressability prong is satisfied by showing that the agency decision "could be influenced" by the procedures at issue. NRDC (2022), 38 F.4th at 56 (citing Hall v. Norton, 266 F.3d 969, 977 (9th Cir. 2001)). Here, nationwide consultation on cadmium 304(a) criteria would require EPA to collaborate with an expert agency, and 304(a) criteria "could be influenced" as a result. *See id.*; 50 C.F.R. §§ 402.13-402.14. That is the purpose of consultation. EPA also acknowledges that "nationwide consultation for Section 304(a) criteria would tend to produce more stringent recommendations." Doc. 31 at 12. Therefore, EPA's approach to consultation could influence EPA's determination of 304(a) criteria.

d. EPA's objections are unpersuasive.

EPA objects that the Center lacks standing because any harm flows from multiple subsequent **[*21]** regulatory steps, specifically a state-level process, expert agency consultation, and EPA review and approval. Doc. 31 at 17. EPA focuses on declarant Miller as an example, asserting that Mr. Miller "provides no evidence that [California, Oregon, and Washington] will adopt EPA's 2016 recommended 304(a) criteria for cadmium without modification[.]" Doc. 31 at 18. EPA's point is two-fold: any injury flows from subsequent regulatory steps, not the 304(a) criteria, and, for the same reason, nationwide consultation cannot redress that injury. *See id.* at 17 (citing *Nat. Res. Def. Council, Inc. v. EPA, 16 F.3d 1395, 1408 (4th Cir. 1993)* ("NRDC (1993)"); *Arizona Yage Assembly v. Garland, 595 F. Supp. 3d 869, 880 (D. Ariz. 2022)*).

EPA's argument and cases are unpersuasive for several reasons. First, the injury the Center asserts is not too tenuously connected to EPA's failure to consult because states are required to explain any departure from EPA's criteria and because most states adopt EPA's criteria verbatim. *See also supra* § III(B). Just as 304(a) criteria affect state water-quality standards generally, EPA's procedures generating 304(a) criteria—including nationwide or state-by-state consultation—affect state water-quality standards. That is enough for procedural causation. For redressability, the bar is even lower—the *possibility* ***[*22]*** of influence is enough. *See NRDC (2022), 38 F.4th at 56*. As discussed throughout this Order, the Center has shown more than a possibility. Second, *NRDC (1993)* is not helpful to EPA because its reasoning was based in part on the lack of "compulsory language" accompanying 304(a) criteria, and it was decided before EPA began requiring states to explain any departure from EPA's criteria. *See 16 F.3d at 1407-08*.[4] Similarly, in *Arizona Yage Assembly*, plaintiffs lacked standing because the interim guidance at issue "does not require Plaintiffs to do anything or prevent them from doing anything[.]" *595 F. Supp. 3d at 880*. That is not the case here, where states must justify any departure from EPA's 304(a) criteria. The Center and its declarants are hardly imagining things when they observe an identity between EPA's 304(a) criteria and most states' water-quality standards. EPA's regulations may "only" require states to justify any departure, but that requirement appears to have a powerful effect on what they actually do. That is enough to remove the Center's concerns from the realm of attenuated connections and speculation. But even if that were not enough, the fact that at least 25 states, tribes, and territories have adopted EPA's 2016 criteria means any shortcomings stemming **[*23]** from a failure to consult nationwide have actually materialized. For these reasons, the Court finds that the Center has standing to challenge EPA's decision to revise its 304(a) criteria without conducting nationwide consultation.

B. Issuing 304(a) criteria is an "action" under the ESA.

Section 7 of the ESA defines agency action as "any action authorized, funded, or carried out by [a federal] agency." *16 U.S.C. § 1536(a)(2)*. The ESA implementing regulations provide:

> Action means all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies in the United States or upon the high seas. Examples include, but are not limited to: (a) actions intended to conserve listed species or their habitat; (b) the promulgation of regulations; (c) the granting of licenses, contracts, leases, easements, rights-of-way, permits, or grants-in-aid; or (d) actions directly or indirectly causing modifications to the land, water, or air.

50 C.F.R. § 402.02. Section 7 and its requirements "apply to all actions in which there is discretionary Federal involvement or control." *50 C.F.R. § 402.03*.

The ESA's appearance of broad meaning is not deceiving. Agencies must give endangered species "first priority," even over the agencies' **[*24]** primary missions, "whatever the cost." *Tenn. Valley Auth., 437 U.S. at 184-85, 194*. To that end, "'agency action is to be 'construed broadly.'" *Karuk Tribe, 681 F.3d at 1021* (citation omitted). Unsurprisingly, this broad construction leads courts to find that many agency activities are "actions." *See, e.g.*, *Karuk Tribe, 681 F.3d at 1021* (collecting cases). Some examples are straightforward. *See, e.g.*, *Washington Toxics Coal. v. Env't Prot. Agency, 413 F.3d 1024 (9th Cir. 2005)* (registering a pesticide is an action); *NRDC (1993), 16 F.3d at 1395* (approving states' water-quality standards is an action); *N. Plains Res. Council v. U.S. Army Corps of Engineers, 454 F. Supp. 3d 985 (D. Mont. 2020)* (permitting certain activities nationwide is an action); *see also W. Watersheds Project v. Matejko, 468 F.3d 1099, 1108 (9th Cir. 2006)* ("'inaction' is not 'action'"). Other examples of agency action are more subtle. *See, e.g.*, *Env't Def. Ctr. v. Bureau of Ocean Energy Mgmt., 36 F.4th 850 (9th Cir. 2022)* (issuing guidelines for oil treatment is an action), *cert. denied sub nom. Am. Petroleum Inst. v. Env. Def. Ctr., No. 22-703, 2023 WL 3801206 (U.S. June 5, 2023)*; *Pac. Rivers Council v. Thomas, 30 F.3d 1050 (9th Cir. 1994)* (revising criteria

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[4] *NRDC (1993)* was also decided based on whether issuing 304(a) criteria is a "final action" under the APA, not standing in an ESA context. *Id.*

for future forest management is an action); *Lane County Audubon Society v. Jamison, 958 F.2d 290 (9th Cir. 1992)* (setting criteria for selection of logging land is an action); *see also Marbled Murrelet v. Babbitt, 83 F.3d 1068, 1073-74 (9th Cir. 1996)* (informal compliance advice is not an action).

The Court analyzes whether a given activity is an "action" under the ESA in two steps: first, the Court determines "whether the agency affirmatively authorized, funded, or carried out the underlying activity"; second, the Court determines "whether the agency had discretion to influence or change the [underlying] activity for the benefit of a protected species." *See Karuk Tribe, 681 F.3d at 1021*.

a. Issuing [*25] 304(a) criteria is affirmative because 304(a) criteria establish a condition under which states must explain themselves, "directly or indirectly causing modifications to the ... water."

To start, the Court notes that agency activity itself is not the question, but rather agency activity relative to "underlying activity"—here state adoption of water-quality standards.[5] Agency activity relative to underlying activity is affirmative if it involves "decision[s] about whether, or under what conditions, to allow ... [this underlying] activity to proceed." *Id. at 1027*. At oral argument, the Center emphasized one of the non-exclusive examples of agency action provided by the enacting regulations: "actions directly or indirectly causing modifications to the land, water, or air." *See* Hr'g Tr. at 83:24-84:02 (citing 50 C.F.R. § 402.02).

Here, EPA's 304(a) activity does not decide *whether* state activity may proceed. But EPA's activity does decide *how* a state may proceed: with or without explanation. If a state proposes to adopt EPA's criteria, nothing further is required of it. If a state proposes not to adopt or to depart from EPA's criteria, the state must explain or justify that departure. *See 40 C.F.R. §§ 131.11*, 131.20(a). So although EPA's 304(a) **[*26]** activity does not authorize states to proceed outright, it does decide a condition under which states may proceed. As discussed above, § III.A(b), and below, § III.B(b), EPA's 304(a) criteria both directly and indirectly cause modifications to the water. Those points lead the Court to agree with the Center that EPA's activity issuing 304(a) criteria is affirmative under the ESA and associated regulations.

b. Issuing 304(a) criteria is discretionary and influences states directly and indirectly through the CWA's adopt-or-explain requirement and in other ways.

The second step in the Court's agency "action" analysis has two parts. First, agency actions must be discretionary. *Karuk Tribe, 681 F.3d at 1024* (citation omitted). An agency "cannot escape its obligation to comply with the ESA merely because it is bound to comply with another statute that has consistent, complementary objectives." *Id.* (citation omitted). The competing statutory objective need only leave the agency "some discretion." *Id.* (citation omitted). Second, agency actions must influence states' activity to the benefit of protected species. *Id.* (citation omitted). Otherwise—if an agency's activity could *not* influence an activity to benefit a listed species—consultation **[*27]** would be a "meaningless exercise." *Karuk Tribe, 681 F.3d at 1024* (citation omitted).

Here, and first, EPA's activity issuing 304(a) criteria demonstrates broad discretion throughout its process. To begin the process, EPA chooses when to update the criteria. *See 33 U.S.C. § 1314(a)(1)* (EPA shall revise 304(a) criteria "from time to time"). Once begun, EPA's activity issuing 304(a) criteria is also discretionary because EPA generates the criteria based on its own judgment and assumptions. *See, e.g.*, AR 5410 ("much of [EPA's 304(a) guidance] is necessarily qualitative rather than quantitative; much judgment will usually be required to derive a water quality criterion"); AR 1799 (identifying EPA's decision to discount some findings and studies over others); AR 812-22 (numerous judgments in the external peer review process). Finally, EPA's activity issuing 304(a) criteria is discretionary because EPA may choose how to respond to peer review and public comment. AR 864, 868 (accommodating studies); AR 874 (modifying dataset).

Second, EPA's activity issuing 304(a) criteria influences states directly and indirectly through the adopt-or-explain requirement. The fact that states must explain

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[5] If an agency's activity "authorizing, funding, or carrying out" its own programs were sufficient to be an "agency action," then EPA's activity would be affirmative because it conducted a comprehensive data review, issued a public notice and call for additional data, developed draft criteria, issued another public notice and call for peer review and public input, and published the final criteria in the Federal Register. *See 63 Fed. Reg. 67548, 67549*; AR 722-883. The issue here is not so simple.

any departure from EPA's criteria distinguishes the function **[*28]** of EPA's activity from a mere recommendation. A recommendation is advice on how to proceed. Take it or leave it. That is not the situation here. States do not have the luxury of "leaving" EPA's 304(a) criteria because they must in every case consider it—i.e., use it, even if only as a point of departure. *See* *40 C.F.R. §§ 131.11*, 131.20(a). Not only that, but states must take additional steps if they choose not to use EPA's criteria in a particular way. *Id.* In its Reply, EPA emphasizes that a state's "explanation" could include non-scientific reasons such as budgetary constraints or that "[the state] will continue to review efforts by other states to implement EPA's ... recommended [304(a)] criteria[.]" Doc. 37 at 6-7, 7; Hr'g Tr. at 59:12-61:16. EPA appears to assert that states can put off indefinitely their obligation to "adopt ... water quality criteria .... based on ... [1] 304(a) Guidance ...; [2] 304(a) Guidance modified to reflect site-specific conditions; or [3] [o]ther scientifically defensible methods[.]" *40 C.F.R. § 131.11(a)-(b)*. If that were true, it would be surprising that virtually all states now use some vintage of 304(a) criteria. If states could put off their obligation indefinitely, that would also be in significant tension with the **[*29]** CWA's very purpose of prompting states to reduce and eventually eliminate the discharge of pollutants into the nation's waters. *33 U.S.C. § 1251(a)*; *see also* 56 Fed. Reg. 58420-01 (EPA's proposed 1991 criteria explaining that 304(a) criteria "are essential to the process of controlling toxics because they allow States and EPA to evaluate the adequacy of existing and potential control measures to protect aquatic ecosystems and human health"); *id. at 58424* (EPA explaining its more forceful approach in terms of "Congressional impatience" with state progress toward adopting water quality standards).

Thus, EPA's activity issuing 304(a) criteria does more than offer a helpful recommendation. It directly impacts the states' water-quality standard process by changing the threshold for a states' obligation to explain itself, modify 304(a) criteria, or develop an alternative, scientifically justifiable approach.[6] EPA's activity also indirectly impacts states' processes by making the alternative to adopting EPA's criteria costly. Developing unique water quality standards and justifying their departure from EPA's criteria is time-consuming and expensive. *See* AR5138-39 (NMFS comment to this effect); *cf.* *80 Fed. Reg. 51020, 51028* (EPA noting that updating 304(a) criteria **[*30]** recommendations requires "investing significant resources"); *see also* AR1-721 (2016 cadmium criteria document spanning over 700 pages). These direct and indirect impacts on the underlying activity of state water-quality standards distinguish EPA's activity from simple "recommendations."

Finally, EPA's activity issuing 304(a) criteria also influences states indirectly in different ways. First, EPA's 304(a) criteria become a sort of default. If a state fails to maintain standards consistent with the CWA, EPA directly promulgates water quality standards for them. *See* *33 U.S.C. § 1313(c)(4)*. When EPA does, it frequently uses its 304(a) criteria. *See, e.g.*, *82 Fed. Reg. 9166-01 (Oregon); 66 Fed. Reg. 9960-01 (California); 60 Fed. Reg. 22229-01* (Alaska, Arkansas, California, Idaho, Kansas, Michigan, New Jersey, Vermont, and Washington). In fact, only five states do not use EPA's 304(a) criteria. Doc. 29 at 40-41; *see generally* Doc. 31 (no dispute); Hr'g Tr. at 57:16-58:5. EPA also uses its 304(a) criteria to set contaminated property cleanup requirements, *42 U.S.C. § 9621(d)(2)(A)*, and to support its national effluent limit guidelines. Doc. 29 at 9; *see generally* Doc. 31 (no dispute); Doc. 37 at 8-9 (emphasizing additional steps but not fundamentally disputing); *Pronsolino v. Nastri, 291 F.3d 1123, 1127 (9th Cir. 2002)* ("[CWA water quality standards are] central to the [CWA's] **[*31]** carrot-and-stick approach to attaining acceptable water quality without direct federal regulation of nonpoint sources of pollution."). And EPA proposes to use its criteria as "[f]ederal water quality standards (WQS) for Indian reservation waters that currently do not have WQS in effect under the Clean Water Act." *See* *88 Fed. Reg. 29496, 29506* (providing five options for translating narrative water quality criteria into numeric values, including using unmodified 304(a) criteria); Doc. 37 at 8. Like the requirement that states explain any departure, the reality of how EPA's criteria are used makes them less like a recommendation and more like a plan. A plan identifies future actions an agency intends to take. EPA's 304(a) criteria similarly signal critical contours of EPA's action given a CWA violation, property cleanup,

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[6] This is why EPA's argument about the CWA as an "independent framework" is unpersuasive. EPA urges, essentially, that the CWA is the real actor here, not EPA. *See* Doc. 31 at 24-25 ("The CWA ... provide[s] an independent framework for ... state water quality standards and criteria, and for using those ... standards as a regulatory tool. ... Section 304(a) criteria do not."). But EPA does more than plug a number into a statutory variable, then stand back and let CWA's obligations work. EPA is CWA's enforcer, and its criteria raise or lower the CWA bar at which a state must explain itself.

effluent permit request, and, potentially, for certain Indian reservation waters.

These distinctions bring EPA's 304(a) criteria under a line of cases considering programmatic actions. Programmatic actions—as opposed to site-specific actions—include "proposed ... plan[s or] polic[ies] ... providing a framework for future proposed actions." *50 C.F.R. § 402.02*. Issuing programmatic documents, for example, constitutes "agency action **[*32]** because [programmatic documents] 'set forth criteria' that would influence future activities" without explicitly authorizing them. *Env't Def. Ctr., 36 F.4th at 884-85* (citing *Pac. Rivers Council, 30 F.3d at 1055*). In *Environmental Defense Center*, the court specifically noted that although issuing programmatic documents "does not directly authorize private activity," it is an action because it "establishes criteria for *future* private activity and has an 'ongoing and long-lasting effect.'" *Id. at 884* (emphasis in original) (citation omitted). Consultation is thus required even if the criteria are not "binding." *See id. at 885*.

The court's reasoning in *Environmental Defense Center* applies squarely to EPA's 304(a) activity. EPA's activity does not directly authorize states' activity, but it does influence state activity by establishing criteria for states to consider in the future. EPA's 304(a) activity has an ongoing effect because states must consider 304(a) criteria every time they conduct their triennial water-quality standard review. EPA's activity also has a long-lasting effect because it remains in effect until EPA updates the 304(a) criteria "from time to time"—most recently a period of 15 years. *See* AR 16. And EPA's activity has an effect because its 304(a) criteria **[*33]** are rarely rejected and have become the default option for most states. Finally, EPA's 304(a) activity is binding in the sense that states must consider EPA's 304(a) criteria, but EPA's activity would still require consultation even if it were not binding. Several older cases also support this result.

In *Pacific Rivers Council*, the Forest Service violated the ESA when it failed to consult with expert agencies about the effects of certain Land and Resource Management Plans ("LRMPs"). *30 F.3d at 1051*. These LRMPS established "standards and guidelines to which all projects must adhere for up to 15 years[,]" as well as "measures for preventing the destruction or adverse modification of critical habitat for threatened or endangered species." *Id. at 1052*. All uses "of the forest must be consistent with the LRMP." *Id.* The court reasoned that LRMPs required consultation because "every individual project planned in both national forests involved in this case is implemented according to [them]." *Id. at 1053*. This reasoning applies to EPA's activity issuing 304(a) criteria to the extent 304(a) criteria are like plans that identify future agency action, but also because EPA's criteria come with an adopt-or-explain requirement. That **[*34]** requirement creates strong consistency between the EPA's 304(a) criteria and states' criteria—as evidenced by the fact that few states depart from it.

Similarly, in *Lane County Audubon Society*, the Bureau of Land Management ("BLM") violated the ESA when it failed to consult before promulgating a document self-described as "Management Guidelines." *958 F.2d at 292-94*. The Guidelines established interim timber management standards, including land-use allocations, "annual allowable harvest" for each designated forest district, and detailed criteria for developing individual timber sales each year. *Id.* BLM subsequently consulted with an expert agency for individual timber sales but did not submit the Management Guidelines themselves for consultation. *Id. at 292*. On appeal, BLM argued that consultation at the programmatic level was not required because BLM consulted at the individual sale level. *Id. at 293*. The court rejected that argument, holding that BLM's activity issuing the Management Guidelines were "without a doubt" agency action that may affect a protected species because they "set[] forth criteria for harvesting owl habitat." *Id. at 294*; *accord N. Plains Res. Council, 454 F. Supp 3d at 992-93* (project-level consultation does not eliminate the need for programmatic-level consultation); *Citizens for Better Forestry v. U.S. Dep't of Agric., 481 F. Supp. 2d 1059, 1095 (N.D. Cal. 2007)* (same). Here, **[*35]** EPA's activity "sets forth [304(a)] criteria" for individual states to consider when updating their water-quality standards. Like a guideline that sets an annual allowable harvest, the 304(a) criteria set a maximum cadmium concentration from which any departure must be justified. And like BLM's violation of the ESA despite its consultation for individual timber sales, EPA's failure to consult when issuing its criteria violates the ESA even though EPA consults with expert agencies when individual states propose to adopt or reject EPA's criteria.

c. EPA's cases are distinguishable.

The adopt-or-explain requirement and direct and indirect impacts of EPA's 304(a) criteria on state water-quality standards also distinguish EPA's best cases. *See* Doc.

31 at 22-23 (citing *Matejko, 468 F.3d at 1111*, and *Marbled Murrelet, 83 F.3d at 1073-74*). In *Matejko*, the Bureau of Land Management chose not to regulate hundreds of river and stream diversions after a statutory regime change gave BLM discretion to do so given a "substantial deviation in their use or location." *468 F.3d at 1103-04, 1110*. The court decided that BLM's inaction did not require consultation in part because it was not affirmative. *Id. at 1108* (noting the "affirmative nature of the[] words ... 'authorized, funded, carried[.]'"). The court **[*36]** also decided BLM's inaction did not require consultation because it was not discretionary. *Id. at 1110-11*. The court noted "BLM had 'no ability to influence' a project based on a right-of-way granted before the ESA was enacted," and had "no retained power to 'inure to the benefit of the protected species.'" *Id.* (citation omitted); *see also Env't Prot. Info. Ctr. v. Simpson Timber Co., 255 F.3d 1073, 1082 (9th Cir. 2001)* (activity not discretionary where it was "legally foreordained by an earlier decision"). As discussed above, here EPA's 304(a) criteria affirmatively decide the condition under which a state must explain itself and powerfully influence states' water-quality processes. EPA's 304(a) activity is also discretionary because the criteria are not legally foreordained, arising instead from a process EPA initiates and controls. EPA's influence over its 304(a) criteria also can inure to the benefit of protected species because EPA can issue a higher or lower allowable cadmium concentration, AR 15, and lower concentrations are more protective. *See* Doc. 31 at 12 ("nationwide consultation ... would tend to produce more stringent recommendations"); AR 21-23, 25 (any level of cadmium is harmful to wildlife).

EPA's other primary case is also distinguishable. In *Marbled Murrelet*, several lumber **[*37]** companies sought permission from the California Department of Forestry ("CDF") to harvest dead, dying, and diseased trees from an old-growth redwood stand that was potentially important to protected wildlife. *83 F.3d at 1071*. In response, FWS sent joint letters with CDF describing and subsequently clarifying "specific conditions that had to be met to comply with ... the ESA." *See id. at 1071-72*. FWS did not consult with expert agencies before sending the letters. *See id.* The court held that consultation was not required because FWS "merely provided advice on how the Lumber Companies could [comply with] ... the ESA." *Id. at 1074*. The court also noted that requiring consultation for compliance advice "would [create] a disincentive for the agency to give such advice[,]" to the detriment of protected species. *Id. at 1074-75*; *see also* Doc. 31 at 22 (emphasizing this point). Here, EPA's 304(a) criteria are more than advice on how to comply with the CWA. Advice, particularly the informal advice in *Marbled Murrelet*, does not require anything and may be ignored. By contrast, EPA's 304(a) criteria come with the requirement that states consider it and adopt it or explain their departure, and the vast majority of states adopt it, likely because the alternative is **[*38]** so costly. And the CWA requires EPA to update its 304(a) criteria, so EPA's willingness to do so likely will not be chilled by an additional consultation requirement.

Finally, EPA's activity issuing 304(a) criteria may "inure to the benefit of protected species" because more conservative or restrictive 304(a) criteria directly and indirectly lower the maximum allowable cadmium concentration in the nation's waters. For these reasons, EPA's activity issuing 304(a) criteria is an "action" under the ESA. EPA's decision to issue 304(a) cadmium criteria in 2016 without consulting the Services was therefore arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law.

C. 304(a) criteria "may affect" protected species.

"May affect" is a "relatively low" bar. *Karuk Tribe, 681 F.3d at 1027* (citation omitted). "*Any possible effect*, whether beneficial, benign, adverse or of an undetermined character, triggers the [Section 7 consultation] requirement." *Id. at 1028* (citations omitted, emphasis in the original). An agency may avoid the consultation requirement only if it determines that its action will have "no effect" on a listed species or its critical habitat. *Id. at 1027* (citation omitted).

Here, issuing 304(a) criteria "may affect" protected **[*39]** species by exposing them to more or less pollution than otherwise. The whole point of 304(a) criteria is that they affect state water-quality standards. *56 Fed. Reg. 58420-01*; *id. at 58424*; *40 C.F.R. § 131.20(a)*. If, for example, EPA nearly triples the maximum chronic freshwater criterion for a pollutant, and if that criterion is adopted verbatim by most states, then protected species in those states' waters may be exposed to more of that pollutant than if EPA had lowered the criterion, kept it constant, or increased it by a smaller amount. That chain of possibilities is not long. Its links fit snugly together—by design. EPA essentially concedes as much when it writes that nationwide consultation would "tend to produce" more stringent criteria. *See* Doc. 31 at 12; AR 871. A "tendency" is a "beneficial, benign, adverse or ... undetermined" effect. *See Karuk Tribe, 681 F.3d at 1027*. The only way more stringent criteria would not in turn produce a "beneficial, benign, adverse or ... undetermined" effect on protected species is if states universally chose not to adopt them. But the opposite is true. Most states adopt EPA's criteria at least in part because the alternative is costly.

EPA's arguments to the contrary are unpersuasive. EPA first argues an explicit "no effect" **[*40]** finding was not required. Doc. 31 at 25; Doc. 37 at 19-20. According to EPA, issuing 304(a) criteria is like "hiring more employees in an urban office setting," in the sense that both so obviously have no effect on protected species that an implicit no-effect finding is sufficient. *See* Doc. 31 at 25. The Court disagrees. Issuing 304(a) criteria is not like hiring employees because one is designed to influence state water-quality standards and the other is not. EPA revised its cadmium guidance without finding that its actions would have no effect on a listed species or endangered habitat as required by the ESA. *See* Hr'g Tr. at 70:25; 72:18-21. But the ESA requires all federal agencies to "review its actions at the earliest possible time to determine whether any action may affect listed species or critical habitat." 50 C.F.R. § 402.14(a). The issue, then, is not simply that EPA's finding was unreasonable, but that it did not make one in the first place. That alone is enough to violate the ESA enacting regulations.[7]

EPA next argues that its implicit no-effect finding was reasonable primarily because nationwide consultation is expensive and time-consuming. *See* Doc. 31 at 25-28. But EPA's policy and past effort **[*41]** to conduct nationwide consultations are largely irrelevant. *See* Doc. 31 at 28-30. EPA asserts that its implicit no-effect finding was reasonable because the process took several years and would still require state-level consultation. *Id.* EPA overlooks some important details. As discussed above, EPA's view of proper or efficient policy must yield to the ESA's policy—whatever the cost. *See supra* § III(A)(b). Furthermore, the record does not support EPA's position. EPA's main observation is that state-level consultations were still anticipated despite EPA's nationwide consultation with the Services. Doc. 31 at 29-30 (citing draft nationwide biological opinions by FWS (AR 4788) and NMFS (AR 5395)). But FWS wrote that "much of the [nationwide] analysis would carry over, so that the [state-level] consultation ... need only focus on potential effects of elements that were not fully considered here." AR 4788; *accord* AR 5395 (NMFS cabining state-level consultations in context of incidental take permits not related to the main pollutant at issue); *see also* Hr'g Tr. at 90:1-16 (making the point that nationwide consultations likely would become more efficient over time through practice). Really, **[*42]** though, the bottom line here is that EPA does not have discretion to avoid its obligations under the ESA because EPA thinks they are inconvenient. And EPA's assertion that its non-existent no-effect finding was reasonable flies in the face of EPA's own recognition that nationwide consultation would tend to produce more stringent criteria.[8]

For those reasons, the Court finds that EPA's 304(a) criteria may affect protected species, such that consultation with expert agencies was required before revising the cadmium criteria in 2016.

D. Relief

The Center asks the Court to vacate EPA's 2016 freshwater chronic cadmium criterion, remand all four 2016 criteria back to EPA, and to order EPA to initiate consultation on all four criteria during remand. Doc. 29 at 38.

a. Vacatur

In the Center's view, only partial vacatur is desirable because EPA lowered the maximum allowable concentration for three of four cadmium criteria. Doc. 29 at 38. Vacating those three could thus have a counter-productive effect. *Id.* EPA does not respond to the Center's vacatur argument. *See* Doc. 31 at 37.

Vacatur is presumptive and normally accompanies a remand when the Court finds an unlawful agency action produces an invalid **[*43]** result. Alliance for the Wild Rockies v. U.S. Forest Serv., 907 F.3d 1105, 1121 (9th Cir. 2018) (citations and internal quotations omitted);

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[7] In its Reply, EPA appears to argue that EPA can avoid any obligation to consult simply by choosing not to make an effects determination (or making an implicit no-effect finding). Doc. 37 at 19:16-23. That would be surprising.

[8] EPA also argues that its implicit no-effect finding was reasonable because no effects were "reasonably likely to occur." Doc. 37 at 18-20 (drawing on regulatory definition of "effect"). This argument is unpersuasive for the same reasons discussed throughout this Order, namely that both practically (through cost considerations), legally (through the adopt-or-explain requirement), and by design, effects are nearly certain to occur.

*Ctr. for Biological Diversity v. Haaland, 2022 U.S. Dist. LEXIS 94822, *8-9* ("Because vacatur is the presumptive remedy, the [agency] bears the burden of demonstrating vacatur is inappropriate.") (citation and internal quotation marks omitted). Remand without vacatur should be ordered "only in limited circumstances," with invalid rules left in place "only when equity demands." *Pollinator Stewardship Council v. U.S. E.P.A., 806 F.3d 520, 532 (9th Cir. 2015)* (citations and internal quotations omitted). The Court considers three factors to determine whether vacatur is appropriate: (1) the seriousness of the agency's error weighed against the disruption that vacatur would cause; (2) the risk to environmental harm of either vacating or leaving the decision in place; and (3) likelihood of the agency's ability adopt the same rule on remand. *NRDC (2022), 38 F.4th at 51-52*.

Here, all three factors weigh in favor of partial vacatur. First, EPA's violation was serious because it ignored an ESA requirement that likely would produce more stringent criteria. *See* Doc. 31 at 10; AR 871. Vacating the 2016 freshwater chronic criterion likely would cause no disruption because states subsequently revising their water-quality standards would simply use EPA's 2001 criterion. And states that already adopted EPA's 2016 criteria could **[*44]** continue to rely on EPA's approval until their next triennial review. Second, and similarly, the risk to environmental harm of leaving the freshwater chronic criterion in place is high given the shortcomings of EPA's state-by-state consultation as discussed above. This factor also weighs in favor of partial vacatur, because vacating the three more stringent criteria would risk environmental harm for the same reasons leaving the fourth criterion in place would risk environmental harm. Third, EPA is unlikely to adopt the same rule on remand because nationwide consultation likely will produce more stringent criteria. *See* Doc. 31 at 12; AR 871. And the Court has found EPA's 304(a) criteria "may affect" protected species as a matter of law. Thus, the balance of these factors weighs in favor of partial vacatur.

EPA fails to identify any equitable reasons why the Court should not vacate the freshwater chronic cadmium criterion. *See* Doc. 31 at 37.[9] Considering that concession and the factors above, the Court is persuaded that partial vacatur is warranted. The Court will vacate EPA's 2016 chronic freshwater cadmium criterion, but not EPA's 2016 acute freshwater cadmium criterion, or the 2016 **[*45]** chronic and acute marine cadmium criteria.

b. Consultation on Remand

The Center also urges the Court to remand all four 2016 cadmium criteria to EPA and order it to initiate consultation during remand. Doc. 29 at 38. EPA responds that the Court should instead limit the Center's remedy "to a remand for EPA to reconsider its no-effect determination and make new ESA effects determination for those criteria." Doc. 31 at 37 (citing without argument *Ctr. For Biological Diversity v. Leavitt*, No. C 02-01580JSW, 2005 WL 2277030, at *3 (N.D. Cal. Sept. 19, 2005); *Ctr. for Biological Diversity v. EPA, 861 F.3d 174, 189 n.13 (D.C. Cir. 2017)*; *Pac. Rivers Council v. Robertson, 854 F. Supp. 713, 723 n. 14 (D. Or. 1993)*, *rev'd as to injunctive relief by* *Pac. Rivers Council, 30 F.3d at 1057*).

EPA's implied argument is unpersuasive because the cases it cites are distinguishable. None of them involve a situation where, as here, the agency concedes that consultation likely would produce more stringent criteria. *See* Doc. 31 at 12; AR 871. This case is more similar to *Karuk Tribe*, where the court determined "almost ... as a textual matter" that the agency action "may affect" critical habitat. *Karuk Tribe, 681 F.3d at 1027*. The issue there was mining activity that, by definition, might disturb fish habitat. *Id.* The issue here is 304(a) activity that, by design, influences state water-quality standards.

Nevertheless, the Court prefers not to manage an intricate and ongoing process. EPA has acted in good faith, and the Court has no reason to **[*46]** believe it will not respond to partial vacatur and remand appropriately. Ordering consultation is therefore unnecessary.

IV. Order

For these reasons,

IT IS ORDERED GRANTING IN PART the Center for Biological Diversity's Motion for Summary Judgment (Doc. 29) consistent with this Order.

IT IS FURTHER ORDERED DENYING the United States Environmental Protection Agency's Motion for Summary Judgment (Doc. 31).

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[9] In its Reply, EPA still does not identify equitable considerations, but requests further briefing on remedy if the Court finds for the Center. Doc. 37 at 22. Given the Court's disposition below, further briefing is unnecessary.

IT IS FURTHER ORDERED VACATING EPA's 2016 304(a) chronic freshwater cadmium criterion.

IT IS FURTHER ORDERED REMANDING EPA's 2016 304(a) cadmium criteria for proceedings consistent with this Order.

The Clerk of the Court shall enter judgment accordingly.

Dated this 18th day of August, 2023.

/s/ John C. Hinderaker

John C. Hinderaker

United States District Judge

End of Document

United States
Environmental Protection
Agency

Office of Water
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EPA-820-R-16-002
March 2016

AQUATIC LIFE

AMBIENT WATER QUALITY CRITERIA

CADMIUM - 2016

EPA 820-R-16-002

AQUATIC LIFE

AMBIENT WATER QUALITY CRITERIA

CADMIUM

(CAS # 7440-43-9)

2016

March 2016

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Health and Ecological Criteria Division
Washington, D.C.

NOTICES

This document provides information to states and tribes authorized to establish water quality standards under the Clean Water Act (CWA), to protect aquatic life from toxic effects of cadmium. Under the CWA, states and tribes are to establish water quality criteria to protect designated uses. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from these criteria when appropriate. While this document contains EPA's scientific recommendations regarding ambient concentrations of cadmium that protect aquatic life, it does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. EPA may change this document in the future. This document has been approved for publication by the Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document can be downloaded from: http://www.epa.gov/waterscience/criteria/aqlife.html Notices.

FOREWORD

Section 304(a) (l) of the Clean Water Act, 33 U.S.C. § 1314(a)(1), directs the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is EPA's new recommended ambient water quality criteria (AWQC) for the protection of aquatic life based upon consideration of available information relating to effects of cadmium on aquatic organisms, and consideration of independent external peer review and EPA workgroup comments.

The term "water quality criteria" is used in two sections of the Clean Water Act: section 304(a)(l) and section 303(c)(2). The term has different meanings in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological and human health effects. The criteria presented in this document are such a scientific assessment of ecological effects. In section 303(c), the term water quality criteria refers to criteria adopted by a state as part of their legally-binding water quality standards. Criteria in water quality standards establish the maximum acceptable pollutant concentrations in ambient waters protective of the state's designated uses. States may adopt water quality criteria in their water quality standards that have the same numerical values as EPA's recommended section 304(a)(1) criteria. However, states may decide to adopt water quality criteria different from EPA's section 304 recommendations to reflect local environmental conditions and human exposure patterns. Alternatively, states may use different data and assumptions than EPA in deriving numeric criteria that are scientifically defensible and protective of designated uses. It is not until their adoption as part of state water quality standards and approved by EPA (or in limited instances promulgated by EPA) under section 303(c) that criteria become applicable water quality standards for Clean Water Act purposes. Information to assist the states and Indian tribes in modifying the recommended criteria presented in this document is contained in the Water Quality Standards Handbook (U.S. EPA 2014). This handbook and additional information on the development of water quality standards and other water-related programs of this agency have been developed by the Office of Water.

This document does not establish or affect legal rights or obligations. It does not establish a binding norm and cannot be finally determinative of the issues addressed. Agency decisions in any particular situation will be made by applying the Clean Water Act and EPA regulations on the basis of specific facts presented and scientific information then available.

Elizabeth Southerland
Director
Office of Science and Technology

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ACR	Acute-to-Chronic Ratio
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation Factor
CCC	Criterion Continuous Concentration
CF	Conversion Factor
CMC	Criterion Maximum Concentration
CV	Chronic Value (expressed in this document as an EC_{20} or MATC)
CWA	Clean Water Act
EC_x	Effect Concentration at X Percent Effect Level
ELS	Early Life Stage
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FACR	Final Acute-to-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
GMAV	Genus Mean Acute Value
GMCV	Genus Mean Chronic Value
LC_x	Lethal Concentration at X Percent Survival Level
LOEC	Lowest Observed Effect Concentration
MATC	Maximum Acceptable Toxicant Concentration (expressed mathematically as the geometric mean of the NOEC and LOEC)
MDR	Minimum Data Requirements
NOEC	No Observed Effect Concentration
NPDES	National Pollutant Discharge Elimination System
SD	Sensitivity Distribution
SMACR	Species Mean Acute-to-Chronic Ratio
SMAV	Species Mean Acute Value
SMCV	Species Mean Chronic Value
TMDL	Total Maximum Daily Load
TRAP	EPA’s Statistical Program: Toxicity Relationship Analysis Program (Version 1.21)
WQBELS	Water Quality-based Effluent Limitations
WQC	Water Quality Criteria
WQS	Water Quality Standards

EXECUTIVE SUMMARY

EPA has updated the Agency's recommended cadmium aquatic life ambient water quality criteria in accord with provisions of §304(a) of the Clean Water Act to periodically revise Ambient Water Quality Criteria (AWQC) in order to reflect the latest scientific knowledge. EPA originally developed recommended 304(a) water quality criteria for cadmium in 1980 (EPA 440/5-80-025, U.S. EPA 1980), and subsequently updated in 1985 (EPA 440/5-84-032, U.S. EPA 1985c), 1995 (EPA-820-B-96-001, U.S. EPA 1996a) and 2001 (EPA-822-R-01-001, U.S. EPA 2001). EPA has updated cadmium aquatic life criteria in this revision consistent with methods described in U.S. EPA's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (1985 Guidelines) (Stephan et al. 1985).

EPA based these revisions in this update on data that have become available since 2001. Literature searches of laboratory aquatic toxicity tests with cadmium published prior to 2016 identified over 100 new studies containing acute and chronic toxicity data that are acceptable for deriving the updated cadmium criteria. EPA also updated the relationship of cadmium toxicity to total hardness with the newly acquired data (see **Table 6** and **Table 8**). The 2016 update incorporates data for 75 new species and 49 new genera. The dataset used to develop the updated criteria is composed of 75 freshwater genera for acute toxicity (compared to 55 genera in the 2001 criteria), 20 freshwater genera for chronic toxicity (compared to 16 genera in the 2001 criteria), and 79 estuarine/marine genera for acute toxicity (compared to 54 genera in the 2001 criteria). No new chronic toxicity data were available for estuarine/marine genera.

Studies evaluating the freshwater acute toxicity of cadmium are available for nine Federally-listed species (hereafter referred to as Listed Species). Eight of these species are fish and one is a freshwater mussel. The most sensitive Listed species are in the family Salmonidae, as represented by the genera *Oncorhynchus* (*O. kisutch, O. mykiss* and *O. tshawytscha*) and *Salvelinus* (*S. confluentus*). Acute toxicity data are also available for the Listed freshwater mussel Neosho mucket (*Lampsilis rafinesqueana*). Studies evaluating the freshwater chronic toxicity of cadmium are available for four Federally-listed species, three of which are also represented by the genus *Oncorhynchus* (*O. kisutch, O. mykiss* and *O. tshawytscha*) and one by the genus *Salmo* (*S. salar*). Acute estuarine/marine toxicity data are available for the Listed

Oncorhynchus kisutch. There are no acceptable chronic toxicity data for estuarine/marine Listed species. Summaries provided in the document describe the best available data for Listed species that have been tested for sensitivity to cadmium; these data demonstrate that the 2016 cadmium criteria update is protective of these tested species.

Sufficient toxicity data were available to fulfill requirements of calculating acute and chronic freshwater and acute estuarine/marine criteria using a species sensitivity distribution, as described in the 1985 Guidelines. Data were not sufficient to calculate the chronic estuarine/marine criterion, and Acute-Chronic Ratios (ACRs) were therefore used to derive this criterion. The Final Acute-Chronic Ratio (FACR) for this update was derived from seven genera ACRs (two freshwater invertebrate genera, four freshwater fish genera, and one acutely sensitive saltwater mysid genus). The freshwater ACR values used represent a range of species acute sensitivities, from very sensitive to moderately sensitive, and have taxonomically-related marine species. This differs from the 2001 update, where only two saltwater ACRs were available and used to calculate the saltwater FACR; however these two species are now re-classified as a single genus, *Americamysis*.

EPA updated the acute and chronic hardness slopes with data for several new species. The updated acute cadmium hardness slope incorporates data for 13 species (eight species used in the 2001 criteria and five new species) (see **Table 6**). The updated chronic slope incorporates data for four species (two species used in the 2001 criteria and two new species) (see **Table 8**). The new chronic slope uses EC_{20} estimates for three of the four species, instead of only Maximum Acceptable Toxicant Concentrations (MATCs) used for the 2001 chronic slope (MATCs were used only for *Daphnia magna* in the 2016 slope to retain the invertebrate species).

The 2016 freshwater and estuarine/marine acute criteria, known as the Criterion Maximum Concentrations (CMCs) and the chronic criteria, known as the Criterion Continuous Concentrations (CCCs) values for cadmium are summarized and compared to corresponding 2001 criteria values in **Table 1**. The available freshwater toxicity data for cadmium, evaluated using procedures described in the 1985 Guidelines, indicate that freshwater aquatic life should be protected if the 1-hour average CMC does not exceed:

$$\text{CMC } (\mu\text{g/L, dissolved conc.}) = e^{(0.9789 \text{ x } \ln(\text{hardness}) - 3.866)} \text{ x CF} \qquad \text{(Eq. 1)}$$

Where CF (conversion factor from total to dissolved) = 1.136672 - [(ln hardness) x (0.041838)]; and the four-day average CCC does not exceed:

$$\text{CCC } (\mu g/L, \text{ dissolved conc.}) = e^{(0.7977 \times \ln(\text{hardness}) - 3.909)} \times \text{CF} \qquad \text{(Eq. 2)}$$

Where CF (conversion factor from total to dissolved) = 1.101672 - [(ln hardness) x (0.041838)]. These values are recommended not to be exceeded more than once every three years on average.

The 2016 freshwater acute criterion (CMC) is 1.8 μg/L dissolved cadmium based on a hardness of 100 mg/L as $CaCO_3$. EPA derived the CMC to be protective of the commercially and recreationally important rainbow trout (*Oncorhynchus mykiss*), consistent with procedures described in the 1985 Guidelines, and is also protective of all salmonid species for which toxicity data are available. This value is lower than the 2001 CMC of 2.0 μg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_3$. For the 2016 acute criteria, EPA has changed the duration to 1-hour from the 24 hours EPA applied in the 2001 final cadmium criteria document. EPA made this change to the 2016 criteria to reflect the acute criteria duration recommended in the 1985 Guidelines (see **Section 5.1.4**). The 2016 freshwater chronic CCC is 0.72 μg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_3$, and is an increase (i.e., less stringent) from the 2001 criteria of 0.25 μg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_3$. This increase is primarily due to use of EC_{20}s over MATCs, new data for existing species and the inclusion of a new sensitive genus (*Cottus*), which now represents the third most sensitive genus.

The 2016 estuarine/marine acute CMC of 33 μg/L dissolved cadmium is more stringent than the 2001 recommended criterion of 40 μg/L, which is primarily due to the addition of three new sensitive genera, consisting of a mysid (*Neomysis*), a copepod (*Tigriopus*), and a jellyfish (*Aurelia*). The estuarine/marine chronic CCC based on the use of an acute-to-chronic ratio (ACR) is now 7.9 μg/L dissolved cadmium compared to the 2001 CCC of 8.8 μg/L. The estuarine/marine chronic criteria is lower than the 2001 value based primarily on the lowering of the acute value in conjunction with use of an ACR to derive the chronic value. Available data suggest the acute toxicity of cadmium may be influenced by salinity, with a trend of decreasing sensitivity to cadmium with increasing salinity. However, this trend could not be definitively characterized and a mathematical relationship could not be described to define the dependency (see **Section 5.4.1**), thus salinity was not included in the estuarine/marine criteria derivation.

Table 1. Summary of 2001 and 2016 Aquatic Life AWQC Recommendations for Dissolved Cadmium.

	2016 AWQC Update[a]		2001 AWQC[a]	
	Acute (1-hour, dissolved Cd)[d]	**Chronic (4-day, dissolved Cd)**	**Acute (1-day, dissolved Cd)**	**Chronic (4-day, dissolved Cd)**
Freshwater (Total Hardness = 100 mg/L as $CaCO_3$)[b]	1.8 µg/L[c]	0.72 µg/L	2.0 µg/L[c]	0.25 µg/L
Estuarine/marine	33 µg/L	7.9 µg/L	40 µg/L	8.8 µg/L

[a] Values are recommended not to be exceeded more than once every three years on average.

[b] Freshwater acute and chronic criteria are hardness-dependent and were normalized to a hardness of 100 mg/L as $CaCO_3$ to allow the presentation of representative criteria values.

[c] Lowered to protect the commercially and recreationally important species (rainbow trout), as per the 1985 Guidelines, Stephan et al. (1985).

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

1 INTRODUCTION AND BACKGROUND

National Recommended Ambient Water Quality Criteria (AWQC) are established by the United States Environmental Protection Agency (EPA) under the Clean Water Act (CWA). Section 304(a)(1) aquatic life criteria serve as recommendations to states and tribes by defining ambient water concentrations that will protect against unacceptable adverse ecological effects to aquatic life resulting from exposure to pollutants found in water. Aquatic life criteria address the CWA goals of providing for the protection and propagation of fish and shellfish. Once EPA publishes final section 304(a) recommended water quality criteria, states and authorized tribes may adopt these criteria into their water quality standards to protect designated uses of water bodies. States and authorized tribes may also modify these criteria to reflect site-specific conditions or use other scientifically-defensible methods to develop criteria before adopting these into standards. After adoption, states are to submit new and revised water quality standards (WQS) to EPA for review and approval or disapproval. When approved by EPA, the state's WQS become applicable WQS for CWA purposes. Such purposes include identification of impaired waters and establishment of TMDLs under CWA section 303(d) and derivation of water quality-based effluent limitations in permits issued under the CWA section 402 National Pollutant Discharge Elimination System (NPDES) permit program.

As required by the CWA, EPA periodically reviews and revises section 304(a) AWQC to ensure they are consistent with the latest scientific information. This 2016 peer-reviewed and finalized update supersedes the AWQC for cadmium that EPA last updated in 2001 (EPA-822-R-01-001, U.S. EPA 2001). EPA updated the cadmium water quality criteria provided in this document in accordance with methods outlined in the Agency's "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*" (referred to as the 1985 Guidelines) (Stephan et al. 1985). This document describes scientifically defensible water quality criteria values for cadmium pursuant to CWA section 304(a), derived utilizing best available data in a manner consistent with the 1985 Guidelines and reflecting best professional scientific judgments of toxicological effects.

1.1 History of the EPA Cadmium AWQC for Aquatic Life

EPA first published AWQC for cadmium in 1980 (EPA 440/5-80-025), and updated the criteria in 1985 (EPA 440/5-84-032), 1995 (EPA-820-B-96-001) and again in 2001 (EPA-822-R-

01-001[1]). Each update supersedes the previous EPA aquatic life water quality criteria and uses the most recent data to estimate maximum and continuous concentrations of cadmium that would protect most aquatic organism populations from unacceptable short- or long-term effects.

The 1980 acute and chronic freshwater and saltwater criteria were expressed as total recoverable cadmium. The acute and chronic freshwater criteria were adjusted for ambient water hardness since the presence of calcium and other ions in freshwater are known to reduce the toxicity of cadmium. An acute saltwater criterion was calculated and the effects of temperature and salinity were considered, but no clear relationship to toxicity could be established with the available data, thus the acute saltwater criteria was not adjusted for temperature or salinity. Because of a limited dataset at the time, a chronic saltwater criterion was not developed. Data for aquatic plants indicated that a reduction in growth occurred at concentrations above the lowest effect concentrations for fish and invertebrates, so aquatic life criteria were not developed for plants.

The 1985 criteria update was developed using the measurement of acid-soluble cadmium instead of total recoverable cadmium, based on the conservatism of using total recoverable cadmium in situations where it is occluded in minerals, clays, and sand, or strongly sorbed to particulate matter. While the 1985 criteria provided extensive scientific and practical rationale for using acid-soluble cadmium measurements, no standard analytical method was available. In the absence of an EPA-approved method for the measurement of acid-soluble cadmium, total recoverable cadmium was considered the preferred concentration measure.

Acute toxicity values for 44 freshwater genera (52 species) were used for the 1985 criteria update to develop a Final Acute Value (FAV), which was lowered further to protect the commercially important rainbow trout, the most sensitive species. The acute freshwater criterion was set at 3.589 µg/L at a hardness of 50 mg/L as $CaCO_{3,}$ not to be exceeded over a 1-hour average more than once every 3 years, on average. Acute toxicity values were available at that time for 35 estuarine/marine species (33 genera)(**Table 2**) and the most sensitive genera was *Mysidopsis.* Acute toxicity was generally found to increase with decreasing salinity, while the effect of temperature on acute toxicity appeared to occur on a species-specific basis. However,

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[1] http://www.epa.gov/nscep/

correction factors were not developed for either due to limitations in supporting data. The estuarine/marine FAV was 85.09 µg/L, not to be exceeded over a 1-hour average more than once every 3 years, on average.

Chronic freshwater toxicity values used to derive the 1985 criteria were available for 16 species (13 genera). The Final Chronic Value (FCV) was calculated in the same manner as the FAV because the acute-to-chronic ratios, which were available for eight species, varied widely. The resulting freshwater FCV was 0.6582 µg/L at a hardness of 50 mg/L as $CaCO_3$, not to be exceeded over a 4-day average more than once every 3 years, on average. The mean acute-to-chronic ratio for two saltwater species was used to calculate an estuarine/marine FCV of 9.345 µg/L, not to be exceeded over a 4-day average more than once every 3 years, on average.

The 1995 criteria revision (U.S. EPA 1996a) updated freshwater criteria based on the incorporation of new acute and chronic data and the re-evaluation of existing data. Several Species Mean Acute Values (SMAVs) were changed based on a preference for flow-through tests and measured test concentrations. Data from tests conducted with uncharacterized river water were removed from the acceptable acute dataset. The resulting acute dataset consisted of 43 Genus Mean Acute Values (GMAVs). The FAV was 4.134 µg/L total recoverable cadmium, normalized to a hardness of 50 mg/L. The FAV was not lowered to protect a commercially or recreationally important species. Genus Mean Chronic Values (GMCVs) were changed based on the availability of additional test data, the removal of two test values conducted in river water, and the removal of a test value where cadmium concentrations were not measured. The resulting chronic dataset consisted of 12 GMCVs. The FCV was calculated using an “N” of 43, which was the number of GMAVs, rather than 12, the number of GMCVs. The FCV was 1.429 µg/L total recoverable cadmium, normalized to a hardness of 50 mg/L.

The 2001 criteria update was based on dissolved cadmium (passing through a 0.45 µm filter) to more accurately account for bioavailability and reflect the latest EPA policy for metals risk assessment (U.S. EPA 1993b). Freshwater SMAVs for cadmium were available for 65 species in 55 genera (24 fish, 39 invertebrates, 1 frog, and 1 salamander) (**Table 2**). The most sensitive vertebrate species was brown trout (*Salmo trutta*). The most sensitive invertebrate species was *Daphnia magna*, which was approximately nine times less sensitive than brown trout. Freshwater criteria were corrected for hardness based on separate acute and chronic cadmium toxicity versus hardness slopes that were generated using acute data for 12 species and chronic data for three species. Conversion factors were applied to convert total recoverable to dissolved cadmium concentrations.

Acceptable freshwater chronic test data were available for 14 fish species and 7 invertebrate species (**Table 2**), with the amphipod *Hyalella azteca* identified as the most sensitive species in the 2001 criteria. Acute-to-chronic ratios were calculated for 6 species. The 2001 estuarine/marine acute criterion was based on SMAVs for 61 species in 54 genera (50 invertebrates and 11 fish species) (**Table 2**), with mysids and striped bass identified as the most sensitive species. Chronic saltwater tests were available for two mysid species, from which acute-to-chronic ratios were calculated.

Bioconcentration factors (BCFs) reported in the 2001 criteria document for freshwater species ranged from 7 to 6,910 for invertebrates and from 3 to 2,213 for fishes. BCFs for saltwater invertebrates ranged from 5 to 3,160. Toxicity values for freshwater and saltwater aquatic plants were reviewed and acute values were found to be in the same range as toxicity values for fish and invertebrates, while chronic values were found to be considerably higher.

The resulting 2001 freshwater acute criterion (or CMC) was 2.0 μg/L dissolved cadmium and the resulting freshwater chronic criterion (or CCC) was 0.25 μg/L dissolved cadmium, when normalized to a total hardness of 100 mg/L as $CaCO_3$. The 2001 saltwater CMC was 40 μg/L dissolved cadmium, while the 2001 saltwater CCC was 8.8 μg/L.

Table 2. Number of Aquatic Species Included in Cadmium AWQC.

	Freshwater Acute	Freshwater Chronic	Estuarine/Marine Acute	Estuarine/Marine Chronic
1980	29	13	31	1
1985	52	16	35	2
1995	NA[a]	NA	NA	NA
2001	65	21	61	2
2016	101	27	94	2

[a] NA = Not Available

For the 2016 update, EPA conducted a literature search and review of acute and chronic toxicity data that have become available since the 2001 update. This update incorporates additional toxicity data for the development of both freshwater and estuarine/marine acute and chronic criteria and new toxicity data related to water hardness, which remains the primary quantitative correlation used to modify metal toxicity estimates in fresh water (U.S. EPA 1996a). EPA also re-evaluated studies with *Hyalella azteca* and freshwater mussel glochidia (a larval stage of unionid mussels), both of which were used in the development of the 2001 criteria. EPA re-evaluated studies with *H. azteca* because recent research has shown that the outcome of toxicity tests with *H. azteca* can be impacted by culture and test conditions (e.g., chloride concentration, food quantity and composition) and that tests using standard recommended test methods may not be acceptable. All *Hyalella* studies were therefore re-evaluated for acceptability with newly developed guidelines (**Appendix K**). The acceptable duration of tests using glochidia was also reconsidered. Glochidia are a larval stage of unionid freshwater mussels that occur in the water column and remain viable for only a limited period of time prior to attaching to a host fish. The duration of an acceptable toxicity test was adjusted to 24 hours to account for potential adverse effects to glochidia during this larval stage, as recent information indicates that glochidia can be the most sensitive life stage for some chemicals and plays an important role in the viability of unionid mussel populations.

2 PROBLEM FORMULATION

Problem formulation provides a strategic framework to develop water quality criteria by providing an overview of a chemical's sources and occurrence, fate and transport in the environment, and toxicological characteristics and factors affecting toxicity. A problem formulation uses this information to develop a conceptual model and identify the most relevant chemical properties and endpoints for evaluation. The structure of the problem formulation developed for cadmium is consistent with U.S. EPA's Guidelines for Ecological Risk Assessment (U.S. EPA 1998).

2.1 Overview of Cadmium Sources and Occurrence

Cadmium is a relatively rare, naturally occurring metal found in mineral deposits and distributed widely at low concentrations in the environment. Cadmium is a minor metallic element that was first discovered in Germany in 1817 as a by-product of the zinc refining process (International Cadmium Association 2013). The primary current industrial uses of cadmium are for manufacturing batteries, pigments, plastic stabilizers, metal coatings, alloys and electronics (Fulkerson and Goeller 1973; Hutton 1983; Pickering and Gast 1972; Wilson 1988). Nickel-cadmium (NiCd) batteries account for the majority (over 80%) of global cadmium consumption, followed by its use in pigments, coatings and plating, stabilizers for plastics, nonferrous alloys and other specialized uses (e.g., photovoltaic devices) (USGS 2013). Of particular note is the recent use of cadmium (as cadmium selenide or cadmium sulfide) in the manufacture of nanoparticles (also referred to as quantum dots) used as a semiconductor in photovoltaic devices (e.g., solar cells and emitters for color displays). The ecological and toxicological effects of these emerging materials to aquatic organisms are largely unknown at this time, and therefore represent a new source of cadmium to the environment (Tang 2013). Demand for cadmium has increased based on its use in NiCd batteries, while more traditional uses of cadmium in coatings, pigments and stabilizers have been declining due to environmental and health concerns (USGS 2013). Cadmium is also present as an impurity in zinc, lead and copper ore mine wastes, fossil fuels, iron and steel, cement, and fertilizers (Cook and Morrow 1995; International Cadmium Association 2013), and is present as a natural or introduced constituent in inorganic phosphate fertilizers (MNDH 2014).

In 2012, approximately 70 percent of the world's new cadmium supply was produced in Asia, with China, the Republic of Korea and Japan representing the leading producers (USGS 2013). Cadmium is no longer actively mined in the U.S. or Canada (USGS 2013), but it is produced domestically as a by-product of the extraction, smelting and refining of zinc, copper and lead ores. A leading source of cadmium (23% of the global supply) is from the recovery of spent NiCd batteries and other cadmium-bearing scrap materials (International Cadmium Association 2013; USGS 2013). In 2010, an estimated 637 metric tons of refined cadmium was produced domestically from recovered materials (USGS 2013). The amount of cadmium contained in products imported to the U.S. in 2007 was estimated to be about 1,900 metric tons (USGS 2007).

Cadmium concentrations in natural sources vary with geographic location and type of deposit. Concentrations of cadmium in mineral deposits, such as mineral sulfides, typically range from 0.1 to 0.2 mg/kg, with an average concentration of 0.18 mg/kg (Babich and Stotzky 1978; EC 2001; Nriagu 1980). As a phosphate rock impurity, cadmium can vary in concentration from as low as 0.1 mg/kg in Tennessee ores to as high as 980 mg/kg in western ores (U.S. EPA 1993a). In the U.S., cadmium concentrations in coal range from 5.47 mg/kg in the Interior Province, to 2.89 mg/kg in the Illinois Basin, 0.28 mg/kg in Alaska, and 0.13 mg/kg in the Appalachian region. This range in cadmium concentration depends on the type of coal, with bituminous coal having the highest average concentration (0.91 mg/kg) and anthracite coal having the lowest average concentration (0.22 mg/kg).

Cadmium enters the environment as a result of both natural processes (weathering and erosion of rock and soils, natural combustion from volcanoes and forest fires) and anthropogenic sources (mining, agriculture, urban activities, and waste streams from industrial processes, manufacturing, coal ash ponds/pits, fossil fuel combustion, incineration and municipal effluent) (Hem 1992; Hutton 1983; Morrow 2001; Pickering and Gast 1972; Shevchenko et al. 2003; U.S. EPA 2016; WHO 2010). Anthropogenic sources account for more than 90 percent of the total cadmium present in surface water, with atmospheric particulate deposition from fossil fuel combustion (including coal) contributing approximately 40 percent of the total cadmium present in surface water (Wood et al. 2012). The agricultural application of phosphate fertilizer releases 33 to 56 percent of total anthropogenic cadmium to the environment (Pan et al. 2010; Panagapko

2007). Waste from cement manufacturing and metallurgic smelting and refining operations account for the other major sources (Pan et al. 2010; Wood et al. 2012).

In the U.S., industrial and manufacturing facilities and mining operations report the volume of cadmium and other toxic substances released to the environment via the U.S. EPA Toxics Release Inventory (TRI). Data from the TRI indicate the average yearly release of cadmium and cadmium compounds to the environment from all industries (between 2002 and 2012) ranged from approximately 2.6 million pounds in 2009 to 10 million pounds in 2012. In coastal zones, continental riverine runoff represents a major secondary source of cadmium to estuaries and adjoining coastal waters (Cullen and Maldonado 2013), and elevated cadmium concentrations are often detected in runoff from urban and industrial areas, which increases the loading of cadmium to nearby waterways and sediments (Gobel et al. 2007).

Cadmium concentrations in unpolluted freshwaters are typically very low and frequently below analytical detection limits (Mebane 2006). In natural waters, cadmium co-occurs with zinc at a dissolved Cd/Zn ratio of approximately 0.3 percent (Wanty et al. 2009). Dissolved cadmium concentrations in unpolluted waters of the U.S. have been estimated to range from 0.002 to 0.08 µg/L (Stephan et al. 1994). Surface water monitoring of the Great Lakes between 2003 and 2006 indicated cadmium concentrations ranging from <0.001 µg/L (below detection limit) to 0.015 µg/L in Lake Huron, 0.098 µg/L in Lake Erie, 0.028 µg/L in Lake Ontario, 0.015 µg/L in Lake Superior and 0.005 µg/L in Lake Michigan (Lochner and Water Quality Monitoring and Surveillance 2008; Rossmann and Barres 1992). Cadmium concentrations in the world's oceans are estimated to range from <0.005 to 0.110 µg/L, with higher concentrations reported near some coastal areas (Cook and Morrow 1995; Elinder 1985; Jensen and Bro-Rasmussen 1992; OECD 1994; Pan et al. 2010; WHO 1992). Cadmium concentrations in surface waters of impacted environments are frequently 2-3 µg/L or greater (Abbasi and Soni 1986; Allen 1994; Annune et al. 1994; Flick et al. 1971; Friberg et al. 1971; Henriksen and Wright 1978; Nilsson 1970; Spry and Wiener 1991).

2.2 Environmental Fate and Transport of Cadmium in the Aquatic Environment

Cadmium has two oxidation states. The metallic state (Cd^0) is insoluble and rarely present in water, while several salts of the divalent state (e.g., $CdCl_2$ and $CdSO_4$) freely dissolve in water (Merck 1989). Divalent cadmium is the predominant form in most well oxygenated freshwaters that are low in organic carbon. The physical and chemical properties of cadmium are summarized in **Table 3**.

Table 3. Physical and Chemical Properties of Cadmium.

CAS Registry Number	7440-43-9
Atomic weight	112.40 g/mol
Physical form	Soft, white solid
Density	8.64 g/cm^3 (@ room temperature)
Melting point[a]	321ºC
Boiling point[a]	765ºC
Vapor pressure[b]	1 torr at 394ºC
Water solubility (g/L)[a]	
Cadmium	Insoluble
Cadmium carbonate ($CdCO_3$)	Insoluble
Cadmium chloride ($CdCl_2$)	1400 @ 20ºC
Cadmium hydroxide ($Cd(OH)_2$)	0.0026 @ 26ºC
Cadmium nitrate ($Cd(NO_3)_2$)	Soluble
Cadmium sulfate ($CdSO_4$)	755 @ 0ºC

[a] Reference: Merck 1989.
[b] Reference: ATSDR 2012.

Upon entering the freshwater or estuarine/marine aquatic environment, cadmium becomes strongly adsorbed to clays, muds, humic and organic materials and some hydrous oxides (Watson 1973). This complexation tends to remove cadmium from the water column by precipitation (Lawrence et al. 1996), where it may not be bioavailable except to benthic feeders and bottom dwellers (Callahan et al. 1979; Kramer et al. 1997). It is estimated that up to 93 percent of cadmium entering surface waters will react with constituents in the water column and will be removed to sediments (Lawrence et al. 1996), and the formation of these complexes is considered to be the most important factor in determining the fate and transport of cadmium in the aquatic environment.

Once in sediments, cadmium can be re-suspended in particulate form or can return to the water column in dissolved form following hydrolysis or via upwelling in coastal zones (Bewers et al. 1987; U.S. EPA 1979). The solubility of cadmium compounds in water depends both on the specific cadmium compound (**Table 3**) and on abiotic conditions, such as pH, alkalinity, hardness and organic matter. Sorption processes, for example, become increasingly important with increasing pH.

2.3 Mode of Action and Toxicity

Cadmium is a non-essential metal (NRC 2005) with no biological function in aquatic animals (Eisler 1985; Lee et al. 1995; McGeer et al. 2012; Price and Morel 1990; Shanker 2008). In one study comparing the acute toxicity of all 63 atomically stable heavy metals in the periodic table, cadmium was found to be the most acutely toxic metal to the amphipod, *Hyalella azteca*, based on the results of seven-day acute aquatic toxicity tests (Borgmann et al. 2005). In addition to acute toxicity, cadmium is a known teratogen and carcinogen, is a probable mutagen and is known to induce a variety of other short- and long-term adverse physiological effects in fish and wildlife at both the cellular and whole-animal level (ATSDR 2012; Eisler 1985; Okocha and Adedeji 2011). Chronic exposure leads to adverse effects on growth, reproduction, immune and endocrine systems, development, and behavior in aquatic organisms (McGeer et al. 2012). Other toxic effects include histopathologies 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 (Giari et al. 2007; Jarup et al. 1998; McGeer et al. 2011; Okocha and Adedeji 2011; Shanker 2008).

Toxic effects are thought to result from the free ionic form of cadmium (Goyer et al. 1989), which causes acute and chronic toxicity in aquatic organisms primarily by disrupting calcium homeostasis and causing oxidative damage. In freshwater fish, cadmium competes with calcium at high affinity binding sites in the gill membrane and blocks the uptake of calcium from water by interfering with ion uptake in specialized calcium channels that are located in the mitochondria-rich chloride cells (Carroll et al. 1979; Evans 1987; McGeer et al. 2012; Morel and Hering 1993; Pagenkopf 1983; Tan and Wang 2009). The combined effect of competition for the binding sites and blockage of calcium uptake on the gill membrane results in acute hypocalcaemia in freshwater fish, which is characterized by cadmium accumulation in tissues as well as decreased calcium concentrations in plasma (McGeer et al. 2011; Roch and Maly 1979; Wood et al. 1997). This mechanism is also thought to be the target of cadmium toxicity in marine fish (McGeer et al. 2012; Schlenk and Benson 2005), although cadmium is generally considered to be less toxic in sea water than in fresh water. The lesser sensitivity of marine fish and aquatic organisms in general may be both a function of physiology and environmental condition. Rocha et al. (2015) observed an increase in catalase activity (oxidative stress) in the marine mussel, *Mytilus galloprovincialis*, suggesting a possible mode of action for this taxon. Mebane et al. (2006), for example, suggests the energy demands for fish to maintain homeostasis in the lower ionic composition freshwater environment may make fish more sensitive to metals, such as cadmium, which inhibit ion regulation. Higher levels of calcium and chloride in seawater are also believed to compete to a greater degree with cadmium, potentially making it less bioavailable to aquatic life (Engel and Flower 1979). However, application of the calcium competition for apical entry and the subsequent osmoregulatory disturbance toxicity mechanism for insects has been questioned by Poteat and Buchwalter (2013). Their research (Poteat et al. 2012, 2013) has demonstrated the lack of interaction between calcium and cadmium at the apical surface of aquatic insects in dissolved exposures. Cadmium exposure is also associated with the disruption of sodium balance and accompanying Na^+/K^+-ATPase activity (Atli and Canli 2007). Once inside the cell, cadmium can disrupt enzymatic function (Okocha and Adedeji 2011), by either directly affecting Ca-ATPase activity or inhibiting antioxidant processes. Cadmium also inhibits enzymes such as catalase, glutathione reductase, and superoxide dismutase and reducing agents such as GSH, ascorbate, b-carotene and a-tocopherol, all of which can lead to the generation of excess reactive oxygen species and reduced ATP production (McGeer et al. 2012).

Cadmium can bioaccumulate in aquatic organisms, with total uptake depending on the environmental cadmium concentration, exposure route and the duration of exposure (Annabi et al. 2013; Francis et al. 2004; McGeer et al. 2000; Roméo et al. 1999). Cadmium concentrations typically build up in tissues at the site of exposure, such as the gill surface and gut tract wall (Chevreuil et al. 1995). Cadmium is then transferred via circulation to nearly all other tissues and organs, with the liver and kidney (in addition to the gill or gut) typically accumulating high concentrations relative to muscle tissues (Annabi et al. 2013; McGeer et al. 2012). Although cadmium bioaccumulates in some aquatic species, there does not appear to be a consistent relationship between body burden and toxicological effect. In a detailed review of this relationship, Mebane (2006) concluded that for both aquatic invertebrates and fish, tissue concentrations associated with adverse effects regularly overlap with tissue concentrations where no adverse effects were observed. This inconsistent relationship between whole body tissue concentration and effect may be related to specific organs and/or tissues within which the accumulation is occurring and which would not be accurately quantified by whole body tissue residue analysis, and/or to the metabolic bioavailability of cadmium in tissues. Detoxification mechanisms in aquatic organisms, including the formation and activation of antioxidants, metallothionein, glutathione, and heat shock proteins (McGeer et al. 2011), effectively sequester the metal in a detoxified form, thereby allowing the organism to accumulate elevated levels of cadmium before displaying a toxic response. While the amount of detoxified metal that an aquatic organism can accumulate is theoretically unlimited, an organism will only experience toxic effects once the concentration of metabolically available metal is exceeded (Mebane 2006; Rainbow 2002). Under natural conditions, most accumulated cadmium in tissues is expected to exist in the detoxified state, which may explain the poor relationship between toxic effect and whole body tissue residue concentrations of trace metals reported by Rainbow (2002) for aquatic invertebrates and fish. Mebane (2006) concluded that, although there were not adequate data to establish acceptable tissue effect concentrations for aquatic life, cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at calculated chronic criterion concentrations. The evaluation of direct exposure effects to organisms via water is therefore considered more applicable to the development of criteria for aquatic life.

Mammals and avian wildlife could be exposed to cadmium while foraging in aquatic habitats or via the ingestion of prey that have bioaccumulated cadmium from the aquatic environment. Although few adverse effects to mammals and avian wildlife have been demonstrated from the presence of cadmium in the aquatic environment, a number of laboratory-based investigations have demonstrated a range of sublethal and lethal toxic effects, the majority of which are associated with chronic exposure (Burger 2007; Cooke and Johnson 1996; Eisler 1985; Furness 1996; Henson and Chedrese 2004). However, the biological integrity of aquatic systems is considered to be at greater risk from cadmium than terrestrial systems based on the greater sensitivity of aquatic organisms relative to birds and mammals (Burger 2007; Wren et al. 1995). Freshwater biota are the most sensitive to cadmium, marine organisms are generally considered to be more resistant than freshwater organisms, while mammals and birds are considered to be comparatively resistant to cadmium (Burger 2007; Eisler 1985). Based on this trend, criteria that are protective of aquatic life are also considered to be protective of mammalian and avian wildlife (including aquatic-dependent wildlife) and are accordingly the focus of this evaluation.

2.3.1 Water quality parameters affecting cadmium toxicity

Water quality parameters such as hardness, pH, salinity, alkalinity, some metals, and organic carbon can alter the toxicity of metals to aquatic organisms. When adequate data are available, water quality criteria can be adjusted to quantify how these environmental factors affect the toxicity of a chemical. Water hardness, which is the amount of minerals (primarily calcium and to a lesser extent magnesium) dissolved in surface water, is one important water quality parameter influencing the toxicity of cadmium.

The acute toxicity of cadmium has been shown to decrease with increasing water hardness in most tested freshwater animals (Sprague 1985). Available data for 14 genera (representing six of the eight required Minimum Data Requirements (MDR) families) listed in **Appendix A** indicate that cadmium is more acutely toxic in soft than in hard water. Acute tests conducted with *Daphnia magna* at three different water hardness levels, for example, demonstrate that daphnids are at least five times more sensitive to cadmium in soft water than in hard water (Chapman et al. 1980). Similarly, the acute toxicity of cadmium to *D. magna* was reduced (48-hr LC_{50} increased from 7.5 to 24.8 µg/L) as the calcium concentration was increased from 0.46 to 192 mg/L (Tan and Wang 2011). The ability of calcium to reduce the toxicity of cadmium was also observed in water with *D. pulex* (Clifford and McGeer 2010), rainbow trout (*Oncorhynchus mykiss*) (Niyogi et al. 2008) and brook trout (*Salvelinus fontinalis*) (Carroll et al. 1979).

In addition to hardness, other water quality characteristics have been shown to influence the toxicity of cadmium to aquatic species. Increased levels of dissolved organic carbon, for example, have been shown to reduce the toxicity of cadmium to daphnids by reducing the bioavailability of cadmium through complexation (Clifford and McGeer 2010; Giesy et al. 1977; Niyogi et al. 2008). Conversely, other water chemistry variables, including magnesium, pH and alkalinity have been shown to have little or no effect on cadmium toxicity (Clifford and McGeer 2010; Niyogi et al. 2008). The relationship between salinity and temperature and cadmium effects could not be quantitatively established. These analyses are described in detail in **Section 5.4.1**.

Development of an initial (phase I) biotic ligand model (BLM – formerly the “gill model”) was attempted for cadmium to better account for the bioavailability of this metal to aquatic life. The cadmium BLM is based on a conceptual model similar to the gill site model proposed by Pagenkopf (1983), but it is recognized that the gill itself may be a general surrogate for the actual site of toxic action. For cadmium, it is thought that more highly specific enzymatic binding sites affecting the activity of Ca^{2+}-ATPase may be the actual site of toxic action (Fu et al. 1989; Hogstrand and Wood 1996). Based on the preliminary findings in 2003 during the Phase I development of a cadmium BLM (HydroQual 2003), a significant pH effect was also observed when pH was decreased from 7.0 to 4.7 for steelhead trout, *Oncorhynchus mykiss*. In the BLM framework, this was explained as a competitive interaction between H^+ and Cd^{2+} at the biotic ligand, rather than a change in cadmium speciation. Preliminary results for the cadmium BLM for more complex interactions indicate the effect levels should generally increase with increasing DOC, pH and hardness (both as calcium and magnesium) (U.S. EPA 2004). Further development of the BLM for cadmium may help to better quantify the bioavailable fraction of this chemical. However, because hardness is a surrogate for other ions affecting cadmium toxicity, and based on available data, EPA believes that a cadmium BLM model is not necessary for the current criteria update.

2.4 Conceptual Model

A conceptual model characterizes relationships between human activities, stressors, and ecological effects on the assessment endpoints identified for evaluation (U.S. EPA 1998). The conceptual model links exposure characteristics with the ecological endpoints important for the development of management goals. Under the CWA, these management goals are established by states and tribes as designated uses of waters of the United States (for example, the protection of aquatic life). In deriving aquatic life criteria, EPA is developing acceptable thresholds for pollutants that, if not exceeded, are expected to be protective of aquatic life. A state and/or tribe may implement these criteria by adopting them into their respective water quality standards.

The conceptual model depicted in **Figure 1** provides a broad overview of how aquatic organisms could be exposed to cadmium. As depicted in **Figure 1** and discussed in **Section 2.1**, cadmium enters the environment from both natural and anthropogenic sources. Natural sources of cadmium, which largely result from the weathering and erosion of rock and soils, represent a relatively minor source to the environment compared to anthropogenic sources. Although there are multiple anthropogenic sources (see **Section 2.1**), emissions of cadmium to the atmosphere (e.g., combustion, smelting/refining, and manufacturing) and contributions from leaching/runoff (via the application of phosphate fertilizers) represent the major cadmium inputs (40 and up to 56 percent, respectively) to surface water (Pan et al. 2010).

Up to 93 percent of cadmium entering surface water will react with organic and inorganic constituents in the water column, including particulate matter, iron oxides, and clay materials, and will be removed to sediments (Lawrence et al. 1996). Sediments are therefore a reservoir for cadmium in the aquatic environment and can become a source of exposure for benthic and water column dwelling aquatic life and higher trophic level species. **Figure 1** depicts exposure pathways for the biological receptors of concern (e.g., aquatic animals) and the potential attribute changes (i.e., effects such as reduced survival, growth and reproduction) in those receptors from cadmium exposure. Although the multiple potential exposure pathways depicted in **Figure 1** are likely to be complete, the development of the water quality criteria for cadmium focuses on evaluating the direct exposure of aquatic life to cadmium in surface water because this potential exposure pathway, and the potential for adverse effects on survival, growth, and reproduction from direct aqueous exposure, is considered to represent the greatest potential risk to most aquatic species, and is consistent with the approach established in the 1985 Guidelines. Nevertheless, consideration of the fate and transport mechanisms, exposure pathways, and receptors depicted in **Figure 1** may be helpful for states and tribes as they adopt criteria into standards and evaluate potential exposure pathways affecting designated uses.

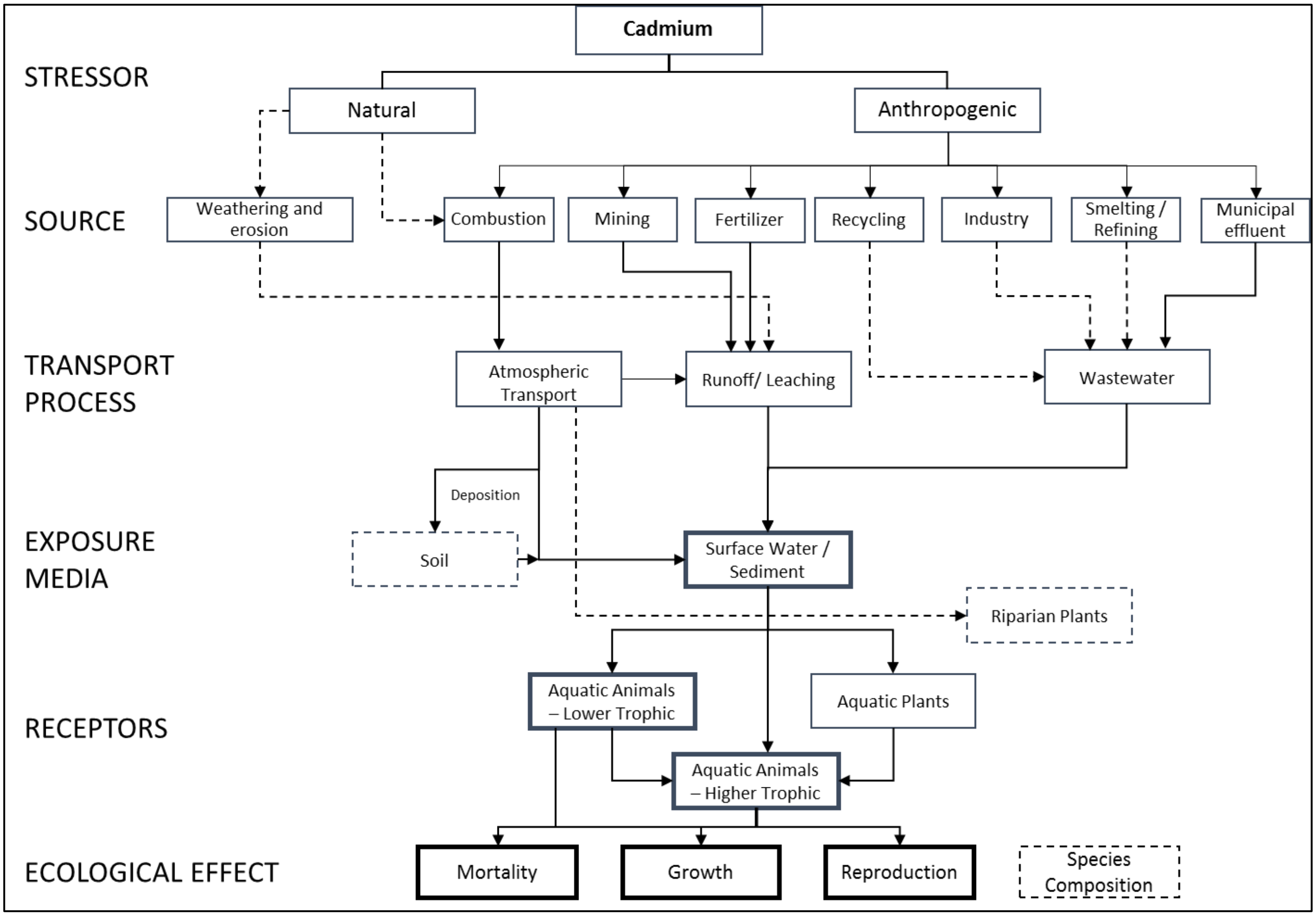

Figure 1. Conceptual Model Depicting the Major Sources, Transport and Exposure Media and Ecological Effects of Cadmium in the Environment.
(Note: Solid line indicates potentially important pathway/media/receptor; dashed line indicates secondary pathway/media/receptor).

2.5 Assessment Endpoints

Assessment endpoints are defined as the explicit expressions of the environmental values to be protected and are comprised of both the ecological entity (e.g., a species, community, or other entity) and the attributes or characteristics of the entity to be protected (U.S. EPA 1998). Assessment endpoints may be identified at any level of organization (e.g., individual, population, community). In context of the CWA, aquatic life criteria for toxic substances are typically determined based on the results of toxicity tests with aquatic organisms, for which adverse effects on growth, reproduction, or survival are measured. This information is aggregated into a species sensitivity analysis that characterizes an impact to the aquatic community. Criteria are designed to be protective of the vast majority of aquatic animal species in an aquatic community (i.e., approximately the 95th percentile of tested aquatic animals representing the aquatic community). Assessment endpoints consistent with the criteria developed in this document are summarized in **Table 4**.

The concept of using laboratory toxicity tests to protect North American bodies of water and resident aquatic species and their uses is based on the theory that effects occurring to a species in appropriate laboratory tests will generally occur to the same species in comparable field situations. Since aquatic ecosystems are complex and diversified, the 1985 Guidelines require acceptable data be available for at least eight genera with a specified taxonomic diversity (the standard eight-family minimum data requirement, or MDR). The intent of the eight-family MDR is to serve as a typical surrogate sample community representative of the larger and generally much more diverse natural aquatic community, not necessarily the most sensitive species in a given environment. For many aquatic life criteria, enough data are available to describe a species sensitivity distribution to represent the distribution of sensitivities in natural ecosystems. In addition, since aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places are not deemed necessary (the intent is to protect 95 percent of a group of diverse taxa, and any commercially and recreationally important species). Thus, if properly derived and used, the combination of a freshwater or estuarine/marine acute CMC and chronic CCC should provide an appropriate degree of protection of aquatic organisms and their uses from acute and chronic toxicity to animals, toxicity to plants, and bioaccumulation by aquatic organisms (Stephan et al. 1985).

2.6 Measurement Endpoints

Assessment endpoints require one or more measures of ecological effect, which are termed “measurement endpoints”. Measurement endpoints are the measures of ecological effect used to characterize or quantify changes in the attributes of an assessment endpoint or changes in a surrogate entity or attribute, in this case a response to chemical exposure. Toxicity data are used as measures of direct and indirect effects on representative biological receptors. The selected measures of effect for the development of aquatic life criteria encompass changes in the growth, reproduction, and survival of aquatic organisms.

The toxicity data used for the development of aquatic life criteria depend on the availability of applicable toxicity test outcomes, the acceptability of test methodologies, and an in-depth evaluation of the acceptability of each specific test, as performed by EPA. Measurement endpoints for the development of aquatic life criteria are derived using acute and chronic toxicity studies for representative test species, which are then quantitatively and qualitatively analyzed, as described in the Analysis Plan below. Measurement endpoints considered for each assessment endpoint in this criteria document are summarized in **Table 4**. The following sections discuss toxicity data requirements for the fulfillment of these measurement endpoints.

Overview of Toxicity Data Requirements

EPA has specific data requirements to assess the potential effects of a stressor on an aquatic ecosystem and develop 304(a) aquatic life criteria under the CWA. Acute toxicity test data (short term effects on survival) for species from a minimum of eight diverse taxonomic groups are required for the development of acute criteria to ensure the protection of various components of an aquatic ecosystem.

- Acute freshwater criteria require data from the following taxonomic groups:
    - the family Salmonidae in the class Osteichthyes
    - a second family in the class Osteichthyes, preferably a commercially or recreationally important warmwater species (e.g., bluegill, channel catfish)
    - a third family in the phylum Chordata (may be in the class Osteichthyes or may be an amphibian)
    - a planktonic crustacean (e.g., cladoceran, copepod)
    - a benthic crustacean (e.g., ostracod, isopod, amphipod, crayfish)
    - an insect (e.g., mayfly, dragonfly, damselfly, stonefly, caddisfly, mosquito, midge)
    - a family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca)
    - a family in any order of insect or any phylum not already represented
- Acute estuarine/marine criteria require data from the following taxonomic groups:
    - two families in the phylum Chordata
    - a family in a phylum other than Arthropoda or Chordata
    - a family from either Mysidae or Penaeidae
    - three other families not in the phylum Chordata (may include Mysidae or Penaeidae, whichever was not used above)
    - any other family

Chronic toxicity test data (longer-term effects on survival, growth, or reproduction) are generally required for a minimum of three taxa, with at least one chronic test being from an acutely-sensitive species. Acute-chronic ratios (ACRs) can be calculated with data for species of aquatic animals from at least three different families if the following data requirements are met:

- at least one is a fish
- at least one is an invertebrate
- at least one is an acutely sensitive freshwater species, for freshwater chronic criterion (the other two may be saltwater species)
- at least one is an acutely sensitive saltwater species for estuarine/marine chronic criterion (the other two may be freshwater species)

Because acceptable chronic values for all eight MDRs were available for cadmium in fresh water, the chronic criterion was derived following the same genus level sensitivity distribution (SD) approach used to calculate the acute criterion (see the 1985 Guidelines for additional detail). The chronic estuarine/marine criterion for cadmium was derived using the ACR approach.

The 1985 Guidelines also require at least one acceptable test with a freshwater alga or vascular plant. If plants are among the aquatic organisms most sensitive to the chemical, results of a plant in another phylum should also be available. Data on toxicity to aquatic plants are examined to determine whether plants are likely to be unacceptably affected by concentrations below those expected to cause unacceptable effects on aquatic animals. However, as discussed in **Section 2.7**, the relative sensitivity of fresh and estuarine/marine algae and plants to cadmium (**Appendix E** and **Appendix F**) is less than vertebrates and invertebrates, so plant criteria are not developed.

Measures of Effect

Measure of cadmium exposure concentration

Consistent with previous AWQC documents for cadmium, only effects data from tests that used the following cadmium salts (either anhydrous or hydrated) were used for development of the AWQC:

- cadmium chloride ($CdCl_2$) (CAS # 10108-64-2)
- cadmium nitrate ($Cd(NO_3)_2$) (CAS # 10325-94-7)
- cadmium sulfate ($CdSO_4$) (CAS # 10124-36-4)

Measured concentrations of cadmium can be expressed as either total recoverable cadmium, acid-soluble cadmium, or total dissolved cadmium (using a conversion factor) based on the different forms of cadmium present in the aquatic environment. Previous aquatic life criteria for cadmium were expressed either in terms of total recoverable cadmium (U.S. EPA 1980; 1983a) or as acid-soluble cadmium (U.S. EPA 1985c). Since 1993, EPA has recommended using dissolved metal concentrations (defined as the metal in solution that passes through a 0.45-µm membrane filter) for developing criteria, based on the greater bioavailability of dissolved metals in surface water. Cadmium criteria are accordingly expressed as dissolved metal concentrations consistent with current recommendations (Prothro 1993; U.S. EPA 1993b, 1994a), which typically involves converting measured total recoverable cadmium concentrations to estimated dissolved cadmium concentrations using a conversion factor. It should be noted, however, the majority of cadmium present in natural surface water is in the dissolved form and differences between the 0.45-µm filtered (dissolved) and unfiltered (total) concentrations in surface water samples are usually small, with dissolved concentrations typically averaging 90 to 95 percent of the concentration present in an unfiltered sample (Clark 2002; Mebane 2006; Stephan 1995). These averages are generally consistent with the dissolved fraction present in unfiltered concentrations of 94 percent for fresh water (at a total hardness of 100 mg/L as $CaCO_3$) and 99 percent for marine environments that are used for the updated criteria, respectively.

The acute freshwater conversion factors were determined empirically whereby total and dissolved cadmium concentrations were measured during actual 48- and 96-hour *Daphnia magna* and fathead minnow fed and unfed static toxicity tests conducted at different total hardness levels (Stephan 1995; University of Wisconsin – Superior 1995). Either cadmium chloride or cadmium sulfate were spiked in Lake Superior water and measured at test initiation and completion. The time weighted averages obtained for percent dissolved cadmium for each simulation were used to determine the freshwater acute conversion factors of 0.973 at 50 mg/L, 0.944 at 100 mg/L and 0.915 at 200 mg/L total hardness (see **Appendix Table A-3**). Freshwater chronic conversion factors obtained from the same acute tests and extrapolation procedures were 0.938, 0.909 and 0.880 at 50, 100 and 200 mg/L total hardness (see **Appendix Table C-3**), respectively. The lower chronic conversion factors are due to the longer time weighted average period employed relative to the acute factors. The acute saltwater conversion factor of 0.99 determined by Lussier et al. (1999) was based on an *Americamysis bahia* 96-hr flow-through exposure and mean weighted total and dissolved cadmium concentrations. Narragansett Bay seawater was spiked with cadmium chloride and exposure concentrations were measured at 1- and 96 hours after test initiation.

All concentrations for toxicity tests are expressed as total cadmium in this document, not as the form of the chemical tested. In the aquatic environment, cadmium is measured as total recoverable metal or free divalent metal.

Acute measures of effect

The acute measures of effect on aquatic organisms are the LC_{50}, EC_{50}, and IC_{50}. LC stands for "Lethal Concentration" and an LC_{50} is the concentration of a chemical that is estimated to kill 50 percent of the test organisms. EC stands for "Effect Concentration" and the EC_{50} is the concentration of a chemical that is estimated to produce a specific effect in 50 percent of the test organisms. IC stands for "Inhibitory Concentration" and the IC_{50} is the concentration of a chemical that is estimated to inhibit some biological process (e.g., growth) in 50 percent of the test organisms. Data that were determined to have acceptable quality and to be useable in the derivation of water quality criteria as described in EPA's 1985 Guidelines for the derivation of a freshwater and estuarine/marine criteria are presented in **Appendix A** and **Appendix B**, respectively.

Acute toxicity data on freshwater mussel glochidia life stage

Glochidia are an early parasitic life stage of unionid freshwater mussels, which are free living in the water column prior to finding an appropriate fish host. Based on their unique life history compared to most aquatic life, glochidia toxicity tests were carefully examined to determine if they provided ecologically relevant toxicological information for the derivation of aquatic life criteria. Glochidia may be present in the water column for a period of time ranging from seconds to days, depending on the species, and they have potential to be exposed to contaminants in surface water during that time. EPA determined it was important to consider the potential for adverse effects to glochidia in the development of water quality criteria for cadmium because adverse effects on this sensitive early life stage could have implications on the viability of unionid mussel populations. The potential for adverse effects to glochidia was also considered in the development of ammonia criteria (U.S. EPA 2013).

In order for the toxicity test results with glochidia to be ecologically relevant, the duration of the acute toxicity test must be comparable to the duration of the free-living stage of glochidia prior to attaching to a host. Research conducted by Fritts et al. (2014) supports the recommendation of a maximum test duration of 24 hours for glochidia, corresponding with the ecologically relevant period of host infectivity of this parasitic life stage. Survival of glochidia at the end of 24 hours should be at least 90% in the laboratory control and if the viability is less than 90% at 24 hours in the control, then the next longest duration less than 24 hours that had at least 90% survival in the control is considered acceptable for use. These requirements for the acceptance of glochidia tests were put forward in the 2013 ammonia criteria document and were peer reviewed at that time (U.S. EPA 2013). Acceptable cadmium glochidia data were available only for the fatmucket (*Lampsilis siliquoidea*), but this life stage was less sensitive than the juvenile life stage and therefore glochidia results were not used to calculate the SMAV for this species.

Chronic measures of effect

The endpoint for chronic exposure is the EC_{20}, which represents a 20 percent effect/inhibition concentration. This is in contrast to a concentration that causes a low level of reduction in response, such as an EC_5 or EC_{10}, which is rarely statistically significantly different from the control treatment. EPA selected an EC_{20} to estimate a low level of effect that would be statistically different from control effects, but not severe enough to cause chronic effects at the population level (see U.S. EPA 1999c). Reported NOECs (No Observed Effect Concentrations) and LOECs (Lowest Observed Effect Concentrations) were only used for the derivation of chronic criterion when an EC_{20} could not be calculated for the genus. A NOEC is the highest test concentration at which none of the observed effects are statistically different from the control. A LOEC is the lowest test concentration at which the observed effects are statistically different from the control. When LOECs and NOECs are used, a Maximum Acceptable Toxicant Concentration (MATC) is calculated, which is the geometric mean of the NOEC and LOEC.

Regression analysis was used to characterize a concentration-effect relationship and to estimate concentrations at which chronic effects are expected to occur. For the calculation of chronic criterion, point estimates were selected for use as the measure of effect in favor of

MATCs, as MATCs are highly dependent on the concentrations tested. Point estimates also provide additional information that is difficult to determine with an MATC, such as a measure of effect level across a range of tested concentrations. Chronic toxicity data that met the test acceptability and quality assurance/control criteria in EPA's 1985 Guidelines for the derivation of freshwater and estuarine/marine criteria are presented in **Appendix C** and **Appendix D**, respectively.

Table 4. Summary of Assessment Endpoints and Measures of Effect Used in Criteria Derivation.

Assessment Endpoints for the Aquatic Community	Measures of Effect
Survival, growth, biomass, and reproduction of fish and invertebrates (freshwater and estuarine/marine)	Acute: LC_{50}, EC_{50} Chronic: EC_{20}, MATC (only used when an EC_{20} could not be calculated for the genus)
Maintenance and growth of aquatic plants from standing crop or biomass (freshwater and estuarine/marine)	LOEC, EC_{20}, EC_{50}, IC_{50}, reduced growth rate, cell viability, calculated MATC

MATC = Maximum acceptable toxicant concentration (geometric mean of NOEC and LOEC)
NOEC = No observed effect concentration
LOEC = Lowest observed effect concentration
LC_{50} = Lethal concentration to 50% of the test population
EC_{50}/EC_{20} = Effect concentration to 50%/20% of the test population
IC_{50} = Concentration of cadmium at which some effect is inhibited 50% compared to control organism

Use of data from chronic tests with Hyalella azteca

The use of *H. azteca* data for criteria derivation has created an uncertainty due to issues with culture and testing conditions. Laboratory evidence indicates that sufficient levels of bromide and chloride are required for maintaining healthy *H. azteca* cultures, which are important to accurately characterizing the toxicity of pollutants to *H. azteca* (U.S. EPA 2009a). In response to this concern, each *H. azteca* acute and chronic toxicity test was evaluated with the acceptability criteria recommended by U.S. EPA (2012) (**Appendix K**). These criteria address the minimum levels of bromide and chloride in dilution water, along with other factors such as the use of a substrate and minimum survival of control to characterize test acceptability.

2.7 Analysis Plan

During CWA §304(a) criteria development, EPA reviews and considers all relevant toxicity test data. Information available for all relevant species and genera are reviewed to identify: 1) data from acceptable tests that meet data quality standards; and 2) whether the acceptable data meet the minimum data requirements (MDRs) as outlined in EPA's 1985 Guidelines (Stephan et al. 1985; U.S. EPA 1986a). The taxa represented by the different MDR groups represent taxa with different ecological, trophic, taxonomic and functional characteristics in aquatic ecosystems, and are intended to be a representative subset of the diversity within a typical aquatic community.

For this cadmium criteria update, the MDRs described in **Section 2.6** are met, and criteria values are developed for acute and chronic freshwater and acute and chronic estuarine/marine species. **Table 5** provides a summary of the Phyla, Families, Genera and Species for which toxicity data are available and that were used to fulfill the MDRs for calculation of acute and chronic criteria for both freshwater and estuarine/marine organisms. A relatively large number of tests from acceptable studies of aquatic algae and vascular plants are also available for possible derivation of a Final Plant Value. However, the relative sensitivity of fresh and estuarine/marine algae and plants to cadmium (**Appendix E** and **Appendix F**) is less than aquatic vertebrates and invertebrates so plant criteria are not developed.

Table 5. Summary Table of Acceptable Toxicity Data Used to Meet the Minimum Data Requirements in the "1985 Guidelines" and Count of Phyla, Families, Genera and Species.

Family Minimum Data Requirement (Freshwater)	**Acute (Phylum / Family / Genus)**	**Chronic (Phylum / Family / Genus)**
Family Salmonidae in the class Osteichthyes	Chordata / Salmonidae / Oncorhynchus	Chordata / Salmonidae / Oncorhynchus
Second family in the class Osteichthyes	Chordata / Catostomidae / Catostomus	Chordata / Catostomidae / Catostomus
Third family in the phylum Chordata	Chordata / Ambystomatidae / Ambystoma	Chordata / Cyprinodontidae / Jordanella
Planktonic Crustacean	Arthropoda / Daphniidae / Daphnia	Arthropoda / Daphniidae / Daphnia
Benthic Crustacean	Arthropoda / Cambaridae / Orconectes	Arthropoda / Hyalellidae / Hyalella
Insect	Arthropoda / Baetidae / Baetis	Arthropoda / Chironomidae / Chironomus
Family in a phylum other than Arthropoda or Chordata	Mollusca / Unionidae / Lampsilis	Mollusca / Unionidae / Lampsilis
Family in any order of insect or any phylum not already represented	Annelida / Tubificidae / Tubifex	Annelida / Lumbriculidae / Lumbriculus
Family Minimum Data Requirement (Estuarine/Marine)	**Acute (Phylum / Family / Genus)**	**Chronic (Phylum / Family / Genus)**
Family in the phylum Chordata	Chordata / Fundulidae / Fundulus	-
Family in the phylum Chordata	Chordata / Salmonidae / Oncorhynchus	-
Either the Mysidae or Penaeidae family	Arthopoda / Mysidae / Americamysis	Arthopoda / Mysidae / Americamysis
Family in a phylum other than Arthropoda or Chordata	Mollusca / Mytilidae / Mytilus	-
Family in a phylum other than Chordata	Echinodermata / Strongylocentrotidae / Strongylocentrotus	-
Family in a phylum other than Chordata	Echinodermata / Asteriidae / Asterias	-
Family in a phylum other than Chordata	Annelida / Capitellidae / Capitella	-
Any other family	Mollusca / Pectinidae / Argopecten	-

Dash (-) indicates requirement not met (*i.e.*, no acceptable data).

	Freshwater Acute			**Freshwater Chronic**			**Estuarine/Marine Acute**			**Estuarine/Marine Chronic**		
Phylum	**Families**	**GMAVs**	**SMAVs**	**Families**	**GMCVs**	**SMCVs**	**Families**	**GMAVs**	**SMAVs**	**Families**	**GMCVs**	**SMCVs**
Annelida	4	11	12	2	2	2	6	10	10	-	-	-
Arthropoda	18	22	32	3	4	6	30	37	44	1	1	2
Bryozoa	3	3	3	-	-	-	-	-	-	-	-	-
Chordata	15	27	35	8	11	16	14	14	16	-	-	-
Cnidaria	1	1	4	-	-	-	2	2	2	-	-	-
Echinodermata	-	-	-	-	-	-	3	3	4	-	-	-
Mollusca	4	9	13	3	3	3	9	12	17	-	-	-
Nematoda	-	-	-	-	-	-	1	1	1	-	-	-
Platyhelminthes	2	2	2	-	-	-	-	-	-	-	-	-
Total	**47**	**75**	**101**	**16**	**20**	**27**	**66**	**79**	**94**	**1**	**1**	**2**

2.7.1 Hardness adjustment

The hardness adjustment is used as a surrogate for this criteria revision to estimate the effect of all ions on the toxicity of cadmium. EPA's 1985 Guidelines state that when sufficient data are available to demonstrate that toxicity is related to a water quality characteristic, the relationship should be taken into account using an analysis of covariance (Stephan et al. 1985). As noted in the 1985 Guidelines, the relationship between hardness and the toxicity of metals in freshwater is best described by a log-log relationship. The ratio of calcium and magnesium ions influence the toxicity of cadmium and the subsequent cadmium toxicity-hardness relationship, especially since cadmium is known to behave like a calcium analog (Playle et al. 1993a). An analysis of covariance was conducted to examine the relationship between hardness and cadmium toxicity to freshwater aquatic animals. The analysis of covariance was performed separately for acute and chronic toxicity, using the R statistical program (Dixon and Brown 1979; Neter and Wasserman 1974; R Core Team 2015).

Before conducting the analysis of covariance, currently available toxicity data with available hardness values were evaluated for each species to determine if they were useful for characterizing the relationship between hardness and cadmium toxicity in freshwater. The 1985 Guidelines do not provide explicit rules regarding whether data for a particular species are useful, but they do emphasize the importance of having a range of tested hardness values for a particular species. Since the publication of the 1985 Guidelines, EPA has determined that in order to meet the precondition for inclusion in the covariance model for determining the hardness relationship, a species should have definitive toxicity values available over a range of hardness levels, such that the highest hardness is at least three times the lowest, and at least 100 mg/L higher than the lowest (U.S. EPA 2001). As such, EPA evaluated the cadmium studies per the 1985 Guidelines conditions prior to inclusion in the covariance model and excluded studies from the analysis where only a single acute toxicity value was available, or where multiple tests were conducted at the same hardness. Examples of excluded tests include those that were conducted to evaluate the effects of cadmium to a non-hardness parameter, such as Na or K (e.g., Clifford 2009). In cases where the hardness-toxicity relationship for a particular species is highly divergent between studies, then data from these studies were only used when they were specifically designed to investigate the effects of hardness, and when both the toxicity and hardness values provided were definitive (not greater than or less than values). For example, the hardness-toxicity relationship for the fathead minnow is highly divergent from one life stage to another. Adult fathead minnow responses are highly correlated, while fry responses are not, so only tests conducted with adults were used (U.S. EPA 2001).

As noted above, this 2016 cadmium update evaluated definitive toxicity values available over a specified range of hardness levels to develop the acute and chronic hardness-toxicity relationships. This procedure was very similar to that used for the 2001 update and the 2015 draft cadmium criteria, except that only studies where the concentrations of cadmium was measured were used, multiple tests conducted at the same hardness level were excluded, and data from the same study were favored over highly divergent data from multiple studies for a particular species. In addition, EC_{20} and MATC values are used in the chronic slope for this effort, whereas the 2001 update used only MATCs. The data used to calculate the acute and chronic hardness-toxicity relationships are identified in **Appendix Table A-2** and **Appendix Table C-2**, respectively.

An analysis of covariance, to evaluate the relationship between natural log transformed hardness and natural log transformed cadmium toxicity to the tested species, is the first step following data selection. If the analysis of covariance model term describing the similarity of hardness slopes among individual species is not statistically significant at an alpha of 0.05 ($P>0.05$), then a model with a single hardness slope is statistically equivalent to a model with separate hardness slopes for each species, and a pooled slope can be calculated. The pooled hardness slope is then calculated using linear regression, and is considered the best estimate for characterizing the relationship between toxicity and hardness for all test species. The results of the acute and chronic hardness correction procedures are described in **Section 3.1.1** and **Section 3.1.2**, respectively, and individual species slopes are provided in **Table 6** and **Table 8**.

2.7.2 Acute criterion

Acute criteria are derived from the sensitivity distribution (SD) of genus mean acute values (GMAVs), calculated from species mean acute values (SMAVs) for available and acceptable data. SMAVs are calculated using the geometric mean for all acceptable toxicity tests for a given species (e.g., all tests for *Daphnia magna*). If only one test is available, the SMAV is that test value by default. As stated in the 1985 Guidelines, flow-through measured test data are normally given preference over other test exposure types (i.e., renewal, static, unmeasured) for a species, when available. When relationships are apparent between life-stage and sensitivity, only values for the most sensitive life-stage are considered.

GMAVs are calculated using the geometric means of all calculated SMAVs within a given genus (e.g., all SMAVs for genus *Daphnia* – including *Daphnia pulex, Daphnia magna*). If only one SMAV is available for a genus, then the GMAV is represented by that value. GMAVs derived for each of the genera are then rank-ordered by sensitivity, from most (Rank 1) to least sensitive (Rank *N*).

Acute freshwater and estuarine/marine criteria are based on the Final Acute Value (FAV). The FAV is determined by first ordering the GMAVs by rank from most to least sensitive for regression analysis. The regression analysis is typically driven by the four most sensitive genera in the sensitivity distribution, based on the need to interpolate or extrapolate (as appropriate) to the 5th percentile of the distribution represented by the tested genera. Use of a sensitivity distribution where the criteria values are based on the four most sensitive taxa in a triangular distribution represents a censored statistical approach that improves estimation of the lower tail when the shape of the whole distribution is uncertain, while accounting for the total number of genera within the whole distribution. Since there were more than 59 GMAVs in both the freshwater and estuarine/marine cadmium acute datasets, the four GMAVs closest to the 5th percentile of the distribution were used to calculate the FAV, consistent with procedures described in the 1985 Guidelines. The acute criterion, defined as the Criterion Maximum Concentration (CMC), is then calculated by dividing the FAV by two, which is intended to provide an acute criterion protective of nearly all individuals in the distribution (Stephan et al. 1985); the FAV/2 approach was developed to estimate minimal effect levels, those which approximate control mortality limits, and is based on the analysis of 219 acute toxicity tests for a range of chemicals, as described in the *Federal Register* on May 18, 1978 (43 FR 21506-18).

2.7.3 Chronic criterion

A chronic criterion is typically determined by one of two methods. If MDRs are met with acceptable chronic test data available for all eight families, then the chronic criteria can be derived using the same method as for the acute criteria, employing chronic values (e.g., EC_{20}) estimated from acceptable toxicity tests. While this is the case for the freshwater cadmium chronic dataset, acceptable chronic data are not available for all eight families for estuarine/

marine species. For the estuarine/marine chronic dataset, the chronic criterion was therefore derived by determining an appropriate Final Acute-Chronic Ratio (FACR).

The procedure used to calculate an FACR involves dividing an acute toxicity test value by a “paired” chronic test value. Tests for a chemical are considered paired when they are conducted by the same laboratory, with the same test organism and with the same dilution water (see Stephan et al. 1985). If there is a clear trend, the FACR may be the geometric mean of the available ACRs, or an individual ACR (or combination thereof), based on the most sensitive taxa. The Final Chronic Value (FCV) for estuarine/marine aquatic animals was obtained by dividing the FAV by the FACR, consistent with procedures described in Section IV.A of Stephan et al. (1985).

Available chronic toxicity data for freshwater and estuarine/marine plants were reviewed to determine whether plants are more sensitive to cadmium than freshwater and estuarine/marine animals (see **Appendix A**, **Appendix B**, **Appendix E** and **Appendix F**). Plants were found to be less sensitive, and in most cases, at least an order of magnitude less sensitive to cadmium than other aquatic species. It was therefore not necessary to develop chronic criteria based on plant toxicity values in this update.

3 EFFECTS ANALYSES FOR AQUATIC ORGANISMS

The data used to update the acute and chronic criteria for cadmium were collected via literature searches of EPA's ECOTOX database, as described in the ECOTOX User Guide Version 4.0 (see: http://cfpub.epa.gov/ecotox/blackbox/help/userhelp4.pdf). ECOTOX is an extensive database of selected toxicity data for aquatic life, terrestrial plants, and wildlife created and maintained by the U.S. EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory's Mid-Continent Ecology Division (U.S. EPA 2007a). The search of cadmium and cadmium compounds for this update includes data entered in ECOTOX through December 2015.

Newly acquired data were evaluated for acceptability based on data quality guidelines given in the1985 Guidelines (Stephan et al. 1985). Selected data included in the 2001 cadmium criteria were re-evaluated for various reasons (e.g., divergent values for a species, hardness normalization derivation, etc.), as part of the 2016 update, as needed. All acute and chronic toxicity data (see **Appendices A-I**) determined to be applicable and reliable were used to recalculate the CMC and the CCC, consistent with the 1985 Guidelines and as described in the following sections.

3.1 Freshwater Toxicity to Aquatic Animals

3.1.1 Acute toxicity

Acceptable data on the acute effects of cadmium in freshwater are available for a total of 101 species representing 75 genera (**Appendix Table A-1**), the diversity of which satisfy the eight taxonomic MDRs specified in the 1985 Guidelines. Ranked GMAVs for cadmium in freshwater based on acute toxicity are identified in **Table 7** and plotted in **Figure 3**. The following sections detail the derivation of these GMAV summaries.

Hardness correction

The hardness adjustment is used as a surrogate to estimate the effect of primarily calcium on the toxicity of cadmium. Data to be used for the calculation of the hardness correction were selected according to procedures described in **Section 2.7.1**. An analysis of covariance was then performed using a subset of the data from **Appendix A** (each study used in the acute hardness slope is compiled in **Appendix Table A-2**) for the 13 species for which the appropriate data were available, as shown in **Table 6**. These included eight species used in the determination of the acute toxicity hardness slope in the 2001 criteria document (U.S. EPA 2001) and five new species. For all 13 species, the highest hardness was at least three times the lowest, and the highest hardness was at least 100 mg/L greater than the lowest (**Appendix Table A-1**). One major difference between this 2016 update and previous cadmium criteria documents, including the 2015 draft criteria, is that only measured studies were evaluated for use in the acute toxicity hardness slope. In addition, for *Hydra circumcincta, Daphnia pulex*, *Chironomus riparius*, and *Danio rerio*, only studies for which multiple tests were conducted across a hardness gradient were used. Consistent with data quality criteria used for development of the 2001 AWQC for cadmium and as discussed in **Section 2.7.1**, the dataset used for *Pimephales promelas* consisted of only tests conducted with adults. For *Daphnia magna*, the relationship between acute toxicity and hardness had a very shallow slope and a large confidence interval (and large standard error), indicating a poor correlation. This outcome was based on the poor correlation between hardness and acute toxicity for *D. magna* across the various studies. Accordingly, only the five *D. magna* tests from Chapman et al. (1980) were used since the author specifically evaluated the effects of hardness on the less than 24-hr old neonates. Finally, several data sources were eliminated from further evaluation. Data from six tests by Davies et al. (1993) were excluded because hardness was manipulated with magnesium instead of calcium; data from two tests by Davies and Brinkman (1994b) were excluded based on the use of atypical control water; data from three tests by Niyogi et al. (2008) were excluded because water quality parameters in addition to hardness were manipulated; data from Niyogi et al. (2004b) were excluded because they were identified as possible outliers; and data from studies by Hollis et al. (1999, 2000a) were excluded because fish may have been fed.

Based on the final dataset used to calculate the acute hardness slope and consistent with the 1985 Guidelines, an analysis of covariance was performed to determine if a single pooled species slope would be acceptable. The P-value of the model term describing the relationship between hardness and species was 0.42, indicating that the individual species hardness slopes are not significantly different from one another, and that a single pooled slope could be calculated.

The pooled slope for the log-log relationship between hardness and acute toxicity was 0.9789. A list of the species and accompanying slopes used to estimate the final acute hardness slope is provided in **Table 6** and graphically illustrated in **Figure 2**.

Table 6. Pooled and Individual Species Slopes Calculated for the Cadmium Acute Toxicity vs. Hardness Relationship.

Species	**n**	**Slope**	**R^2 Value**	**95% Confidence Interval**	**df**
***Hydra circumcincta*[a]**	3	0.5363*	1.000	0.4706 – 0.6020	1
Limnodrilius hoffmeisteri	2	0.7888	---	---	0
Villosa vibex	2	0.9286	---	---	0
Daphnia magna[b]	5	1.182*	0.915	0.5194-1.845	3
Daphnia pulex[c]	7	0.9307*	0.867	0.5113-1.350	5
***Chironomus riparius*[d]**	2	0.4571	---	---	0
***Oncorhynchus mykiss*[e]**	28	0.9475*	0.681	0.6862-1.209	26
Salmo trutta	6	1.256*	0.900	0.6762-1.837	4
Carassius auratus[f]	2	1.588	---	---	0
***Danio rerio*[g]**	2	0.9270	---	---	0
Pimephales promelas	13	1.814*	0.475	0.5494-3.078	11
Lepomis cyanellus	2	0.4220	---	---	0
Lepomis macrochirus	6	0.8548*	0.955	0.5975-1.112	4
Final Pooled Model	80	0.9789*#	0.971	0.7907-1.167	66

Species highlighted in bold are new for the 2016 updated hardness slope.

* Slope is significantly different than 0 ($p<0.05$)

\# Individual species slopes not significantly different ($p=0.42$)

a – 3 tests from Clifford (2009) at different hardness levels where hardness was manipulated as Ca.

b – Following the procedure described in the 2001 AWQC document, used 5 tests from Chapman et al. (Manuscript) performed at different hardness levels.

c – 7 tests from Clifford (2009); Clifford and McGeer (2010) at different hardness levels where hardness was manipulated as Ca.

d – 2 tests from Gillis and Wood (2008) at different hardness levels.

e – Excluded 6 tests from Davies et al. (1993) where hardness manipulated as Mg; excluded 2 tests from Davies and Brinkman (1994b) because of atypical control water; excluded 3 tests from Niyogi et al. (2008) that manipulated water quality parameters in addition to hardness; excluded possible outliers (Niyogi et al. 2004b); excluded studies where the fish were possibly fed (Hollis et al. 1999, 2000a).

f – 2 tests from McCarty et al. (1978) at different hardness levels.

g – 2 tests from Alsop and Wood (2011) at different hardness levels.

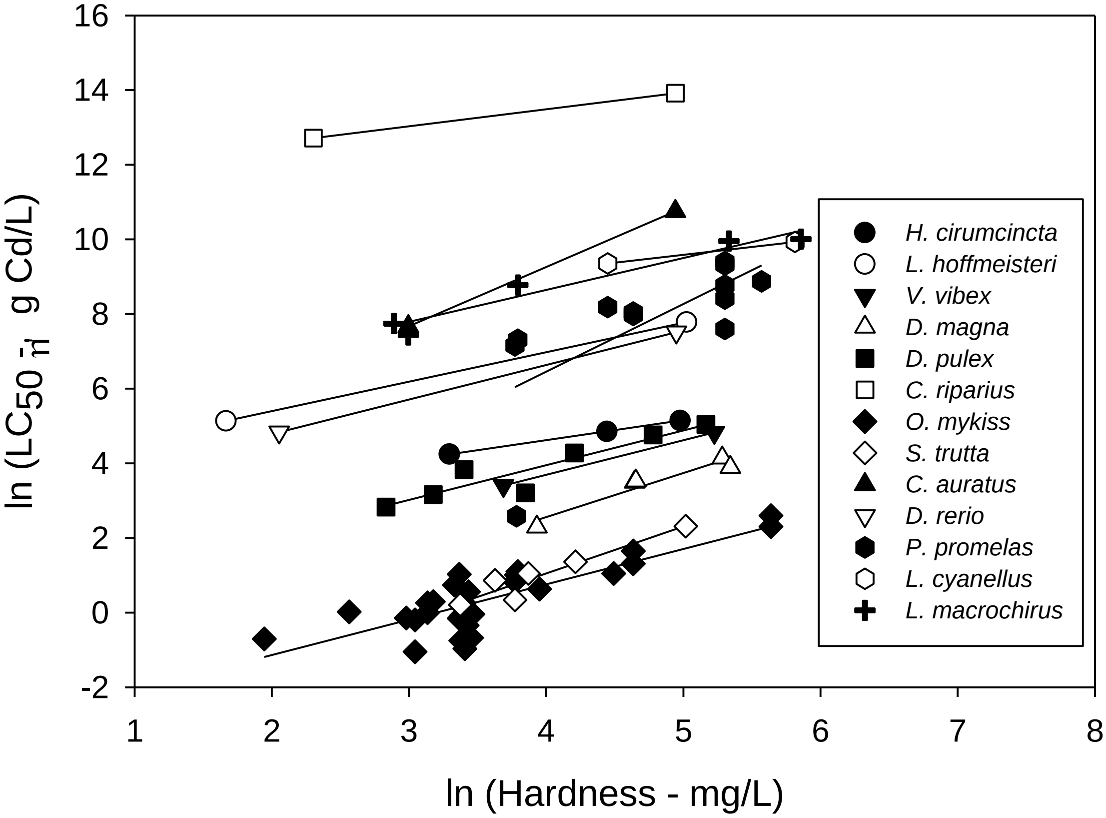

Figure 2. Species Acute Hardness Slopes.
Natural log transformed hardness and acute toxicity concentrations for each species used to calculate the pooled acute hardness correction slope. Results of individual regression lines are shown in **Table 6.**

Summaries of studies used in acute criterion determination

The 2016 update includes acute toxicity data for 66 invertebrate species, 33 fish species, one salamander species, and one frog species, for a total of 101 species grouped into 75 genera. Of the 75 Genus Mean Acute Values (GMAV) in the updated dataset, 38 genera have new data (**Table 7** and **Appendix A**). The most sensitive genus is the fish *Salvelinus* with a GMAV of 4.190 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate genus is represented by the amphipod *Hyalella azteca*, with the seventh most sensitive normalized GMAV of 23.00 µg/L. As noted in **Table 7**, if the SMAVs for a genus differ by greater than a factor of 10, then the most sensitive SMAV(s) is used in the GMAV calculation. This difference was primarily due to the sensitivity between the life stage tested for each species and was applied to the GMAV calculation for *Salvelinus*, *Ptychocheilus*, *Physa* and *Orconectes*. This approach ensures that the most sensitive effect level is used for each genus.

The pooled slope of 0.9789 was used to normalize the freshwater acute values in **Appendix A** to a hardness = 100 mg/L $CaCO_3$, except where it was not possible because no hardness value was reported or a value could not be estimated. SMAVs were calculated as geometric means of the normalized acute values. Only the underlined EC_{50}/LC_{50} values shown in **Appendix A** were used to calculate the SMAVs for each species.

The SMAVs for freshwater invertebrates ranged from 23.00 µg/L total cadmium for the amphipod, *H. azteca*, to >152,301 µg/L total cadmium for the midge, *Chironomus riparius*. Of the fish species tested, the rainbow trout, *Oncorhynchus mykiss*, had the lowest SMAV of 3.727 µg/L total cadmium, and the tilapia, *Oreochromis niloticus*, had the highest SMAV of 66,720 µg/L total cadmium. As indicated by the data, both invertebrate and fish species display a wide range of sensitivities to cadmium.

Fish species represent the six most acutely sensitive genera to cadmium (**Table 7**), and salmonids (*Salmo*, *Salvelinus*, *Oncorhynchus* and *Prosopium*) represent four of the six most sensitive fish genera. The most sensitive genus, *Salvelinus*, a vertebrate genus, is over 11,700 times more sensitive than the most resistant, *Chironomus*, an invertebrate genus.

The second through fifth most sensitive genera (out of a total of 75) were used in the computation of the Final Acute Value (FAV). As stated above, whenever there are 59 or more GMAVs in the acute criteria dataset, the FAV is calculated using the four GMAVs closest to the 5th percentile of the distribution. The distribution of ranked freshwater GMAVs for cadmium is depicted in **Figure 3** and is expressed as normalized total cadmium (see **Section 4.3.1**).

The four taxa and hardness-normalized associated endpoint (GMAV) used in calculating the acute criterion (sensitivity rank 2-5) are ranked below from most to least sensitive:

2. *Cottus* (GMAV=4.411 µg/L total Cd)
3. *Salmo trutta*, Brown trout (GMAV=5.642 µg/L total Cd)
4. *Morone saxatilis*, Striped bass (GMAV=5.931 µg/L total Cd)
5. *Oncorhynchus* (GMAV=6.141 µg/L total Cd)

The most sensitive genus, *Salvelinus* (GMAV of 4.190 µg/L total cadmium), represented by brook trout data, is not included in the criteria numeric calculation because its rank falls below the 5th percentile in the distribution of 75 genera included in the dataset (see **Section 2.7.2**). Because there is a greater than 10-fold difference in SMAVs for the genus, consistent with the 1985 Guidelines, only the most sensitive SMAV is used in the calculation. Therefore, only bull trout, and not brook trout, was used to determine GMAV for *Salvelinus*. The calculated FAV for *Salvelinus* is 5.733 µg/L total cadmium. However, despite the *Salvelinus* genus ranking as the most sensitive taxa for the freshwater acute data, its GMAV is greater than the commercially and recreationally important rainbow trout (*Oncorhyncus mykiss*) SMAV (**Table 7**). The rainbow trout SMAV is also lower than the calculated FAV, and the SMAVs for cutthroat trout, brown trout, bull trout, and shorthead and mottled sculpin. Thus, as recommended by the 1985 Guidelines, the freshwater FAV for total cadmium is being lowered to protect the commercially and recreationally important rainbow trout, resulting in an FAV of 3.727 µg/L at a hardness of 100 mg/L. Because rainbow trout was the most sensitive salmonid species tested (and lowest SMAV in the acute dataset), this lowered value is also expected to be protective of all the salmonid species for which toxicity data are available, and other sensitive fish species as well. Summaries are provided below for the individual species or genera (in cases where more than one species is included in the calculation of the GMAV) used to calculate the freshwater FAV. All values are provided in terms of total cadmium.

Cottus

Two species of sculpin, *Cottus bairdii* and *Cottus confusus*, are used to derive the normalized GMAV of 4.411 µg Cd/L, the second most sensitive genus in the acute dataset, and the lowest of the four GMAVs used to calculate the FAV (**Table 7**). Besser et al. (2006, 2007) and Brinkman and Vieira (2007) exposed fry of *C. bairdii* to flow-through measured conditions to yield normalized 96-hr LC_{50}s ranging from 2.817 to >65.08 µg/L, with the SMAV of 4.418 µg/L cadmium. The *C. confusus* normalized SMAV of 4.404 µg/L cadmium is based on the static-renewal measured test result reported by Mebane et al. (2012).

Salmo trutta

The hardness-normalized SMAV/GMAV of 5.642 µg/L total cadmium for the brown trout is based on the geometric mean of five 96-hr LC_{50}s as reported by Davies and Brinkman (1994c), Brinkman and Hansen (2004a, 2007) and Stubblefield (1990). All tests were flow-through measured exposures and used either the fingerling or fry life stage (see **Appendix Table A-1**). The GMAV for the brown trout is the third lowest in the acute dataset.

Morone saxatilis

Two acceptable acute values from one study (Palawski et al. 1985) were used to calculate the hardness-normalized SMAV/GMAV for the striped bass, *Morone saxatilis*. The 63-day old fish were exposed in static, unmeasured chambers at two different test hardness levels (40 and 285 mg/L as $CaCO_3$). The GMAV for the species is 5.931 µg/L total cadmium and is the fourth lowest in the acute dataset.

Oncorhynchus

The hardness-normalized GMAV of 6.141 µg/L total cadmium for the genus *Oncorhynchus* is the fifth lowest in the acute dataset, and is calculated from SMAVs of four different species (cutthroat trout, *Oncorhynchus clarkii;* coho salmon, *O. kisutch*; rainbow trout, *O mykiss*; Chinook salmon, *O. tshawytscha*). *Oncorhynchus* is one of the most widely tested genera in the freshwater acute dataset. All but the cutthroat trout are Listed species. Hardness-normalized SMAVs range from 3.727 to 11.88 µg/L total cadmium (**Table 7**) and are composed of anywhere from one (*O. kisutch*) to 30 (*O. mykiss*) acute values (**Appendix Table A-1**). As noted above, despite *Oncorhynchus* ranking as the fifth most sensitive genus to acute cadmium exposure, the SMAV for the commercially and recreationally important rainbow trout species (3.727 µg/L at a hardness of 100 mg/L) is the basis for the acute criteria FAV, as recommended by the 1985 Guidelines. Rainbow trout was the most sensitive species tested, thus the use of the rainbow trout SMAV as the basis for the acute criteria is expected to be protective of all salmonid species and all other sensitive species for which toxicity data are available.

As noted in the 1985 Guidelines, acute values that appear to be questionable in comparison with other acute data for the same species and for other species in the same genus probably should not be used in the calculation of a SMAV. Consistent with the 1985 Guidelines, several values were identified as outliers and removed from the *Oncorhynchus mykiss* dataset. Values from Hollis (1999, 2000a) (normalized LC_{50} of 15.82 and 10.00 µg/L, respectively) and Niyogi (2004) (normalized LC_{50} of 15.89 µg/L) were not used in the SMAV calculation for rainbow trout because cadmium nitrate salts were used, and for salmonids, tests with cadmium nitrate averaged three to four times higher than tests with chloride or sulfate, the dominant forms of cadmium in surface water. Acute values for Davies (1993) with high test water hardness (>400 mg/L) were also removed from the SMAV calculation because magnesium alone was used to adjust the test hardness which is not reflective of conditions in most water bodies where calcium is the dominant mineral influencing water hardness (i.e., the acute values were lower than expected). Values for insensitive life stages were also not used for chinook salmon and rainbow trout SMAV calculations because data were available that demonstrated clear life stage sensitivity differences. For chinook salmon, insensitive parr and smolt normalized LC_{50} values of 14.75 µg/L and >12.22 µg/L, respectively, were not used in the SMAV calculation, while the normalized LC_{50} values for juveniles (5.477 µg/L) and swim-up fry (7.586 µg/L) were retained from the Chapman study (1978). Similarly from Chapman (1978), insensitive smolt and alevin rainbow trout normalized LC_{50} values of >12.22 µg/L and >113.8 µg/L, respectively, were not used, while the normalized LC_{50} values for swim-up fry (5.479 µg/L) and parr (4.214 µg/L) were retained for calculation of the SMAV (**Appendix Table A-1**).

Table 7. Ranked Freshwater GMAVs.
(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$ and expressed as total cadmium).
(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
75	**49,052**	Midge, *Chironomus plumosus*	**15,798**
-	-	Midge, *Chironomus riparius*	**>152,301**
74	**30,781**	Common carp, *Cyprinus carpio*	**30,781**
73	**26,837**	Nile tilapia, *Oreochromis niloticus*	**66,720**
-	-	Mozambique tilapia, *Oreochromis mossambica*	**10,795**
72	**26,607**	Planarian, *Dendrocoelum lacteum*	**26,607**
71	**22,138**	Mayfly, *Rhithrogena hageni*	**22,138**
70	**>20,132**	Little green stonefly, *Sweltsa sp.*	**>20,132**
69	12,100	Mosquitofish, *Gambusia affinis*	12,100
68	**11,627**	Oligochaete, *Branchiura sowerbyi*	**11,627**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
67	11,171	Oligochaete, *Rhyacodrilus montana*	11,171
66	11,045	Threespine stickleback, *Gasterosteus aculeatus*	11,045
65	9,917	Channel catfish, *Ictalurus punctatus*	9,917
64	9,752	Oligochaete, *Stylodrilus heringianus*	9,752
63	**7,798**	Mayfly, *Hexagenia rigida*	**7,798**
62	7,752	Green sunfish, *Lepomis cyanellus*	6,276
-	-	Bluegill, *Lepomis macrochirus*	9,574
61	7,716	Red shiner, *Cyprinella lutrensis*	7,716
60	7,037	Oligochaete, *Spirosperma ferox*	6,206
-	-	Oligochaete, *Spirosperma nikolskyi*	7,979
59	**6,808**	Yellow perch, *Perca flavescens*	**6,808**
58	6,738	Earthworm, *Varichaetadrilus pacificus*	6,738
57	5,947	White sucker, *Catostomus commersonii*	5,947
56	5,674	Oligochaete, *Quistadrilus multisetosus*	5,674
55	5,583	Flagfish, *Jordanella floridae*	5,583
54	4,929	Guppy, *Poecilia reticulata*	4,929
53	4,467	Mayfly, *Ephemerella subvaria*	4,467
52	**4,193**	Tubificid worm, *Tubifex tubifex*	**4,193**
51	3,350	Amphipod, *Crangonyx pseudogracilis*	3,350
50	**3,121**	Copepod, *Diaptomus forbesi*	**3,121**
49	**2,967**	Zebrafish, *Danio rerio*	**2,967**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
48	**2,231**	African clawed frog, *Xenopus laevis*	**2,231**
47	**1,983**	Crayfish, *Procambarus acutus*	**812.8**
-	-	Crayfish, *Procambarus alleni*	**6,592**
-	-	Red swamp crayfish, *Procambarus clarkii*	**1,455**
46	1,656	Goldfish, *Carassius auratus*	1,656
45	**>1,637**	Caddisfly, *Arctopsyche sp.*	**>1,637**
44	1,593	Oligochaete, *Limnodrilus hoffmeisteri*	1,593
43	**1,582**	Fathead minnow, *Pimephales promelas*	**1,582**
42	1,023	Northwestern salamander, *Ambystoma gracile*	1,023
41	983.8	Isopod, *Caecidotea bicrenata*	983.8
40	**>808.4**	Snail, *Gyraulus sp.*	**>808.4**
39	**651.3**	Lake whitefish, *Coregonus clupeaformis*	**651.3**
38	539.7	Bryozoa, *Plumatella emarginata*	539.7
37	501.7	Cladoceran, *Alona affinis*	501.7
36	453.0	Cyclopoid copepod, *Cyclops varicans*	453.0
35	**427.9**	Pond snail, *Lymnaea stagnalis*	**427.9**
34	**410.4**	Planarian, *Dugesia dorotocephala*	**410.4**
33	392.5	Leech, *Glossiphonia complanata*	392.5
32	**350.4**	Mayfly, *Baetis tricaudatus*	**350.4**
31	346.6	Bryozoa, *Pectinatella magnifica*	346.6
30	275.0	Worm, *Lumbriculus variegatus*	275.0

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
29	208.0	Snail, *Physa acuta*	**2,152[b]**
-	-	Pouch snail, *Physa gyrina*	208.0
28	204.1	Snail, *Aplexa hypnorum*	204.1
27	154.3	Amphipod, *Gammarus pseudolimnaeus*	154.3
26	**145.5**	Worm, *Nais elinguis*	**145.5**
25	**120.1**	Hydra, *Hydra circumcincta*	**184.8**
-	-	Hydra *Hydra oligactis*	**154.8**
-	-	Green hydra, *Hydra viridissima*	**38.85**
-	-	Hydra, *Hydra vulgaris*	**187.1**
24	**103.1**	Cladoceran, *Diaphanosoma brachyurum*	**103.1**
23	99.54	Isopod, *Lirceus alabamae*	99.54
22	**94.67**	Crayfish, *Orconectes immunis*	>22,579[b]
-	-	Crayfish, *Orconectes juvenilis*	**134.0**
-	-	Crayfish, *Orconectes placidus*	**66.89**
-	-	Crayfish, *Orconectes virilis*	22,800[b]
21	86.51	Cladoceran, *Moina macrocopa*	86.51
20	80.38	Bonytail, *Gila elegans (LS)*	80.38
19	76.02	Razorback sucker, *Xyrauchen texanus (LS)*	76.02
18	74.28	Bryozoa, *Lophopodella carteri*	74.28
17	**73.67**	Cladoceran, *Ceriodaphnia dubia*	**64.03**
-	-	Cladoceran, *Ceriodaphnia reticulata*	84.76

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
16	**71.76**	Mussel, *Utterbackia imbecillis*	**71.76**
15	70.76	Southern rainbow mussel, *Villosa vibex*	70.76
14	**68.51**	Mussel, *Lasmigona subviridis*	**68.51**
13	67.90	Mussel, *Actinonaias pectorosa*	67.90
12	**61.42**	Cladoceran, *Daphnia ambigua*	**24.81**
-	-	Cladoceran, *Daphnia magna*	**40.62**
-	-	Cladoceran, *Daphnia pulex*	**109.2**
-	-	Cladoceran, *Daphnia similis*	**129.3**
11	57.71	Cladoceran, *Simocephalus serrulatus*	57.71
10	**51.34**	Neosho mucket, *Lampsilis rafinesqueana (LS)*	**44.67**
-	-	Fatmucket, *Lampsilis siliquoidea*	**35.73**
-	-	Southern fatmucket, *Lampsilis straminea claibornensis*	93.17
-	-	Yellow sandshell, *Lampsilis teres*	46.71
9	**46.79**	Colorado pikeminnow, *Ptychocheilus lucius (LS)*	46.79
-	-	Northern pikeminnow, *Ptychocheilus oregonensis*	4,265[b]
8	**<33.78**	White sturgeon, *Acipenser transmontanus (LS)*	**<33.78**
7	**23.00**	Amphipod, *Hyalella azteca*	**23.00**
6	**>15.72**	Mountain whitefish, *Prosopium williamsoni*	**>15.72**
5	**6.141**	Cutthroat trout, *Oncorhynchus clarkii*	**5.401**
-	-	Coho salmon, *Oncorhynchus kisutch (LS)*	11.88
-	-	Rainbow trout, *Oncorhynchus mykiss (LS)*	**3.727**

Rank[a]	**GMAV (µg/L total)**	**Species**	**SMAV (µg/L total)**
-	-	Chinook salmon, *Oncorhynchus tshawytscha (LS)*	**5.949**
4	5.931	Striped bass, *Morone saxatilis*	5.931
3	**5.642**	Brown trout, *Salmo trutta*	**5.642**
2	**4.411**	Mottled sculpin, *Cottus bairdii*	**4.418**
-	**-**	Shorthead sculpin, *Cottus confusus*	**4.404**
1	**4.190**	Bull trout, *Salvelinus confluentus*	4.190
-	-	Brook trout, *Salvelinus fontinalis (LS)*	**3,055**[b]

[a] Ranked from least to most sensitive based on Genus Mean Acute Value.

[b] There is a 10-fold difference in SMAVs for the genus, only most sensitive SMAV is used in the calculation. Therefore, only bull trout, and not brook trout, was used to determine GMAV for *Salvelinus*.

[The following species were not included in the Ranked GMAV Table because hardness was not reported and therefore toxicity values could not be normalized to the standard total hardness of 100 mg/L as $CaCO_3$: Leech, *Nephelopsis obscura*; Crayfish, *Orconectes limosus*; Prawn, *Macrobrachium rosenbergii*; Mayfly, *Drunella grandis grandis*; Stonefly, *Pteronarcella badia*; Midge, *Culicoides furens*; Grass carp, *Ctenopharyngodon idellus*.]

LS = Federally-listed species

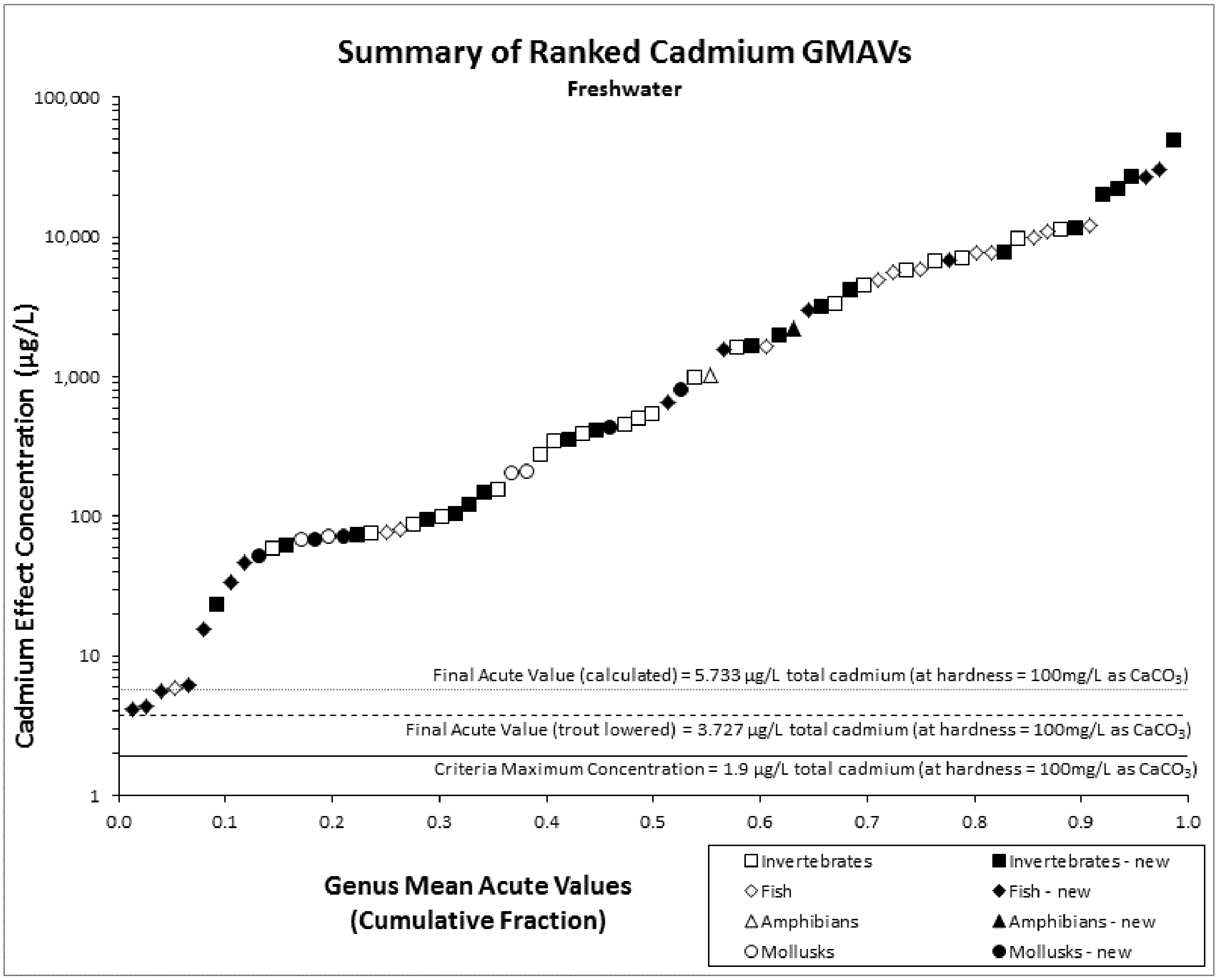

Figure 3. Ranked Freshwater Cadmium GMAVs.

3.1.2 Chronic toxicity

Acceptable data on the chronic effects of cadmium in freshwater are available for 27 species, grouped into 20 genera (**Appendix C**). As with the freshwater cadmium acute dataset, the diversity of species representing the chronic dataset satisfy the eight MDRs specified in the 1985 Guidelines, and regression analysis was therefore used to derive the new freshwater CCC. This is in contrast to the acute-chronic ratio methodology, which can be used when the MDRs are not met. Ranked GMCVs for cadmium in fresh water based on chronic toxicity are identified in **Table 9** and plotted in **Figure 5**. The following sections detail the derivation of these GMCV summaries.

Hardness correction

Following the procedures described in **Section 2.7.1**, an analysis of covariance was applied to the data in **Appendix C** (each study used in the chronic hardness slope derivation is compiled in **Appendix Table C-2**) to calculate the chronic hardness correction slope for four species (*Daphnia magna*, *Oncorhynchus mykiss*, *Salmo trutta* and *Salvelinus fontinalis*) (**Table 8**). Two of the four species (*O. mykiss* and *S. fontinalis*) were not included in the 2001 AWQC dataset. Although included in the 2001 revision, data for *P. promelas* were not used for the hardness correction slope in the 2016 update because no EC_{20} values and only MATCs were available for these tests. For *D. magna*, both EC_{20} values and MATCs were available, but the EC_{20} values from multiple studies were too divergent. Therefore, the same three MATC values from Chapman et al. (Manuscript) used in the 2001 revision were retained in the 2016 update so that an invertebrate species could be included in the calculation of the chronic cadmium toxicity-hardness slope. The acceptable data for rainbow trout were limited to data from Brown et al. (1994), Davies and Brinkman (1994b), Besser et al. (2007), and Mebane et al. (2008). Rainbow trout data from Davies et al. (1993) were not included, as differences in toxicity due to different levels of hardness were attributed entirely to magnesium amendments.

Using the final dataset to calculate the chronic cadmium toxicity-hardness slope, an analysis of covariance test was performed to determine whether a single pooled species slope was acceptable for use in the criteria derivation. The P-value of the resulting relationship between hardness and individual species slopes was 0.15, indicating that individual species hardness slopes were not significantly different from one another, and that a single pooled slope could be used. The pooled slope for the log-log relationship between hardness and chronic toxicity was 0.7977. A list of the species and accompanying slopes used to estimate the final chronic hardness slope is provided in **Table 8** and graphically illustrated in **Figure 4**.

Table 8. Pooled and Individual Species Slopes Calculated for the Cadmium Chronic Toxicity vs. Hardness Relationship.

Species	n	Slope	R^2 Value	95% Confidence Interval	df
Daphnia magna[a]	3	0.7712	0.962	-1.166-2.709	1
Oncorhynchus mykiss[b]	6	0.4602*	0.705	0.04712-0.8732	4
Salmo trutta	6	1.329*	0.765	0.3072-2.350	4
Salvelinus fontinalis	3	1.078	0.862	-4.406-6.563	1
Final Model	18	0.7977*#	0.841	0.4334-1.162	13

Species highlighted in bold are new relative to the 2001 AWQC hardness slope estimation.

* Slope is significantly different than 0 ($p<0.05$).

Individual species slopes not significantly different ($p=0.15$).

[a] Includes 3 MATCs from Chapman et al. (Manuscript).

[b] Includes one value from Brown et al. (1994), two values from Davies and Brinkman (1994b), one value from Besser et al. (2007) and two from Mebane et al. (2008). Excluded 3 values from Davies et al. (1993) because hardness was manipulated using magnesium.

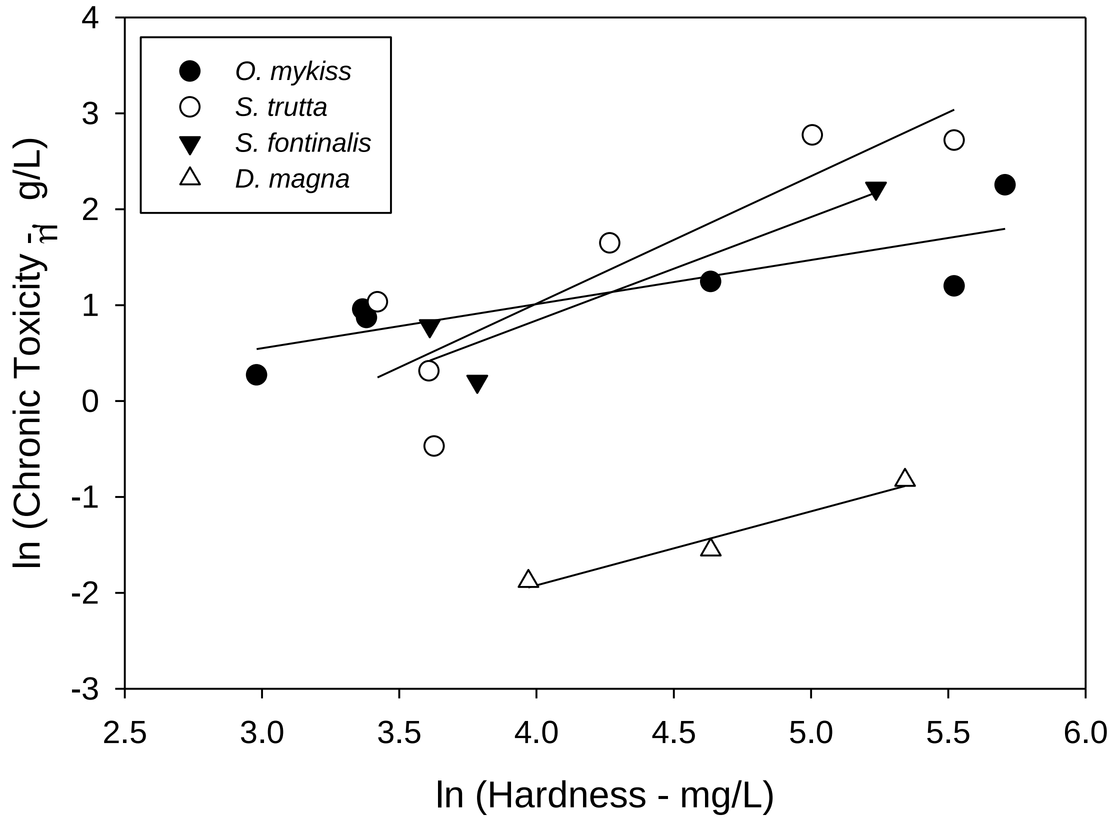

Figure 4. Species Chronic Hardness Slopes.

Natural log transformed hardness and chronic toxicity concentrations for each species used to calculate the pooled chronic hardness correction slope. Results of individual regression lines are shown in **Table 8**.

Summaries of studies used in chronic freshwater criterion determination

Of the 20 Genus Mean Chronic Values (GMCV) in the updated chronic criteria dataset, four of the genera included previously in the 2001 update have new data. A new species in the updated dataset, mottled sculpin (*C. bairdii*) now represents the most sensitive fish species and the third most sensitive genus in the distribution with a GMCV = 1.470 µg/L (total cadmium and normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate is the amphipod *Hyalella azteca* with a normalized GMCV = 0.7453 µg/L (based on the 42-day reproduction endpoint). There are sufficient data to fulfill the requirements to calculate a chronic freshwater criterion using the species sensitivity distribution (SD) method. Acceptable data on the chronic effects of cadmium on freshwater animals include 11 species of invertebrates and 16 species of fish grouped into 20 genera (**Table 9**). Six new species include the oligochaete (*Lumbriculus variegatus*), the fatmucket (*Lampsilis siliquoidea*), the snail (*Lymnaea stagnalis*), the Rio Grande cutthroat trout (*O. clarkii virginalis*), the mottled sculpin (*C. bairdii*) and the cladoceran (*Ceriodaphnia reticulata*). All of the toxicity values and SMCVs derived are tabulated and included in **Appendix C**. The first through fourth most sensitive genera (out of a total of 20) were used in the computation of the Final Chronic Value (FCV) and are ranked below from most to least sensitive:

1. *Hyalella azteca,* Amphipod (GMCV=0.7453 µg/L total Cd)
2. *Ceriodaphnia*, Cladoceran (GMCV=1.293 µg/L total Cd)
3. *Cottus bairdii*, Mottled sculpin (GMCV=1.470 µg/L total Cd)
4. *Chironomus dilutus*, Midge (GMCV=2.000 µg/L total Cd)

The resulting calculated FCV is 0.7945 µg/L total cadmium. Summaries are provided below for the individual species or genera (in cases where more than one species is included in the calculation of the GMCV) used to calculate the freshwater FCV. All values are provided in terms of total cadmium.

Hyalella azteca

One full-life cycle study satisfied the acceptability criteria for *H. azteca* (Ingersoll and Kemble 2001) based on recently recommended culture and control conditions, which were also used in the 2013 ammonia criteria (see **Appendix K**). *H. azteca* were exposed under flow-through measured conditions (control, low, middle and high exposures) at a mean temperature of

23°C and a total hardness of 280 mg/L as $CaCO_3$. A 3-mm nylon mesh substrate was provided during the test. The seven- to eight-day old amphipods were exposed to water only mean total cadmium concentrations of 0.10 (control), 0.12, 0.32, 0.51, 1.9 and 3.2 µg/L for 42 days. The water used for this test (USGS Columbia Lab well water) is acceptable for *H. azteca* studies (around 25 mg Cl/L and 0.08 mg Br/L). For this study, both dry weight (measured by scale) and length data were taken as measures of growth, and there are differences in the growth inferred by these two measures. Through direct consultation with the study authors, it was determined that at the time this study was conducted length provided a more accurate and reliable measure of growth than the direct measure of weight. This was based largely on the small sizes of the organisms and limitations in the accuracy of the scales at the time the study was conducted. This same laboratory has developed a robust empirical relationship between amphipod length and weight, which has been used in multiple peer reviewed publications (Besser et al. 2013, 2015a,b; Ivey and Ingersoll 2016; Kemble et al. 2013). Applying this formula, the 28-d average control length of 4.37 mm represents an average dry weight of 0.434 mg and the 42-d average control length of 4.67 mm translates to an average dry weight of 0.524 mg. These weight values are above the minimum control performance values listed in **Appendix K** and in ASTM (2005). In addition, the average control reproduction (6.4 young/female) also met minimum performance values. Although the feeding rate used in this test was below that recommended for *H. azteca* exposures lasting longer than 10 days, the finding that control organisms met performance criteria applied in tests using a higher feeding rate supports retaining these data for use in deriving AWQC. The most sensitive endpoint from this test was reproduction; the reproduction EC_{20} for this test is 1.695 µg/L, or 0.7453 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_3$. *H. azteca* is now the most chronically sensitive genus in the dataset with a hardness-normalized SMCV/GMCV of 0.7453 µg/L (**Table 9**). This value is a revision to the 42-day MATC of 0.9844 µg/L that was previously used in the 2001 AWQC cadmium document (see **Section 5.2.1** for additional discussion on suitability of chronic *Hyalella* studies).

Ceriodaphnia dubia

An acceptable *C. dubia* seven-day static-renewal toxicity test was conducted by Jop et al. (1995) using reconstituted soft laboratory water. The <24-hr old neonates were exposed to 1, 5, 10, 19 and 41 µg/L measured cadmium concentrations in addition to a laboratory water control at 25°C. The NOEC and LOEC were 10 and 19 µg/L cadmium, respectively, with a resulting chronic value of 13.78 µg/L cadmium. An EC_{20} could not be calculated with the information provided for this test. Similarly, both Spehar and Fiandt (1986) and Brooks et al. (2004) lacked the details necessary to calculate EC_{20}s. MATCs for these tests were reported at 2.20 and 1.93 µg/L total cadmium, respectively. Chronic values for these three studies ranged from 1.264 to 49.75 µg/L total cadmium when normalized to a total hardness of 100 mg/L as $CaCO_3$.

Researchers at Southwest Texas State University (2000) also evaluated the chronic toxicity of cadmium to *C. dubia*. Five replicate tests were conducted using static-renewal exposures and laboratory reconstituted hard water at a hardness of 270 mg/L as dilution water for the five cadmium concentrations. For reproduction, NOECs ranged from 1.073 to 5.457 µg/L, LOECs from 2.391 to 9.934 µg/L, and the MATCs from 1.602 to 7.259 µg/L cadmium. Reproductive EC_{20}s for these tests were very similar to the MATCs, and ranged from 1.341 to 6.129 µg/L cadmium at 270 mg/L hardness, which is equivalent to 0.6071 to 2.775 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_{3.}$ An EC_{20} could not be estimated for *C. reticulata* (**Table 9**), and data from this study were not used in the GMCV calculation. The resultant hardness-normalized SMCV and GMCV for this species is 1.293 µg/L, and is the second most sensitive genus in the chronic dataset.

<u>*Cottus bairdii*</u>

Besser et al. (2007) evaluated the chronic toxicity of cadmium to the mottled sculpin, (*Cottus bairdii*), via a 28-day flow-through measured concentration early life stage (ELS) test. Swim-up fry were exposed to five cadmium concentrations diluted with a well water/reverse osmosis treated water mixture (103 mg/L average total hardness). Survival, growth and biomass were evaluated at test termination. Survival was the most sensitive endpoint with a NOEC, LOEC and MATC of 1.4, 2.6 and 1.91 µg/L cadmium, respectively. The estimated hardness-normalized 28-day survival EC_{20} of 1.721 µg/L cadmium is very similar to the MATC at the test hardness of 103 mg/L. The authors also conducted a 21-day ELS test with the mottled sculpin using the same dilution water, and observed a more sensitive survival effect concentration of 0.8758 µg/L cadmium for the MATC, and an estimated EC_{20} of 1.285 µg/L cadmium. Both tests were used to calculate a SMCV/GMCV of 1.470 µg/L cadmium, and ranks *Cottus* as the third most chronically sensitive genus to cadmium.

Chironomus dilutus

Ingersoll and Kemble (2001) exposed the midge *Chironomus dilutus* to cadmium under the same conditions listed above for the amphipod *H. azteca*, except that a thin 5 mL layer of sand was provided as a substrate. The <24-hr old larvae were exposed to water-only mean measured total cadmium concentrations of 0.15 (control), 0.50, 1.5, 3.1, 5.8 and 16.4 µg/L cadmium for 60 days. The mean weight, biomass, percent emergence and percent hatch 20-day NOEC and LOEC values for all endpoints were 5.8 and 16.4 µg/L cadmium, respectively. The calculated EC_{20} based on percent hatch was 4.548 µg/L total cadmium or 2.000 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_3$, and is the fourth most sensitive genus to cadmium in the chronic dataset.

Table 9. Ranked Freshwater GMCVs.
(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$ and expressed as total cadmium).
(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMCV (µg/L total)	Species	SMCV (µg/L total)
20	>38.66	Blue tilapia, *Oreochromis aureus*	>38.66[c]
19	**36.70**	Oligochaete, *Aeolosoma headleyi*	**36.70**
18	16.43	Bluegill, *Lepomis macrochirus*	16.43
17	**15.16**	Oligochaete, *Lumbriculus variegatus*	**15.16**
16	14.22	Smallmouth bass, *Micropterus dolomieu*	14.22[c]
15	14.17	Northern pike, *Esox lucius*	14.17[c]
14	14.16	Fathead minnow, *Pimephales promelas*	14.16
13	13.66	White sucker, *Catostomus commersonii*	13.66[c]
12	**11.29**	Fatmucket, *Lampsilis siliquoidea*	**11.29**
11	**9.887**	Pond snail, *Lymnaea stagnalis*	**9.887**
10	8.723	Flagfish, *Jordanella floridae*	8.723

Rank[a]	**GMCV (µg/L total)**	**Species**	**SMCV (µg/L total)**
9	3.516	Snail, *Aplexa hypnorum*	3.516
8	**3.360**	Atlantic salmon, *Salmo salar (LS)*	2.389
-	-	Brown trout, *Salmo trutta*	**4.725**
7	**3.251**	Rio Grande cutthroat trout, *Oncorhynchus clarkii virginalis*	**3.543**
-	**-**	Coho salmon, *Oncorhynchus kisutch (LS)*	**NA[b]**
-	-	Rainbow trout, *Oncorhynchus mykiss (LS)*	**2.192**
-	-	Chinook salmon, *Oncorhynchus tshawytscha (LS)*	4.426
6	2.356	Brook trout, *Salvelinus fontinalis*	2.356
-	-	Lake trout, *Salvelinus namaycush*	**NA[b]**
5	**2.024**	Cladoceran, *Daphnia magna*	**0.9150**
-	-	Cladoceran, *Daphnia pulex*	**4.478**
4	2.000	Midge, *Chironomus dilutus*	2.000
3	**1.470**	Mottled sculpin, *Cottus bairdii*	**1.470**
2	**1.293**	Cladoceran, *Ceriodaphnia dubia*	**1.293**
-	-	Cladoceran, *Ceriodaphnia reticulata*	**NA[b]**
1	0.7453	Amphipod, *Hyalella azteca*	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.
[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 to the standard hardness of 100 mg/L as $CaCO_3$: Mudsnail, *Potamopyrgus antipodarum*.]
LS = Federally-listed species

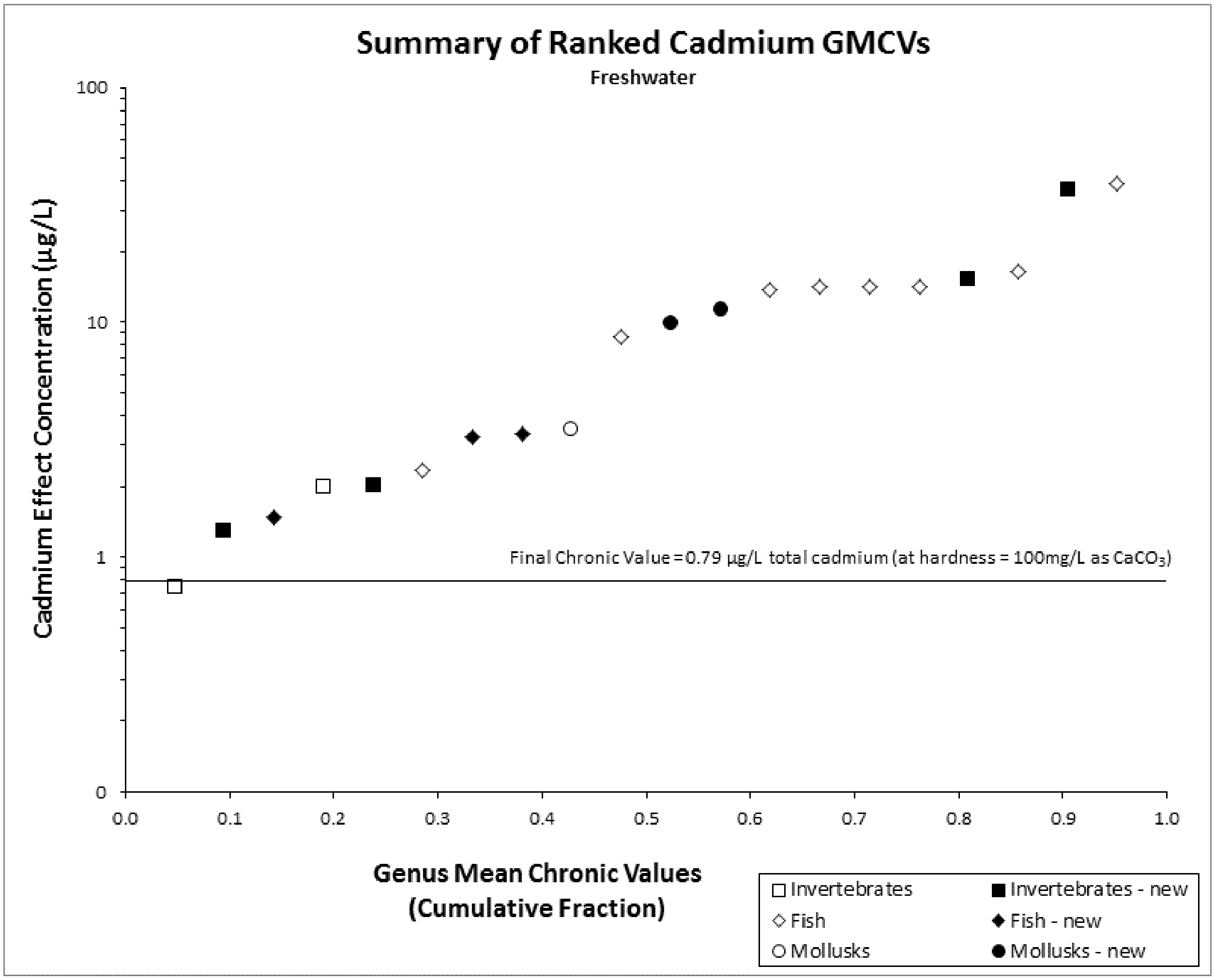

Figure 5. Ranked Freshwater Cadmium GMCVs.

3.2 Estuarine Toxicity to Aquatic Animals

3.2.1 Acute toxicity

Acceptable acute data for cadmium are available for 94 different estuarine/marine species representing 79 genera (**Table 10**). **Figure 6** plots the ranked GMAVs for cadmium in estuarine/marine environments based on acute toxicity. The following sections detail the derivation of these GMAV summaries.

Water quality parameters affecting toxicity

Estuarine/marine fish species are generally more resistant to cadmium than freshwater fish species with SMAVs ranging from 75.0 µg/L for the striped bass (at a salinity of 1 g/kg) to >80,000 µg/L for the Mozambique tilapia (**Appendix B**). There are several water quality parameters that appear to affect the toxicity of cadmium to estuarine/marine species. In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, for example, Voyer (1975) found that 96-hr LC_{50}s at a salinity of 32 g/kg were about one-half of 96-hr LC_{50}s at salinities of 10 and 20 g/kg. As discussed in **Section 5.4.1**, this increase in toxicity with increasing salinity is not consistent with other data reported in **Appendix B** and **Appendix I**, and a salinity correction factor could not be developed.

Limited investigations have been conducted to characterize the influence of temperature on cadmium toxicity. O'Hara (1973a) investigated the effect of water temperature and salinity on the toxicity of cadmium to the fiddler crab, *Uca pugilator*. LC_{50}s at 20°C were 32,300, 46,600 and 37,000 µg/L at salinities of 10, 20 and 30 g/kg, respectively. Increasing the water temperature from 20 to 30°C lowered the LC_{50} at all of the salinities tested. Toudal and Riisgard (1987) reported that increasing the water temperature from 13 to 21°C at a salinity of 20 g/kg also lowered the LC_{50} value of cadmium for the copepod, *Acartia tonsa*. Thus, increasing temperature levels generally resulted in the greater toxicity of cadmium to aquatic organisms, but sufficient data are not available to develop a quantitative relationship.

Summaries of studies used in acute estuarine/marine criterion determination

Suitable cadmium acute toxicity test results for estuarine/marine organisms are now available for 78 invertebrate species and 16 fish species, for a total of 94 species grouped into 79 genera (**Appendix B**). Forty of the 79 GMAVs in the updated dataset have new data. Three new invertebrate species, *Neomysis americana*, *Tigriopus brevicornis* and *Aurelia aurita* now represent the three most sensitive taxa in the distribution (GMAVs of 28.14, 29.14 and 61.75 µg/L, respectively). The most sensitive fish is the striped bass, *Morone saxatilis*, with a GMAV = 75.0 µg/L and ranked the 5th most sensitive species in the new dataset (**Table 10**).

Acute sensitivity ranges widely amongst the estuarine/marine genera for which acute values are available, with the most sensitive species approximately 6,000 times more sensitive than the most resistant species. The GMAVs for estuarine/marine invertebrate species range from 28.14 µg/L for the mysid, *Neomysis* to 169,787 µg/L for the horseshoe crab, *Limulus* (**Table 10**). The SMAVs for estuarine/marine polychaetes range from 200 µg/L for *Capitella capitata* to 12,052 µg/L for *Neanthes arenaceodentata*. Estuarine/marine molluscs have SMAVs that range from 60 µg/L for the horse clam (*Tresus capax*) to 23,200 µg/L for the dog whelk (*Nucella lapillus*). Acute values are available for more than one species in each of 15 genera, and the range of SMAVs within each genus is no more than a factor of 10 for 14 of the 15 genera. Oysters (*Crassostrea*) include SMAVs that differ by a factor of 21.9, which is possibly due to different exposure conditions between the tested species. As described for the freshwater data, only the most sensitive SMAV is used in calculating the GMAV for *Crassostrea*. Furthermore, to avoid using test results from studies in which the life stage tested is known to be less sensitive than other life stages (**Appendix B**), only the data from Reish et al. (1976) were used for *C. capitata*, and only data from Martin et al. (1981) and Nelson et al. (1988) were used for *M. edulis*. Similarly, only data from Sullivan et al. (1983) were used for *E. affinis*, while only data from Wright and Frain (1981) were used for *Marinogammarus obtusatus*. Finally, only data from Cripe (1994) were used for *F. duorarum*, only data from Park et al. (1994) were used for *Rivulus marmoratus* and only data from Hilmy et al. (1985) were used for *Mugil cephalus*. The distribution of ranked estuarine/marine GMAVs for cadmium is depicted in **Figure 6**.

There are sufficient data to fulfill the necessary requirements to calculate an acute criterion for cadmium in estuarine/marine water using the species sensitivity distribution (SD) method. The second through fifth most sensitive genus were used in the computation of the Final Acute Value (FAV) and are ranked below from most to least sensitive:

2. *Tigriopus brevicornis*, Copepod (GMAV=29.14 µg/L total Cd)
3. *Aurelia aurita*, Moon jellyfish (GMAV=61.75 µg/L total Cd)
4. *Americamysis* (GMAV=67.39 µg/L total Cd)
5. *Morone saxatilis*, Striped bass (GMAV=75.0 µg/L total Cd)

The most sensitive genus was represented by the species, *Neomysis americana* (GMAV=28.14 µg/L total cadmium), which is not included in the criteria numeric calculation because it is not within the four GMAVs closest to the 5th percentile of sensitivity in the distribution of 79 genera included in the dataset. In the 2015 draft criteria document, this genus was represented by the species *Neomysis integer*, which was the third most sensitive genus. *Neomysis integer* has been subsequently removed from the database since it does not occur in North America waters and data for the North American estuarine/marine species, *Neomysis americana*, has been obtained, thus making the use of a non-native species as a surrogate for this genus unnecessary. The resulting calculated FAV is 66.25 µg/L total cadmium. Summaries are provided below for the individual species or genera (in cases where more than one species is included in the calculation of the GMAV) used to calculate the estuarine/marine FAV. All values are provided in terms of total cadmium.

Tigriopus brevicornis

The GMAV/SMAV of 29.14 µg/L cadmium for the copepod, *Tigriopus brevicornis*, is based on the geometric mean of three 96-hr LC_{50}s from tests conducted with three different life stages and a salinity that ranged from 34.5 to 35 g/kg. (Forget et al. 1998). The copepods were exposed to unmeasured static cadmium chloride solutions and the resulting acute values were 17.4, 29.7 and 47.9 µg/L cadmium for the nauplius, copepodid and ovigerous female life stages, respectively (**Appendix B**).

Aurelia aurita

Free-swimming larvae (ephyra) of the moon jellyfish, *Aurelia aurita*, were exposed to cadmium nitrate in a static, unmeasured test for 48-hr (Faimali et al. 2013). The SMAV/GMAV of 61.75 µg/L cadmium is the fifth most sensitive species in the estuarine/marine acute dataset and the third most sensitive genus (**Table 10**).

Americamysis

The GMAV of 67.39 µg/L cadmium for *Americamysis* is the geometric mean of the SMAVs for the two mysid species *A. bahia* and *A. bigelowi* (formerly identified as *Mysidopsis bigelowi*). Acceptable acute values for *A. bahia* range from 11.1 to 110 µg/L total cadmium. While there are 14 acceptable acute values, the SMAV of 41.29 µg/L total cadmium is calculated from only the two flow-through measured exposures conducted at salinities of 10-17 g/kg (Nimmo et al. 1977a) and 30 g/kg (Gentile et al. 1982; Lussier et al. 1985).

Morone saxatilis

The striped bass has a GMAV/SMAV of 75.0 µg/L cadmium and is the most sensitive fish species and the fifth most sensitive genus in the estuarine/marine acute dataset (Palawski et al. 1985). This value is based on a test where 63-day old fish were exposed to static and unmeasured concentrations of cadmium chloride for 96-hr at a salinity of 1 g/kg.

Table 10. Ranked Estuarine/Marine GMAVs.

(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
79	**169,787**	Horseshoe crab, *Limulus polyphemus*	**169,787**
78	135,000	Oligochaete worm, *Monopylephorus cuticulatus*	135,000
77	**>80,000**	Mozambique tilapia, *Oreochromis mossambicus*	**>80,000**
76	**62,000**	Scorpionfish, *Scorpaena guttata*	**62,000**
75	**28,196**	Sheepshead minnow, *Cyprinodon variegatus*	**28,196**
74	**25,900**	Cunner, *Tautogolabrus adspersus*	**25,900**
73	24,000	Oligochaete worm, *Tubificoides gabriellae*	24,000
72	**23,200**	Dog whelk, *Nucella lapillus*	**23,200**
71	**22,887**	Amphipod, *Eohaustorius estuarius*	**22,887**
70	19,550	Mummichog, *Fundulus heteroclitus*	18,200
-	-	Striped killifish, *Fundulus majalis*	21,000
69	19,170	Eastern mud snail, *Nassarius obsoletus*	19,170
68	14,297	Winter flounder, *Pseudopleuronectes americanus*	14,297
67	**12,755**	Fiddler crab, *Uca pugilator*	21,238
-	-	Fiddler crab, *Uca triangularis*	**7,660**
66	**12,052**	Polychaete worm, *Neanthes arenaceodentata*	**12,052**
65	11,000	Shiner perch, *Cymatogaster aggregata*	11,000
64	>10,200	California market squid, *Loligo opalescens*	>10,200
63	10,114	Polychaete worm, *Alitta virens*	10,114
62	10,000	Oligochaete, *Tectidrilus verrucosus*	10,000

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
61	**9,217**	Striped mullet, *Mugil cephalus*	7,079
-	-	White mullet, *Mugil curema*	**12,000**
60	**9,100**	Nematode, *Rhabditis marina*	**9,100**
59	**>8,000**	Isopod, *Excirolana sp.*	**>8,000**
58	7,400	Sand dollar, *Dendraster excentricus*	7,400
57	7,120	Wood borer, *Limnoria tripunctata*	7,120
56	6,700	Amphipod, *Diporeia spp.*	6,700
55	6,600	Atlantic oyster drill, *Urosalpinx cinerea*	6,600
54	**4,900**	Mud crab, *Eurypanopeus depressus*	**4,900**
53	4,700	Polychaete, *Nereis grubei*	4,700
52	4,100	Green shore crab, *Carcinus maenas*	4,100
51	**4,058**	Blue crab, *Callinectes sapidus*	2,594
-	-	Lesser blue crab, *Callinectes similis*	**6,350**
50	**3,925**	Polychaete, *Ophryotrocha diadema*	**3,925**
49	3,500	Scud, *Marinogammarus obtusatus*	3,500
48	**3,142**	Polychaete worm, *Ctenodrilus serratus*	**3,142**
47	2,900	Amphipod, *Ampelisca abdita*	2,900
46	2,600	Cone worm, *Pectinaria californiensis*	2,600
45	2,413	Common starfish, *Asterias forbesi*	2,413
44	**2,110**	Pacific sand crab, *Emerita analoga*	**2,110**
43	**2,060**	Gastropod, *Tenguella granulata*	**2,060**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
42	**1,720**	Tiger shrimp, *Penaeus monodon*	**1,720**
41	1,708	Copepod, *Pseudodiaptomus coronatus*	1,708
40	1,672	Soft-shell clam, *Mya arenaria*	1,672
39	**1,510**	Amphipod, *Rhepoxynius abronius*	**1,510**
38	**1,506**	Brown mussel, *Perna perna*	**1,146**
-	-	Green mussel, *Perna viridis*	**1,981**
37	1,500	Coho salmon, *Oncorhynchus kisutch (LS)*	1,500
36	**1,271**	White shrimp, *Litopenaeus setiferus*	**990**
-	-	White shrimp, *Litopenaeus vannamei*	**1,632**
35	1,228	Daggerblade grass shrimp, *Palaemonetes pugio*	1,983
-	-	Grass shrimp, *Palaemonetes vulgaris*	760
34	**1,184**	Starlet sea anemone, *Nematostella vectensis*	**1,184**
33	**1,054**	Atlantic silverside, *Menidia menidia*	**1,054**
32	**1,041**	Amphipod, *Corophium insidiosum*	**1,041**
31	**1,000**	Pinfish, *Lagodon rhomboides*	**1,000**
30	**862.9**	Green sea urchin, *Strongylocentrotus droebachiensis*	1,800
-	-	Purple sea urchin, *Strongylocentrotus purpuratus*	**413.7**
29	800	Rivulus, *Rivulus marmoratus*	800
28	794.5	Harpacticoid copepod, *Nitokra spinipes*	794.5
27	**765.6**	Bay scallop, *Argopecten irradians*	1,480
-	-	Scallop, *Argopecten ventricosus*	**396**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
26	**739.2**	Amphipod, *Leptocheirus plumulosus*	**739.2**
25	**736.2**	Blue mussel, *Mytilus edulis*	1,073
-	-	Blue mussel, *Mytilus trossolus*	**505.0**
24	716.2	Amphipod, *Elasmopus bampo*	716.2
23	645.0	Longwrist hermit crab, *Pagurus longicarpus*	645.0
22	**630.7**	Amphipod, *Grandidierella japonica*	**630.7**
21	630	Amphipod, *Chelura terebrans*	630
20	**490**	Barnacle, *Amphibalanus amphitrite*	**490**
19	**422.6**	Mangrove oyster, *Isognomon californicum*	**422.6**
18	**410.3**	Mysid, *Praunus flexuosus*	**410.3**
17	410.0	Isopod, *Joeropsis sp.*	410.0
16	320	Sand shrimp, *Crangon septemspinosa*	320
15	310.5	Northern pink shrimp, *Farfantepenaeus duorarum*	310.5
14	235.7	Rock crab, *Cancer plebejus*	250
-	-	Dungeness crab, *Cancer magister*	222.3
13	224	Harpacticoid copepod, *Sarsamphiascus tenuiremis*	224
12	>200	Cabezon, *Scorpaenichthys marmoratus*	>200
11	200	Polychaete worm, *Capitella capitata*	200
10	**188.1**	Horse clam, *Tresus capax*	**60**
-	-	Horse clam, *Tresus nuttalli*	**590**
9	**173.2**	Pacific oyster, *Crassostrea gigas*	**173.2**

Rank[a]	GMAV (µg/L total)	Species	SMAV (µg/L total)
-	-	American oyster, *Crassostrea virginica*	**3,800**[b]
8	147.7	Calanoid copepod, *Eurytemora affinis*	147.7
7	130.7	Copepod, *Acartia clausi*	144
-	-	Calanoid copepod, *Acartia tonsa*	118.7
6	78	American lobster, *Homarus americanus*	78
5	75.0	Striped bass, *Morone saxatilis*	75.0
4	67.39	Mysid, *Americamysis bahia*	41.29
-	-	Mysid, *Americamysis bigelowi*	110
3	**61.75**	Moon jellyfish, *Aurelia aurita*	**61.75**
2	**29.14**	Harpacticoid copepod, *Tigriopus brevicornis*	**29.14**
1	**28.14**	Mysid, *Neomysis americana*	**28.14**

[a] Ranked from least 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 calculation.

LS = Federally-listed species

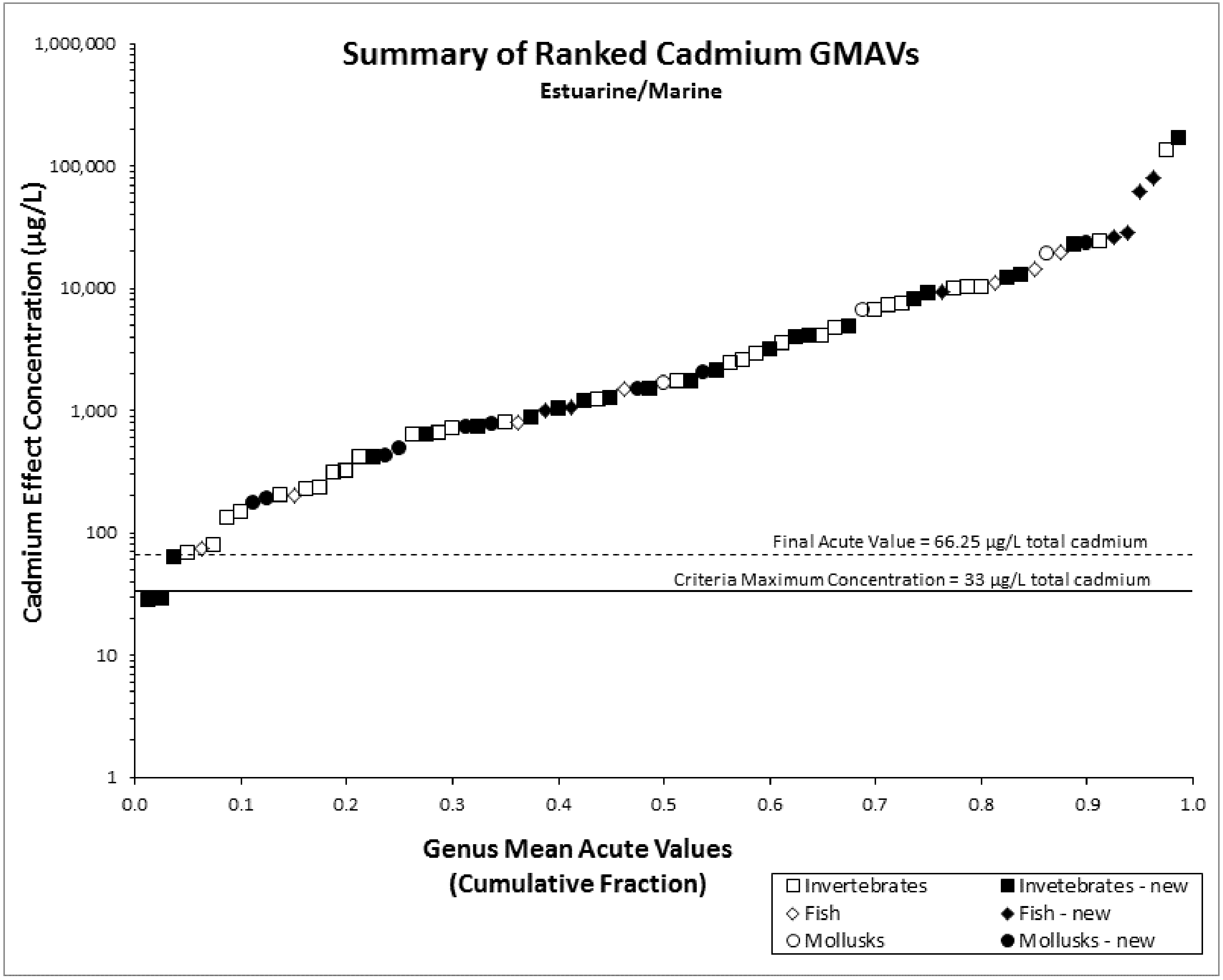

Figure 6. Ranked Estuarine/Marine Cadmium GMAVs.

3.2.2 Chronic toxicity

Chronic studies were available for only two species of mysids for consideration in deriving a chronic criterion for cadmium in estuarine/marine water. The taxonomic nomenclature of one of those species has recently changed so there is now only one genus represented by the two species (**Table 11**). Because the MDR is not met for derivation of the estuarine/marine FCV, the ACR approach was employed whereby the estuarine/marine FAV is divided by the FACR (see **Section 4.4.2**). Although three ACRs are typically required to calculate an FACR, only two ACRs for estuarine/marine species were used in 2001 to calculate the estuarine/marine FACR. Freshwater ACRs were not used in 2001 to support the derivation of the estuarine/marine FACR because the range of freshwater ACR values was considered too large for inclusion (see **Section 5.9.5**). With the availability of additional freshwater toxicity data, the updated estuarine/marine

FACR now incorporates six freshwater genus-level ACRs and one estuarine/marine genus-level ACR. EPA believes that inclusion of the freshwater species ACRs (that are acutely sensitive and have taxonomically-related marine species) with the estuarine/marine species ACRs is the most appropriate and representative method for deriving the FACR.

The GMCV for estuarine/marine species based on chronic cadmium toxicity in a saltwater medium is identified in **Table 11**. This GMCV is plotted in **Figure 7** in relation to the new FCV/CCC of 8.0 µg/L total cadmium. The following presents a discussion of estuarine/marine chronic data used in deriving the estuarine/marine chronic criterion for cadmium. The chronic values are based on estimated EC_{20} values for each of two species. The EC_{20} values and SMCVs derived are tabulated and included in **Appendix D**.

Americamysis

Three chronic toxicity tests have been conducted with the estuarine/marine invertebrate, *Americamysis bahia*, formerly classified as *Mysidopsis bahia*, and one acceptable study was conducted with *Americamysis bigelowi*, formerly classified as *Mysidopsis bigelowi*. Nimmo et al. (1977a) conducted a 23-day life-cycle test with *A. bahia* at a temperature ranging from 20 to 28°C and a salinity ranging from 15 to 23 g/kg. Survival was 10 percent at 10.6 µg/L cadmium, 84 percent at the next lower test concentration of 6.4 µg/L cadmium, and 95 percent in the controls. No unacceptable effects were observed at cadmium concentrations $\leq$ 6.4 µg/L. The chronic toxicity limits, therefore, are 6.4 and 10.6 µg/L cadmium, with a MATC chronic value of 8.237 µg/L cadmium. The accompanying reproductive EC_{20} estimate was 5.605 µg/L cadmium and the 96-hr LC_{50} was 15.5 µg/L cadmium, resulting in an acute-chronic ratio of 2.765.

Another life-cycle test was conducted with *A. bahia* at a constant temperature of 21°C and salinity of 30 g/kg (Gentile et al. 1982; Lussier et al. 1985). All organisms died in 28 days at 23 µg/L cadmium. At 10 µg/L cadmium, a series of morphological aberrations occurred at the onset of sexual maturity. External genitalia in males were aberrant, females failed to develop brood pouches, and both sexes developed a carapace malformation that prohibited molting after release of the initial brood. Although initial reproduction at this concentration was successful, successive broods could not be born because molting resulted in death. No reproductive effects on initial or successive broods were noted in the controls or at 5.1 µg/L cadmium. Thus, the chronic limits for this study are 5.1 and 10 µg/L cadmium, resulting in a MATC of 7.141 µg/L cadmium. The corresponding EC_{20} estimate for survival was 10.93 µg/L cadmium and the LC_{50}

at 21°C and salinity of 30 g/kg was 110 µg/L cadmium, which results in an ACR of 10.06 from this study (Gentile et al. 1982; Lussier et al. 1985).

These Nimmo et al. (1977a) and the Gentile et al. (1982) and Lussier et al. (1985) studies had excellent agreement between the chronic values, but considerable divergence between the acute values and acute-chronic ratios. As discussed in **Section 5.4.1**, several studies have demonstrated an increase in the acute toxicity of cadmium with decreasing salinity and increasing temperature (**Appendix B** and **Appendix I**), and the observed differences in acute toxicity to the mysids might be partially explained on this basis. Nimmo et al. (1977a) conducted their acute test at 20 to 28°C and salinity of 15 to 23 g/kg, whereas the test conducted by Gentile et al. (1982) and Lussier et al. (1985) was performed at 21°C and salinity of 30 g/kg.

A third *A. bahia* chronic study was conducted by Carr et al. (1985) at a salinity of 30 g/kg, but the temperature varied from 14 to 26°C over the 33 day study. At test termination, >50 percent of the organisms had died in cadmium exposures ≥8 µg/L. After 18 days of exposure, growth in 4 µg/L cadmium, the lowest concentration treatment group, was significantly reduced when compared to the controls. The resultant chronic limits based on growth are a NOEC <4 µg/L and a LOEC of 4 µg/L (LOEC) cadmium. The accompanying survival EC_{20} estimate was 5.833 µg/L cadmium. The SMCV for *A. bahia* is the geometric mean of the three EC_{20} values, or 6.149 µg/L. Acute data were not reported for this study.

Gentile et al. (1982) also conducted a life-cycle test with the mysid, *A. bigelowi*, and the results were very similar to those for *A. bahia*. The EC_{20} for this test was 11.61 µg/L cadmium and the ACR is 9.475 when paired with the acute LC_{50} for *A. bigelowi* of 110 µg/L cadmium. The resulting GMCV for *Americamysis* is 8.449 µg/L cadmium (**Table 11**) and is the only GMCV in the estuarine/marine chronic dataset.

Table 11. Ranked Estuarine/Marine GMCVs.
(Values in bold are new/revised data since the 2001 AWQC).

Rank[a]	GMCV (µg/L total)	Species	SMCV (µg/L total)
1	8.449	Mysid, *Americamysis bahia*	6.149
-	-	Mysid, *Americamysis bigelowi*	11.61

[a] Ranked from least to most sensitive based on Genus Mean Chronic Value.

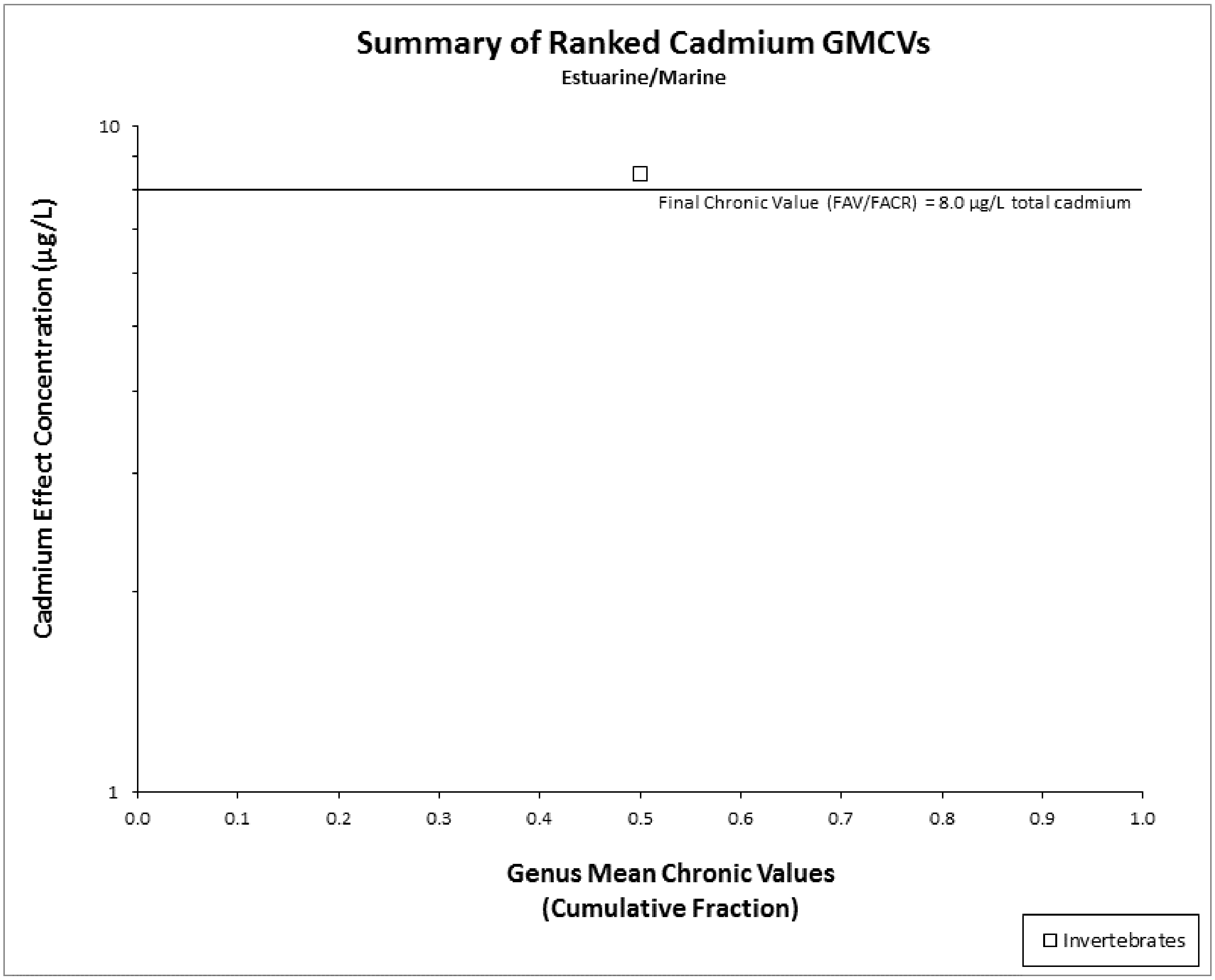

Figure 7. Ranked Estuarine/Marine Cadmium GMCVs.

3.3 Bioaccumulation

No U.S. Food and Drug Administration (FDA) action level or other maximum acceptable concentration in tissue, as defined in the 1985 Guidelines, is available for cadmium. Therefore, a Final Residue Value was not developed for fish tissue. However, as discussed in **Section 2.3**, although cadmium can bioaccumulate in the tissues of aquatic life, at criteria concentrations it is unlikely to accumulate to levels that would result in adverse effects to aquatic invertebrates, fish, or wildlife from the ingestion of aquatic life that have accumulated cadmium in their tissues. This conclusion is supported by the extensive amount of tissue residue-effects data in the literature, more than is available for any other chemical (Jarvinen and Ankley 1999, Bridges and Lutz 1999). Most aquatic organisms are considered to be more susceptible to cadmium from direct aqueous exposure than through bioaccumulation, and the development of criteria protective of direct exposure effects are considered more applicable to the development of criteria for aquatic life. Acceptable bioaccumulation data are provided in **Appendix G** and discussed in **Section 5.6**.

3.4 Toxicity to Aquatic Plants

Available data for aquatic plants and algae were reviewed to determine if they were more sensitive to cadmium than aquatic animals (see **Appendix A** and **Appendix E** for freshwater species; see **Appendix B** and **Appendix F** for estuarine/marine species). Effect concentrations for freshwater plants and algae were well above the freshwater criteria. With only a few exceptions, estuarine/marine plants were less sensitive than estuarine/marine animals, and it was therefore unnecessary to develop criteria based on the toxicity of cadmium to aquatic plants in this update. The only two exceptions were the green algae *Dunaliella viridis* and *Scenedesmus sp.*, each having a static-unmeasured 10-d MATC of 7.07 µg/L cadmium. As recommended in the 1985 Guidelines (Stephan et al. 1985), these unmeasured plant studies were not used for the derivation of a Final Plant Value.

4 THE NATIONAL CRITERIA FOR CADMIUM

4.1 The Freshwater Cadmium Criteria

Freshwater Acute Criterion, the Criterion Maximum Concentration (CMC)

$$\text{CMC} = e^{(0.9789 \text{ x } \ln(\text{hardness}) - 3.866)} \text{ x CF}$$

Where CF (conversion factor from total to dissolved) = 1.136672 - [(ln hardness) x (0.041838)]. The resultant **CMC of 1.8 µg/L** for dissolved cadmium at a hardness of 100 mg/L as $CaCO_3$. The CMC was derived to be protective of the commercially and recreationally important rainbow trout (*Oncorhynchus mykiss*), consistent with procedures described in the 1985 Guidelines, and is below all the SMAVs in **Table 7,** when the SMAVs are expressed on a dissolved basis. A comparison of the updated CMC to the 2001 CMC across various hardness levels is presented in **Table 12**.

Freshwater Chronic Criterion, the Continuous Concentration (CCC)

$$\text{CCC} = e^{(0.7977 \text{ x } \ln(\text{hardness}) - 3.909)} \text{ x CF}$$

Where CF (conversion factor from total to dissolved) = 1.101672 - [(ln hardness) x (0.041838)]. The resultant **CCC of 0.72 µg/L** for dissolved cadmium at a hardness of 100 mg/L is below all the SMCVs in **Table 9**. A comparison of the updated CCC to the 2001 CCC across various hardness levels is presented in **Table 12**.

Table 12. Freshwater CMC and CCC at Various Water Hardness.

Hardness (mg/L as $CaCO_3$)	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

4.2 The Estuarine/Marine Cadmium Criteria

Estuarine/Marine Criterion Maximum Concentration (CMC)

CMC:

Total Cadmium Final Acute Value = 66.25 μg/L

Total Cadmium Criterion Maximum Concentration = (66.25 μg/L)/2 = 33.13 μg/L

Dissolved Cadmium Criterion Maximum Concentration = 0.994 x (33.13 μg/L) = **33 μg/L**

Estuarine/Marine Criterion Continuous Concentration (CCC)

CCC:

Final Acute-Chronic Ratio = 8.291 (see **Section 4.4.2**)

Total Cadmium Final Chronic Value = (66.25 μg/L)/8.291 = 7.991 μg/L

Dissolved Cadmium Final Chronic Value = 0.994 x (7.991 μg/L) = **7.9 μg/L**

4.3 Freshwater Criteria Calculations

4.3.1 Acute

The freshwater Final Acute Value (FAV) for total cadmium at a total hardness of 100 mg/L as $CaCO_3$ was calculated to be 5.733 μg/L total cadmium (**Table 13**), based on the fGMAVs shown in **Table 7**. This value is below all other SMAVs listed in **Table 7** (see also **Figure 3**), with the exception of the SMAVs for rainbow trout, mottled sculpin, shorthead sculpin, bull trout, cutthroat trout and brown trout. However, since the SMAV for the commercially and recreationally important rainbow trout is below this value, the FAV was lowered to 3.727 μg/L total cadmium (at a hardness of 100 mg/L) to protect this species. This lowered value is also protective of all other species, including salmonids, for which toxicity data are available. The resulting freshwater Criterion Maximum Concentration (CMC) at a hardness of 100 mg/L as $CaCO_3$ for total cadmium is (in μg/L) = $e^{(0.9789[\ln(\text{hardness})]-3.866)}$, and is equal to 1.9 μg/L. When the CMC based on total cadmium concentration is converted to dissolved cadmium using the 0.944 conversion factor, which was determined at a hardness of 100 mg/L as $CaCO_3$ (Stephan 1995; Univ. of Wisconsin-Superior 1995), the freshwater CMC for dissolved cadmium (in μg/L) = 0.944 x [$e^{(0.9789[\ln(\text{hardness})]-3.866)}$]. The resultant 1.8 μg/L CMC for dissolved cadmium at a hardness of 100 mg/L is lower than all of the SMAVs/GMAVs presented in **Table 7**, as illustrated graphically in **Figure 3**.

Conversion factors

Although past water quality criteria for cadmium (and other metals) have been established based upon the loosely defined term of "acid soluble metals," EPA made the decision to allow the expression of metal criteria on the basis of dissolved metal concentration (U.S. EPA 1994), which is operationally defined as the portion of metal that passes through a 0.45 µm filter. Because most of the data in existing databases are from tests that provide only total cadmium concentrations, a procedure was required to convert total to dissolved concentrations. Conversion factors (CFs), corresponding to the percent of the total recoverable metal that are dissolved, were applied to total metal concentrations to estimate dissolved metal concentrations. The CFs for cadmium were derived using data from "simulation tests" that were conducted to test the relationship between total and dissolved cadmium concentrations at a range of different hardness values. The objective of the simulation tests was to estimate the cadmium concentrations that would have been detected if dissolved metal concentrations had been measured (Lussier et al. 1995; Stephan 1995; Univ. of Wisconsin-Superior 1995). Hardness was the focus of the simulation tests (and development of the CFs) because it was determined to be the most important variable affecting cadmium toxicity in freshwater.

The data presented in this document are in most cases provided as total cadmium. Only the final cadmium criteria values are converted from total to dissolved concentrations using the appropriate CFs, which are hardness-dependent in fresh water. Acute freshwater total cadmium concentrations were converted to dissolved concentrations using the factor of 0.973 at a total hardness of 50 mg/L as $CaCO_3$, 0.944 at a total hardness of 100 mg/L as $CaCO_3$, and 0.915 at a total hardness of 200 mg/L as $CaCO_3$. The equation for the acute freshwater conversion factor is CF = 1.136672 - [(ln hardness) x (0.041838)] where the (ln hardness) is the natural logarithm of the hardness (Stephan 1995; U.S. EPA 2009b).

Table 13. Freshwater FAV Calculation.

GMAV *N*	Rank	Genus	GMAV	ln(GMAV)	$\ln(GMAV)^2$	P=R/(N+1)	sqrt(P)
75	5	*Oncorhynchus*	6.141	1.82	3.29	0.066	0.256
	4	*Morone*	5.931	1.78	3.17	0.053	0.229
	3	*Salmo*	5.642	1.73	2.99	0.039	0.199
	2	*Cottus*	4.411	1.48	2.20	0.026	0.162
	Sum:			**6.81**	**11.66**	**0.184**	**0.847**

S^2 = 13.60
L = 0.922
A = 1.746
FAV = 5.733
FAV (trout lowered) 3.727
CMC= **1.9**

Where, S=slope, L=intercept, A=ln(FAV); and FAV=final acute value (total cadmium).

4.3.2 Chronic

All chronic values, which were expressed as EC_{20}s whenever possible and MATCs when necessary, were adjusted to a total hardness of 100 mg/L as $CaCO_3$ using the pooled slope of 0.7977 (see **Section 3.1.2**). Normalized chronic values agreed well for most test organisms within a species and for most species within a genus. The exception was the three values for Atlantic salmon, which were very different. Twenty-seven SMCVs were calculated from the underlined values in **Appendix C**. From these 27 SMCVs, 20 GMCVs were calculated and ranked (**Table 9**). A freshwater Final Chronic Value was calculated from the 20 GMCVs using regression analysis (**Table 14**). The freshwater Final Chronic Value for total cadmium at a hardness of 100 mg/L as $CaCO_3$ is (in µg/L) = $e^{(0.7977[\ln(\text{hardness})]-3.909)}$, and is equal to 0.79 µg/L. For dissolved cadmium, the Final Chronic value at a hardness of 100 mg/L as $CaCO_3$ is (in µg/L) = 0.909 x [$e^{(0.7977[\ln(\text{hardness})]-3.909)}$], and is equal to 0.72 µg/L. The equation for the chronic freshwater conversion factor is CF = 1.101672 - [(ln hardness) x (0.041838)]. At a hardness of 100 mg/L as $CaCO_3$, all of the SMCVs and GMCVs are above the CCC (dissolved metal basis).

Table 14. Freshwater FCV Calculation.

FCV *N*	Rank	Genus	GMCV	ln(GMCV)	$\ln(\mathrm{GMCV})^2$	P=R/(N+1)	sqrt(P)
20	4	*Chironomus*	2.000	0.69	0.48	0.190	0.436
	3	*Cottus*	1.470	0.39	0.15	0.143	0.378
	2	*Ceriodaphnia*	1.293	0.26	0.07	0.095	0.309
	1	*Hyalella*	0.7453	-0.29	0.09	0.048	0.218
	Sum:			**1.04**	**0.78**	**0.476**	**1.34**

S^2 = 19.27
L = -1.212
A = -0.230
FCV = 0.79 µg/L

Where, S=slope, L=intercept, A=ln(FCV); and FCV=final chronic value (total cadmium).

4.4 Estuarine/Marine Criteria Calculations

4.4.1 Acute

The estuarine/marine Final Acute Value for total cadmium calculated from the Genus Mean Acute Values shown in **Table 10** is 66.25 µg/L. This FAV is below the SMAV for striped bass (75.0 µg/L), but higher than the SMAVs for the mysid *N. americana* (28.14 µg/L), copepod *T. brevicornis* (29.14 µg/L), mysid *A. bahia* (41.29 µg/L), moon jellyfish *Aurelia aurita* (61.75 µg/L) and horse clam *Tresus capax* (60 µg/L). The resultant estuarine/marine Criterion Maximum Concentration (CMC) for total cadmium is 33 µg/L (FAV/2 or 66.25 µg/L/2). If the total cadmium CMC is converted to dissolved cadmium using the 0.994 factor determined experimentally by EPA according to the procedure described in **Section 4.3.1**, the estuarine/marine CMC for dissolved cadmium is 33 µg/L (**Table 15**). The resultant CMC of 33 µg/L based on dissolved cadmium is below all but two of the estuarine/marine SMAVs (the copepod, *Tigriopus brevicornis* and mysid, *Neomysis americana*) presented in **Table 10** (**Figure 6**).

Table 15. Estuarine/Marine FAV Calculation.

GMAV *N*	Rank	Genus	GMAV	ln(GMAV)	$\ln(GMAV)^2$	P=R/(N+1)	sqrt(P)
79	5	*Morone*	75.0	4.32	18.64	0.063	0.250
	4	*Americamysis*	67.39	4.21	17.73	0.050	0.224
	3	*Aurelia*	61.75	4.12	17.00	0.038	0.194
	2	*Tigriopus*	29.14	3.37	11.37	0.025	0.158
	Sum:			**16.02**	**64.74**	**0.18**	**0.83**

S^2 = 118.2
L = 1.763
A = 4.193
FAV = 66.25
CMC = 33

Where, S=slope, L=intercept, A=ln(FAV); and FAV=final acute value.

4.4.2 Chronic

While there were sufficient data to calculate a freshwater chronic criterion using regression analysis, the estuarine/marine chronic database consists of data representing only one Genus/Family (**Appendix D**). Therefore, the alternative ACR approach was used for deriving an estuarine/marine chronic criterion. This AWQC document update for cadmium recommends the use of seven genus-level ACRs to calculate the FACR for estuarine/marine water (four freshwater fish genera represented by five species, two freshwater invertebrate genera represented by three species, and one acutely sensitive saltwater mysid genera represented by two species). Acceptable ACRs are available for six freshwater invertebrates, eight freshwater fish and two saltwater invertebrate species representing a diverse number of families (**Table 16**). Unfortunately, none of the four methods suggested in the 1985 Guidelines (Stephan et al. 1985) for calculating the FACR are appropriate for cadmium (e.g., the species mean ACR does not increase or decrease as the SMAV increases; the ACRs for a number of species are greater than a factor of ten). Thus, an alternate approach was used to determine the FACR.

The recommended FACR of 8.291 was obtained from the geometric mean of seven genus-level ACRs: one based on estuarine/marine mysids (7.070, which is the geometric mean of 5.275 for *Americamysis bahia* and 9.476 for *A. bigelowi*), two based on freshwater invertebrates (the cladocerans *Ceriodaphnia dubia* (19.84) and *Daphnia* (23.90, which is the geometric mean of 57.23 for *D. magna* and 9.977 for *D. pulex*), and four based on freshwater fish (the mottled sculpin, *Cottus bairdii* (11.22), the salmonids *Oncorhynchus* and *Salmo* (both raised to 2.0 since the ACRs for *O. mykiss*, *O. tshawytscha* and *S. trutta* were all below 2.0), and the fathead minnow, *Pimephales promelas* (17.90)). The fish *C. bairdii, S. trutta, Oncorhynchus* and *P. promelas* represent the second, third, fifth and forty-third most acutely sensitive freshwater genera, respectively, and the cladocerans *Daphnia* and *C. dubia* are the twelfth and seventeenth most acutely sensitive genera. The seven ACRs differ by a factor of 11.95, represent a diverse mix of species, and are protective of the marine environment. The ACRs for the other freshwater species were not used because they have no taxonomically-related marine species (e.g., pulmonate snails), and/or the ACRs appear to be outliers.

This approach was chosen because EPA believes that use of combined ACRs for a variety of freshwater and estuarine/marine species is the most appropriate and representative method for deriving the FACR. When the estuarine/marine Final Acute Value of 66.25 µg/L is divided by the FACR of 8.291, the resulting estuarine/marine FCV is 8.0 µg/L total cadmium. The dissolved cadmium FCV is computed by multiplying the total FCV by the conversion factor of 0.994, resulting in a concentration of 7.9 µg/L.

Table 16. Acute-to-Chronic Ratios.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Species ACR	Reference
		FRESHWATER SPECIES			
Snail, *Aplexa hypnorum*	93	4.002	23.24	-	Holcombe et al. 1984; Phipps and Holcombe 1985
Snail, *Aplexa hypnorum*	93	0.8737	106.4	49.74	Holcombe et al. 1984; Phipps and Holcombe 1985
Pond snail, *Lymnaea stagnalis*	367.5	28.68	12.81	12.81	Pais 2012
Fatmucket, *Lampsilis siliquoidea*	16	5.868	2.727	2.727	Wang et al. 2010d
Cladoceran, *Ceriodaphnia dubia*	38.3	1.93	19.84	19.84	Brooks et al. 2004
Cladoceran, *Daphnia magna*	9.9	0.1523	65.00	-	Chapman et al. manuscript
Cladoceran, *Daphnia magna*	33	0.2118	155.8	-	Chapman et al. manuscript
Cladoceran, *Daphnia magna*	49	0.3545	138.2	-	Chapman et al. manuscript
Cladoceran, *Daphnia magna*	30	0.37	81.08	-	Canton and Slooff 1982
Cladoceran, *Daphnia magna*	12.66[a]	1.10	11.51	-	Baird et al. 1990; 1991

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Species ACR	Reference
Cladoceran, *Daphnia magna*	>6.85[e]	2.496	>2.745[b]	-	Chadwick Ecological Consultants 2003
Cladoceran, *Daphnia magna*	>3.43[e]	2.373	>1.446[b]	-	Chadwick Ecological Consultants 2003
Cladoceran, *Daphnia magna*	41.1	1.528	26.89	57.23	Jemec et al. 2007; 2008
Cladoceran, *Daphnia pulex*	62	6.214	9.977	-	Niederlehner 1984
Cladoceran, *Daphnia pulex*	>14.6[e]	3.051	>4.785[b]	9.977	Chadwick Environmental Consultants 2003
Rio Grande cutthroat trout, *Oncorhynchus clarkii virginalis*	2.467	1.871	1.319	1.319	Brinkman 2012
Rainbow trout, *Oncorhynchus mykiss*	2.834[f]	2.473	1.146	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	4.391[f]	4.762	0.922	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	6.564[f]	3.808	1.724	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	8.54	1.82	4.692	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	13.4	9.508	1.409	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	2.79	2.604	1.071	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	5.200	3.471	1.498	-	Besser et al. 2007
Rainbow trout, *Oncorhynchus mykiss*	>12	5.3	>2.264[b]	1.527	Wang et al. 2014a
Chinook salmon, *Oncorhynchus tshawytscha*	1.41	1.465	0.9626	0.9626	Chapman 1975, 1982
Brown trout, *Salmo trutta*	2.37	0.6240	3.798	-	Davies and Brinkman 1994c
Brown trout, *Salmo trutta*	10.1	13.56	0.7448	-	Brinkman and Hansen 2004a; 2007
Brown trout, *Salmo trutta*	3.9	6.36	0.6132	-	Brinkman and Hansen 2004a; 2007
Brown trout, *Salmo trutta*	1.23	2.807	0.4382	0.9337	Brinkman and Hansen 2004a; 2007
Fathead minnow, *Pimephales promelas*	5,995[c]	24.71	242.6	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	13.2	10.0	1.320	17.90	Spehar and Fiandt 1986
Flagfish, *Jordanella floridae*	2,500	5.018	498.2	498.2	Spehar 1976a;b

Species	**Acute Value (µg/L)**	**Chronic Value (µg/L)**	**Ratio**	**Species ACR**	**Reference**
Bluegill, *Lepomis macrochirus*	21,100	29.35	718.9	718.9	Eaton 1974, 1980
Mottled sculpin, *Cottus bairdii*	19.77[d]	1.76	11.22	11.22	Besser et al. 2007
ESTUARINE/MARINE SPECIES					
Mysid, *Americamysis bahia*	15.5	5.605	2.766	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	110	10.93	10.06	5.275	Gentile et al. 1982; Lussier et al. 1985
Mysid, (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	110	11.61	9.476	9.476	Gentile et al. 1982

[a] Geometric mean of 6 LC_{50}s from Baird et al. (1991).

[b] Not used to calculate the species ACR because it is an undefined value.

[c] Geometric mean of 5 LC_{50}s from Pickering and Gast (1972).

[d] Geometric mean of 2 LC_{50}s from Besser et al. (2007).

[e] Test species fed.

[f] Geometric mean of 2 LC_{50}s from Davies et al. 1993.

5 EFFECTS CHARACTERIZATION

The purpose of this section is to characterize the potential effects of cadmium on aquatic life based on available test data and to describe additional lines of evidence not used directly in the criteria calculations, but which support the 2016 criteria values. This section also provides a summary of the uncertainties and assumptions associated with the criteria derivation and explanations for decisions regarding data acceptability and usage in the effects assessment. Finally, this section describes substantive differences between the 2001 cadmium AWQC and the 2016 update resulting from incorporation of the latest scientific knowledge.

All acceptable acute and chronic values used to derive criteria are presented in **Appendix A** (Acceptable Freshwater Acute Toxicity Data), **Appendix B** (Acceptable Estuarine/Marine Acute Toxicity Data), **Appendix C** (Acceptable Freshwater Chronic Toxicity Data) and **Appendix D** (Acceptable Estuarine/Marine Chronic Toxicity Data). Acceptable aquatic plant toxicity data are presented in **Appendix E** (Acceptable Freshwater Plant Toxicity Data) and **Appendix F** (Acceptable Estuarine/Marine Plant Toxicity Data), though as discussed in **Section 3.4**, the vast majority of plants are less sensitive than other aquatic species and were not directly used for the derivation of criteria. Acceptable bioaccumulation data are presented in **Appendix G** (Acceptable Bioaccumulation Data), and since direct toxic effects occur more rapidly than bioaccumulation effects, direct effects were therefore the focus of the criteria development. Studies identified as scientifically sound, but that do not meet the screening guidelines for inclusion in criterion calculations (e.g., duration too long or short, too few exposure concentrations, unmeasured chronic test, atypical endpoint) are presented in **Appendix H** (Other Freshwater Toxicity Data) and **Appendix I** (Other Estuarine/Marine Toxicity Data). Where appropriate, these other data are often used qualitatively to support toxicity data compiled for existing species to derive the criteria. The toxicity values in **Appendix H** and **Appendix I** for *Hyalella azteca* and the glochidia and juvenile life stages of mussels represent studies that did not satisfy the recommended test procedures and/or latest science as described in **Sections 2.6**, **5.1.2** and **5.2.1** of this document.

5.1 Freshwater Acute Toxicity Data

Acceptable acute toxicity data supporting the development of acute criteria are available for 101 freshwater species grouped into 75 genera. In general, fish are more acutely sensitive to cadmium than are aquatic invertebrates. Fish comprise eight of the ten most sensitive genera to cadmium, with an amphipod (*H. azteca*) ranked eighth, and a mussel (*Lampsilis*) ranked tenth. The least sensitive genus is the midge *Chironomus.*

Several fish studies were identified as not meeting screening guidelines for inclusion in the criteria calculations (**Appendix H**), but showed similar ranges of response to the most sensitive fish species. Davies and Brinkman (1994a) reported a 96-hr LC_{50} of 1.87 µg/L cadmium for *S. trutta* (fed during the exposure), which is very similar to the unfed 96-hr LC_{50} of 2.37 µg/L determined by the same authors using the same dilution water. The data generated for rainbow trout and reported in Hansen et al. (2002b) showed similar sensitivities to other acceptable data for rainbow trout. Five-day LC_{50} values ranged from 1.108 to 2.729 µg/L when normalized to a total hardness of 100 mg/L as $CaCO_3$. Buhl and Hamilton (1991) and Chapman and Stevens (1978) reported LC_{50}s for Coho salmon of 14.36 µg/L (96-hr) and 8.804 µg/L (217-hr), respectively, when normalized to a total hardness of 100 mg/L as $CaCO_3$. In unmeasured, flow-through cadmium exposures with sockeye salmon, Servizi and Martens (1978) reported unnormalized 7-day LC_{50} values ranging from 8 to 4,500 µg/L for fry and alevins, respectively. The range in sensitivity of the life stages tested by these authors is similar to other salmonid studies used quantitatively to derive the acute criterion (**Appendix A**).

Sublethal effects of cadmium to invertebrate and vertebrate species have been reported by a number of authors (**Appendix H**), many above the 2016 criteria levels. Bluegill sunfish (*Lepomis macrochirus*) cough rate increased when exposed to 50 µg/L cadmium for three days (Bishop and McIntosh 1981) and Low (2009) observed an increase in the auditory threshold for fathead minnows exposed to 2.1 µg/L cadmium for four days. Ivankovic et al. (2010) reported increased metallothionein levels in zebra mussels (*Dreissena polymorpha*) exposed to 10 µg/L cadmium for seven days, and after 10 days limb regeneration of the Northwestern salamander (*Ambystoma gracile*) was adversely affected at 44.6 µg/L cadmium (Nebeker et al. 1994). Shorter exposures using adult *Daphnia magna* (3-hr) and larval *Chironomus dilutes* (24-hr) resulted in a reduced phototactic index at 30 µg/L and increased HSP gene expression at 200 µg/L cadmium, respectively (Yuan et al. 2003; Lee et al. 2006b). In addition, rainbow trout exhibited significant avoidance to 52 µg/L cadmium after an 80 minute exposure (Black and Birge 1980).

5.1.1 Acute toxicity data for freshwater mussels

The only acceptable tests evaluating the acute toxicity of cadmium to glochidia were for the fatmucket, *Lampsilis siliquoidea*. However, the glochidia data were not used to derive the SMAV for this species because data for a more sensitive life stage were available (Wang et al. 2010d). For the fatmucket, *Lampsilis siliquoidea,* 5-day old juveniles (LC_{50} of 35.73 µg/L) were much more sensitive than glochidia (LC_{50} of >507.0 µg/L), and the data for the 5-day old juveniles were included in the acute toxicity dataset.

All other glochidia test results were considered unacceptable and were not included in the acute dataset (see Section 2.6). These included results from tests conducted by Black (2001), who exposed *Fusconia masoni* and *Utterbackia imbecillis* glochidia to cadmium for 24 hours but did not report the control mortality adequately for the data to be used quantitatively.

5.1.2 Suitability of acute *Hyalella azteca* data

Eleven studies investigated the acute toxicity of cadmium to the amphipod, *H. azteca*. Of those 11 studies, only one was considered acceptable for quantitative use, while the others were classified as supporting data and not used to derive the SMAV for this species (**Table 17**). Data from the ten studies were deemed unacceptable for the following reasons: test species were fed (Schubauer-Berigan et al. 1993; Collyard et al. 1994; Suedel et al. 1997); dilution water was not adequately characterized (Mackie 1989); the dilution water was river water and had high TOC (Spehar and Carlson 1984); or the test duration was too short (<96 hr) (McNulty et al. 1999; Gust 2006) or too long (Phipps et al. 1995; Borgmann et al. 2005).

Only results reported in Nebeker et al. (1986b) were considered acceptable and only the EC_{50} of 8 µg/L cadmium from Nebeker et al. (1986b) was used to derive the *H. azteca* SMAV, which is equivalent to 23.00 µg/L cadmium when normalized to a total hardness of 100 mg/L as $CaCO_3$. As demonstrated in **Table 7**, the amphipod *H. azteca* is the most acutely sensitive invertebrate species in the cadmium database.

Table 17. Acute Studies of Hyalella azteca Evaluated for Cadmium Freshwater Criterion.

Reference	Life stage	Hardness (mg/L as $CaCO_3$)	Concentration (µg/L)	Normalized Effect Concentration (µg/L)[a]	Result of Evaluation
Nebeker et al. 1986b	Large juvenile & young adult	34	8	23.00	Acceptable
Spehar and Carlson 1984a,b	-	55-79	285	421.7	High TOC; River dilution water not characterized
Mackie 1989	-	15.3 (pH=5.0)	12	75.37	Dilution water not adequately characterized (Cl- concentration unknown)
Mackie 1989	-	15.3 (pH=5.5)	16	100.5	Dilution water not adequately characterized (Cl- concentration unknown)
Mackie 1989	-	15.3 (pH=6.0)	33	207.3	Dilution water not adequately characterized (Cl- concentration unknown)
Schubauer-Berigan et al. 1993	-	280-300	230	81.10	Test species fed
Collyard et al. 1994	0-2 d	90	≈13	14.41	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	2-4 d	90	≈7.5	8.313	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	4-6 d	90	≈9.5	10.53	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	10-12 d	90	≈7	7.759	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	16-18 d	90	≈11.5	12.75	Test species fed; Data graphed, could only get approximate value
Collyard et al. 1994	24-26 d	90	≈14	15.52	Test species fed; Data graphed, could only get approximate value
Phipps et al. 1995	-	44-47	2.8	6.051	Duration too long (10 d)
Suedel et al. 1997	14-21 d	17	2.8	15.86	Test species fed; Did not meet specific acceptability criteria for this species
McNulty et al. 1999	-	217-301 (starved for 48 hr before test)	99.34	39.13	Duration too short (24 hr)
McNulty et al. 1999	-	217-301 (starved for 72 hr before test)	82.17	32.36	Duration too short (24 hr)
McNulty et al. 1999	-	217-301 (starved for 96 hr before test)	65.00	25.60	Duration too short (24 hr)
McNulty et al. 1999	-	217-301	107.3	42.27	Duration too short (24 hr)
McNulty et al. 1999	-	217-301	75.42	29.71	Duration too short (24 hr)
McNulty et al. 1999	-	217-301	74.20	29.22	Duration too short (24 hr)
Jackson et al. 2000	7-10 d	48	3.8	7.794	Lack of control survival information; No bromide in dilution water
Jackson et al. 2000	7-10 d	118	12.1	10.29	Lack of control survival information; No bromide in dilution water

Reference	Life stage	Hardness (mg/L as $CaCO_3$)	Concentration (µg/L)	Normalized Effect Concentration (µg/L)[a]	Result of Evaluation
Borgmann et al. 2005	1-11 d	18	0.15	0.8036	Duration too long (7 d)
Borgmann et al. 2005	1-11 d	124	1.60	1.296	Duration too long (7 d)
Gust 2006	-	-	1.9	-	Duration too short (72 hr)

[a] Normalized to a hardness of 100 mg/L using the pooled acute slope of 0.9789.

5.1.3 Uncertainty in the freshwater FAV calculation

A number of uncertainties are associated with calculation of the freshwater FAV as recommended by the 1985 Guidelines (Stephan et al. 1985), and include use of limited data for a species or genus, acceptability of widely variable data for a genus, application of safety factors, and extrapolation of laboratory data to field situations. There are a number of cases in the acute database where only one acute test is used to determine the SMAV and subsequently the GMAV is based on the one acute test. In this situation there is a level of uncertainty associated with the GMAV based on the one test result since it does not incorporate the range of values that would be available if multiple studies were available. The GMAV is still valid, in spite of absence of these additional data.

The acute database also includes several genera where two or more widely different SMAVs (>10x factor) are available for estimating the GMAV. In this case the 1985 Guidelines recommend that some or all of the values probably should not be used in calculations. To resolve this, only the more sensitive SMAV (primarily due to a more sensitive life stage tested) was used to calculate the GMAV, thereby ensuring protection of the genus, as explained in **Section 3.1.1**.

The final step in the acute criteria derivation process is to divide the FAV by a safety factor of 2 to yield the CMC. The CMC is set equal to half of the FAV to represent a low level of effect for the fifth percentile genus, rather than a 50% effect. This adjustment factor was derived from an analysis of 219 acute toxicity tests with a variety of chemicals (see 43 FR 21506-21518 for a complete description) where mortality data were used to determine the highest tested concentration that did not cause mortality greater than that observed in the control (or between 0 and 10%). Application of this safety factor is justified in that the concentration represents minimal acute toxicity to the species.

Application of water-only laboratory toxicity tests to protect aquatic species is a basic premise of the 1985 Guidelines, supported by the requirements of a diverse assemblage of eight families and the protection of 95 percent of all species. Confirmation has been reported by a number of researchers, thereby indicating that on the whole, extrapolation of laboratory data does a reasonably good job of protecting natural aquatic communities. Certain exoskeleton bearing aquatic organisms (e.g., aquatic insects), however, may not be adequately protected due to their differential accumulation of aqueous vs. dietary cadmium (Poteat and Buchwalter 2014), and this therefore represents uncertainty in the derived CMC. As discussed in **Section 5.6.1**, selected insect species evaluated by different researchers exhibited cadmium dietary effect levels lower than aqueous exposed organisms. The most sensitive insect in the acute database based on water-only laboratory toxicity tests is the mayfly *Baetis*, ranked as the 32nd most sensitive genus.

5.1.4 Acute criteria duration

For the 2016 acute cadmium criteria, EPA has changed the duration to 1-hour from the 24 hours EPA applied in the 2001 final cadmium criteria document. EPA made this change to the 2016 criteria to reflect the acute criteria duration recommended in the 1985 Guidelines. The draft 2001 cadmium criteria document used a 1-hour duration, which EPA subsequently revised to 24 hours in the final criteria document. The final cadmium criteria document did not detail the rationale for this change, and EPA has further examined this issue as part of the 2016 criteria update.

The 24-hour duration used in the 2001 final cadmium criteria document was based on a limited number of fish toxicity studies that were conducted in the mid-1990s and which suggested that cadmium time-to-effect may be longer than reflected by the 1-hour averaging period. These studies were focused on fish and did not address trends in duration for other aquatic species, such as invertebrates. Because of the limited nature of these investigations and absence of additional supporting information, EPA decided to revise the acute duration in this document to be consistent with the more protective 1-hour duration, which is generally supported by and consistent with the 1985 Guidelines. Page 5 of the 1985 Guidelines, for example, states that “For the CMC the averaging period should again be substantially less than the lengths of the tests it is based on, i.e., substantially less than 48 to 96 hours. One hour is probably an appropriate averaging period because high concentrations of some materials can cause death in one to three hours. Even when organisms do not die within the first hour or so, it is not known how many might have died due to delayed effects of this short of an exposure. Thus it is not appropriate to allow concentrations above the CMC to exist for as long as one hour. The durations of the averaging periods in national criteria have been made short enough to restrict allowable fluctuations in the concentration of the pollutant in the receiving water and to restrict the length of time that the concentration in the receiving water can be continuously above a criterion concentration." Page 6 of the 1985 Guidelines further states that "the one-hour average should never exceed the CMC."

Additional information supporting the 1-hour averaging period is presented in page 35 of the *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA 1991) which states that "For acute criteria, EPA recommends an averaging period of 1-hour. That is, to protect against acute effects, the 1-hour average exposure should not exceed the CMC. The 1-hour acute averaging period was derived primarily from data on response time for toxicity to ammonia, a fast-acting toxicant. The l-hour averaging period is expected to be fully protective for the fastest-acting toxicants, and even more protective for slower-acting toxicants." The frequency of allowed exceedances is once in three years on average, as recommended in the Guidelines (Stephan et al. 1985). This is based on the ability of aquatic ecosystems to recover from the exceedences, which will depend in part on the magnitudes and durations of the exceedences. Frequency and duration will be further considered as part of the 1985 Guidelines update, but the duration for the 2016 cadmium acute criteria will be 1-hour.

5.2 Freshwater Chronic Toxicity Data

Acceptable chronic toxicity data are available for 27 freshwater species representing 20 different genera (**Appendix C**). In contrast to the acute toxicity test results, invertebrates were generally more sensitive to cadmium than fish based on chronic toxicity. The four most sensitive genera were the amphipod *Hyalella*, followed by the cladoceran *Ceriodaphnia*, the sculpin *Cottus*, and the midge *Chironomus*. For the acceptable chronic toxicity data, normalized chronic toxicity values ranged from 0.7453 to 36.70 µg/L for invertebrates, and from 1.470 to >38.66 µg/L for fish. The blue tilapia was the least sensitive organism to cadmium and had a normalized MATC of >38.66 µg/L.

Additional chronic toxicity data that were not used quantitatively to derive a criterion are available for cadmium (**Appendix H**). Suedel et al. (1997) conducted a *C. dubia* static, measured life-cycle assessment. The normalized NOEC of 4.110 µg/L and LOEC of 16.44 µg/L reported for this study are only slightly higher than chronic values that were used quantitatively to derive a criterion (**Appendix C**). The 17 to 21-day NOEC and LOEC values reported for *Daphnia magna* and *D. pulex* by Biesinger and Christensen (1972), Winner (1986), Winner and Whitford (1987), Enserink et al. (1993), and Knops et al. (2001) were similar to other acceptable chronic values reported in **Appendix C** for these species, as were values from long term studies with Atlantic salmon (Rombough and Garside 1982; Peterson et al. 1983) and brown trout (Davies and Brinkman 1994c; Brinkman and Hansen 2004a, 2007).

Other sublethal effects data also not used to derive criteria are provided in **Appendix H**, with many studies again reporting effect levels above the criteria. Asian clams (*Corbicula fluminea*) exhibited reduced phagocytosis activity when exposed to 3 µg/L cadmium for 30 days (Champeau et al. 2007), and goldfish (*Carassius auratus*) experienced reduced plasma sodium levels when exposed to 44.5 µg/L cadmium for 50 days (McCarty and Houston 1976). Scherer et al. (1997) evaluated lake trout (*Salvelinus namaycush*) for eight months and reported decreased thyroid follicle epithelial cell height at 5 µg/L cadmium. Delayed development and forelimb emergence was observed in African clawed frog (*Xenopus laevis*) embryos after a 47 day exposure to 855 µg/L cadmium (Sharma and Patino 2008).

An artificial stream channel employed by Riddel et al. (2005a) assessed the prey choice and capture efficiency of *Salvelinus fontinalis* exposed to two cadmium concentrations (0.5 and 5.0 µg/L) for 30 days using dechlorinated tap water at a total hardness of 156 mg/L (as $CaCO_3$). The juvenile brook trout preferred non-motile over motile prey, and prey capture efficiency decreased by 20-55% with increasing Cd concentration. Additional artificial stream channel studies by Riddel et al. (2005b) that employed the same two cadmium exposures and dilution water evaluated the foraging and predator avoidance behaviors of mayfly nymphs (*Baetis tricaudatus*), and predator-prey interactions of stonefly nymphs (*Kogotus nonus*) and the longnose dace (*Rhinichthys cataractae*). Altered mayfly and stonefly behaviors were observed at 5.0 µg/L, whereas the foraging behavior of the dance was unaffected by the highest cadmium exposure. Mebane et al. (2104) exposed larval insects for 32 days to four cadmium concentrations (0.018, 0.091, 0.35 and 1.02 µg/L) in experimental streams that circulated river water with a total hardness of 17 mg/L. Preliminary results indicate that reduced mayfly abundance EC_{20}s normalized to a total hardness of 100 mg/L ranged from 0.41 µg/L for *Ephemerella infrequens* to 3.29 µg/L for *Rhithrogena sp.*

For the 2016 chronic cadmium criteria, the duration is a four-day averaging period as recommended in the Guidelines (Stephan et al 1985). This averaging period is short enough to restrict allowable fluctuations in the concentration of the pollutant in the receiving water and to restrict the length of time that the concentration in the receiving water can be continuously above a criterion concentrations. In addition, the frequency of allowed exceedances is once in three years on average, same as for the acute criteria.

5.2.1 Suitability of chronic *Hyalella azteca* data

A total of eight *H. azteca* chronic studies were reviewed for acceptability as recommended in **Appendix K**. Only data from the Ingersoll and Kemble (2001) study using USGS Columbia, Missouri Lab well water as dilution water was considered acceptable for deriving a freshwater chronic criterion (**Appendix C**). Thus, the *H. azteca* normalized SMCV (and GMCV) of 0.7453 µg/L cadmium is based on only this study. Although the seven other studies were not used for deriving the updated cadmium freshwater chronic criterion, the effect levels observed for each study are provided below and demonstrate the similar sensitivity of the amphipod to cadmium, despite the issues which precluded their use in developing the SMCV and GMCV. The normalized effect concentrations for these seven studies ranged from 0.3749 to 4.907 µg/L cadmium, with the majority of values ranging from 0.4-2.0 µg/L (**Table 18**).

Table 18. Chronic Studies of Hyalella azteca Evaluated for Cadmium Freshwater Criterion.

Reference	Method[a]	Life stage	Exposure	Effect	EC_{20}/ MATC (TH=100) (µg/L)	Result of Evaluation
Ingersoll and Kemble (2001)	F, M	7-8 d old	42 days	Reproduction	0.7453	Acceptable
Borgmann et al. 1989b	R, M	<7-d old	42 days	Survival	0.6348	Not acceptable Only 64% control survival (need ≥80%)
Borgmann et al. 1991	R, M	<7-d old	42 days	Survival	0.4299 (EC_{50})	Not acceptable Low control weight of 0.34 mg dwt (need ≥ 0.50 mg dwt after 42 days of testing)

Reference	Method[a]	Life stage	Exposure	Effect	EC_{20}/ MATC (TH=100) (µg/L)	Result of Evaluation
Suedel et al. 1997	S, M	14-21 d old	14 days	Survival/ growth	0.6576	Not acceptable Test organisms underfed (control weights not reported). Low ionic composition of dilution water.
Chadwick Ecological Consultants 2003	F, M	7-8 d old	28 days (recon lab water)	Survival	0.3749	Not acceptable Low control weight of 0.25 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)
Chadwick Ecological Consultants 2003	F, M	7-8 d old	28 days (surface water)	Survival	0.4461	Not acceptable 0.2 µg Cd/L in dilution water
Stanley et al. 2005	R, M	7-14 d old	42 days	Survival	2.414	Not acceptable Only 45% control survival (need ≥80%)
Straus 2011	R, M	2-9 d old	21 days	Survival	4.907	Not acceptable Low control weight of 0.136 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)
Straus 2011	R, M	2-9 d old	28 days	Survival	2.277	Not acceptable Low control weight of 0.064 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)
Pais 2012	R, M	2-9 d old	28 days	Survival	0.5127	Not acceptable Low control weight of 0.135 mg dwt (need ≥ 0.35 mg dwt after 28 days of testing)

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured; TH=total hardness

Borgmann et al. (1989b) Chronic Survival Study

This long-term (6 week) study investigated the effect of cadmium on *H. azteca* survival, growth and reproduction and was primarily a methods development effort. The static-renewal life cycle test was initiated with <7-day old organisms and was conducted at 25°C in dechlorinated Burlington City tap water with exposure concentrations of 0.28 (control), 0.57, 0.92, 1.49, 2.23, 3.42 and 6.28 µg/L cadmium. The water used for testing is acceptable, with a chloride concentration of approximately 26 mg/L and bromide concentration of around 0.047 mg/L. Other common ion (Na, K, Ca, Mg, SO4, and HCO_3) concentrations in this water are reasonable for testing with *H. azteca*. However, the food and feeding levels used in this test are questionable. The authors tested up to 20 organisms in each beaker and added 4 mg Tetramin flakes once per week to each test beaker, with additional feedings given up to two times each week on an as needed basis. It is not clear how they determined when more food was required.

Furthermore, the reported control survival was only 64 percent, while 80 percent is considered to be the minimum acceptable control survival for a 6-week test. The calculated EC_{20} for survival was 0.7827 µg/L, or 0.6348 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$.

Borgmann et al. (1991) Chronic Survival Study

An additional *H. azteca* 6-week chronic test was conducted by Borgmann using the same dechlorinated Burlington City tap water. As mentioned previously, this tap water is considered acceptable for *H. azteca* testing. However, it appears that organisms in this long-term test were also underfed (similar to other tests conducted by this group). The authors state that the animals were fed Tetramin at a rate of only 5 mg Tetramin/beaker/week, which equates to about 0.25 mg/organism/week. This feeding rate is much lower than currently recommended for chronic tests. Results of other chronic amphipod tests with diets limited to Tetramin had limited success, suggesting that amphipods require dietary supplements in addition to the Tetramin (e.g., YCT or diatoms) to achieve acceptable growth and reproduction (J.R. Hockett, personal communication). Based on the organism control weights obtained at the end of the test (0.34 mg estimated average dry weight), it appears amphipod growth was limited by the feeding rate and dietary composition. Acceptable average ending dry weights typically fall within the range of 0.7 to 1.0 mg/organism for a 42-d test. This poor growth and low feeding rate excluded the use of these data in calculating the SMCV for this species. The reported EC_{50} for survival in the study was 0.53 µg/L, or 0.4299 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$.

Suedel et al. (1997) Chronic Survival and Growth Study

This paper presents the results of several toxicity tests. Although limited information is provided, the tests appear to be static exposure without renewal. Five tests were conducted (48-hr, 96-hr, 7-day, 10-day, and 14-day exposures). Organisms were fed in each test by adding leached, ground maple leaves to the test chambers at the beginning of each exposure. Especially for the longer duration tests (10-day and 14-day), it does not appear the test organisms were fed sufficiently, although this remains unclear because body weight data were not reported. Little information is provided about the test/control water other than hardness (6 to 28 mg/L), alkalinity (8 to 18 mg/L) and conductivity (22 to 130 µS/cm), which indicates the dilution water was low in ion composition. The authors noted that water conditions represent the limits of environmental tolerance for the tested species. The chronic value of 0.16 µg/L (based on growth and survival), or 0.6576 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$, was not used quantitatively in this assessment.

Chadwick Ecological Consultant (2003) Chronic Survival Study

The chronic toxicity of cadmium to *H. azteca* was tested with 28-day flow-through measured test procedures using two different dilution waters (reconstituted laboratory water and natural surface water from Horsetooth Reservoir) with different hardness levels. Both dilution waters were augmented with bromide and chloride to achieve nominal concentrations of approximately 0.80 mg/L Br and 60 mg/L Cl^-, which are above the minimum recommended levels of 0.02 mg/L Br and 15 mg/L Cl. The 28-day control survival was ≥90 percent for each test, which exceeds the 80 percent minimum requirement. The test organisms were fed 1.0 ml YCT daily and the authors reported mean control dry weights at day 28 of 0.25 mg for the reconstituted water test and 0.43 mg for the natural surface water test. The recommended mean control dry weight at day 28 is ≥0.35 mg and only the natural surface water test met the feeding/average control dry weight requirement. Even though the control dry weight of the natural surface water test met the recommended 0.35 mg average, there is an elevated level of cadmium in the Horsetooth Reservoir water (about 0.2 µg/L cadmium). In addition, the cadmium concentration measured at day 28 in the lowest nominal exposure concentration (0.6 µg/L) was very similar to the next higher concentration, which raises questions about whether organism response in the lowest concentration was exaggerated by an excursion in cadmium concentration, or if the measured concentration was an analytical anomaly. The 28-day MATC for the surface water test was 1.02 µg/L cadmium, which was slightly higher than the estimated 28-day survival EC_{20} of 0.6264 µg/L, or 0.4461 µg/L when normalized to a hardness of 100 mg/L as $CaCO_3$. The MATC for the reconstituted water was 0.74 µg/L, which was also higher than the normalized calculated EC_{20} of 0.3749 µg/L cadmium.

Stanley et al. (2005) Chronic Survival Study

Stanley et al. (2005) conducted one *H. azteca* 42-day chronic test in laboratory reconstituted water (ASTM hard water) and at a feeding rate of 1 ml YCT/test chamber/day. The lack of sufficient chloride and bromide ions in the dilution water and sub-optimal diet would not support the health of *H. azteca*, especially after 10 days of testing (**Appendix K**). Additionally, the control survival in this test was poor (45%). The results of this test were accordingly not used to develop AWQC. The non-normalized chronic limits based on survival are 2.49 and 5.09 µg/L with a MATC of 2.414 µg cadmium/L when normalized to a hardness of 100 mg/L as $CaCO_3$.

Straus (2011) Chronic Survival Studies

H. azteca neonates (2-9 days old) were exposed to cadmium for 21 days in artificial Lake Ontario reconstituted laboratory water (total hardness of 120-140 mg/L as $CaCO_3$) and for 28 days in a mixture of reverse osmosis and dechlorinated City of Waterloo tap water (blended to a total hardness of 22 mg/L as $CaCO_3$). Water in both tests was renewed every 48 hours and cotton gauze was used as a substrate. Although the test organisms were cultured in artificial media containing bromide, it is not clear if the artificial Lake Ontario water or the reverse osmosis/tap water mix contained bromide. The chloride concentrations also were not reported for either dilution water, although the nominal chloride concentration of the artificial Lake Ontario water is estimated to be approximately 28 mg/L. Test recommendations in **Appendix K** note that natural waters with a hardness of <80 mg/L as $CaCO_3$ typically have <10 mg Cl^-/L. Control organism survival was 93 percent in the 21-day test and 81.8 percent in the 28-day test. Control organism mean dry weight averaged 0.136 for the 21-day test and 0.064 mg for the 28-day test. When all factors are considered, these two studies do not meet the test acceptability requirements outlined in **Appendix K**. The EC_{20}s calculated for these two tests based on survival are 6.42 µg/L for the 21-day test and 0.68 µg/L for the 28-day test, or 4.907 for the 21-day test and 2.277 µg/L for the 28-day test when normalized to a hardness of 100 mg/L as $CaCO_3$.

Pais (2012) Chronic Survival Study

H. azteca neonates (2-9 days old) were exposed to cadmium for 28 days in laboratory water that was renewed every 48 hours. The dilution water was a mix of reverse osmosis and dechlorinated City of Waterloo tap water blended to a total hardness of 90 mg/L as $CaCO_3$. A cotton gauze substrate was used during the test. The bromide and chloride levels were not reported by the author, but since the total hardness of the reverse osmosis/tap water blend was 90 mg/L as $CaCO_3$, the dilution water may have contained an acceptable amount of chloride. U.S. EPA (2012) notes that natural waters with a hardness of <80 mg/L as $CaCO_3$ typically have chloride concentrations of <10 mg/L. The bromide level was not reported, but the tap water may have supplied the minimum bromide level (0.02 mg Br/L) recommended in **Appendix K**. The 28-day control survival was 100 percent, which exceeds the 80 percent minimum requirement.

However, the authors reported a mean control organism weight of 0.135 mg, which is much less than the recommended ≥0.35 mg dwt at day 28. Accordingly, this study does not meet the test acceptability requirements and the normalized 28-day survival EC_{20} of 0.5127 µg/L was not used for criteria derivation.

5.2.2 Uncertainty in the freshwater FCV calculation

In addition to the uncertainties described above for the freshwater acute criteria derivation (**Section 5.1.3**), the freshwater FCV calculation is also influenced by the availability of limited data, estimation of chronic values with either EC_{20} or MATC methods, selection of either life cycle or early life-stage test results for a species, and the use of the most representative test duration for the *C. bairdii* ELS test.

The freshwater chronic database is comprised of 27 species and 20 genera that satisfy the eight-family MDR as recommended in the 1985 Guidelines (Stephan 1985). There are several factors that contribute some uncertainty to the freshwater FCV (e.g., use of EC_{20}s over MATCs, the limited data used to develop the hardness relationship, limited data for *H. azteca*, selection of most appropriate exposure scenarios, and other data that is only used qualitatively). In this update EC_{20}s were selected as the most appropriate effect level, but not all studies reported EC_{20}s or did not provide the raw data in the paper so EC_{20}s could be calculated (Note: for all studies where raw data necessary to calculate EC_{20}s were not provided, authors were contacted to request the raw data, if available. Some requests are still outstanding). While EC_{20}s are the preferred effect level, so that chronic toxicity can be compared equally, this preference limits the amount of data that are used quantitatively in SMCV and GMCV calculations (**Table 9** and **Appendix C**). This was the case for several species (*C. dubia*, *C. reticulata*, *D. magna*, *O. kisutch*, *O. mykiss*, *S. trutta*, *S. fontinalis*, *S. namaycush*, and *P. promelas*). Conversely, only MATCs were available for several genera, and therefore the effect levels associated with those MATC concentrations are unknown (*Oreochromis*, *Micropterus*, *Esox*, and *Catostomus*). These values were retained in the ranked table to avoid losing the genus.

The use of EC_{20}s also limited the amount of data that were used to develop the chronic hardness relationship. Currently there are only enough EC_{20} data to explore this relationship for three fish species. This preference for EC_{20}s precluded the inclusion of data for *P. promelas*, but MATC data from a single study for *D. magna* (Chapman et al. Manuscript) were used so that an invertebrate could be included in the analysis. The rationale for the exclusion of *P. promelas* is that the effect of hardness would be better evaluated without the confounding factor of the level of effect being unknown (see **Section 2.6, Chronic measures of effect**).

The 1985 Guidelines recommend the use of full life-cycle (LC) tests over early life-cycle tests (ELS), with the rationale that LC tests will be more sensitive. However, this relationship was not always apparent. Normalized EC_{20}s of LC tests were more sensitive (lower effect concentrations) for *S. fontinalis* and *O. mykiss*, but ELS tests were more sensitive for *S. trutta*. To be conservative, the ELS tests were used to derive the SMAV for *S. trutta*.

As discussed above there is only one acceptable study using the new test requirements for *H. azteca*. While the other unacceptable data were not used quantitatively it appears that effect concentrations were similar, however the SMAV/GMAV for the most sensitive species in the freshwater chronic database is based on the results from one study (Ingersoll and Kemble 2001).

5.3 Additional Aquatic Life Water Quality Assessments for Cadmium

Mebane (2006) recently derived freshwater ambient water quality criteria for cadmium and included data from studies that focused on species and surface water conditions in Idaho. Acute and chronic toxicity were calculated from available effects data and normalized for hardness based on hardness-toxicity regression analyses. The four most sensitive genera to acute exposures were the fish *Oncorhynchus* (Northwest trout and Pacific salmon), *Salvelinus* (“char” trout), *Salmo* (other trout and Atlantic salmon), and *Cottus* (sculpin). The four most sensitive genera to chronic exposures were the aquatic invertebrates *Hyalella* and *Gammarus* and the fish *Cottus* and *Salvelinus*. Mebane (2006) reported a CMC of 0.75 µg/L total cadmium and a CCC of 0.37 µg/L total cadmium, based on a hardness of 50 mg/L as $CaCO_3$. Mebane (2006) reported cadmium in total (unfiltered) instead of dissolved (0.45-µm filtered) concentrations, but indicated that because cadmium is highly soluble in water, the difference between total and dissolved concentrations would be small, with dissolved cadmium concentrations expected to average about 90 to 95 percent of total concentrations (Stephan 1995; Clark 2002; Mebane 2006). When adjusted to a total hardness of 100 mg/L as $CaCO_3$, the CMC and CCC calculated using equations reported by Mebane (2006) are 1.35 and 0.55 µg/L, respectively. These values are lower than the 2016 updated EPA CMC of 1.9 µg/L and CCC of 0.79 µg/L, based on total cadmium and a hardness of 100 mg/L as $CaCO_3$. The differences in the criteria derived by

Mebane (2006) and this 2016 update are primarily due the addition of new data since 2006, the subsequent estimation of different updated acute and chronic hardness-toxicity slopes, and exclusion of specific test results based on EPA data acceptability criteria.

The British Columbia Ministry of Environment (BC-MOE) recently released a draft assessment of ambient water quality criteria for cadmium in freshwater to protect species resident to British Columbia, Canada (BC-MOE 2014). The proposed acute and chronic criteria are based on dissolved cadmium concentrations in freshwater. The criteria were adjusted for hardness using established methods to derive an equation from the results of multiple published studies (Mebane 2006; Stephan et al. 1985; U.S. EPA 2001). The BC-MOE used the lowest value from a primary study and applied a factor of 3.5 to account for uncertainty and protect the survival of the most sensitive species (<10% mortality) at all life stages. The resulting draft CMC of 0.339 µg/L total cadmium at a water hardness of 100 mg/L $CaCO_3$ was based on effects on rainbow trout fry growth after a 5-d exposure, as reported in Hansen et al. (2002b). The resulting draft CCC (30 days) of 0.0772 µg/L at a water hardness of 100 mg/L $CaCO_3$ was based on effects on *Hyalella azteca* survival, as reported in Ingersoll and Kemble (2001). The short-term hardness slope factor was 1.04 and the long-term hardness slope factor was 0.762; compared to the 2016 hardness slope factors of 0.9789 and 0.7977, respectively. The BC-MOE (2014) cadmium water quality guideline for long term exposure in marine environments is 0.12 µg/L. This is in contrast to the higher EPA 2016 estuarine/marine chronic CCC of 7.9 µg/L dissolved cadmium. No short term exposure guideline has been developed by BC-MOE for the marine environment. The BC-MOE proposed cadmium criteria are all lower than the EPA 2016 criteria, primarily due to differences in the methodology employed (use of lowest value), larger safety factors applied and hardness slope factor differences.

5.4 Estuarine/Marine Acute Toxicity Data

Acute toxicity data are available for 94 estuarine/marine species representing 79 genera. These data are adequate to support the development of an estuarine/marine acute criterion. SMAVs for cadmium range from 28.14 to 169,787 µg/L. The four most sensitive genera were invertebrates with GMAVs ranging from 28.14 to 67.39 µg/L (**Appendix B**).

Additional toxicity data on the effect of cadmium on estuarine/marine species were available, but did not meet standards of acceptability and were not used quantitatively in development of the criteria (**Appendix I**). However, the acute and chronic toxicity values for these tests are similar to those of the accepted studies, providing additional supporting evidence about the toxicity of cadmium to estuarine/marine aquatic life. These include data from Roast et al. (2001b), who reported a 6-day LC_{50} for *P. flexuosus* of 83.11 µg/L, which represents a similar outcome to those provided in **Appendix B**. Nimmo et al. (1977a) and Gentile et al. (1982) reported similar outcomes for *A. bahia* with 8 to 17-day EC_{50} values ranging from 11.3 to 60 µg/L.

Other non-traditional endpoints for marine/estuarine organisms exposed to cadmium for shorter time periods are presented in **Appendix I**. Daggerblade grass shrimp (*Palaemonetes pugio*) had increased LPO and ubiquitin levels when exposed for eight hours to 112.4 µg/L cadmium (Downs et al. 2001a). Reduction in swimming speed and reduced serum osmolality were observed for nauplii of the calanoid copepod *Eurytemora affinis* and the mysid *Americamysis bahia* subjected for 24 hours to 130 and 3.62 µg/L cadmium, respectively (Sullivan et al. 1983; De Lisle and Roberts 1994). Bellas et al. (2004) determined a 70-hr larval attachment EC_{50} of 752 µg/L for the sea squirt *Ciona intestinalis*, and the mud snail *Nassarius obsoletus* had increased oxygen consumption when exposed to 500 µg/L cadmium for 72 hours (MacInnes and Thurberg 1973). Osmotic pressure of the shore crab *Carcinus maenas* was affected at 34 µg/L cadmium after 10 days, but not at 3.4 µg/L (Burke et al. 2003). Choi et al. (2008) found that Pacific oysters (*Crassostrea gigas*) exposed to 10 µg/L cadmium for 11 days had an increased expression of MT mRNA in digestive gland and gills. Coho salmon (*Oncorhynchus kisutch*) exposed to 3.7 µg/L cadmium over 48 hours exhibited histological injury to the olfactory epithelium, and a significant loss of olfaction at concentrations greater than 347 µg/L, with the adverse effects of each still evident after a 16-day depuration in clean water (Williams and Gallagher 2013). The persistent nature of these effects could adversely alter the return rates of anadromous salmon species as noted by Baldwin et al. (2009).

5.4.1 Uncertainty in estuarine/marine FAV calculation

The influence of salinity on the acute toxicity of cadmium was investigated with 10 different genera of estuarine/marine animals. A general trend of decreasing toxicity with increasing salinity was observed for the majority of genera (**Appendix B**). Frank and Robertson (1979) reported that the acute toxicity of cadmium to juvenile blue crabs was reduced by increasing salinity levels, with 96-hr LC_{50}s of 320, 4,700 and 11,600 µg/L at salinities of 1, 15 and 35 g/kg, respectively (**Appendix B**). The same trend was observed by Bengtsson and Bergstrom (1987) for the harpacticoid copepod, *Nitocra spinipes*, Ringwood (1990) for the mangrove oyster, *Isognomon californicum*, Wu and Chen (2004) and Frias-Espericueta et al. (2001) for the white shrimp, *Litopenaeus vannamei*, and De Lisle and Roberts (1988) for the mysid, *Americamysis bahia*, amongst other species.

In contrast to the results presented above, several authors reported possible relationships with salinity that seem contradictory, some of which may have been influenced by other test variables. In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, *Fundulus heteroclitus*, Voyer (1975) found that 96-hr LC_{50}s at a salinity of 32 g/kg were about half of what they were at lower salinities of 10 and 20 g/kg. When tested at approximately 20°C, the 96-hr LC_{50}s were 73,000, 78,000 and 30,000 µg/L at salinities of 10, 20 and 32 g/kg, respectively (all exposures had sufficient dissolved oxygen levels throughout the test). The fiddler crab, *Uca pugilator*, showed a similar trend in that the crab was more sensitive to cadmium at the highest salinity tested (30 g/kg) as compared to the mid-level salinity (20 g/kg) test, and about the same sensitivity as the lowest salinity (10 g/kg) (O'Hara 1973a). Cadmium also appears to be more toxic to purple sea urchin embryos (*Strongylocentrotus purpuratus*) at a higher salinity, although salinity levels differed by only 4 mg/kg and test temperatures were higher in the higher salinity exposure, which may have confounded potential conclusions (Dinnel et al. 1989; Phillips et al. 2003). The potential relationship between salinity and cadmium saltwater acute toxicity was investigated using an analysis of covariance (Dixon and Brown 1979; Neter and Wasserman 1974) as noted in the 1985 Guidelines (Stephan et al. 1985). Despite the general relationship of decreasing toxicity with increasing salinity, a pooled species slope could not be calculated.

As noted in the 1985 Guidelines, a final acute equation should be derived based on a water quality parameter if acute toxicity is shown to be related to that parameter (Stephan et al. 1985). In order to derive a final acute equation from a water quality parameter, however, sufficient data are required to show that the factor similarly affects the results of tests with a variety of species (U.S. EPA 2001). Because a general trend was observed between increasing salinity and decreasing acute toxicity for the majority of genera, an analysis of covariance (Dixon and Brown 1979; Neter and Wasserman 1974) as noted in the 1985 Guidelines (Stephan et al. 1985) using the “R” statistical program, version 3.2.2 (R Core Team 2015), was performed to examine whether a salinity correction equation could be calculated.

Data for the ten species comprising ten genera were included in the analysis of covariance. These species had definitive acute values (less than or greater than values were not used) over a salinity range of at least 7 g/kg. For any given species, data were limited to studies conducted at representative and similar temperatures and dissolved oxygen concentrations. When test data for multiple life stages were available, data for the most sensitive life stage was used.

In the analysis of covariance model equation, the natural logarithm of the acute value is the dependent variable, species is the grouping variable, and the natural logarithm of salinity is the covariate or independent variable. A species-salinity interaction variable is included to assess the similarity of slopes among species. An F-test is then used to test whether a model with separate slopes for each species gives a statistically significantly better fit to the data than a model with a single pooled slope. If the P-value of the species-salinity interaction term is statistically significant (defined as a P-value of less than 0.05), then the model with separate species slopes provides the better fit to the data, and a single pooled slope cannot be calculated.

When data for all nine species were fit to the analysis of covariance model, the species-salinity interaction term used to test for equality of slopes produced a P=0.008, meaning that the model with separate species slopes provides the better fit to the data, and a single pooled slope could not be calculated. Individual species slopes were variable, ranging from -0.6998 for the mummichog *F. heteroclitus* to 5.538 for the amphipod *G. japonica* (**Table 19**). Individual species slopes were also plotted in **Figure 8**. As can be seen in **Figure 8,** eight of the nine species experience a decrease in acute cadmium toxicity with increasing salinity (i.e., a positive slope).

Table 19. Individual Species Slopes and Selected Regression Statistics for the Equation ln(LC_{50}Cd) = ln(Salinity).

A pooled species slope could not be calculated from these data.

Species name			95% CI				
Scientific	**Common**	**Slope**	**LCL**	**UCL**	**r^2**	**p**	**n**
M. edulis	Blue mussel	0.7399	na	na	na	na	2
I. californicum	Mangrove oyster	1.467	na	na	na	na	2
N. spinipes	Harpacticoid copepod	0.3725	-0.6744	1.419	0.95	0.14	3
A. bahia	Mysid	1.010	0.7158	1.305	0.98	<0.01	5
G. japonica	Amphipod	5.538	na	na	na	na	2
L. vannamei	Whiteleg shrimp	1.032	na	na	na	na	2
C. sapidus	Blue crab	1.006	0.8249	1.186	1.00	<0.01	3
U. pugilator	Fiddler crab	0.1673	-3.499	3.834	0.25	0.67	3
F. heteroclitus	Mummichog	-0.6998	-8.129	6.729	0.59	0.44	3

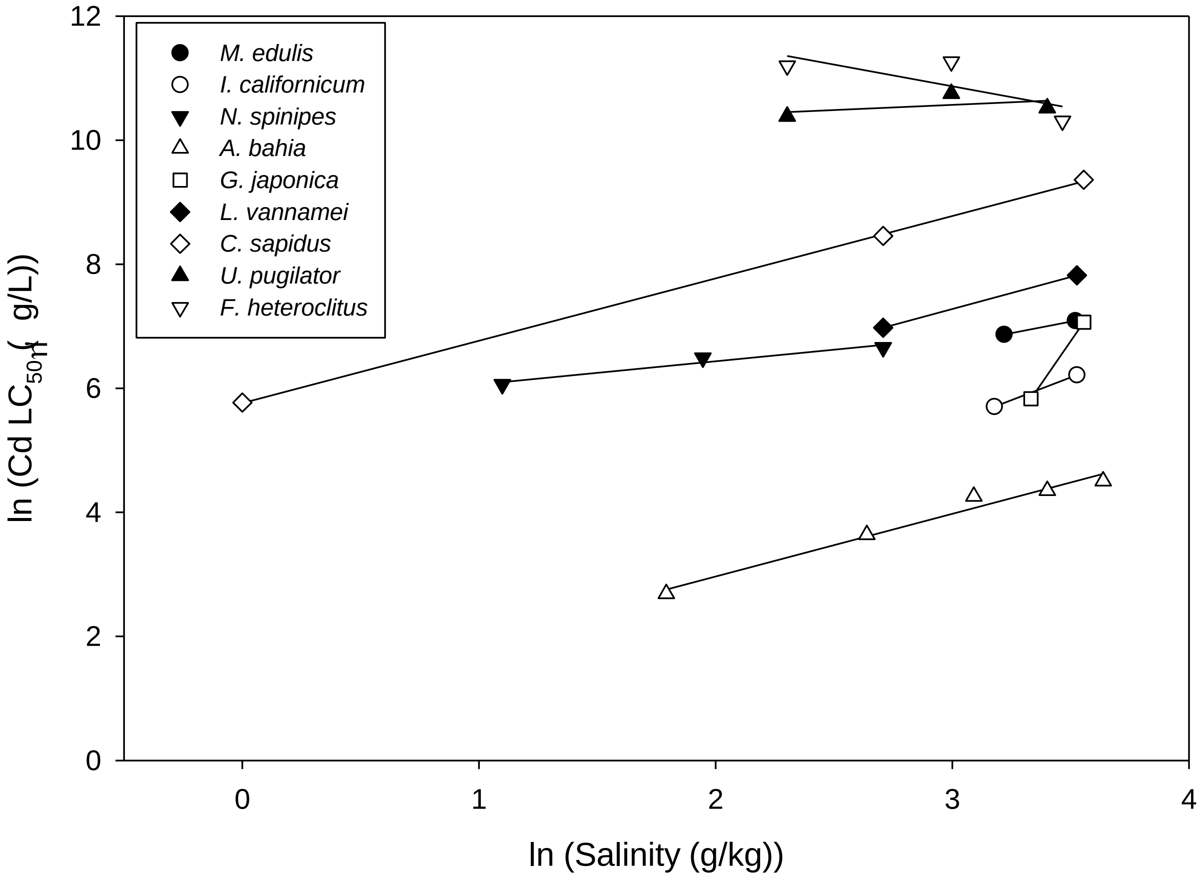

Figure 8. Individual Species Slopes Showing the Relationship between Natural Log Transformed Salinity and Natural Log Transformed Acute Cadmium Toxicity.

Data used to generate species slopes in **Table 19** have already accounted for the most sensitive life stage for a particular species. In addition to that consideration, following the recommendations of the EPA Guidelines (Stephan et al. 1985), individual species slopes were examined and a subsequent analysis of covariance model was used to test whether a pooled species slope could be calculated using only those species with slopes determined to cover a relatively broad range of the relevant water quality parameter, defined here as at least 50% of the range of reported salinities. Five species: *A. bahia*, *C. sapidus*, *F. heteroclitus*, *L. vannamei* and *U. pugilator*, had test data across a salinity range greater than 50% of the salinity range for all species. When data for these five species were fit to the analysis of covariance model, the species-salinity interaction term used to test for equality of slopes produced a P=0.009. As before, the model with separate species slopes provides the better fit to the data, and a single pooled slope could not be calculated. Despite the positive relationship between acute toxicity and salinity observed for eight of the nine species with available data, the species slopes are sufficiently variable that no pooled slope can be calculated. Thus, the estuarine/marine acute data are not normalized for salinity.

In addition to the uncertainties described above for the freshwater acute criteria derivation (**Section 5.1.3**), the lack of a statistically defensible salinity-toxicity relationship to normalize the acute data adds additional uncertainty to the estuarine/marine FAV. Despite the positive relationship between acute toxicity and salinity observed for eight of the nine species included in the analysis of covariance, a pooled slope could not be calculated, precluding salinity normalization of the data. As such, the data are used at the tested salinity level, which may or may not be the most sensitive for the species. Not all studies, however, reported a salinity level which would potentially exclude them from the FAV calculation if the data were salinity normalized.

5.5 Estuarine/Marine Chronic Toxicity Data

Data for only two estuarine/marine mysid species (*Americamysis bahia*, SMCV = 6.149 µg/L and *Americamysis bigelowi*, SMCV = 11.61 µg/L) are suitable for the derivation of a chronic criterion, and limited toxicity data are available for qualitative consideration in this document (see **Appendix I**). A 21-day survival chronic value of 111.8 µg/L was determined for the starlet sea anemone *Nematostella vectensis* (Harter and Matthews 2005), and 28-day LC_{50}s for the polychaete worms *Capitella capitata* and *Neanthes arenaceodentata* ranged from 630 to 3,000 µg/L (Reish et al. 1976). White shrimp (*Litopenaeus vannamei*), pink shrimp (*Farfantepenaeus duorarum*), daggerblade grass shrimp *(Palaemonetes pugio*), rock crab (*Cancer irroratus*) and blue crab (*Callinectes sapidus*) 21 to 30-day effect levels (LC_{50}s and LOECs) ranged from 19 to 720 µg/L (Nimmo et al. 1977b; Vernberg et al. 1977; Johns and Miller 1982; Guerin and Stickle 1995; Wu and Chen 2005a). Scallops were more sensitive to cadmium, with *Argopecten irradians* and *A. ventricosus* 42-day EC_{50} and 30-day LOEC growth effect levels at 10 and 78 µg/L, respectively (Pesch and Stewart 1980; Sobrino-Figueroa et al. 2007). Similarly, Atlantic silverside (*Menidia menidia*), cunner (*Tautogolabrus adspersus*) and winter flounder (*Pseodopleuronectes americanus*) 17 to 60-day survival effects ranged from 100 to >970 µg/L (MacInnes et al. 1977; Voyer et al. 1979). All of these effect levels are above those reported for the two mysid species that were used quantitatively for derivation of the chronic criterion.

Additional studies have reported the chronic sublethal effects of cadmium on estuarine/marine species (**Appendix I**). Delayed development and reduced food consumption were observed for rock crab larvae (*Cancer irroratus*) and white shrimp (*Litopenaeus vannamei*) exposed for 28 days to 50 and 200 µg/L cadmium, respectively (Johns and Miller 1982; Wu and Chen 2005a). Increased ATPase activity was exhibited by the American lobster (*Homarus americanus*) exposed to 6 µg/L cadmium for 30 days (Tucker 1979), and mud crab larvae (*Eurypanopeus depressus*) experienced a delay in metamorphosis when exposed to 10 µg/L cadmium for 44 days (Mirkes et al. 1978). When evaluating fish, significant reduction in gill tissue respiratory rate was reported for the cunner after a 30-day exposure to 50 µg/L (MacInnes et al. 1977). Dawson et al. (1977) also reported a significant decrease in gill-tissue respiration of striped bass at 5 µg/L after a 30-day exposure, as did Calabrese et al. (1975) after a 60-day exposure to 5 µg/L.

5.5.1 Final Acute-to-Chronic Ratio

The limited amount of acceptable estuarine/marine chronic toxicity data precluded the use of regression analysis to calculate the estuarine/marine CCC (as was done with the freshwater CCC). As stipulated in the 1985 Guidelines, the CCC was calculated as the FAV divided by the FACR. As previously mentioned, a minimum of three ACRs (a fish species and an invertebrate species, with one being acutely sensitive in saltwater) are typically used to estimate the FACR. This update has ACRs available for six freshwater invertebrates, eight freshwater fish and two saltwater invertebrate species representing a diverse number of families (**Table 16**). The 1985 Guidelines outline four primary ways to combine ACRs to calculate an appropriate FACR.

- If the species mean acute-chronic ratios seems to increase or decrease as the SMAV increases, the Final Acute-Chronic Ratio should be calculated as the geometric mean of the acute-chronic ratios for species whose SMAVs are close to the Final Acute Value.
- If no major trend is apparent and the acute-chronic ratios for a number of species are within a factor of ten, the Final Acute-Chronic Ratio should be calculated as the geometric mean of all the species mean acute-chronic ratios available for both freshwater and saltwater species.
- For acute tests conducted on metals and possibly other substances with embryos and larvae of barnacles, bivalve molluscs, sea urchins, lobsters, crabs, shrimp, and abalones, it is probably appropriate to assume that the acute-chronic ratio is 2. Thus, if the lowest available SMAVs were determined with embryos and larvae of such species, the Final Acute-Chronic Ratio should probably be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration.
- If the most appropriate species mean acute-chronic ratios are less than 2.0, and especially if they are less than 1.0, acclimation has probably occurred during the chronic test. Because continuous exposure and acclimation cannot be assured to provide adequate protection in field situations, the Final Acute-Chronic Ratio should be assumed to be 2, so that the Final Chronic Value is equal to the Criterion Maximum Concentration.

None of the four methods listed above could be used to calculate the FACR for cadmium. Therefore another approach was chosen to incorporate ACRs of sensitive species from both freshwater and estuarine/ marine environments to calculate an appropriate FACR. There were several possible methods to compile these values. One option would have been to use the ACRs available for the two *Americamysis* species (5.275 for *A. bahia* and 9.476 for *A. bigelowi*), the chinook salmon, *Oncorhynchus tshawytscha* (0.9626), and the fatmucket, *Lampsilis siliquoidea* (2.727). All are acutely sensitive, and the geometric mean of these four values yields an FACR of 3.385. If the freshwater fish is replaced by the rainbow trout, *Oncorhynchus mykiss* (ACR=1.527), the resulting FACR is 3.798. Alternatively, using the acutely sensitive mottled sculpin (*Cottus bairdii*) ACR of 11.22 instead of the ACR for the Chinook salmon results in an FACR of 6.254.

A final option would be to use ACRs from a diverse mix of freshwater and estuarine/marine species representing both invertebrates and fish, with the freshwater species having taxonomically-related marine species. Using this approach, seven genus-level ACRs were used to calculate the FACR for estuarine/marine water (representing five freshwater fish species, three freshwater invertebrate species, and the two acutely sensitive estuarine/marine mysids). An FACR of 8.291 was obtained from the geometric mean of seven genus-level ACRs: *Americamysis* (7.070), *Ceriodaphnia* (19.84), *Daphnia* (23.90), *Cottus* (11.22), *Oncorhynchus* (2.0), *Salmo* (2.0) and *Pimephales* (17.90). The fish *C. bairdii, S. trutta, Oncorhynchus and P. promelas* represent the second, fourth, fifth and forty-fourth most sensitive freshwater genera, respectively, and the cladocerans *Daphnia* and *C. dubia* are the eleventh and eighteenth most sensitive genera. This approach was chosen because EPA believes that use of combined ACRs for a variety of freshwater and estuarine/marine species is the most appropriate and representative method for deriving the FACR.

5.5.2 Uncertainty in the estuarine/marine FCV calculation

The primary source of uncertainty with the derivation of the estuarine/marine FCV is the lack of available data. There have been no new acceptable estuarine/marine chronic data generated since the 2001 AWQC was published. The only data available are for one genus of mysid, *Americamysis*, which is the fourth most sensitive acute genus. The chronic criterion is therefore based on the use of a FACR. The FACR assumes that the relationship between acute and chronic toxicity for each species is constant. Acceptable ACRs are averaged across taxa to calculate the final overall relationship between the acute and chronic toxicity values. Since freshwater ACRs are used to bolster the calculation of the FACR, due to only one estuarine/marine genus-level ACR being available, this creates an additional uncertainty in the estuarine/marine FCV.

The estuarine/marine FAV is also hampered by the lack of a statistically defensible salinity-toxicity relationship to normalize the acute data. Since the FAV is divided by the FACR to calculate the FCV, the FAV may not be representative of the true toxicity of cadmium across various salinity gradients (i.e., may be under protective in low salinity waters).

5.6 Bioaccumulation

Test level bioconcentration factors (BCFs) for cadmium in freshwater (**Appendix G**) range from 3 for brook trout muscle (Benoit et al. 1976) to 65,600 for the amphipod, *H. azteca* (Straus 2011). Fish typically accumulate only small amounts of cadmium in muscle as compared to most other tissues and organs (Benoit et al. 1976; Sangalang and Freeman 1979; Jarvinen and Ankley 1999). However, studies summarized by Jarvinen and Ankley (1999) showed that the skin, spleen, gill, fin, otolith and bone also have low bioconcentration factors. Sangalang and Freeman (1979) found that cadmium residues in fish reach steady-state only after exposure periods greatly exceed 28 days. *D. magna*, and presumably other invertebrates with about the same body size, were found to reach steady-state within a few days (Poldoski 1979).

Cadmium accumulated by fish from water is eliminated slowly (Benoit et al. 1976; Kumada et al. 1980), but Kumada et al. (1980) found that cadmium accumulated from food is eliminated much more rapidly. When all variables, except temperature, are kept the same, Tessier et al. (1994a) found that increased exposure temperature generally increased the rate of soft tissue bioconcentration for the snail, *Viviparus georgianus*, but not for the mussel, *Elliptio complanata*. Poldoski (1979) reported that humic acid decreased the uptake of cadmium by *D. magna*, but Winner (1984) did not find any effect. Ramamoorthy and Blumhagen (1984) reported that fulvic and humic acids increased the uptake of cadmium by rainbow trout.

The only BCF reported for an estuarine/marine fish is a value of 48 from a 21-day exposure of mummichog (Eisler et al. 1972) (**Appendix I**). However, among nine species of invertebrates for which values were available, the BCFs range from 22 to 3,160 for whole body and from 5 to 2,040 for muscle (**Appendix G**). The highest BCF (3,160) was reported for the polychaete, *Ophryotrocha diadema* (Klockner 1979). This BCF was reached after sixty-four days exposure using the renewal technique; however, tissue residues had not reached steady-state at the end of the exposure period.

BCFs for four species of estuarine/marine bivalve molluscs range widely, from 113 for the blue mussel (George and Coombs 1977) to 2,150 for the eastern oyster (Zaroogian and Cheer 1976). The range of reported BCFs is also large for some individual species. For example, two studies with the bay scallop resulted in BCFs of 168 (Eisler et al. 1972) and 2,040 (Pesch and Stewart 1980) and three studies with the blue mussel reported BCFs of 113, 306, and 710

(**Appendix G** and **Appendix I**). George and Coombs (1977) studied the importance of metal speciation on cadmium accumulation in the soft tissues of *Mytilus edulis*. Cadmium complexed as Cd-EDTA, Cd-alginate, Cd-humate, and Cd-pectate (**Appendix I**) was bioconcentrated (directly taken up from water) at twice the rate of inorganic cadmium (**Appendix G**). Because bivalve molluscs usually do not reach steady-state, comparisons between species may be difficult, and the length of exposure may be the major determinant of the BCF.

BCFs for five species of estuarine/marine crustaceans range from 22 to 307 for whole body and from 5 to 25 for muscle (**Appendix G** and **Appendix I**). Nimmo et al. (1977b) reported whole-body BCFs of 203 and 307 for two species of grass shrimp, *Palaemonetes pugio* and *P. vulgaris*. Vernberg et al. (1977) reported a BCF of 140 for *P. pugio* at 25°C (**Appendix I**), and Pesch and Stewart (1980) reported a BCF of 22 for the same species exposed at 10°C, indicating that temperature might be an important variable determining the rate of bioaccumulation. The commercially important crustaceans, the pink shrimp and lobster, were not effective bioaccumulators of cadmium with factors of 57 for whole body and 25 for muscle, respectively (**Appendix G** and **Appendix I**). It should be noted that the inverse relation relationship between BCF and exposure concentration explains much of the variation in the observed BCFs (McGeer et al. 2003; DeForest et al. 2007).

5.6.1 Uncertainty with cadmium exposure routes

As reported in the literature, aquatic organisms can accumulate cadmium from both aqueous and dietary exposure routes. The relative importance of each, however, is dependent upon the species. The filter feeding cladoceran *Ceriodaphnia dubia* was found to accumulate more cadmium from water than diet, and at a more rapid rate (Sofyan et al. 2007a). Barata et al. (2002d) observed during a 24-hour laboratory water exposure experiment that *Daphnia magna* juveniles accumulated approximately twice as much cadmium from laboratory water exposure than from an algal food diet. Water exposure accounted for over 50 percent of the cadmium body burden in the isopod *Asellus aquaticus* (van Hattum et al. 1998). Fisher et al. (2000) found that in *Acartia tonsa* approximately 60 percent of the cadmium was assimilated from water and 40 percent from food. The same trend of accumulating over 50 percent of cadmium from water was observed for the clam *Macoma balthica* (Harvey and Luoma 1985b) and the blue mussel *Mytilus edulis* (Borchardt 1983). In contrast, diet, rather than water, accounted for more than 50 percent of cadmium accumulated in the predatory insects *Chaoborus punctipennis* (Munger and Hare 1997), *Cryptochironomus sp*. and *Sialis velata* (Roy and Hare 1999), the water mite *Limnesia maculate*, the caddisfly *Mystacicks spp*. (Timmermans et al. 1992), and in five of the seven stonefly species evaluated by Martin et al. (2007). Diet also accounted for most (>95%) of the observed cadmium tissue burden of mayflies in the field (Cain et al. 2011). This field observation is consistent with the observations of Xie et al. (2010), who noted that periphyton is often a sink for cadmium in aquatic environments. In a natural lake experiment, Stephenson and Turner (1993) found that the grazing amphipod, *Hyalella azteca* derived more than half (58%) of accumulated cadmium from periphyton, when compared to the aqueous exposure route. In a different lake experiment, rainbow trout and lake whitefish (*Coregonus clupeaformis*) accumulated approximately five times as much cadmium from the food only exposure relative to the water only dose (Harrison and Klaverkamp 1989). Mebane (2006) summarized the contribution of aqueous versus dietary cadmium exposure to the bioaccumulation observed in various aquatic organisms and found the same species specific differences. In summary, the primary route of cadmium accumulation varies among species, with no discernable pattern.

The specific tissues/organs affected in an aquatic organism are also dependent on the exposure route. Wang and Fisher (1996) noted that bivalve molluscs primarily accumulate dissolved cadmium across the gills, and particulate forms via the gut, suggesting that cadmium speciation influences exposure route and the subsequent tissues and organs affected. In crustaceans, aqueous cadmium can be adsorbed to the body surface or taken up internally by ingestion, passive diffusion, or facilitated transport (Wang and Fisher 1998). For example, dissolved cadmium adsorbs onto the chitosan exoskeleton of pelagic and benthic crustaceans (Hook and Fisher 2001; Mohlenberg and Jensen 1980), or inert chitin surfaces of insects (Hare 1992), where it is rendered unavailable to interfere with internal metabolic processes. In contrast, ingested cadmium can accumulate into internal tissues potentially interfering with a variety of metabolic and reproductive processes, such as egg production in copepods (Hook and Fisher 2001). Cadmium assimilated from food is stored in the soft tissue of the oyster *Crassostrea gigas* (Nassiri et al. 1997). Norway lobsters (*Neohrops norvegica*) accumulated aqueous cadmium primarily in their gills and digestive gland, with most of the dietary cadmium deposited in the digestive gland (Canli and Furness 1995). The freshwater crayfish *Astacus leptodactylus* exposed to cadmium in water accumulated the greatest amount of cadmium in the hepatopancreas, with lesser amount in the gills, exoskeleton and abdominal muscles (Guner 2010).

In fish, uptake of dissolved cadmium is mainly across the gills, the primary site of toxic action, followed by transport to different organs (Wang and Fisher 1996; Wood et al. 2012). Accumulation of dissolved cadmium by the gills can be by either passive (diffusion) or active (pump) transport (Neff 2002). Fish exposed to cadmium in the presence of food initially absorb cadmium in the intestinal tract and to some degree the stomach, and subsequently transfer it to other tissues via the circulatory system (Wood et al. 2012). Water-borne cadmium primarily accumulated in the gills of rainbow trout and lake whitefish (Harrison and Klaverkamp 1989), the kidney of brook trout (Sangalang and Freeman 1979) and Nile tilapia *Oreochromis niloticus* (Cogun et al. 2003), and the liver of the perch *Perca fluviatilis* (Edgren and Notter 1980). In comparison, cadmium-spiked food accumulated mainly in muscle and the intestinal tract of rainbow trout (Kumada et al. 1980) and in the intestine, kidney and liver of the eel *Anguilla anguilla* (Haesloop and Schirmer 1985).

In an effort to determine the most toxic exposure route, a number of investigators have compared the adverse effects of cadmium to organisms exposed separately to both aqueous and dietary cadmium. Hook and Fisher (2001) reported that dietary exposure of marine copepods (*Acartia hudsonica and A. tonsa*) to cadmium was approximately 200 times more toxic than an aqueous exposure. Marine copepod reproduction significantly decreased at 0.5 µg/L dietary cadmium (algal food at 7.19 µg Cd/g dw), but it was not affected when the animals were exposed to dissolved cadmium at a similar concentration (reported aqueous LC_{50} of 112.4 µg/L). The hatching rate, ovarian development and egg protein content all decreased at the dietary effect level, suggesting that the process of yolk development (vitellogenesis) was affected. The more than two-fold difference (dietary LOEC of 0.5 µg/L vs. aqueous LOEC of >1.12 µg/L) in effect levels is likely due to the adsorption of aqueous cadmium to the exoskeleton where it is largely unavailable, whereas the food-borne cadmium accumulates in internal tissues and disrupts metabolic and reproductive processes.

Irving et al. (2003) exposed grazing mayfly nymphs (*Baetis tricaudatus*) to cadmium-contaminated diatom mats during a 13-day partial life-cycle experiment and observed significantly reduced grazing and growth at 10 µg/g cadmium (LOEC). The corresponding 96-hr LC_{50} determined for this was 1,611 µg/L. When evaluating the mayfly *Centroptilum triangulifer*, Xie and Buchwalter (2011) found that larvae exposed to dietary cadmium had significantly suppressed catalase and superoxide dismutase activities. Aqueous exposed larvae with similar cadmium tissue levels, however, had normal antioxidant enzyme activity. As shown by these studies, aqueous cadmium is adsorbed onto the chitin surface and potentially rendered unavailable to disrupt metabolic processes, whereas the food-borne cadmium accumulates in tissues and organs, and if not sequestered or detoxified, could interfere with a variety of metabolic and reproductive processes.

Female goldfish (*Carassius auratus*) were exposed to dietary cadmium for three years by Szczerbik et al. (2006) and the authors reported that the highest food dose of 10 mg/g (wet wt.) inhibited growth, disrupted behavior, prevented ovulation and decreased the gonado-somatic index. The lack of ovulation was due to disrupted oocyte development (most likely at the stages of vitellogenesis and oocyte maturation), thereby suggesting the site of toxic action. The only water exposure effects data available for this species were a 50-day reduced plasma sodium LOEC of 44.5 µg/L, a 7-day LC_{50} of 170 µg/L, and a SMAV (96-hr) of 1,656 µg/L.

Understanding the toxicological link between accumulated cadmium tissue levels and observation of adverse effects remains difficult to characterize, and therefore has received considerable interest in recent years (Adams et al. 2011; Mebane 2006; Wood et al 2012). The poorly understood link between cadmium tissue levels and corresponding adverse effects is in part due to the various mechanisms utilized by different species to detoxify and/or sequester cadmium, thereby rendering it biologically unavailable. A well-known and widespread cadmium detoxification mechanism is the production of metal binding proteins (e.g., metallothioneins) by a number of invertebrates and fish in response to a metal exposure. As pointed out by Mebane (2006), it is unclear if the cadmium accumulated in the kidneys of fish is bioavailable or sequestered. Therefore, the link between total cadmium tissue levels and adverse effects is difficult to quantify since the majority of accumulated cadmium may be in a detoxified form (Wood et al. 2012).

A summary of tissue residue levels for various aquatic organisms indicating the presence or absence of adverse cadmium effects is provided by Mebane (2006). He concluded that “the data reviewed on effects of cadmium tissue-residues in fish and invertebrates were insufficient to analyze quantitatively similarly to data on the effects of waterborne cadmium.” For example, data compiled by Mebane (2006) for various studies indicate that different fish species can tolerate gill tissue residues ranging from 2 to 30 mg Cd/kg dw (Benoit et al 1976; Farag et al. 2003), whereas brook trout males died during spawning after exposure to 5.1 mg Cd/kg dw (Benoit et al. 1976). Likewise, kidney residue levels ranging from 10 to 94 mg Cd/kg dw produced no adverse effects, yet 50 mg Cd/kg dw also resulted in brook trout mortality during spawning (Benoit et al. 1976; McGeer et al. 2000). In addition, mayfly adverse effects were reported at whole body residues of 2 mg Cd/kg dw, while no effects were observed at 30 mg Cd/kg dw (Besser et al. 2001; Birge et al. 2000). Mebane (2006) also stated "the data reviewed on bioaccumulation and effects of dietary exposures to cadmium indicate that at chronic criterion concentrations, cadmium is unlikely to bioaccumulate to tissue residue levels expected to cause obvious adverse effects to aquatic invertebrates or fish." Adams et al. (2011) likewise noted that aquatic organisms contain a diverse array of homeostatic mechanisms that are both metal- and species-specific, and therefore the risk to the aquatic organism could not be determined by whole-body tissue residue levels for metals, further suggesting a tissue-based cadmium criteria may not accurately reflect ecotoxicological effects of cadmium under real-world exposure scenarios at the national-level.

5.7 Effects on Aquatic Plants

Ninety acceptable cadmium toxicity tests from 66 studies are available for a large number of freshwater algae and vascular plant species (**Appendix E**). These tests lasted anywhere from 4 to 32 days, and a reduction in growth was the most prominent toxic effect observed. Cadmium effect concentrations for most freshwater aquatic algae and plant species were well above 50 µg/L, and cadmium does not appear to be algicidal at a concentration less than 250,000 µg/L (**Appendix E**). However, several adverse effect concentrations are in the range known to cause chronic toxicity to aquatic life. For example, the growth rate of the diatom, *Asterionella formosa*, was reduced by an order of magnitude at 2 µg/L, while the growth EC_{50} for the green alga, *Chara vulgaris*, is 9.5 µg/L (**Appendix E**). Similarly, a significant reduction in the number of fronds of two aquatic vascular plant species, *Lemna valdiviana* and *Salvina natans*, occurred at 10 µg/L, and the MATC for growth of water lettuce, *Pistia stratiotes*, is 12.72 µg/L. A comparison of the freshwater plant and animal data presented in this document demonstrated that the lowest toxicity values for fish and aquatic invertebrate species are lower than the lowest toxicity values for plants. Thus, water quality criteria which protect freshwater animals should also protect freshwater plants and a final freshwater plant value was therefore not calculated.

Toxicity values are available for 10 species of estuarine/marine diatoms, five species of green microalgae, one dinoflagellate species, and eight species of macroalgae (**Appendix F**). Concentrations causing fifty percent reductions in the growth rates of diatoms range from 50 µg/L for *Chaetoceros calcitrans* and *Isochrysis galbana* to 7,560,000 µg/L for *Phaeodactylum tricornutum*. Green algae were the most sensitive species to cadmium, with reduced chlorophyll production observed for *Dunaliella viridis* and *Scenedesmus sp*. at 7.071 µg/L cadmium. The brown macroalga (kelp) exhibited mid-range sensitivity to cadmium, with an EC_{50}s that ranged from 355.5 to >1,124 µg/L. The most sensitive estuarine/marine macroalgae tested was the red alga, *Champia parvula*, with significant reductions in the growth of both the tetrasporophyte plant and female plant occurring at 22.8 µg/L. The estuarine/marine plant and animal data were also compared, and the most sensitive plant species (*C. parvula*) is more resistant than the most sensitive animal species in chronic tests. Therefore, water quality criteria for cadmium that protect estuarine/marine animals should also protect estuarine/marine plants and a final estuarine/marine plant value was therefore not calculated.

5.8 Protection of Listed Species

The dataset for cadmium is particularly extensive and includes data representing species that are Federally-listed as threatened or endangered by the U.S. Fish and Wildlife Service and/or NOAA National Marine Fisheries Service. Summaries provided here describing the best available data for the Federally-listed species that have been tested for sensitivity to cadmium demonstrate that the 2016 cadmium criteria update is protective of these tested species.

5.8.1 Acute toxicity data for listed species

There are nine Federally-listed freshwater species and one estuarine/marine species that have acceptable acute toxicity data. Eight of these species are fish and one is a freshwater mussel (**Table 20**). All of the freshwater data has been normalized to a hardness of 100 mg/L to facilitate comparison to the acute criteria value expressed at that hardness.

The least sensitive of the Listed freshwater species are bonytail chub, *Gila elegans,* and razorback sucker, *Xyrauchen texanus,* with normalized SMAVs of 80.38 and 76.02 µg/L total cadmium, respectively (**Appendix A**). Another Listed fish from the family Cyprinidae, Colorado pikeminnow (*Ptychocheilus lucius*), had a similar level of sensitivity with a normalized SMAV of 46.79 µg/L total cadmium. This species was much more sensitive to cadmium than the non-Listed northern pikeminnow, *Ptychocheilus oregonensis,* which is in the same genus and has a normalized SMAV of 4,265 µg/L total cadmium. All three endangered species were tested in the laboratory at the U.S. Geological Survey in Yankton, South Dakota, with laboratory test conditions designed to replicate conditions present in the Green River, Utah (Buhl 1997). One endangered freshwater mussel, Neosho mucket (*Lampsilis rafinesqueana*), has a normalized SMAV of 44.67 µg/L total cadmium, indicating a sensitivity that falls within the range of three other freshwater mussel species within the genus, with normalized SMAVs ranging from 93.17 (*Lampsilis straminea claibornensis*) to 35.73 (*Lampsilis siliquoidea*) µg/L total cadmium (**Appendix A**). All of these SMAVs are an order of magnitude higher than the freshwater acute cadmium criteria value.

The most sensitive Listed freshwater species with acceptable acute toxicity data are all from the family Salmonidae. Three species from the genus *Oncorhynchus* had normalized SMAVs that ranged from 3.727 to 11.88 µg/L total cadmium. The bull trout, *Salvelinus confluentus*, was almost as sensitive as the rainbow trout, *Oncorhynchus mykiss,* with a normalized SMAV of 4.190 µg/L total cadmium (*O. mykiss* SMAV of 3.727 µg/L total cadmium). As recommended by the 1985 Guidelines, the freshwater FAV for total cadmium at a hardness of 100 mg/L was lowered to 3.727 µg/L (3.518 µg/L dissolved cadmium) to protect the commercially and recreationally important rainbow trout, which also addresses the Listed steelhead trout. This lowered FAV, and resultant CMC of 1.8 µg/L dissolved cadmium yielded by the 1985 Guidelines procedure of dividing the LC_{50}-based FAV by a factor of 2, is also protective of the bonytail chub, razorback sucker, Colorado pikeminnow, and the freshwater mussel, Neosho mucket, which are less sensitive than all tested species with acceptable acute toxicity data from the family Salmonidae. The FAV/2 approach was developed to estimate minimal effect levels, with approximately equal control mortality limits, based on analysis of 219 acute toxicity tests on a range of chemicals, as described in the *Federal Register* on May 18, 1978 (43 FR 21506-18).

Several life stages of the white sturgeon, *Acipenser transmontanus,* were exposed in flow-through measured exposures by Calfee et al. (2014) and Wang et al. (2014a). The most sensitive life stage were the 61 day post hatch fish with a non-definitive normalized acute value of <33.78 µg/L total cadmium. However, all other test life stages were much less sensitive with normalized effect concentrations that ranged from >11.65 to >355.0 µg/L total cadmium (**Appendix A**).

While the 96-hr acute and 7-d chronic toxicity tests for the fountain darter, *Etheostoma fonticola*, conducted by Southwest Texas State University (2000) indicated this species was very sensitive, the study was determined to be unacceptable for inclusion in the core dataset because the test species was fed in the acute test and the duration was too short for the chronic test to be included (**Appendix H**). While this species is endemic to Texas and has a very limited distribution, the genus *Etheostoma* has several Listed species and widespread distribution across the United States. Despite these data being unacceptable for inclusion in the core criteria dataset, it is noteworthy that the 1.8 µg/L acute and 0.72 µg/L chronic dissolved cadmium criteria are protective of this species. (The reported LC_{50} was 9.62 µg/L dissolved cadmium for this test and found to be unacceptable for use in criteria derivation; the chronic values were in the 1.4 to 11.5 µg/L range).

The mottled sculpin (*Cottus bairdii*) represents the most sensitive of the acutely tested freshwater species with acceptable toxicity data. Similarly, shorthead sculpin (*C. confusus*) is also very sensitive. Although *C. bairdii* and *C. confusus* are not Listed freshwater species, the grotto sculpin (*Cottus specus*) is Listed as endangered and the pygmy sculpin (*Cottus paulus*) is Listed as threatened. Grotto sculpin are found in five cave systems and two surface streams in Perry County, Missouri, while pygmy sculpin is endemic to Alabama. Although no direct toxicity data are available for either of these sculpin species, *C. bairdii* and *C. confusus* had normalized SMAVs of 4.418 and 4.404 µg/L total cadmium, respectively. Dividing the GMAV for *Cottus* by two, which is consistent with the procedure used to derive the CMC from the FAV as indicated above, results in a concentration of 2.205 µg/L total cadmium (or 2.082 µg/L dissolved cadmium), which is a concentration that is expected to result in survival that is no different from the test controls. This normalized concentration is slightly higher than the 2016 freshwater CMC of 1.8 µg/L dissolved cadmium, based on a hardness of 100 mg/L as $CaCO_3$. The available data suggest the 2016 freshwater CMC would be protective of these Listed species.

Coho salmon (*Oncorhynchus kisutch*) smolts tested in natural filtered seawater with 28.83 g/kg salinity were relatively insensitive to cadmium, with an LC_{50} of 1,500 µg/L total cadmium (Dinnel et al. 1989). The estuarine/marine CMC of 33 µg/L total cadmium would be protective of this species.

Table 20. Acute Summary of Listed Species Tests.

Species	Number of normalized acute values	Range of normalized acute values (Hardness=100 mg/L)	SMAV (µg/L) (total cadmium)
Freshwater - Acute			
Neosho mucket, *Lampsilis rafinesqueana*	1*	44.67	44.67
Bonytail, *Gila elegans*	2	75.45 - 85.64	80.38
Razorback sucker, *Xyrauchen texanus*	2	70.86 - 81.56	76.02
Colorado pikeminnow, *Ptychocheilus lucius*	2	39.76 - 55.06	46.79
Coho salmon, *Oncorhynchus kisutch*	4	8.137 - 77.03	11.88
Rainbow trout, *Oncorhynchus mykiss*	56	1.227 - >113.8	3.727
Chinook salmon, *Oncorhynchus tshawytscha*	8	5.068 - >109.6	5.949
Bull trout, *Salvelinus confluentus*	6	2.891 - 9.390	4.190
White sturgeon, *Acipenser transmontanus*	7*	>11.65 - >355.0	<33.78
Estuarine/Marine – Acute			
Coho salmon, *Oncorhynchus kisutch*	1	1,500	1,500

* Indicates new species included since the 2001 cadmium document.

5.8.2 Chronic toxicity data for listed species

Four Listed freshwater fish in the family Salmonidae representing two genera (*Oncorhynchus* and *Salmo*) have acceptable chronic toxicity data for cadmium (**Table 21**). Of the 20 genera in the Ranked SMCV Table, these two genera are ranked seventh and eighth, respectively (**Table 9**). The Chinook salmon (*O. tshawytscha*) and rainbow trout (*O. mykiss*) have similar normalized SMCVs of 4.426 and 2.192 µg/L total cadmium, based on early life stage growth and survival, respectively. Insufficient detail was reported for Coho salmon (*O. kisutch*), the third Listed species in this genus, thus a normalized EC_{20} could not be calculated. A normalized SMCV based on the two MATCs reported for Coho salmon would be 7.467 µg/L total cadmium (**Appendix C**). The most sensitive endangered freshwater species, Atlantic salmon (*Salmo salar*), had a normalized SMCV of 2.389 µg/L total cadmium, which is somewhat more sensitive than brown trout (*Salmo trutta*), the other species in the genus. All of these freshwater fish species are expected to be adequately protected at the freshwater CCC of 0.80 µg/L total cadmium.

Mottled sculpin (*Cottus bairdii*) represent the third most sensitive of the chronically tested freshwater species with acceptable toxicity data. As discussed in the preceding section (**Section 5.8.1**), although *C. bairdii* is not a Listed species, grotto sculpin (*Cottus specus*) is Listed as endangered and pygmy sculpin (*Cottus paulus*) is Listed as threatened. *C. bairdii* had a normalized SMCV of 1.470 µg/L total cadmium. This normalized concentration is above the 2016 freshwater CCC of 0.72 µg/L dissolved cadmium based on a hardness of 100 mg/L as $CaCO_3$. The 2016 freshwater CCC is expected to be protective of these species. There are no acceptable chronic toxicity data for estuarine/marine Listed species.

Table 21. Chronic Summary of Listed Species Tests.

Species	Number of chronic values	Range of normalized chronic values
	Freshwater - Chronic	
Coho salmon, *Oncorhynchus kisutch*	2	4.046 – 13.78 (MATCs)
Rainbow trout, *Oncorhynchus mykiss*	12	0.7962 – 6.989 (EC_{20}s and MATCs)
Chinook salmon, *Oncorhynchus tshawytscha*	1	4.426 (EC_{20})
Atlantic salmon, *Salmo salar*	3	2.389 – 392.5 (EC_{20}s)

5.9 Comparison of 2001 and 2016 Criteria Values

5.9.1 Comparison of acute freshwater criterion to 2001 document

The 2001 cadmium freshwater acute criterion was based on data from 39 species of invertebrates, 24 species of fish and 1 species each of salamander and frog for a total of 65 species grouped into 55 genera (**Table 22**). This 2016 update now includes 66 species of invertebrates, 33 species of fish, one salamander species, and one frog species for a total of 101 species grouped into 75 genera.

Of the 75 Genus Mean Acute Values (GMAV) in the updated dataset, 38 genera have new data for either species represented in the 2001 database or new species added to the GMAV calculation in this update (**Table 7**). A new genus in the updated dataset, sculpin (*Cottus*), also represents the second most sensitive genera in the distribution with a GMAV of 4.411 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate genus is represented by the amphipod *Hyalella azteca* with a normalized GMAV of 23.00 µg/L.

Table 22. Freshwater GMAVs Comparing Species Listed in the 2001 and 2016 Documents.
(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$).
(Values in bold new/revised data since the 2001 AWQC).

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	*Acipenser*	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 23 provides a comparison of the second to fifth most sensitive taxa (≥59 genera) used to calculate the freshwater CMC in this 2016 AWQC update document compared to the four most sensitive taxa used to calculate the CMC in the 2001 AWQC document. The 2016 CMC of 1.9 µg/L total cadmium is slightly lower than the 2.1 µg/L total cadmium CMC given in the 2001 document, both of which are normalized to a total hardness of 100 mg/L as $CaCO_3$ and lowered to protect a commercially and recreationally important salmonid species. Several genera (*Morone*, *Salmo*, *Salvelinus* and *Oncorhynchus*) are the most sensitive in both the 2001 and 2016 document, but the new genus, *Cottus*, is now one of the most sensitive in the current update.

One additional difference is that *Salvelinus*, previously the second most sensitive genus in the 2001 document, is now the most sensitive genus in the 2016 document. This is due to the reassessment and reclassification of the brook trout test by Carroll et al. (1979) as an unacceptable study because the measured concentration of cadmium in control water was greater than the LC_{50} value of 1.5 µg/L and the control had 100% survival. Elimination of this LC_{50} yields the normalized SMAV of 3,055 µg/L based on the studies by Drummond and Benoit (1976) and Holcombe et al. (1983). However, since there is greater than a 10-fold difference in the SMAVs for the genus only the SMAV for the more sensitive species, *S. confluentus*, was used in the GMAV calculation.

In addition, the number of GMAVs used to calculate the CMC increased from 55 in the 2001 criteria document to 75 in the current update based on the addition of the GMAVs for *Hydra*, worm *Nais*, planarian *Dugesia*, mussel *Lasmigona*, snails *Lymnaea* and *Gyraulus*, copepod *Diaptomus*, amphipod *Hyalella*, cladoceran *Diaphanosoma*, mayflies *Baetis*, *Hexagenia* and *Rhithrogena*, stonefly *Sweltsa*, caddisfly *Arctopsyche*, and fish *Acipenser*, *Coregonus*, *Cottus*, *Danio*, *Perca* and *Prosopium*.

Table 23. Comparison of the Four Taxa Used to Calculate the Freshwater FAV and CMC in the 2001 Cadmium Document and 2016 Update.

2001 Cadmium Freshwater FAV and CMC				2016 Cadmium Update Freshwater FAV and CMC		
Species	**SMAV[a] (µg/L)**	**SMAV[b] (µg/L)**	**GMAV[b] [Rank] (µg/L)**	**Species**	**SMAV[c] (µg/L)**	**GMAV[c] [Rank] (µg/L)**
				Cutthroat trout, *Oncorhynchus clarkii*	5.401	6.141 [5]
				Coho salmon, *Oncorhynchus kisutch*	11.88	
				Rainbow trout, *Oncorhynchus mykiss*	3.727	
Coho salmon, *Oncorhynchus kisutch*	6.221	12.58	7.760 [4]	Chinook salmon, *Oncorhynchus tshawytscha*	5.949	
Chinook salmon, *Oncorhynchus tshawytscha*	4.305	8.708		Striped bass, *Morone saxatilis*	5.931	5.931 [4]
Rainbow trout, *Oncorhynchus mykiss*	2.108	4.265		Brown trout, *Salmo trutta*	5.642	5.642 [3]
Striped bass, *Morone saxatilis*	2.925	5.916	5.916 [3]	Mottled sculpin, *Cottus bairdii*	4.418	4.411 [2]
Brook trout, *Salvelinus fontinalis*	<1.791	<3.623	<3.971 [2]	Shorthead sculpin, *Cottus confusus*	4.404	
Bull trout, *Salvelinus confluentus*	2.152	4.353		Bull trout, *Salvelinus confluentus*	4.190	4.190[e] [1]
Brown trout, *Salmo trutta*	1.613	3.263	3.263 [1]	Brook trout, *Salvelinus fontinalis*	3,055[d]	
Number of GMAVs	55			Number of GMAVs	75	
FAV (calculated)	2.764[a]	5.590[b]		FAV (calculated)	5.733[c]	
FAV (lowered to protect *O. mykiss*)	2.108[a]	4.265[b]		FAV (lowered to protect *O. mykiss*)	3.727	
CMC	1.054[a]	2.132[b]		CMC	1.9[c]	

[a] Normalized to total hardness of 50 mg/L as $CaCO_3$ (using pooled slope of 1.0166).
[b] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 1.0166).
[c] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 0.9789).
[d] There is a 10x difference in SMAVs for the genus, only most sensitive SMAV is used in the GMAV calculation.
[e] Not used in FAV calculation due to the number of genera (N≥59) (see text).

5.9.2 Comparison of chronic freshwater criterion to 2001 document

Of the 20 Genus Mean Chronic Values (GMCV) in the updated dataset, nine genera have new data for either species represented in the 2001 database or new species added to the GMCV calculation in this update (**Table 24**). A new species in the updated dataset, mottled sculpin (*C. bairdii*) represents the most sensitive fish species and the third most sensitive genus in the distribution with a GMCV of 1.470 µg/L (normalized to a total hardness of 100 mg/L as $CaCO_3$). The most sensitive invertebrate is the amphipod, *Hyalella azteca*, with a normalized GMCV of 0.7453 µg/L. There are sufficient data to fulfill the requirements to calculate chronic criteria using species sensitivity distribution (SD) method.

Acceptable data on the chronic effects of cadmium on freshwater animals include 11 species of invertebrates and 16 species of fish grouped into 20 genera (**Table 9**). The previous updated criteria (2001) contained data from 7 species of invertebrates and 14 species of fish grouped into 16 genera. The update includes data for six new species added to the dataset, consisting of the oligochaete, *Lumbriculus variegatus*, fatmucket, *Lampsilis siliquoidea*, snail, *Lymnaea stagnalis*, Rio Grande cutthroat trout *Oncorhynchus clarkii virginalis*, mottled sculpin, *C. bairdii*, and cladoceran, *Ceriodaphnia reticulata*.

One additional difference between the 2001 document and this 2016 update is the estimation of EC_{20} values as the chronic endpoint for each acceptable toxicity test. EC_{20} values were used to estimate a low level of effect observed in chronic datasets that are available for cadmium (see **Section 2.6**, **Chronic measures of effect**).

Table 24. Freshwater GMCVs Comparing Species Listed in the 2001 and 2016 Documents.
(Note: All data adjusted to a total hardness of 100 mg/L as $CaCO_3$).
(Values in bold new/revised data since the 2001 AWQC).

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

2016 GMCV[a] (µg/L)	**2001 GMCV (µg/L)**	**Species**	**2001 SMCV (µg/L)**	**2016 SMCV (µg/L)**	**Comment**
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
-	-	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

2016 GMCV[a] (µg/L)	**2001 GMCV (µg/L)**	**Species**	**2001 SMCV (µg/L)**	**2016 SMCV (µg/L)**	**Comment**
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*.]

Four new genera were added to the 2016 chronic freshwater database. The amphipod *Hyalella* is the most sensitive in both documents, but the cladoceran *Ceriodaphnia*, the mottled sculpin *Cottus* and the midge *Chironomus* are now the second, third and fourth most sensitive genera in the 2016 update (**Table 9**). The change in the four most sensitive genera presented in the 2016 update is partly due to the inclusion of the new sensitive genus *Cottus*, but also to the estimation of the chronic value by EC_{20} analysis and not the MATC (geometric mean of the NOEC and LOEC) as was done in the 2001 document.

As indicated in **Table 25**, the 2016 freshwater CCC is about 3 times the magnitude of the 2001 CCC (0.79 vs. 0.27 µg/L total cadmium) due to differences in the data used for the CCC derivations. As a result, the four lowest GMCVs in the 2016 CCC have a smaller range of variation in values (0.7453 to 2.000) when compared to the four lowest GMCVs in the 2001 CCC, which decreases the uncertainty of the 5th percentile GMCV estimation. In the 2001 CCC, there were also only 16 GMCVs in the dataset used to derive the CCC. In the 2016 CCC, there are 20 GMCVs used to derive the CCC, based on the addition of the GMCVs for the oligochaete, *Lumbriculus*, snail, *Lymnaea*, fatmucket, *Lampsilis* and the mottled sculpin, *Cottus*. The new GMCVs affect the chronic species sensitivity distribution. The cumulative probability (P) decreases as a function of the increased number of GMCVs and results in an increase in the FCV.

Table 25. Comparison of the Four Taxa Used to Calculate the Freshwater FCV and CCC in the 2001 Cadmium Document and 2016 Update.

2001 Cadmium Freshwater FCV and CCC				2016 Cadmium Update Freshwater FCV and CCC		
Species	**SMCV[a] (µg/L)**	**SMCV[b] (µg/L)**	**GMCV[b] [Rank] (µg/L)**	**Species**	**SMCV[c] (µg/L)**	**GMCV[c] [Rank] (µg/L)**
Midge, *Chironomus tentans*	2.804	4.686	4.686 [4]			
Coho salmon, *Oncorhynchus kisutch*	4.265	7.127	4.082 [3]			
Chinook salmon, *Oncorhynchus tshawytscha*	2.612	4.366		Midge, *Chironomus dilutus*	2.000	2.000 [4]
Rainbow trout, *Oncorhynchus mykiss*	1.308	2.186		Mottled sculpin, *Cottus bairdii*	**1.470**	1.470 [3]
Cladoceran, *Daphnia magna*	<0.3794	<0.6340	<0.6340 [2]	Cladoceran, *Ceriodaphnia dubia*	**1.293**	1.293 [2]
Cladoceran, *Daphnia pulex*	6.167	10.30[d]		Cladoceran, *Ceriodaphnia reticulata*	**NA[e]**	
Amphipod, *Hyalella azteca*	0.2747	0.4590	0.4590 [1]	Amphipod, *Hyalella azteca*	**0.7453**	0.7453 [1]
Number of GMCVs	16			Number of GMCVs	20	
FCV (calculated)	0.1618[a]	0.2703[b]		FCV (calculated)	0.79[c]	

[a] Normalized to total hardness of 50 mg/L as $CaCO_3$ (using pooled slope of 0.7490).

[b] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 0.7490).

[c] Normalized to total hardness of 100 mg/L as $CaCO_3$ (using pooled slope of 0.7977).

[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.

[e] Not included in the GMCV calculation because normalized EC_{20} data available for the genus.

5.9.3 Hardness correlation and equations for cadmium toxicity adjustment

Hardness is used as a surrogate for the ions that can affect the results of toxicity tests on cadmium. In spite of its limitations, hardness is currently the best surrogate available for metal toxicity adjustment. The hardness toxicity relationship applies the same methodology (covariance) as presented in the 2001 update. The hardness-toxicity relationship used to normalize the data for this revision is described above. A comparison of the data used in 2001 and this update is shown in **Table 26**.

Table 26. Hardness-Toxicity Relationship Data used in U.S. EPA (2001) Compared to this Update.

		Sample size	**Number of Vertebrates / Invertebrates Species**	**Hardness Range (mg $CaCO_3$/L)**
2001 AWQC	Acute	64	7 / 5	5.3 – 360
	Chronic	7	2 / 1	44 – 250
2016 Update	Acute	80	7 / 6	5.3 – 350
	Chronic	18	3 / 1	19.7 – 301

5.9.4 Comparison of acute estuarine/marine criterion to 2001 document

Of the 79 Genus Mean Acute Values (GMAV) in the updated dataset, 40 genera have new data for either species represented in the 2001 database or new species added to the GMAV calculation in this update (**Table 27**). Three new species in the updated dataset, the mysid, *Neomysis americana*, the copepod, *Tigriopus brevicornis,* and moon jellyfish, *Aurelia aurtia*, represent the three most sensitive species in the distribution with GMAVs of 28.14, 29.14 and 61.75 µg/L, respectively. The most sensitive fish species is the striped bass, *Morone saxatilis*, with a GMAV of 75.0 µg/L. There are sufficient data to fulfill the requirements to calculate acute criterion using the species sensitivity distribution (SD) method.

Suitable tests of the acute toxicity of cadmium to estuarine/marine organisms are now available for 78 species of invertebrates and 16 species of fish, or a total of 94 species grouped into 79 genera. The 2001 criteria were based on data from 50 species of invertebrates and 10 species of fish for a total of 60 species grouped into 54 genera (**Table 27**).

Table 27. Estuarine/Marine GMAVs Comparing Species Listed in the 2001 and 2016 Documents.

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
169,787	-	Horseshoe crab, *Limulus polyphemus*	-	**169,787**	New genus
135,000	135,000	Oligochaete worm, *Monopylephorus cuticulatus*	135,000	135,000	-
>80,000	-	Mozambique tilapia, *Oreochromis mossambicus*	-	**>80,000**	New genus
62,000	-	Scorpionfish, *Scorpaena guttata*	-	**62,000**	New genus
28,196	50,000	Sheepshead minnow, *Cyprinodon variegatus*	50,000	**28,196**	New data for existing species
25,900	-	Cunner, *Tautogolabrus adspersus*	-	**25,900**	New genus
24,000	24,000	Oligochaete worm, *Tubificoides gabriellae*	24,000	24,000	-
23,200	-	Dog whelk, *Nucella lapillus*	-	**23,200**	New genus
22,887	27,992	Amphipod, *Eohaustorius estuarius*	27,992	**22,887**	New data for existing species

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
19,550	19,550	Mummichog, *Fundulus heteroclitus*	18,200	18,200	-
-	-	Striped killifish, *Fundulus majalis*	21,000	21,000	-
19,170	19,170	Eastern mud snail, *Nassarius obsoletus*	19,170	19,170	-
14,297	14,297	Winter flounder, *Pseudopleuronectes americanus*	14,297	14,297	-
12,755	21,238	Fiddler crab, *Uca pugilator*	21,238	21,238	-
-	-	Fiddler crab, *Uca triangularis*	-	**7,660**	New species added to GMAV calculation
12,052	12,836	Polychaete worm, *Neanthes arenaceodentata*	12,836	**12,052**	New data for existing species
11,000	11,000	Shiner perch, *Cymatogaster aggregata*	11,000	11,000	-
>10,200	>10,200	California market squid, *Loligo opalescens*	>10,200	>10,200	-
10,114	6,895	Polychaete worm, *Alitta virens*	10,114	10,114	(formerly, *Nereis virens*)
10,000	10,000	Oligochaete, *Tectidrilus verrucosus*	10,000	10,000	(formerly, *Limnodriloides verrucosus*)
9,217	7,079	Striped mullet, *Mugil cephalus*	7,079	7,079	-
-	-	White mullet, *Mugil curema*	-	**12,000**	New species added to GMAV calculation
9,100	-	Nematode, *Rhabditis marina*	-	**9,100**	New genus (formerly, *Pellioditis marina*)
>8,000	-	Isopod, *Excirolana sp.*	-	**>8,000**	New genus
7,400	7,400	Sand dollar, *Dendraster excentricus*	7,400	7,400	-
7,120	7,120	Wood borer, *Limnoria tripunctata*	7,120	7,120	-
6,700	6,700	Amphipod, *Diporeia spp.*	6,700	6,700	-
6,600	6,600	Atlantic oyster drill, *Urosalpinx cinerea*	6,600	6,600	-
4,900	-	Mud crab, *Eurypanopeus depressus*	-	**4,900**	New genus

2016 GMAV[a] (µg/L)	**2001 GMAV (µg/L)**	**Species**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Comment**
4,700	6,895	Polychaete, *Nereis grubei*	4,700	4,700	-
4,100	4,100	Green shore crab, *Carcinus maenas*	4,100	4,100	-
4,058	2,594	Blue crab, *Callinectes sapidus*	2,594	2,594	-
-	-	Lesser blue crab, *Callinectes similis*	-	**6,350**	New species added to GMAV calculation
3,925	-	Polychaete, *Ophryotrocha diadema*	-	**3,925**	New genus
3,500	3,500	Scud, *Marinogammarus obtusatus*	3,500	3,500	-
3,142	-	Polychaete worm, *Ctenodrilus serratus*	-	**3,142**	New genus
2,900	2,900	Amphipod, *Ampelisca abdita*	2,900	2,900	-
2,600	2,600	Cone worm, *Pectinaria californiensis*	2,600	2,600	-
2,413	2,413	Common starfish, *Asterias forbesi*	2,413	2,413	-
2,110	-	Pacific sand crab, *Emerita analoga*	-	**2,110**	New genus
2,060	-	Gastropod, *Tenguella granulata*	-	**2,060**	New genus (formerly, *Morula granulata*)
1,720	-	Tiger shrimp, *Penaeus monodon*	-	**1,720**	New genus
1,708	1,708	Copepod, *Pseudodiaptomus coronatus*	1,708	1,708	-
1,672	1,672	Soft-shell clam, *Mya arenaria*	1,672	1,672	-
1,510	-	Amphipod, *Rhepoxynius abronius*	-	**1,510**	New genus
1,506	-	Brown mussel, *Perna perna*	-	**1,146**	New genus (formerly, *Perna indica*)
-	-	Green mussel, *Perna viridis*	-	**1,981**	New genus
1,500	1,500	Coho salmon, *Oncorhynchus kisutch*	1,500	1,500	-
1,271	-	White shrimp, *Litopenaeus setiferus*	-	**990**	New genus (formerly, *Penaeus setiferus*)

2016 GMAV[a] (µg/L)	**2001 GMAV (µg/L)**	**Species**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Comment**
-	-	White shrimp, *Litopenaeus vannamei*	-	**1,632**	New genus
1,228	1,228	Daggerblade grass shrimp, *Palaemonetes pugio*	1,983	1,983	-
-	-	Grass shrimp, *Palaemonetes vulgaris*	760	760	-
1,184	-	Starlet sea anemone, *Nematostella vectensis*	-	**1,184**	New genus
1,054	779.8	Atlantic silverside, *Menidia menidia*	779.8	**1,054**	Acute value removed after re-review of Cardin 1985
1,041	929.3	Amphipod, *Corophium insidiosum*	929.3	**1,041**	New data for existing species
1,000	-	Pinfish, *Lagodon rhomboides*	-	**1,000**	New genus
862.9	948.7	Green sea urchin, *Strongylocentrotus droebachiensis*	1,800	1,800	-
-	-	Purple sea urchin, *Strongylocentrotus purpuratus*	500	**413.7**	New data for existing species
800	800	Rivulus, *Rivulus marmoratus*	800	800	-
794.5	794.5	Harpacticoid copepod, *Nitokra spinipes*	794.5	794.5	(formerly, *Nitocra spinipes*)
765.6	1,480	Bay scallop, *Argopecten irradians*	1,480	1,480	-
-	-	Scallop, *Argopecten ventricosus*	-	**396**	New species added to GMAV calculation
739.2	590.5	Amphipod, *Leptocheirus plumulosus*	590.5	**739.2**	New data for existing species
736.2	1,073	Blue mussel, *Mytilus edulis*	1,073	1,073	-
-	-	Blue mussel, *Mytilus trossolus*	-	**505.0**	New species added to GMAV calculation
716.2	716.2	Amphipod, *Elasmopus bampo*	716.2	716.2	-
645.0	645.0	Longwrist hermit crab, *Pagurus longicarpus*	645.0	645.0	-
630.7	1,170	Amphipod, *Grandidierella japonica*	1,170	**630.7**	New data for existing species
630	630	Amphipod, *Chelura terebrans*	630	630	-

2016 GMAV[a] (µg/L)	2001 GMAV (µg/L)	Species	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Comment
490	-	Barnacle, *Amphibalanus amphitrite*	-	**490**	New genus
422.6	-	Mangrove oyster, *Isognomon californicum*	-	**422.6**	New genus
410.3	-	Mysid, *Praunus flexuosus*	-	**410.3**	New genus
410.0	410.0	Isopod, *Joeropsis sp.*	410.0	410.0	(Formerly, *Jaeropsis sp.*)
320	320	Sand shrimp, *Crangon septemspinosa*	320	320	-
310.5	310.5	Northern pink shrimp, *Farfantepenaeus duorarum*	310.5	310.5	(formerly, *Penaeus duorarum*)
235.7	235.7	Rock crab, *Cancer plebejus*	250	250	(formerly, *Cancer irroratus*)
-	-	Dungeness crab, *Cancer magister*	222.3	222.3	-
224	224	Harpacticoid copepod, *Sarsamphiascus tenuiremis*	224	224	(formerly, *Amphiascus tenuiremis*)
>200	>200	Cabezon, *Scorpaenichthys marmoratus*	>200	>200	-
200	200	Polychaete worm, *Capitella capitata*	200	200	-
188.1	-	Horse clam, *Tresus capax*	-	**60**	New genus
-	-	Horse clam, *Tresus nuttalli*	-	**590**	New genus
173.2	930.6	Pacific oyster, *Crassostrea gigas*	227.9	**173.2**	U.S. EPA (2001) did not use the >100 values from Watling 1982 in the SMAV calculation
-	-	American oyster, *Crassostrea virginica*	3,800	3,800[b]	Ten-fold difference in SMAVs for the genus, only most sensitive SMAV used in GMAV calculation
147.7	147.7	Calanoid copepod, *Eurytemora affinis*	147.7	147.7	-
130.7	130.7	Copepod, *Acartia clausi*	144	144	-
-	-	Calanoid copepod, *Acartia tonsa*	118.7	118.7	-
78	78	American lobster, *Homarus americanus*	78	78	-
75.0	75.0	Striped bass, *Morone saxatilis*	75.0	75.0	-

2016 GMAV[a] (μg/L)	2001 GMAV (μg/L)	Species	2001 SMAV (μg/L)	2016 SMAV (μg/L)	Comment
67.39	41.29	Mysid, *Americamysis bahia*	41.29	41.29	-
-	110	Mysid, *Americamysis bigelowi*	110	110	(formerly, *Mysidopsis bigelowi*)
61.75	-	Moon jellyfish, *Aurelia aurita*	-	**61.75**	New genus
29.14	-	Harpacticoid copepod, *Tigriopus brevicornis*	-	**29.14**	New genus
28.14	-	Mysid, *Neomysis americana*	-	**28.14**	New genus

[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.

New acute data for estuarine/marine species have also been added to the 2016 document. A total of 79 genera are now used to derive the estuarine/marine CMC of 33 μg/L in the 2016 update in contrast to 54 genera and resultant CMC of 40.28 μg/L in the 2001 document (**Table 28**). The four most sensitive genera are once again used to calculate the CMC in the 2001 document (n<59), and the second to fifth most sensitive genera are used in the 2016 update (n≥59). The approximately 18 percent lower 2016 CMC is primarily due to the addition of three new sensitive genera, the mysid, *Neomysis*, the jellyfish, *Aurelia* and the copepod, *Tigriopus*. Both *A. bahia* (mysid) and the striped bass GMAVs are used to calculate the CMC in each document version. Additional genera included in the 2016 update include the polychaete worms, *Ctenodrilus* and *Ophryotrocha*, nematode, *Rhabditis*, mussel, *Perna*, clam, *Tresus*, whelk, *Nucella*, gastropod, *Tenguella*, barnacle, *Amphibalanus*, oyster, *Isognomon*, horseshoe crab, *Limulus*, isopod, *Excirolana*, copepod *Tigriopus*, amphipod, *Rhepoxynius*, mysids, *Neomysis* and *Praunus*, sea anemone *Nematostella*, shrimps, *Litopenaeus* and *Penaeus*, crabs, *Emerita* and *Eurypanopeus*, jellyfish *Aurelia*, and fish, *Lagodon*, *Oreochromis*, *Scorpaena* and *Tautogolabrus*.

Table 28. Comparison of the Four Taxa Used to Calculate the Estuarine/Marine FAV and CMC in the 2001 Cadmium Document and 2016 Update.

2001 Cadmium Estuarine/Marine FAV and CMC			**2016 Cadmium Update Estuarine/Marine FAV and CMC**		
Species	**SMAV (µg/L)**	**GMAV [Rank] (µg/L)**	**Species**	**SMAV (µg/L)**	**GMAV [Rank] (µg/L)**
			Striped bass, *Morone saxatilis*	75.0	75.0 [5]
			Mysid, *Americamysis bahia*	41.29	67.39 [4]
Mysid, *Mysidopsis bigelowi*	110	110 [4]	Mysid, (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	110	
American lobster, *Homarus americanus*	78	78 [3]	Moon jellyfish, *Aurelia aurita*	61.75	61.75 [3]
Striped bass, *Morone saxatilis*	75.0	75.0 [2]	Harpacticoid copepod, *Tigriopus brevicornis*	29.14	29.14 [2]
Mysid, *Americamysis bahia*	41.29	41.29 [1]	Mysid, *Neomysis americana*	28.14	28.14[a] [1]
Number of GMAVs	54		Number of GMAVs	79	
FAV (calculated)	80.55		FAV (calculated)	66.25	
CMC	40.28		CMC	33.13	

[a] Not used in FAV calculation due to the number of genera (N>59) (see text).

5.9.5 Comparison of chronic estuarine/marine criterion to 2001 document

No new data were identified on the chronic effects of cadmium to estuarine/marine species since the 2001 update (**Table 29** and **Table 30**). The same estuarine/marine chronic data presented in the 2001 cadmium document are also used in the 2016 document update (note that the mysid *Mysidopsis bigelowi* is now classified as *Americamysis bigelowi*). Due to the limited amount of estuarine/marine chronic data the CCC is derived by dividing the FAV by the FACR. In the 2001 document the FACR was determined based only on the two estuarine/marine ACRs. This is because the freshwater ACRs covered such a wide range, it was deemed inappropriate to use any of the available freshwater ACRs in the calculation of the saltwater FCV. Also the two estuarine/marine species for which acute-chronic ratios were available had SMAVs in the same range as the saltwater FAV, and it seemed reasonable to use the geometric mean of only those two ACRs. Given the addition of new sensitive estuarine/marine species to the acute criteria dataset, a new FACR was calculated using a combination of both freshwater and estuarine/marine ACRs (see **Section 5.5.1**). The 2016 estuarine/marine chronic CCC is 8.0 µg/L total cadmium (66.25 / 8.291) and the 2001 CCC is 8.9 µg/L total cadmium (80.55 / 9.106).

Table 29. Estuarine/Marine GMCVs Comparing Species Listed in the 2001 and 2016 Documents.

2016 GMCV (µg/L)[a]	2001 GMCV (µg/L)	Species	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Comment
8.449	6.173	Mysid, *Americamysis bahia*	6.173	6.149	-
-	7.141	Mysid, *Americamysis bigelowi*	7.141	11.61	(formerly, *Mysidopsis bigelowi*)

[a] Ranked from most resistant to most sensitive based on 2016 Genus Mean Chronic Value.

Table 30. Total Number of Toxicity Values for Species and Genera in 2001 AWQC and 2016 Update.

	2001 Criteria	2016 Update
Freshwater Acute Criterion		
Total # new acute toxicity values	-	53[a]
SMAV	65	101
GMAV	55	75
Freshwater Chronic Criterion		
Total # new chronic toxicity values	-	14[b]
SMCV	21	27
GMCV	16	20
Estuarine/Marine Acute Criterion		
Total # new acute toxicity values	-	43[c]
SMAV	61	94
GMAV	54	79
Estuarine/Marine Chronic Criterion		
Total # new chronic toxicity values	-	0[d]
SMCV	2	2
GMCV	2	1[e]

[a] See **Table 22**
[b] See **Table 24**
[c] See **Table 27**
[d] See **Table 29**
[e] Note: *Americamysis bigelowi* was formerly called *Mysidopsis bigelowi*.

6 UNUSED DATA

For this 2016 criteria update document, EPA considered and evaluated all available data that could possibly be used to derive the new acute and chronic criteria for cadmium in fresh and estuarine/marine waters. A substantial amount of those data were associated with studies that did not meet the basic QA/QC requirements described in the 1985 Guidelines (see Stephan et al. 1985). A list of all other studies considered but removed from consideration for use in deriving the criteria is provided in **Appendix J** with rationale indicating the reason(s) for exclusion. Note that unused studies from previous AWQC documents were not reevaluated.

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Appendix A Acceptable Freshwater Acute Toxicity Data

Appendix Table A-1. Acceptable Freshwater Acute Toxicity Data

(Values normalized to total hardness=100 mg/L as $CaCO_3$ using pooled hardness slope of 0.9789 and expressed as total cadmium).
(Underlined values are used in SMAV calculation and values in bold represent new/revised values since 2001 AWQC document).
(Species are organized phylogenetically).

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Hydra, (formerly, *Hydra attenuata*) *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**<u>251.1</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	85.1	128.1	**<u>150.0</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	145	172.0	**<u>119.5</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**<u>251.1</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	73.8	83.18	**<u>112.0</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	125	76.44	**<u>61.43</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**<u>251.1</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	61.83	**<u>222.7</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	84.31	**<u>303.7</u>**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	66.32	**<u>238.9</u>**	-	-	Clifford 2009

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	69.69	**251.1**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	58.45	**210.6**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	43.84	**157.9**	-	-	Clifford 2009
Hydra, *Hydra circumcincta*	S, M	Cadmium reference standard	27.0	57.33	**206.5**	-	**184.8**	Clifford 2009
Hydra (Monecious species), *Hydra oligactis*	S, M	-	210	320.00	**154.8**	-	**154.8**	Karntanut and Pascoe 2002
Green hydra (non-budding), *Hydra viridissima*	S, U	Cadmium chloride	19.5 (19-20)	3.0	**14.86**	-	-	Holdway et al. 2001
Green hydra (Monecious species), *Hydra viridissima*	S, M	-	210	210.0	**101.6**	-	**38.85**	Karntanut and Pascoe 2002
Hydra (male clone, Zurich strain), *Hydra vulgaris*	S, M	Cadmium chloride	204	310	**154.2**	-	-	Karntanut and Pascoe 2000
Hydra (non-budding), *Hydra vulgaris*	S, U	Cadmium chloride	19.5 (19-20)	82.5	**408.7**	-	-	Holdway et al. 2001
Hydra (male clone, Zurich strain), *Hydra vulgaris*	S, M	-	210	520	**251.5**	-	-	Karntanut and Pascoe 2002
Hydra (Dioecious strain), *Hydra vulgaris*	S, M	-	210	160	**77.38**	-	**187.1**	Karntanut and Pascoe 2002
Planarian, *Dendrocoelum lacteum*	R,M	Cadmium chloride	87	23,220	**26,607**	28,454	**26,607**	Ham et al. 1995

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Planarian (10-15 mm), *Dugesia dorotocephala*	S, U	Cadmium sulfate	170 (160-180)	690	**410.4**	-	**410.4**	Garcia-Medina et al. 2013
Worm (adult), *Lumbriculus variegatus*	S, M	Cadmium nitrate	290	780	275.0	264.2	275.0	Schubauer-Berigan et al. 1993
Worm (adult, 1.0 cm), *Nais elinguis*	R, M	Cadmium chloride	17.89	27	**145.5**	-	**145.5**	Shuhaimi-Othman et al. 2012b
Oligochaete, *Branchiura sowerbyi*	S, M	Cadmium sulfate	5.3	240	4,255	-	-	Chapman et al. 1982
Oligochaete (2.0 cm, 2.05 mg), *Branchiura sowerbyi*	S, U	Cadmium chloride	185	58,020	**31,767**	4,754	**11,627**	Ghosal and Kaviraj 2002
Oligochaete, *Limnodrilus hoffmeisteri*	S, M	Cadmium sulfate	5.3	170	3,014[i]	-	-	Chapman et al. 1982
Oligochaete (30-44 mm), *Limnodrilus hoffmeisteri*	F, M	Cadmium	152	2,400	1,593	1,568	1,593	Williams et al. 1985
Oligochaete, *Quistadrilus multisetosus*	S, M	Cadmium sulfate	5.3	320	5,674	6,338	5,674	Chapman et al. 1982
Oligochaete, *Rhyacodrilus montana*	S, M	Cadmium sulfate	5.3	630	11,171	12,479	11,171	Chapman et al. 1982
Oligochaete, *Spirosperma ferox*	S, M	Cadmium sulfate	5.3	350	6,206	6,933	6,206	Chapman et al. 1982
Oligochaete, *Spirosperma nikolskyi*	S, M	Cadmium sulfate	5.3	450	7,979	8,913	7,979	Chapman et al. 1982
Oligochaete, *Stylodrilus heringianus*	S, M	Cadmium sulfate	5.3	550	9,752	10,894	9,752	Chapman et al. 1982

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium sulfate	5.3	320	5,674	-	-	Chapman et al. 1982
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium chloride	128	3,200	2,513	-	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium chloride	128	1,700	1,335	-	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	-	1,032	NA[d]	-	-	Fargasova 1994a
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (15ºC)	56,000	**24,059**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (20ºC)	51,900	**22,297**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (25ºC)	61,470	**26,409**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	237 (30ºC)	28,550	**12,266**	-	-	Rathore and Khangarot 2002
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	12	130	**1,036**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	45	440	**961.3**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	173	7,950	**4,648**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	305	8,500	**2,853**	-	-	Rathore and Khangarot 2003
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	250	1,658	**676.0**	-	-	Redeker and Blust 2004
Tubificid worm (4-5 wk), *Tubifex tubifex*	S, M	Cadmium chloride	-	400	NA[d]	2,753	**4,193**	Maestre et al. 2009
Earthworm, (formerly, *Varichaeta pacifica*) *Varichaetadrilus pacificus*	S, M	Cadmium sulfate	5.3	380	6,738	7,527	6,738	Chapman et al. 1982
Leech (1-20 mm), *Glossiphonia complanata*	R, M	Cadmium chloride	122.8	480	392.5	389.5	392.5	Brown and Pascoe 1988

Species	**Method[a]**	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Acute Value (µg/L)**	**Normalized Acute Value[b] (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Leech (cocoon), *Nephelopsis obscura*	S, M	Cadmium chloride	-	832.6	-	-	**NA[e]**	Wicklum et al. 1997
Pond snail (juvenile, stage I, 4 wk), *Lymnaea stagnalis*	S, M	Cadmium chloride	250	752	**306.6**	-	-	Coeurdassier et al. 2004
Pond snail (juvenile, stage II, 9 wk), *Lymnaea stagnalis*	S, M	Cadmium chloride	250	1,515	**617.7**	-	-	Coeurdassier et al. 2004
Pond snail (adult, 20 wk), *Lymnaea stagnalis*	S, M	Cadmium chloride	250	1,585	**646.3**	-	-	Coeurdassier et al. 2004
Pond snail (juvenile, 25 mm), *Lymnaea stagnalis*	R, M	Cadmium chloride	135 (130-140)	367.5[f] (347 reported-dissolved)	**273.9**	-	**427.9**	Pais 2012
Snail, *Aplexa hypnorum*	F, M	Cadmium chloride	44.8	93	204.1	210.3	204.1	Holcombe et al. 1984; Phipps and Holcombe 1985
Snail, *Gyraulus sp.*	R, M	Cadmium chloride	24	>467.7[f] (>455 reported dissolved)	**>1,891**	-	-	Mebane et al. 2012
Snail, *Gyraulus sp.*	R, M	Cadmium chloride	21	>75.04[f] (>73 reported dissolved)	**>345.7**	-	**>808.4**	Mebane et al. 2012
Snail (adult, 3.3-15 mm), *Physa acuta*	R, U	Cadmium chloride	44	963.6	**2,152**	-	**2,152**	Woodard 2005
Pouch snail (adult), *Physa gyrina*	S, M	-	200	1,370	695.0[c]	-	-	Wier and Walter 1976
Pouch snail (juvenile), *Physa gyrina*	S, M	-	200	410	208.0	202.6	208.0	Wier and Walter 1976
Mussel (juvenile), *Actinonaias pectorosa*	S, M	-	82	46.40	56.34	-	-	Keller, Unpublished
Mussel (juvenile), *Actinonaias pectorosa*	S, M	-	84	69	81.83	68.38	67.90	Keller, Unpublished

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Neosho mucket (juvenile, 5 d), *Lampsilis rafinesqueana*	R, M	Cadmium nitrate	44 (40-48)	20	**44.67**	-	**44.67**	Wang et al. 2010d
Fatmucket (glochidia), *Lampsilis siliquoidea*	S, M	Cadmium nitrate	44 (40-48)	>227	**>507.0**[c]	-	-	Wang et al. 2010d
Fatmucket (juvenile, 5 d), *Lampsilis siliquoidea*	R, M	Cadmium nitrate	44 (40-48)	16	**35.73**	-	-	Wang et al. 2010d
Fatmucket (juvenile, 2 mo.), *Lampsilis siliquoidea*	R, M	Cadmium nitrate	44 (40-48)	>62	**>138.5**[c]	-	-	Wang et al. 2010d
Fatmucket (juvenile, 6 mo.), *Lampsilis siliquoidea*	R, M	Cadmium nitrate	44 (40-48)	199	**444.4**[c]	-	**35.73**	Wang et al. 2010d
Southern fatmucket, *Lampsilis straminea claibornensis*	S, M	-	40	38	93.17	96.44	93.17	Keller, Unpublished
Yellow sandshell, *Lampsilis teres*	S, M	-	40	11	26.97	-	-	Keller, Unpublished
Yellow sandshell (juvenile), *Lampsilis teres*	S, M	-	40	33	80.91	48.35	46.71	Keller, Unpublished
Mussel (juvenile), *Lasmigona subviridis*	R, M	Cadmium chloride	84	57.77	**68.51**	-	**68.51**	Black 2001
Mussel, *Utterbackia imbecillis*	S, M	Cadmium chloride	90	114.7	127.1	-	-	Keller, Unpublished
Mussel, *Utterbackia imbecillis*	S, M	Cadmium chloride	90	111.8	123.9	-	-	Keller, Unpublished
Mussel (juvenile), *Utterbackia imbecillis*	S, M	Cadmium chloride	86	93.0	107.8	-	-	Keller, Unpublished
Mussel (juvenile), *Utterbackia imbecillis*	S, M	Cadmium chloride	92	81.9	88.85	-	-	Keller, Unpublished
Mussel (juvenile, 12 d), *Utterbackia imbecillis*	S, M	Cadmium chloride	39	9	22.62	-	-	Keller and Zam 1991

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mussel (juvenile, 12 d), *Utterbackia imbecillis*	S, M	Cadmium chloride	90	107	118.6	-	-	Keller and Zam 1991
Mussel (juvenile), *Utterbackia imbecillis*	R, M	Cadmium chloride	84	20.42	**24.22**	86.82	**71.76**	Black 2001
Southern rainbow mussel (juvenile), *Villosa vibex*	S, M	-	40	30	73.55	-	-	Keller, Unpublished
Southern rainbow mussel (juvenile), *Villosa vibex*	S, M	-	186	125	68.08	71.16	70.76	Keller, Unpublished
Cladoceran, *Alona affinis*	S, U	Cadmium nitrate	109	546	501.7	500.1	501.7	Ghosh et al. 1990
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90	54	59.86	-	-	Bitton et al. 1996
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	R, M	Cadmium chloride	80	54.5	67.79	-	-	Diamond et al. 1997
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90	55.9	61.96	-	-	Lee et al. 1997
Cladoceran (3rd-4th instar), *Ceriodaphnia dubia*	S, M	Cadmium chloride	80	64.26	**79.93**	-	-	Black 2001
Cladoceran (neonate), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90	40.1	**44.45**	-	-	Jun et al. 2006
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M	Cadmium chloride	40	31.47	**77.16**	63.46	**64.03**	Shaw et al. 2006
Cladoceran (1st instar larva, <24 hr), *Ceriodaphnia reticulata*	S, U	Cadmium chloride	240	184	78.08	-	-	Elnabarawy et al. 1986
Cladoceran (<6hr), *Ceriodaphnia reticulata*	S, U	Cadmium chloride	120	110	92.00	83.08	84.76	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia ambigua*	S, M	Cadmium chloride	40	10.12	**24.81**	-	**24.81**	Shaw et al. 2006

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	<1.6	NA[d]	-	-	Anderson 1948
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	45	65	142.0	-	-	Biesinger and Christensen 1972
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	27.07	NA[d]	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	28.36	NA[d]	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	35.45	NA[d]	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	51	9.9	19.13	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	104	33	31.75	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	105	34	32.41	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	197	63	32.44	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	209	49	23.81	-	-	Chapman et al. Manuscript, 1980
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium chloride	105	30	28.60	-	-	Canton and Slooff 1982
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium chloride	209.2	30	14.56	-	-	Canton and Slooff 1982
Cladoceran (1st instar larva, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	240	178	75.54	-	-	Elnabarawy et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	20	16.73	-	-	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	40	33.46	-	-	Hall et al. 1986
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	76	59	**77.17**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	74	84	**112.8**	-	-	Nebeker et al. 1986a

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	41	99	**236.9**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	38	164	**422.8**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	76	71	**92.87**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	74	178	**239.0**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	74	116	**155.7**	-	-	Nebeker et al. 1986a
Cladoceran (<4 hr), *Daphnia magna*	S, M	Cadmium chloride	71	101	**141.2**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	71	4	**5.592**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	41	8	**19.15**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	38	16	**41.25**	-	-	Nebeker et al. 1986a
Cladoceran (1 d), *Daphnia magna*	S, M	Cadmium chloride	74	146	**196.0**	-	-	Nebeker et al. 1986a
Cladoceran (genotype A), *Daphnia magna*	S, M	Cadmium chloride	170	3.6	2.141	-	-	Baird et al. 1991
Cladoceran (genotype A-1), *Daphnia magna*	S, M	Cadmium chloride	170	9.0	5.353	-	-	Baird et al. 1991
Cladoceran (genotype A-2), *Daphnia magna*	S, M	Cadmium chloride	170	9.0	5.353	-	-	Baird et al. 1991
Cladoceran (genotype B), *Daphnia magna*	S, M	Cadmium chloride	170	4.5	2.676	-	-	Baird et al. 1991
Cladoceran (genotype E), *Daphnia magna*	S, M	Cadmium chloride	170	27.1	16.12	-	-	Baird et al. 1991
Cladoceran (genotype S-1), *Daphnia magna*	S, M	Cadmium chloride	170	115.9	68.93	-	-	Baird et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	10	37.9	**361.0**	-	-	Hickey and Vickers 1992

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<24 hr, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	129.4	76.96	-	-	Stuhlbacher et al. 1992, 1993
Cladoceran (<24 hr, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	24.5	14.57	-	-	Stuhlbacher et al. 1992, 1993
Cladoceran (neonate, 3 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	228.8	136.1[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 3 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	25.4	15.11[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 6 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	49.1	29.20[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 6 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	250.1	148.7[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 10 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	131.2	78.03[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 10 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	319.3	189.9[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 20 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	326.3	194.1[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 20 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	139.9	83.21[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 30 d, clone F), *Daphnia magna*	S, M	Cadmium chloride	170	146.7	87.25[c]	-	-	Stuhlbacher et al. 1993
Cladoceran (neonate, 30 d, clone S-1), *Daphnia magna*	S, M	Cadmium chloride	170	355.3	211.3[c]	-	-	Stuhlbacher et al. 1993
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	250	280	114.2	-	-	Crisinel et al. 1994

Species	**Method[a]**	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Acute Value (µg/L)**	**Normalized Acute Value[b] (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	360	NA[d]	-	-	Fargasova 1994a
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170	9.5	5.650	-	-	Guilhermino et al. 1996
Cladoceran (clone S-1), *Daphnia magna*	S, M	Cadmium sulfate	46.1	112	239.0	-	-	Barata et al. 1998
Cladoceran (clone S-1), *Daphnia magna*	S, M	Cadmium sulfate	90.7	106	116.6	-	-	Barata et al. 1998
Cladoceran (clone S-1), *Daphnia magna*	S, M	Cadmium sulfate	179	233	131.8	-	-	Barata et al. 1998
Cladoceran (clone A), *Daphnia magna*	S, M	Cadmium sulfate	46.1	30.1	64.22	-	-	Barata et al. 1998
Cladoceran (clone A), *Daphnia magna*	S, M	Cadmium sulfate	90.7	23.4	25.74	-	-	Barata et al. 1998
Cladoceran (clone A), *Daphnia magna*	S, M	Cadmium sulfate	179	23.6	13.35	-	-	Barata et al. 1998
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	18	66	**353.6**	-	-	Baer et al. 1999
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	18	69	**369.6**	-	-	Baer et al. 1999
Cladoceran (<24 hr), *Daphnia magna*	S, M	-	170	3.3	**1.963**	-	-	Barata and Baird 2000
Cladoceran (≤ 24 hr; Source 1), *Daphnia magna*	S, M	Cadmium chloride	170	26	**15.46**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 2), *Daphnia magna*	S, M	Cadmium chloride	170	34	**20.22**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 3), *Daphnia magna*	S, M	Cadmium chloride	170	39	**23.20**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 4), *Daphnia magna*	S, M	Cadmium chloride	170	48	**28.55**	-	-	Ward and Robinson 2005

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (≤ 24 hr; Source 5), *Daphnia magna*	S, M	Cadmium chloride	170	55	**32.71**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 6), *Daphnia magna*	S, M	Cadmium chloride	170	63	**37.47**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 7), *Daphnia magna*	S, M	Cadmium chloride	170	100	**59.48**	-	-	Ward and Robinson 2005
Cladoceran (≤ 24 hr; Source 8), *Daphnia magna*	S, M	Cadmium chloride	170	>120	>**71.37**	-	-	Ward and Robinson 2005
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	40	101.20	**248.1**	-	-	Shaw et al. 2006
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	44	3	**6.700**	-	-	Yim et al. 2006
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	150	4	**2.689**	-	-	Yim et al. 2006
Cladoceran (<24 hr), *Daphnia magna*	S, M	Cadmium chloride	-	41.1	**NA**[d]	-	-	Jemec et al. 2007
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, U	Cadmium chloride	93	318.76	**342.2**	-	-	Mohammed 2007
Cladoceran (neonate, <24 hr), *Daphnia magna*	S, M	Cadmium chloride	240	77.6	**32.91**	-	-	Xie et al. 2007
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170	79.05	**47.02**	-	-	Ferreira et al. 2008a
Cladoceran (<24 hr, clone O), *Daphnia magna*	S, M	Cadmium chloride	-	250	**NA**[d]	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone E), *Daphnia magna*	S, M	Cadmium chloride	-	260	**NA**[d]	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone R), *Daphnia magna*	S, M	Cadmium chloride	-	285	**NA**[d]	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone F), *Daphnia magna*	S, M	Cadmium chloride	-	320	**NA**[d]	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone B), *Daphnia magna*	S, M	Cadmium chloride	-	330	**NA**[d]	-	-	Haap and Kohler 2009

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Cladoceran (<24 hr, clone X), *Daphnia magna*	S, M	Cadmium chloride	-	355	**NA[d]**	-	-	Haap and Kohler 2009
Cladoceran (<24 hr, clone K), *Daphnia magna*	S, M	Cadmium chloride	-	550	**NA[d]**	-	-	Haap and Kohler 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	85 (80-90)	19.87	**23.29**	-	-	Kim et al. 2009
Cladoceran (<24 hr), *Daphnia magna*	S, U	-	170 (160-180)	571.5	**339.9**	-	**-**	Perez and Beiras 2010
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	~170	20.1	**11.95**	-	-	Loureiro et al. 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=0.46 mg/L (pH=8.1)	7.5	**NA[d]**	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=8.1)	14.2	**NA[d]**	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=192 mg/L (pH=8.1)	24.8	**NA[d]**	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=5.8)	>170	**NA[d]**	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=7.0)	46.2	**NA[d]**	-	-	Tan and Wang 2011
Cladoceran (7 d), *Daphnia magna*	S, U	Cadmium chloride	Ca^{2+}=19 mg/L (pH=8.2)	17.5	**NA[d]**	27.14	**40.62**	Tan and Wang 2011
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium nitrate	-	90.23	NA[d]	-	-	Canton and Adema 1978
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	57	47	81.47	-	-	Bertram and Hart 1979
Cladoceran (neonate), *Daphnia pulex*	S, M	Cadmium chloride	65	62	**94.51**	-	-	Niederlehner 1984
Cladoceran (1st instar larva, <24 hr), *Daphnia pulex*	S, U	Cadmium chloride	240	319	135.4	-	-	Elnabarawy et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	80	66.91	-	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	100	83.64	-	-	Hall et al. 1986

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Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium chloride	53.5	70.1	129.3	-	-	Stackhouse and Benson 1988
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85	66	77.37	-	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85	99	116.1	-	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85	70	82.06	-	-	Roux et al. 1993
Cladoceran (≤ 24 hr), *Daphnia pulex*	S, M	Cadmium chloride	40	44.96	**110.2**	-	-	Shaw et al. 2006
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	17.0	16.86	**95.53**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	24.0	23.61	**95.43**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	30.0	46.09	**149.7**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	47.0	24.73	**51.78**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	67.1	71.94	**106.3**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	119	116.9	**98.59**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	175	155.1	**89.68**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	19.0	26.98	**137.1**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32.0	46.09	**140.6**	-	-	Clifford 2009; Clifford and McGeer 2010

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Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	66.9	70.82	**104.9**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	112	89.93	**80.47**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	158	68.57	**43.81**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	46.09	**140.6**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	33.72	**102.9**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	42.72	**130.3**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	46.09	**140.6**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	52.83	**161.2**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	43.84	**133.7**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	48.34	**147.4**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	73.07	**222.9**	-	-	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	62.95	**192.0**	-	-	Clifford 2009; Clifford and McGeer 2010

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Cladoceran (<24 hr), *Daphnia pulex*	S, M	Cadmium reference standard	32	52.83	**161.2**	93.77	**109.2**	Clifford 2009; Clifford and McGeer 2010
Cladoceran (<24 hr), *Daphnia similis*	S, M	Cadmium nitrate	44	57.89	**129.3**	-	**129.3**	Rodgher et al. 2010
Cladoceran, *Diaphanosoma brachyurum*	S, U	Cadmium chloride	67.1	69.80	**103.1**	-	**103.1**	Mano et al. 2011
Cladoceran, *Moina macrocopa*	S, U	Cadmium chloride	82	71.25	86.51	87.16	86.51	Hatakeyama and Yasuno 1981b
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	11.1	7	60.19	-	-	Giesy et al. 1977
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	43.5	24.5	55.33	61.10	57.71	Spehar and Carlson 1984a,b
Cyclopoid copepod, *Cyclops varicans*	S, U	Cadmium nitrate	109	493	453.0	451.6	453.0	Ghosh et al. 1990
Copepod (0.58 mm), *Diaptomus forbesi*	S, U	Cadmium chloride	185	5,700	**3,121**	-	**3,121**	Ghosal and Kaviraj 2002
Isopod, (formerly, *Asellus bicrenata*) *Caecidotea bicrenata*	F, M	Cadmium chloride	220	2,129	983.8	955.0	983.8	Bosnak and Morgan 1981
Isopod, *Lirceus alabamae*	F, M	Cadmium chloride	152	150	99.54	97.98	99.54	Bosnak and Morgan 1981
Amphipod (4 mm), *Crangonyx pseudogracilis*	R, U	Cadmium chloride	50	1,700	3,350	3,439	3,350	Martin and Holdich 1986
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	43.5	68.3	154.3	159.2	154.3	Spehar and Carlson 1984a,b

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Amphipod (large juvenile & young adult), *Hyalella azteca*	S, M	Cadmium chloride	34	8	**23.00**	-	**23.00**	Nebeker et al. 1986b
Prawn (post larva), *Macrobrachium rosenbergii*	R, U	Cadmium chloride	-	36.12	-	-	**NA[e]**	Sowdeswari et al. 2012
Crayfish (adult, 1.8 g), *Orconectes immunis*	F, M	Cadmium chloride	44.4	>10,200	>22,579	>23,281	>22,579	Phipps and Holcombe 1985
Crayfish (adult, 4.58 g), *Orconectes juvenilis*	R, M	Cadmium chloride	44.1	2,440	**5,437[c]**	-	-	Wigginton and Birge 2007
Crayfish (3rd-5th instar, 0.2 g), *Orconectes juvenilis*	R, M	Cadmium chloride	44	60	**134.0**	-	**134.0**	Wigginton 2005; Wigginton and Birge 2007
Crayfish, *Orconectes limosus*	S, M	Cadmium chloride	-	400	-	NA[e]	NA[e]	Boutet and Chaisemartin 1973
Crayfish (adult, 7.06 g), *Orconectes placidus*	R, M	Cadmium chloride	44.1	487	**1,085[c]**	-	-	Wigginton and Birge 2007
Crayfish (3rd-5th instar, 0.2 g), *Orconectes placidus*	R, M	Cadmium chloride	54.6	37	**66.89**	-	**66.89**	Wigginton 2005; Wigginton and Birge 2007
Crayfish, *Orconectes virilis*	F, M	Cadmium chloride	26	6,100	22,800	-	-	Mirenda 1986
Crayfish (adult, 12.8 g), *Orconectes virilis*	R, M	Cadmium chloride	42.5	3,300	**7,625[i]**	23,988	22,800	Wigginton and Birge 2007
Crayfish (adult, 15.5 g), *Procambarus acutus*	R, M	Cadmium chloride	44.5	368	**812.8**	-	**812.8**	Wigginton and Birge 2007
Crayfish (adult, 5.14 g), *Procambarus alleni*	R, M	Cadmium chloride	45.8	3,070	**6,592**	-	**6,592**	Wigginton and Birge 2007

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Red swamp crayfish (juvenile), *Procambarus clarkii*	S, M	Cadmium chloride	30	1,040	3,379[c]	-	-	Naqvi and Howell 1993
Red swamp crayfish (adult, 18.5 g), *Procambarus clarkii*	R, M	Cadmium chloride	52.9	2,660	**4,960**[c]	-	-	Wigginton and Birge 2007
Red swamp crayfish (3rd to 5th instar, 0.02 g), *Procambarus clarkii*	R, M	Cadmium chloride	42.1	624	**1,455**	3,536	**1,455**	Wigginton 2005; Wigginton and Birge 2007
Mayfly, *Baetis tricaudatus*	R, M	Cadmium chloride	24	>456.4[f] (>444 reported dissolved)	**>1,845**[g]	-	-	Mebane et al. 2012
Mayfly, *Baetis tricaudatus*	R, M	Cadmium chloride	21	76.07[f] (74 reported dissolved)	**350.4**	-	**350.4**	Mebane et al. 2012
Mayfly, *Ephemerella subvaria*	S, U	Cadmium sulfate	44	2,000	4,467	4,607	4,467	Warnick and Bell 1969
Mayfly (formerly, *Ephemerella grandis grandis*) *Drunella grandis grandis*	F, M	Cadmium chloride	-	28,000	-	NA[e]	NA[e]	Clubb et al. 1975
Mayfly (nymph, 24 mm), *Hexagenia rigida*	S, M	Cadmium	79.1	6,200	**7,798**	-	**7,798**	Leonhard et al. 1980
Mayfly (nymph), *Rhithrogena hageni*	F, M	Cadmium sulfate	48	10,794[f] (10,500 reported dissolved)	**22,138**	-	**22,138**	Brinkman and Vieira 2007; Brinkman and Johnston 2008
Stonefly, *Pteronarcella badia*	F, M	Cadmium chloride	-	18,000	-	NA[e]	NA[e]	Clubb et al. 1975
Little green stonefly, *Sweltsa sp.*	R, M	Cadmium chloride	26	>5,386[f] (>5,239 reported dissolved)	**>20,132**	-	**>20,132**	Mebane et al. 2012

Species	**Method[a]**	**Chemical**	**Hardness (mg/L CaCO$_3$)**	**Acute Value (µg/L)**	**Normalized Acute Value[b] (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Caddisfly, *Arctopsyche sp.*	R, M	Cadmium chloride	28	>470.8[f] (>458 reported dissolved)	**>1,637**	-	**>1,637**	Mebane et al. 2012
Midge (larva), *Culicoides furens*	S, U	-	-	300	-	-	-	Vedamanikam and Shazilli 2008a
Midge (larva), *Culicoides furens*	S, M	Cadmium chloride	- (35ºC)	245.2	-	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Culicoides furens*	S, M	Cadmium chloride	- (25ºC)	245.2	-	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Culicoides furens*	S, M	Cadmium chloride	- (10ºC)	183.9	-	-	**NA[e]**	Vedamanikam and Shazilli 2008b
Midge (3rd-4th instar larva), *Chironomus plumosus*	S, U	Cadmium chloride	80	12,700	**15,798**	-	-	Fargasova 2001, 2003
Midge (larva), *Chironomus plumosus*	S, U	-	-	400	**NA[d]**	-	-	Vedamanikam and Shazilli 2008a
Midge (larva), *Chironomus plumosus*	S, M	Cadmium chloride	- (35ºC)	367.8	**NA[d]**	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Chironomus plumosus*	S, M	Cadmium chloride	- (25ºC)	245.2	**NA[d]**	-	-	Vedamanikam and Shazilli 2008b
Midge (larva), *Chironomus plumosus*	S, M	Cadmium chloride	- (10ºC)	183.9	**NA[d]**	-	**15,798**	Vedamanikam and Shazilli 2008b
Midge (10-12 mm), *Chironomus riparius*	F, M	-	152	>229,500	>152,301	-	-	Williams et al. 1985
Midge (4th instar larva), *Chironomus riparius*	R, M	Cadmium chloride	124	140,000	113,398[i]	-	-	Pascoe et al. 1990
Midge (3rd instar larva), *Chironomus riparius*	S, U	Cadmium chloride	170 (160-180)	128,840	**76,629[i]**	-	-	Lee et al. 2006a
Midge (3rd-4th instar larva), *Chironomus riparius*	S, M	Cadmium nitrate	10	331,000	**3,152,504[i]**	-	-	Gillis and Wood 2008
Midge (3rd-4th instar larva), *Chironomus riparius*	S, M	Cadmium nitrate	140	1,106,000	**795,496[i]**	195,967	>152,301	Gillis and Wood 2008
Bryozoa (ancenstrulae 2-3 d), *Pectinatella magnifica*	S, U	-	205	700	346.6	337.4	346.6	Pardue and Wood 1980

Species	**Method[a]**	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Acute Value (µg/L)**	**Normalized Acute Value[b] (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Bryozoa (ancenstrulae 2-3 d), *Lophopodella carteri*	S, U	-	205	150	74.28	72.29	74.28	Pardue and Wood 1980
Bryozoa (ancenstrulae 2-3 d), *Plumatella emarginata*	S, U	-	205	1,090	539.7	525.3	539.7	Pardue and Wood 1980
Westslope cutthroat trout, *Oncorhynchus clarkii lewisi*	R, M	Cadmium chloride	32	1.542[f] (1.5 reported dissolved)	**4.703[i]**	-	-	Mebane et al. 2012
Westslope cutthroat trout, *Oncorhynchus clarkii lewisi*	R, M	Cadmium chloride	31	1.234[f] (1.2 reported dissolved)	**3.883[i]**	-	-	Mebane et al. 2012
Westslope cutthroat trout (young of the year), *Oncorhynchus clarkii lewisi*	R, M	Cadmium chloride	21	0.9663[f] (0.94 reported dissolved)	**4.452[i]**	-	-	Mebane et al. 2012
Rio Grande cutthroat trout (fry, 0.26 g), *Oncorhynchus clarkii virginalis*	F, M	Cadmium sulfate	44.9	2.467[f] (2.40 reported dissolved)	**5.401**	-	**5.401**	Brinkman 2012
Coho salmon (adult), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	17.5	77.03[c]	-	-	Chapman 1975
Coho salmon (parr), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	2.7	11.88	-	-	Chapman 1975
Coho salmon (yearling), *Oncorhynchus kisutch*	S, U	Cadmium	90	10.4	11.53[i]	-	-	Lorz et al. 1978
Coho salmon (juvenile), *Oncorhynchus kisutch*	S, U	Cadmium chloride	41	3.4	8.137[i]	12.58	11.88	Buhl and Hamilton 1991
Rainbow trout (4 mo.), *Oncorhynchus mykiss*	F, U	-	-	0.95	**NA[d]**	-	-	Chapman 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	6	NA[d]	-	-	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	7	NA[d]	-	-	Kumada et al. 1973
Rainbow trout (smolt), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	4.1	17.28[c]	-	-	Chapman 1975

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Rainbow trout (130 mm), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	31	1.75	5.506	-	-	Davies 1976a
Rainbow trout (2 mo.), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	-	6.60	NA[d]	-	-	Hale 1977
Rainbow trout (smolt, 68.19 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	>2.9	>12.22[c]	-	-	Chapman 1978
Rainbow trout (swim-up fry, 0.17 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.3	5.479	-	-	Chapman 1978
Rainbow trout (parr, 6.96 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.0	4.214	-	-	Chapman 1978
Rainbow trout (alevin), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	>27	>113.8[c]	-	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	S, U	Cadmium chloride	-	6.0	NA[d]	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	S, M	Cadmium chloride	43.5	2.3	5.194[i]	-	-	Spehar and Carlson 1984a;b
Rainbow trout (8.8 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	44.4	3.0	6.641	-	-	Phipps and Holcombe 1985
Rainbow trout (fry), *Oncorhynchus mykiss*	F, M	Cadmium chloride	9.2	<0.5	<5.167[g]	-	-	Cusimano et al. 1986
Rainbow trout (juvenile, 18.3 g), *Oncorhynchus mykiss*	F, M	Cadmium chloride	52	1.88	**3.565**	-	-	Stubblefield 1990
Rainbow trout (juvenile), *Oncorhynchus mykiss*	S, U	Cadmium chloride	41	1.50	3.590[i]	-	-	Buhl and Hamilton 1991
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	47	2.66	**5.569**	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	204	3.15	**1.567**	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	427	7.56	**1.825**[k]	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	49	3.02	**6.070**	-	-	Davies et al. 1993

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Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	224	6.12	**2.779**	-	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M	-	422	5.70	**1.392**[k]	-	-	Davies et al. 1993
Rainbow trout (fry, 1.0 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	29	2.79	**9.371**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	258 (aged solution)	8.54	**3.376**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	281	13.4	**4.873**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 1.0 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	28	2.09	**7.265**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	276 (aged solution)	10.5	**3.886**	-	-	Davies and Brinkman 1994b
Rainbow trout (fry, 2.5 g), *Oncorhynchus mykiss*	F, M	Cadmium sulfate	281	10.0	**3.637**	-	-	Davies and Brinkman 1994b
Rainbow trout (juvenile, 4.5 g), *Oncorhynchus mykiss*	F, M	Cadmiun nitrate	140	22	**15.82**[j]	-	-	Hollis et al. 1999
Rainbow trout (263 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	30.7	0.71	2.255	-	-	Stratus Consulting 1999
Rainbow trout (659 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	29.3	0.47	1.563	-	-	Stratus Consulting 1999
Rainbow trout (1,150 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	31.7	0.51	1.570	-	-	Stratus Consulting 1999
Rainbow trout (1,130 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	30.2	0.38	1.227	-	-	Stratus Consulting 1999
Rainbow trout (299 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	30.0	1.29	4.191	-	-	Stratus Consulting 1999
Rainbow trout (289 mg), *Oncorhynchus mykiss*	F, M	Cadmium chloride	89.3	2.85	3.183	-	-	Stratus Consulting 1999
Rainbow trout (juvenile, 12 g), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	20	2.07	**10.00**[j]	-	-	Hollis et al. 2000a
Rainbow trout (juvenile, 8-12 g), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	120	19.00	**15.89**[j]	-	-	Niyogi et al. 2004b

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Rainbow trout (swim-up fry, 0.131 g), *Oncorhynchus mykiss*	F, M	-	103	3.7	**3.594**	-	-	Besser et al. 2007
Rainbow trout (juvenile, 0.496 g), *Oncorhynchus mykiss*	F, M	-	103	5.2	**5.051**	-	-	Besser et al. 2007
Rainbow trout (juvenile, 1-3 g), *Oncorhynchus mykiss*	S, M	Cadmium chloride	-	0.753	**NA[d]**	-	-	Birceanu et al. 2008
Rainbow trout (swim-up fry, 0.2-0.4 g), *Oncorhynchus mykiss*	R, M	Cadmium chloride	19.7	0.864[f] (0.84 reported-dissolved)	**4.237[i]**	-	-	Mebane et al. 2007; 2008
Rainbow trout (swim-up fry, 0.2-0.4 g), *Oncorhynchus mykiss*	R, M	Cadmium chloride	29.4	0.915[f] (0.89 reported-dissolved)	**3.032[i]**	-	-	Mebane et al. 2007; 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48)	2.75	**6.142[i]**	-	-	Niyogi et al. 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48) (pH=5.8)	3.21	**7.169[i]**	-	-	Niyogi et al. 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48) (pH=8.8)	3.08	**6.879[i]**	-	-	Niyogi et al. 2008
Rainbow trout (juvenile, 6-8 g), *Oncorhynchus mykiss*	R, M	Cadmium nitrate	44 (40-48) (Alkalinity=90 mg/L)	1.02	**2.278[i]**	-	-	Niyogi et al. 2008
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	21	0.8224[f] (0.8 reported dissolved)	**3.789[i]**	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	7	0.4934[f] (0.48 reported dissolved)	**6.663[i]**	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	13	1.018[f] (0.99 reported dissolved)	**7.500[i]**	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	24	1.336[f] (1.3 reported dissolved)	**5.401[i]**	-	-	Mebane et al. 2012

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Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	32	0.9560[f] (0.93 reported dissolved)	**2.916[i]**	-	-	Mebane et al. 2012
Rainbow trout, *Oncorhynchus mykiss*	R, M	Cadmium chloride	29	0.8532[f] (0.83 reported dissolved)	**2.866[i]**	-	-	Mebane et al. 2012
Rainbow trout (young of the year), *Oncorhynchus mykiss*	R, M	Cadmium chloride	21	0.3495[f] (0.34 reported dissolved)	**1.610[i]**	-	-	Mebane et al. 2012
Rainbow trout (1 dph, 0.08 g, 14.3 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	103	>52.31[f] (>49.40 reported dissolved)	**>50.81[c]**	-	-	Calfee et al. 2014
Rainbow trout (18 dph, 0.1 g, 24.33 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	104	3.061[f] (2.89 reported dissolved)	**2.945**	-	-	Calfee et al. 2014
Rainbow trout (32 dph, 0.12 g, 26.67 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	107	5.115[f] (4.83 reported dissolved)	**4.786**	-	-	Calfee et al. 2014
Rainbow trout (46 dph, 0.22 g, 32.1 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	107	2.933[f] (2.77 reported dissolved)	**2.745**	-	-	Calfee et al. 2014
Rainbow trout (60 dph, 0.33 g, 37.1 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	104	3.929[f] (3.71 reported dissolved)	**3.780**	-	-	Calfee et al. 2014
Rainbow trout (74 dph, 0.42 g, 40.3 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	96	4.808[f] (4.54 reported dissolved)	**5.003**	-	-	Calfee et al. 2014
Rainbow trout (95 dph, 0.7 g, 45.43 cm), *Oncorhynchus mykiss*	F, M	Cadmium chloride	103	3.135[f] (2.96 reported dissolved)	**3.045**	-	-	Calfee et al. 2014
Rainbow trout (1 dph), *Oncorhynchus mykiss*	F, M	Cadmium chloride	100	>12.71[f] (>12 reported dissolved)	**>12.71[c]**	-	-	Wang et al. 2014a
Rainbow trout (juvenile, 26 dph), *Oncorhynchus mykiss*	F, M	Cadmium chloride	100	5.401[f] (5.1 reported dissolved)	**5.400**	4.265	**3.727**	Wang et al. 2014a
Chinook salmon (at hatch), *Oncorhynchus tshawytscha*	F, U	-	-	>25	**NA[d]**	-	-	Chapman 1973

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Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	F, U	-	-	1.9	**NA[d]**	-	-	Chapman 1973
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	25	1.41	5.477	-	-	Chapman 1978; 1982
Chinook salmon (alevin, 0.05 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>26	>109.6[g]	-	-	Chapman 1978
Chinook salmon (swim-up fry, 0.23 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	1.8	7.586	-	-	Chapman 1978
Chinook salmon (parr, 11.58 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	3.5	14.75[c]	-	-	Chapman 1978
Chinook salmon (smolt, 32.46 g), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>2.9	>12.22[c]	-	-	Chapman 1978
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium sulfate	21	1.1	5.068	-	-	Finlayson and Verrue 1982
Chinook salmon (9-13 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	211	26	12.52[i]	-	-	Hamilton and Buhl 1990
Chinook salmon (18-21 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	343	57	17.05[i]	8.708	**5.949**	Hamilton and Buhl 1990
Lake whitefish (yearling, 140 mm, 22 g), *Coregonus clupeaformis*	F, M	-	81	530	**651.3**	-	**651.3**	McNicol 1997
Mountain whitefish (209 g), *Prosopium williamsoni*	F, M	Cadmium chloride	52	>8.29	**>15.72**	-	**>15.72**	Stubblefield 1990
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	43.5	1.4	3.162[i]	-	-	Spehar and Carlson 1984a;b
Brown trout (fingerling, 22.4 g), *Salmo trutta*	F, M	Cadmium chloride	48	2.85	**5.845**	-	-	Stubblefield 1990

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Brown trout (fingerling), *Salmo trutta*	F, M	Cadmium sulfate	37.6	2.37	**6.173**	-	-	Davies and Brinkman 1994c
Brown trout (fry), *Salmo trutta*	F, M	Cadmium sulfate	29.2	1.23	**4.104**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (fry), *Salmo trutta*	F, M	Cadmium sulfate	67.6	3.9	**5.721**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (fry), *Salmo trutta*	F, M	Cadmium sulfate	151	10.1	**6.746**	3.263	**5.642**	Brinkman and Hansen 2004a; 2007
Bull trout (76.1 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	30.7 (pH=7.5)	0.91	2.891	-	-	Stratus Consulting 1999
Bull trout (200 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	29.3 (pH=7.5)	0.99	3.292	-	-	Stratus Consulting 1999
Bull trout (221 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	31.7 (pH=7.5)	1.00	3.079	-	-	Stratus Consulting 1999
Bull trout (218 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	30.2 (pH=7.5)	0.90	2.905	-	-	Stratus Consulting 1999
Bull trout (84.2 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	30.0 (pH=6.5)	2.89	9.390	-	-	Stratus Consulting 1999
Bull trout (72.7 mg), *Salvelinus confluentus*	F, M	Cadmium chloride	89.3 (pH=7.5)	6.06	6.769	4.353	4.190	Stratus Consulting 1999
Brook trout (yearling, 21 cm, 110 g), *Salvelinus fontinalis*	F, M	-	45 (44-46)	>405	**>884.8**	-	-	Drummond and Benoit 1976
Brook trout (100 g), *Salvelinus fontinalis*	F, M	Cadmium chloride	47.4	5,080	10,548	<3.623	**3,055**[h]	Holcombe et al. 1983
Goldfish, *Carassius auratus*	S, U	Cadmium chloride	20	2,340	11,307[i]	-	-	Pickering and Henderson 1966
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	20	2,130	10,293[i]	-	-	McCarty et al. 1978
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	140	46,800	33,661[i]	-	-	McCarty et al. 1978
Goldfish (8.8 g), *Carassius auratus*	F, M	Cadmium chloride	44.4	748.0	1,656	1,707	1,656	Phipps and Holcombe 1985

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Grass carp (18 mm, 17 g), *Ctenopharyngodon idellus*	S, U	Cadmium sulfate	-	9,420	-	-	NA[e]	Yorulmazlar and Gul 2003
Common carp (fry), *Cyprinus carpio*	S, U	Cadmium nitrate	100	4,300	4,299	-	-	Suresh et al. 1993a
Common carp (fingerling), *Cyprinus carpio*	S, U	Cadmium nitrate	100	17,100	17,097	-	-	Suresh et al. 1993a
Common carp (yolk absorbed), *Cyprinus carpio*	R, U	Cadmium chloride	-	140	NA[d]	-	-	Ramesha et al. 1997
Common carp (fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,840	NA[d]	-	-	Ramesha et al. 1997
Common carp (advanced fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,910	NA[d]	-	-	Ramesha et al. 1997
Common carp (fingerling), *Cyprinus carpio*	R, U	Cadmium chloride	-	4,560	NA[d]	-	-	Ramesha et al. 1997
Common carp (fry, 3.34 cm, 0.33 g), *Cyprinus carpio*	S, U	Cadmium chloride	185	220,770	**120,874**	-	-	Ghosal and Kaviraj 2002
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	<125	43,170	**34,693**	-	-	Datta et al. 2003
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	187.5 (125-250)	48,390	**26,148**	-	-	Datta et al. 2003
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	312.5 (250-375)	116,450	**38,164**	-	-	Datta et al. 2003
Common carp (fry, 3.5 cm, 0.65 g), *Cyprinus carpio*	S, U	Cadmium chloride	>375	310,480	**85,122**	8,573	**30,781**	Datta et al. 2003
Red shiner (adult, 0.80-2.0 g), *Cyprinella lutrensis*	S, M	Cadmium sulfate	85.5	6,620	7,716	7,762	7,716	Carrier 1987; Carrier and Beitinger 1988a

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Zebrafish (3-7 d, larva), *Danio rerio*	R, U	Cadmium chloride	177.5	2,113	**1,205**	-	-	Blechinger et al. 2002
Zebrafish (adult), *Danio rerio*	R, M	Cadmium nitrate	141 (28ºC)	4,047[f] (3,822 reported dissolved)	**2,891**	-	-	Alsop and Wood 2011
Zebrafish (larva), *Danio rerio*	R, M	Cadmium nitrate	141 (26.6ºC)	1,832[f] (1,730 reported dissolved)	**1,309**	-	-	Alsop and Wood 2011
Zebrafish (larva), *Danio rerio*	R, M	Cadmium nitrate	7.8 (26.6ºC)	125.2[f] (121.8 reported dissolved)	**1,521**	-	-	Alsop and Wood 2011
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (18ºC)	13,657	**5,569**	-	-	Vergauwen 2012; Vergauwen et al. 2013
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (26ºC)	11,510	**4,693**	-	-	Vergauwen 2012; Vergauwen et al. 2013
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (30ºC)	14,005	**5,710**	-	-	Vergauwen 2012; Vergauwen et al. 2013
Zebrafish (adult), *Danio rerio*	S, U	Cadmium chloride	250 (34ºC)	14,241	**5,807**	-	**2,967**	Vergauwen 2012; Vergauwen et al. 2013
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	20	1,050	5,074[i]	-	-	Pickering and Henderson 1966
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	20	630	3,044[i]	-	-	Pickering and Henderson 1966
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	360	72,600	20,716[i]	-	-	Pickering and Henderson 1966
Fathead minnow (1.5-2.5 in., 1-2 g), *Pimephales promelas*	S, U	Cadmium chloride	360	73,500	20,973[i]	-	-	Pickering and Henderson 1966
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	11,200	5,654	-	-	Pickering and Gast 1972
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	12,000	6,058	-	-	Pickering and Gast 1972
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	6,400	3,231	-	-	Pickering and Gast 1972

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	2,000	<u>1,010</u>	-	-	Pickering and Gast 1972
Fathead minnow (2 g), *Pimephales promelas*	F, M	Cadmium sulfate	201	4,500	<u>2,272</u>	-	-	Pickering and Gast 1972
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	40	21.5	52.71[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	48	11.7	24.00[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	39	19.3	48.51[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	45	42.4	92.63[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	44	29.0	64.77[i]	-	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	47	54.2	113.5[i]	-	-	Spehar 1982
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,060	2,972[i]	-	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	2,900	2,817[i]	-	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,100	3,011[i]	-	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	262.5	7,160	2,783[i]	-	-	Birge et al. 1983
Fathead minnow (30 d), *Pimephales promelas*	S, M	Cadmium chloride	43.5	1,280	2,891[i]	-	-	Spehar and Carlson 1984a;b
Fathead minnow (0.6 g), *Pimephales promelas*	F, M	Cadmium chloride	44.4	1,500	<u>3,320</u>	-	-	Phipps and Holcombe 1985
Fathead minnow (larva), *Pimephales promelas*	S, U	Cadmium chloride	120	>150	>125.5[i]	-	-	Hall et al. 1986
Fathead minnow (30 d), *Pimephales promelas*	F, M	Cadmium nitrate	44	13.2	<u>29.48</u>	-	-	Spehar and Fiandt 1986
Fathead minnow (juvenile), *Pimephales promelas*	S, M	Cadmium chloride	141	3,420	2,443[i]	-	-	Sherman et al. 1987
Fathead minnow (juvenile), *Pimephales promelas*	S, M	Cadmium chloride	141	3,510	2,507[i]	-	-	Sherman et al. 1987

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Fathead minnow (0.8-2.0 g), *Pimephales promelas*	S, M	Cadmium sulfate	85.5	3,580	4,173[i]	-	-	Carrier 1987; Carrier and Beitinger 1988a
Fathead minnow (<24 hr), *Pimephales promelas*	S, M	Cadmium nitrate	290 (pH=6-6.5)	73	25.47[i]	-	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 hr), *Pimephales promelas*	S, M	Cadmium nitrate	290 (pH=7-7.5)	60	21.16[i]	-	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 hr), *Pimephales promelas*	S, M	Cadmium nitrate	290 (pH=8-8.8)	65	22.92[i]	-	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 hr), *Pimephales promelas*	S, U	Cadmium nitrate	60	210	346.2[i]	-	-	Rifici et al. 1996
Fathead minnow (1-2 d), *Pimephales promelas*	S, U	Cadmium nitrate	60	180	296.7[i]	59.08	**1,582**	Rifici et al. 1996
Colorado pikeminnow (larva, 9 mm), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	78	39.76	-	-	Buhl 1997
Colorado pikeminnow (juvenile, 43 mm), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	108	55.06	45.59	46.79	Buhl 1997
Northern pikeminnow (juvenile, 56 mm), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25	1,092	4,241	-	-	Andros and Garton 1980
Northern pikeminnow (juvenile, 60 mm), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25	1,104	4,288	4,493	4,265	Andros and Garton 1980
Bonytail (larva), *Gila elegans*	S, U	Cadmium chloride	199	148	75.45	-	-	Buhl 1997
Bonytail (juvenile), *Gila elegans*	S, U	Cadmium chloride	199	168	85.64	78.32	80.38	Buhl 1997
White sucker, *Catostomus commersoni*	F, M	Cadmium chloride	18	1,110	5,947	6,344	5,947	Duncan and Klaverkamp 1983

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Razorback sucker (larva), *Xyrauchen texanus*	S, U	Cadmium chloride	199	139	70.86	-	-	Buhl 1997
Razorback sucker (juvenile), *Xyrauchen texanus*	S, U	Cadmium chloride	199	160	81.56	74.08	76.02	Buhl 1997
Channel catfish (7.4 g), *Ictalurus punctatus*	F, M	Cadmium chloride	44.4	4,480	9,917	10,225	9,917	Phipps and Holcombe 1985
Flagfish, *Jordanella floridae*	F, M	Cadmium chloride	44	2,500	5,583	5,759	5,583	Spehar 1976a;b
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	900	7,739	-	-	Giesy et al. 1977
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	2,200	18,918	-	-	Giesy et al. 1977
Mosquitofish (juvenile), *Gambusia affinis*	S, U	Cadmium chloride	-	2,354	**NA**[d]	-	-	Annabi et al. 2009
Mosquitofish (adult), *Gambusia affinis*	S, U	Cadmium chloride	-	1,447	**NA**[d]	13,146	12,100	Annabi et al. 2009
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	20	1,270	6,137	-	-	Pickering and Henderson 1966
Guppy (3-4 wk), *Poecilia reticulata*	R, M	Cadmium chloride	105	3,800	3,622	-	-	Canton and Slooff 1982
Guppy (3-4 wk), *Poecilia reticulata*	R, M	Cadmium chloride	209.2	11,100	5,388	-	-	Canton and Slooff 1982
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	-	18,635	**NA**[d]	4,981	4,929	Yilmaz et al. 2004
Threespine stickleback, *Gasterosteus aculeatus*	S, U	Cadmium chloride	115	6,500	5,668	-	-	Pascoe and Cram 1977
Threespine stickleback, *Gasterosteus aculeatus*	R, M	Cadmium chloride	107	23,000	21,522	11,002	11,045	Pascoe and Mattey 1977
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	40	4	9.807	-	-	Palawski et al. 1985

Species	Method[a]	Chemical	Hardness (mg/L CaCO$_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	285	10	3.587	5.916	5.931	Palawski et al. 1985
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	20	2,840	13,724[i]	-	-	Pickering and Henderson 1966
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	360	66,000	18,832[i]	-	-	Pickering and Henderson 1966
Green sunfish, *Lepomis cyanellus*	F, M	Cadmium chloride	335	20,500	6,276	-	-	Jude 1973
Green sunfish (juvenile), *Lepomis cyanellus*	S, M	Cadmium sulfate	85.5	11,520	13,427[i]	5,997	6,276	Carrier 1987; Carrier and Beitinger 1988b
Bluegill (juvenile, 1.5-3.5 g), *Lepomis macrochirus*	F, M	Cadmium sulfate	20	1,700	**8,215**	-	-	Lemke 1965
Bluegill (juvenile, 1.5-3.5 g), *Lepomis macrochirus*	F, M	Cadmium sulfate	20	>2,100	**>10,148**	-	-	Lemke 1965
Bluegill (juvenile, 1.5-3.5 g), *Lepomis macrochirus*	F, M	Cadmium sulfate	350	22,200	**6,512**	-	-	Lemke 1965
Bluegill, *Lepomis macrochirus*	S, U	Cadmium chloride	20	1,940	9,375[i]	-	-	Pickering and Henderson 1966
Bluegill, *Lepomis macrochirus*	F, M	Cadmium chloride	207	21,100	10,349	-	-	Eaton 1980
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	18	2,300	12,322[i]	-	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	18	2,300	12,322[i]	-	-	Bishop and McIntosh 1981
Bluegill (1.0 g), *Lepomis macrochirus*	F, M	Cadmium chloride	44.4	6,470	14,322	12,194	9,574	Phipps and Holcombe 1985
Yellow perch (juvenile, 8-12 g), *Perca flavescens*	F, M	Cadmium nitrate	120	8,140	**6,808**	-	**6,808**	Niyogi et al. 2004b
Nile tilapia (adult, 13.1 cm, 77.2 g), *Oreochromis niloticus*	S, M	Cadmium chloride	36.17	24,660	**66,720**	-	**66,720**	Garcia-Santos et al. 2006

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mozambique tilapia, *Oreochromis mossambica*	R, U	Cadmium chloride	28.4	6,000	20,570	-	-	Gaikwad 1989
Mozambique tilapia (1.52 g), *Oreochromis mossambica*	R, U	Cadmium sulfate	17	1,000	**5,666**	21,569	**10,795**	James and Sampath 1999
White sturgeon (2 dph, 0.03g), *Acipenser transmontanus*	F, M	Cadmium chloride	103	>49.98[f] (>47.2 reported dissolved)	**>48.55[c]**	-	-	Calfee et al. 2014
White sturgeon (30 dph, 0.17g, 30.6 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	106	>375.9[f] (>355 reported dissolved)	**>355.0[c]**	-	-	Calfee et al. 2014
White sturgeon (61 dph, 1.15 g, 62.5 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	108	<36.43[f] (<34.4 reported dissolved)	**<33.78**	-	-	Calfee et al. 2014
White sturgeon (72 dph, 1.89 g, 75.6 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	105	>158.3[f] (>149.5 reported dissolved)	**>150.9[c]**	-	-	Calfee et al. 2014
White sturgeon (89 dph, 3.73 g, 97.57 cm), *Acipenser transmontanus*	F, M	Cadmium chloride	104	>289.6[f] (>273.5 reported dissolved)	**>278.6[c]**	-	-	Calfee et al. 2014
White sturgeon (2 dph), *Acipenser transmontanus*	F, M	Cadmium chloride	100	>11.65[f] (>11 reported dissolved)	**>11.65[c]**	-	-	Wang et al. 2014a
White sturgeon (larva, 27 dph), *Acipenser transmontanus*	F, M	Cadmium chloride	100	>11.65[f] (>11 reported dissolved)	**>11.65[c]**	-	**<33.78**	Wang et al. 2014a
Mottled sculpin (swim-up fry, 0.033 g), *Cottus bairdi*	F, M	Cadmium chloride	103	7.9	**7.673**	-	-	Besser et al. 2006; 2007
Mottled sculpin (juvenile, 0.104 g), *Cottus bairdi*	F, M	Cadmium chloride	103	17	**16.51[c]**	-	-	Besser et al. 2006; 2007
Mottled sculpin (juvenile, 0.260 g), *Cottus bairdi*	F, M	Cadmium chloride	103	23	**22.34[c]**	-	-	Besser et al. 2006; 2007

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mottled sculpin (yearling, 2.3 g), *Cottus bairdi*	F, M	Cadmium chloride	103	>67	**>65.08**[c]	-	-	Besser et al. 2006; 2007
Mottled sculpin (newly hatched), *Cottus bairdi*	F, M	Cadmium chloride	103	2.9	**2.817**	-	-	Besser et al. 2006; 2007
Mottled sculpin (fry), *Cottus bairdi*	F, M	Cadmium sulfate	48.7	1.973[f] (1.92 reported-dissolved)	**3.990**	-	**4.418**	Brinkman and Vieira 2007
Shorthead sculpin, *Cottus confusus*	R, M	Cadmium chloride	21	0.9560[f] (0.93 reported dissolved)	**4.404**	-	**4.404**	Mebane et al. 2012
African clawed frog, *Xenopus laevis*	R, U	Cadmium chloride	116	3,597	3,110	-	-	Sunderman et al. 1991
African clawed frog (blastula stage 8-11), *Xenopus laevis*	R, U	Cadmium nitrate	~100	1,600	**1,600**	3,093	**2,231**	Gungordu et al. 2010
Northwestern salamander (larva), *Ambystoma gracile*	F, M	Cadmium chloride	45	468.4	1,023	1,055	1,023	Nebeker et al. 1995

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured

[b] Normalized to a hardness of 100 mg/L using the pooled acute slope of 0.9789.

[c] Data not used to calculate SMAV because more sensitive lifestage available.

[d] Not used to calculate SMAV because other normalized data available.

[e] Freshwater data not normalized so no SMAV calculated.

[f] Study reported a dissolved value only and this value was converted to total cadmium with a conversion factor of 1.028, 1.059 and 1.093 for total hardness levels of 50, 100 and 200 mg/L, respectively for freshwater species and 1.006 for saltwater species.

[g] Not used to calculate SMAV because either a more definitive value available or value is considered an outlier.

[h] Carroll et al. 1979 not used in the 2016 AWQC update because the authors noted that the Cd measured concentration in the control water was greater than the LC_{50} value of 1.5 µg/L and had 100% survival.

[i] Data not used to calculate SMAV because flow-through measured test(s) available.

[j] Cadmium nitrate salt was not used in the SMAV calcualtion for rainbow trout because the values appear to be outliers. This difference may be based on the use of nitrate, which resulted in LC_{50} values for salmonids that averaged 3 to 4 times higher than tests with chloride or sulfate, which are the dominant forms of cadmium in surface water.

Species	Method[a]	Chemical	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Normalized Acute Value[b] (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference

[k] High hardness values for Davies et al. (1993) were not used in the SMAV calculation for rainbow trout because the dilution water maniupluated total hardness with Mg only, and the protective effects of Ca were not in the dilution water (values abnormally low).

Appendix Table A-2. Acute Values used to develop the Acute Hardness Correction Slope

Species	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Reference
Hydra circumcincta	27.0	69.69	Clifford 2009
Hydra circumcincta	85.1	128.1	Clifford 2009
Hydra circumcincta	145	172.0	Clifford 2009
Limnodrilus hoffmeisteri	5.3	170	Chapman et al. 1982
Limnodrilus hoffmeisteri	152	2,400	Williams et al. 1985
Villosa vibex	40	30	Keller, Unpublished
Villosa vibex	186	125	Keller, Unpublished
Daphnia magna	51	9.9	Chapman et al. Manuscript, 1980
Daphnia magna	104	33	Chapman et al. Manuscript, 1980
Daphnia magna	105	34	Chapman et al. Manuscript, 1980
Daphnia magna	197	63	Chapman et al. Manuscript, 1980
Daphnia magna	209	49	Chapman et al. Manuscript, 1980
Daphnia pulex	17.0	16.86	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	24.0	23.61	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	30.0	46.09	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	47.0	24.73	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	67.1	71.94	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	119	116.9	Clifford 2009; Clifford and McGeer 2010
Daphnia pulex	175	155.1	Clifford 2009; Clifford and McGeer 2010
Chironomus riparius	10	331,000	Gillis and Wood 2008
Chironomus riparius	140	1,106,000	Gillis and Wood 2008
Oncorhynchus mykiss	31	1.75	Davies 1976a
Oncorhynchus mykiss	23	1.3	Chapman 1975; 1978
Oncorhynchus mykiss	23	1.0	Chapman 1978
Oncorhynchus mykiss	43.5	2.3	Spehar and Carlson 1984a;b
Oncorhynchus mykiss	44.4	3.0	Phipps and Holcombe 1985
Oncorhynchus mykiss	52	1.88	Stubblefield 1990
Oncorhynchus mykiss	29	2.79	Davies and Brinkman 1994b
Oncorhynchus mykiss	281	13.4	Davies and Brinkman 1994b
Oncorhynchus mykiss	28	2.09	Davies and Brinkman 1994b
Oncorhynchus mykiss	281	10.0	Davies and Brinkman 1994b
Oncorhynchus mykiss	30.7	0.71	Stratus Consulting 1999
Oncorhynchus mykiss	29.3	0.47	Stratus Consulting 1999
Oncorhynchus mykiss	31.7	0.51	Stratus Consulting 1999
Oncorhynchus mykiss	30.2	0.38	Stratus Consulting 1999
Oncorhynchus mykiss	30.0	1.29	Stratus Consulting 1999
Oncorhynchus mykiss	89.3	2.85	Stratus Consulting 1999
Oncorhynchus mykiss	103	3.7	Besser et al. 2007
Oncorhynchus mykiss	103	5.2	Besser et al. 2007
Oncorhynchus mykiss	19.7	0.864	Mebane et al. 2007; 2008
Oncorhynchus mykiss	29.4	0.915	Mebane et al. 2007; 2008
Oncorhynchus mykiss	44	2.75	Niyogi et al. 2008
Oncorhynchus mykiss	21	0.8224	Mebane et al. 2012
Oncorhynchus mykiss	7	0.4934	Mebane et al. 2012

Species	Hardness (mg/L $CaCO_3$)	Acute Value (µg/L)	Reference
Oncorhynchus mykiss	13	1.018	Mebane et al. 2012
Oncorhynchus mykiss	24	1.336	Mebane et al. 2012
Oncorhynchus mykiss	32	0.9560	Mebane et al. 2012
Oncorhynchus mykiss	29	0.8532	Mebane et al. 2012
Oncorhynchus mykiss	21	0.3495	Mebane et al. 2012
Salmo trutta	43.5	1.4	Spehar and Carlson 1984a;b
Salmo trutta	48	2.85	Stubblefield 1990
Salmo trutta	37.6	2.37	Davies and Brinkman 1994c
Salmo trutta	29.2	1.23	Brinkman and Hansen 2004a; 2007
Salmo trutta	67.6	3.9	Brinkman and Hansen 2004a; 2007
Salmo trutta	151	10.1	Brinkman and Hansen 2004a; 2007
Carassius auratus	20	2,130	McCarty et al. 1978
Carassius auratus	140	46,800	McCarty et al. 1978
Danio rerio	141	1,832	Alsop and Wood 2011
Danio rerio	7.8	125.2	Alsop and Wood 2011
Pimephales promelas	201	11,200	Pickering and Gast 1972
Pimephales promelas	201	12,000	Pickering and Gast 1972
Pimephales promelas	201	6,400	Pickering and Gast 1972
Pimephales promelas	201	2,000	Pickering and Gast 1972
Pimephales promelas	201	4,500	Pickering and Gast 1972
Pimephales promelas	103	3,060	Birge et al. 1983
Pimephales promelas	103	2,900	Birge et al. 1983
Pimephales promelas	103	3,100	Birge et al. 1983
Pimephales promelas	262.5	7,160	Birge et al. 1983
Pimephales promelas	43.5	1,280	Spehar and Carlson 1984a;b
Pimephales promelas	44.4	1,500	Phipps and Holcombe 1985
Pimephales promelas	44	13.2	Spehar and Fiandt 1986
Pimephales promelas	85.5	3,580	Carrier 1987; Carrier and Beitinger 1988a
Lepomis cyanellus	335	20,500	Jude 1973
Lepomis cyanellus	85.5	11,520	Carrier 1987; Carrier and Beitinger 1988b
Lepomis macrochirus	20	1,700	Lemke 1965
Lepomis macrochirus	350	22,200	Lemke 1965
Lepomis macrochirus	207	21,100	Eaton 1980
Lepomis macrochirus	18	2,300	Bishop and McIntosh 1981
Lepomis macrochirus	18	2,300	Bishop and McIntosh 1981
Lepomis macrochirus	44.4	6,470	Phipps and Holcombe 1985

Appendix Table A-3. Acute Freshwater Total to Dissolved Conversion Factors for Cadmium based on Hardness.

Hardness (mg/L as $CaCO_3$)	Conversion Factor[a]
25	1.0020
50	0.9730
75	0.9560
100	0.9440
150	0.9270
200	0.9150
250	0.9057
300	0.8980
350	0.8916
400	0.8860

a The conversion factor (CF) is calculated as: CF = 1.136672 - (ln (hardness) x 0.041838).

Appendix B Acceptable Estuarine/Marine Acute Toxicity Data

Appendix Table B-1. Acceptable Estuarine/Marine Acute Toxicity Data

(Underlined values are used in SMAV calculation and values in bold represent new/revised values since 2001 AWQC document). (Species are organized phylogenetically).

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Nematode (juvenile, 2.5 d), (formerly, *Pellioditis marina*) *Rhabditis marina*	S, U	Cadmium chloride	30	**9,100**	-	**9,100**	Vranken et al. 1985
Polychaete worm (adult), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	12,000	-	-	Reish et al. 1976
Polychaete worm (juvenile), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	12,500	-	-	Reish et al. 1976
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (20°C)	**18,540**	-	-	Reish et al. 1977
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (20°C)	**5,600**	-	-	Reish et al. 1977
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (15°C)	**>5,600**	-	-	Reish et al. 1977
Polychaete worm (2 mo.), *Neanthes arenaceodentata*	S, U	Cadmium chloride	32 (15°C)	**30,030**	-	-	Reish et al. 1977
Polychaete worm, *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	14,100	12,836	**12,052**	Reish and LeMay 1991
Polychaete, *Nereis grubei*	S, U	Cadmium chloride	-	4,700	4,700	4,700	Reish and LeMay 1991
Polychaete worm, (formerly, *Nereis virens*) *Alitta virens*	S, U	Cadmium chloride	20	11,000	-	-	Eisler 1971
Polychaete worm, *Alitta virens*	S, U	Cadmium chloride	20	9,300	10,114	10,114	Eisler and Hennekey 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32	**1,770**	-	-	Reish et al. 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32 (20°C)	**1,370**	-	-	Reish et al. 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32 (15°C)	**4,790**	-	-	Reish et al. 1977

Species	**Method[a]**	**Chemical**	**Salinity (g/kg)**	**Acute Value (µg/L)**	**2001 SMAV (µg/L)**	**2016 SMAV (µg/L)**	**Reference**
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32 (15°C)	**19,090**	-	-	Reish et al. 1977
Polychaete, *Ophryotrocha diadema*	S, U	Cadmium chloride	32	**4,200**	-	**3,925**	Reish 1978
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (20°C)	**2,720**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (20°C)	**2,240**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (15°C)	**3,330**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (15°C)	**6,030**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (10°C)	**3,690**	-	-	Reish et al. 1977
Polychaete worm, *Ctenodrilus serratus*	S, U	Cadmium chloride	32 (10°C)	**2,130**	-	**3,142**	Reish et al. 1977
Polychaete worm (adult), *Capitella capitata*	S, U	Cadmium chloride	-	7,500[c]	-	-	Reish et al. 1976
Polychaete worm (larva), *Capitella capitata*	S, U	Cadmium chloride	-	200	-	-	Reish et al. 1976
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (20°C)	**5,030[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (20°C)	**5,140[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (15°C)	**16,300[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (15°C)	**6,000[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (10°C)	**28,444[c]**	-	-	Reish et al. 1977
Polychaete worm (15 d), *Capitella capitata*	S, U	Cadmium chloride	32 (10°C)	**5,880[c]**	-	-	Reish et al. 1977
Polychaete worm, *Capitella capitata*	S, U	Cadmium chloride	-	2,800[c]	200	200	Reish and LeMay 1991

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Starlet sea anemone (adult, female), *Nematostella vectensis*	S, M	Cadmium chloride	10	**1,284**	-	-	Harter and Matthews 2005
Starlet sea anemone (adult, female), *Nematostella vectensis*	S, M	Cadmium chloride	12	**1,092**	-	**1,184**	Harter and Matthews 2005
Cone worm, *Pectinaria californiensis*	S, U	Cadmium chloride	-	2,600	2,600	2,600	Reish and Lemay 1991
Oligochaete, (formerly, *Limnodriloides verrucosus*) *Tectidrilus verrucosus*	R, U	Cadmium sulfate	-	10,000	10,000	10,000	Chapman et al. 1982
Oligochaete worm, *Monopylephorus cuticulatus*	R, U	Cadmium sulfate	-	135,000	135,000	135,000	Chapman et al. 1982
Oligochaete worm, *Tubificoides gabriellae*	R, U	Cadmium sulfate	-	24,000	24,000	24,000	Chapman et al. 1982
Atlantic oyster drill, *Urosalpinx cinerea*	S, U	Cadmium chloride	-	6,600	6,600	6,600	Eisler 1971
Gastropod (2-15 cm), (formerly, *Morula granulata*) *Tenguella granulata*	R, U	Cadmium chloride	32	**2,060**	-	**2,060**	Devi 1997
Dog whelk (29.6 mm, 601 mg), *Nucella lapillus*	R, U	Cadmium chloride	34	**23,200**	-	**23,200**	Leung and Furness 1999
Eastern mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	10,500	-	-	Eisler 1971
Eastern mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	35,000	19,170	19,170	Eisler and Hennekey 1977

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Barnacle (larva-nauplii II), *Amphibalanus amphitrite*	S, U	Cadmium nitrate	37	**490**	-	**490**	Piazza et al. 2012
Blue mussel, *Mytilus edulis*	S, U	Cadmium chloride	-	25,000[c]	-	-	Eisler 1971
Blue mussel, *Mytilus edulis*	S, M	Cadmium chloride	-	1,620[c]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	3600[c]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	4300[c]	-	-	Ahsanullah 1976
Blue mussel (embryo), *Mytilus edulis*	S, U	Cadmium chloride	33.8	1,200	-	-	Martin et al. 1981
Blue mussel (juvenile), *Mytilus edulis*	R, U	Cadmium chloride	25	960	1,073	1,073	Nelson et al. 1988
Blue mussel (embryo), *Mytilus trossolus*	S, M	Cadmium chloride	-	**505.0**[f] (502 reported-dissolved)	-	**505.0**	Nadella et al. 2009
Bay scallop (juvenile), *Argopecten irradians*	S, U	Cadmium chloride	-	1,480	1,480	1,480	Nelson et al. 1976
Scallop (juvenile, 35 d, 3 mm), *Argopecten ventricosus*	R, U	Cadmium chloride	36	**396**	-	**396**	Sobrino-Figueroa et al. 2007
Pacific oyster (embryo), *Crassostrea gigas*	S, U	Cadmium chloride	33.8	611	-	-	Martin et al. 1981
Pacific oyster (larva, 6 d), *Crassostrea gigas*	R, U	Cadmium chloride	34	85	-	-	Watling 1982
Pacific oyster (larva, 16 d), *Crassostrea gigas*	R, U	Cadmium chloride	34	**>100**	227.9	**173.2**	Watling 1982
American oyster (larva), *Crassostrea virginica*	S, U	Cadmium chloride	25	3,800	3,800	3,800	Calabrese et al. 1973

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Brown mussel (20-24 mm), (formerly, *Perna indica*) *Perna perna*	S, U	Cadmium chloride	-	**2,213**	-	-	Baby and Menon 1986
Brown mussel (20-24 mm), *Perna perna*	R, U	Cadmium chloride	32	**1,357**	-	-	Baby and Menon 1987
Brown mussel (20-24 mm), *Perna perna*	R, U	Cadmium sulfate	32	**818.0**	-	-	Baby and Menon 1987
Brown mussel (20-24 mm), *Perna perna*	R, U	Cadmium nitrate	32	**701.3**	-	**1,146**	Baby and Menon 1987
Green mussel (20-25 mm), *Perna viridis*	S, U	Cadmium chloride	-	**2,500**	-	-	Mohan et al. 1986
Green mussel, *Perna viridis*	R, U	Cadmium chloride	33	**1,570**	-	**1,981**	Chan 1988
Mangrove oysters (embryo), *Isognomon californicum*	S, U	Cadmium chloride	34	**500**	-	-	Ringwood 1990
Mangrove oysters (larva, 3 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**500**	-	-	Ringwood 1990
Mangrove oysters (larva, 10 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**500**	-	-	Ringwood 1990
Mangrove oysters (larva, 24 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**4,000**[c]	-	-	Ringwood 1990
Mangrove oysters (larva, 36 d), *Isognomon californicum*	S, U	Cadmium chloride	34	**4,000**[c]	-	-	Ringwood 1990
Mangrove oysters (embryo), *Isognomon californicum*	S, U	Cadmium chloride	24	**300**	-	-	Ringwood 1990
Mangrove oysters (larva, 3 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**380**			Ringwood 1990
Mangrove oysters (larva, 10 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**400**			Ringwood 1990

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mangrove oysters (larva, 24 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**2,000**[c]			Ringwood 1990
Mangrove oysters (larva, 36 d), *Isognomon californicum*	S, U	Cadmium chloride	24	**2,000**[c]	-	**422.6**	Ringwood 1990
Horse clam (newly hatched embryos), *Tresus capax*	S, U	Cadmium sulfate	30	**60**	-	**60**	Cardwell et al. 1979
Horse clam, Pacific gaper (newly hatched embryos), *Tresus nuttalli*	S, U	Cadmium sulfate	29	**590**	-	**590**	Cardwell et al. 1979
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,200	-	-	Eisler 1971
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	850	-	-	Eisler 1977
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,500	1,672	1,672	Eisler and Hennekey 1977
Horseshoe crab (1st instar larva, 3.3 mm), *Limulus polyphemus*	R, U	Cadmium chloride	20	**167,700**	-		Botton 2000
Horseshoe crab (embryo), *Limulus polyphemus*	R, U	Cadmium chloride	20	**171,900**	-	**169,787**	Botton 2000
California market squid (larva), *Loligo opalescens*	S, M	Cadmium chloride	30	>10,200	>10,200	>10,200	Dinnel et al. 1989
Copepod, *Pseudodiaptomus coronatus*	S, U	Cadmium chloride	-	1,708	1,708	1,708	Gentile 1982
Calanoid copepod, *Eurytemora affinis*	S, U	Cadmium chloride	-	1,080[c]	-	-	Gentile 1982

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Calanoid copepod (newly hatched nauplii), *Eurytemora affinis*	S, U	Cadmium chloride	-	147.7	147.7	147.7	Sullivan et al. 1983
Copepod, *Acartia clausi*	S, U	Cadmium chloride	-	144	144	144	Gentile 1982
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	337	-	-	Sosnowski and Gentile 1978
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	90	-	-	Sosnowski and Gentile 1978
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	220	-	-	Sosnowski and Gentile 1978
Calanoid copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	122	-	-	Sosnowski and Gentile 1978
Calanoid copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	15 (18ºC)	93	-	-	Toudal and Riisgard 1987
Calanoid copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	20 (13ºC)	151	-	-	Toudal and Riisgard 1987
Calanoid copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	21 (21ºC)	29	118.7	118.7	Toudal and Riisgard 1987
Harpacticoid copepod, (formerly, *Nitocra spinipes*) *Nitokra spinipes*	S, U	Cadmium chloride	-	1,800	-	-	Bengtsson 1978
Harpacticoid copepod, *Nitokra spinipes*	F, U	Cadmium chloride	3	430	-	-	Bengtsson and Bergstrom 1987
Harpacticoid copepod, *Nitokra spinipes*	F, U	Cadmium chloride	7	660	-	-	Bengtsson and Bergstrom 1987
Harpacticoid copepod, *Nitokra spinipes*	F, U	Cadmium chloride	15	780	794.5	794.5	Bengtsson and Bergstrom 1987
Harpacticoid copepod, (formerly, *Amphiascus tenuiremis*) *Saramphiascus tenuiremis*	S, M	Cadmium nitrate	30.7	224	224	224	Green et al. 1993

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Harpacticoid copepod (nauplii), *Tigriopus brevicornis*	S, U	Cadmium chloride	34.5-35	**17.4**	-	-	Forget et al. 1998
Harpacticoid copepod (copepodid), *Tigriopus brevicornis*	S, U	Cadmium chloride	34.5-35	**29.7**	-	-	Forget et al. 1998
Harpacticoid copepod (ovigerous female), *Tigriopus brevicornis*	S, U	Cadmium chloride	34.5-35	**47.9**	-	**29.14**	Forget et al. 1998
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	10-17	15.5	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	30	110	-	-	Gentile et al. 1982; Lussier et al. 1985
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	20	**23**[i]	-	-	Roberts et al. 1982
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	6	14.7[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	14	38.0[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	22	70.4[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	30	77.3[i]	-	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M	Cadmium chloride	38	90.3[i]	-	-	De Lisle and Roberts 1988
Mysid (<24 hr), *Americamysis bahia*	S, M	-	10 (20ºC)	30.9[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	10 (25ºC)	20.7[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	10 (30ºC)	<11.1[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	30 (20ºC)	82.0[i]	-	-	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M	-	30 (25ºC)	32.8[i]	-	-	Voyer and Modica 1990

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mysid (<24 hr), *Americamysis bahia*	S, M	-	30 (30ºC)	<11.1[i]	41.29	41.29	Voyer and Modica 1990
Mysid (juvenile, 24 hr), (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	F, M	Cadmium chloride	30	110	110	110	Gentile et al. 1982
Mysid (adult), *Neomysis americana*	S, M	Cadmium chloride	20	**28.14**	-	**28.14**	Roberts et al. 1982
Mysid (adult, 18 mm), *Praunus flexuosus*	R, U	Cadmium chloride	30	**410.3**	-	**410.3**	Roast et al. 2001b
Isopod (adult), *Excirolana vancouverensis*	R, U	Cadmium chloride	28	**>8,000**	-	**>8,000**	Boese et al. 1997
Isopod, (formerly, *Jaeropsis sp.*) *Joeropsis sp.*	S, U	Cadmium chloride	35	410.0	410.0	410.0	Hong and Reish 1987
Wood borer, *Limnoria tripunctata*	S, U	Cadmium chloride	35	7,120	7,120	7,120	Hong and Reish 1987
Amphipod (adult), *Ampelisca abdita*	F, M	Cadmium chloride	-	2,900	2,900	2,900	Scott et al. Manuscript
Amphipod, *Chelura terebrans*	S, U	Cadmium chloride	35	630	630	630	Hong and Reish 1987
Amphipod, *Corophium insidiosum*	S, U	Cadmium chloride	35	1,270	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Corophium insidiosum*	S, U	Cadmium chloride	-	680	-	-	Reish 1993
Amphipod, *Corophium insidiosum*	R, U	Cadmium chloride	28	**960**	-	**-**	Boese et al. 1997

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Amphipod (2-4 mm), *Corophium insidiosum*	S, M	Cadmium chloride	35.9 (10ºC)	**2,110**	-	-	Prato et al. 2008
Amphipod (2-4 mm), *Corophium insidiosum*	S, M	Cadmium chloride	35.9 (25ºC)	**700**	929.3	**1,041**	Prato et al. 2008
Amphipod (juvenile), *Diporeia spp.*	S, M	Cadmium chloride	20 (4ºC)	49,400[g]	-	-	Gossiaux et al. 1992
Amphipod (juvenile), *Diporeia spp.*	S, M	Cadmium chloride	20 (10ºC)	17,500[g]	-	-	Gossiaux et al. 1992
Amphipod (juvenile), *Diporeia spp.*	S, M	Cadmium chloride	20 (15ºC)	6,700	6,700	6,700	Gossiaux et al. 1992
Amphipod, *Elasmopus bampo*	S, U	Cadmium chloride	35	570	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Elasmopus bampo*	S, U	Cadmium chloride	-	900	716.2	716.2	Reish 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M	Cadmium chloride	30 (held 11 days before testing)	41,900	-	-	Meador 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M	Cadmium chloride	30 (held 17 days before testing)	36,100	-	-	Meador 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M	Cadmium chloride	30 (held 121 days before testing)	14,500	-	-	Meador 1993
Amphipod, *Eohaustorius estuarius*	R, U	Cadmium chloride	28	**12,510**	27,992	**22,887**	Boese et al. 1997
Amphipod, *Grandidierella japonica*	S, U	Cadmium chloride	35	1,170	-	-	Hong and Reish 1987
Amphipod, *Grandidierella japonica*	R, U	Cadmium chloride	28	**340**	1,170	**630.7**	Boese et al. 1997
Amphipod, *Leptocheirus plumulosus*	R, U	Cadmium chloride	20	**1,450**	-	**-**	Boese et al. 1997

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Amphipod (500 um), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	360	-	-	McGee et al. 1998
Amphipod (700 um), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	650	-	-	McGee et al. 1998
Amphipod (1,000 um), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	880	590.5	739.2	McGee et al. 1998
Amphipod, *Rhepoxynius abronius*	R, U	Cadmium chloride	28	**1,510**	-	**1,510**	Boese et al. 1997
Scud (adult), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	13,000[c]	-	-	Wright and Frain 1981
Scud (young), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	3,500	3,500	3,500	Wright and Frain 1981
Northern pink shrimp (subadult), (formerly, *Penaeus duorarum*) *Farfantepenaeus duorarum*	F, M	Cadmium chloride	-	3,500[c]	-	-	Nimmo et al. 1977b
Northern pink shrimp (2nd post larva), *Farfantepenaeus duorarum*	S, U	Cadmium chloride	25	310.5	310.5	310.5	Cripe 1994
White shrimp (juvenile), (formerly, *Penaeus setiferus*) *Litopenaeus setiferus*	S, M	Cadmium chloride	11	**990**	-	**990**	Vanegas et al. 1997
Whiteleg shrimp (post larva), *Litopenaeus vannamei*	R, U	Cadmium chloride	34	**2,490**	-	-	Frias-Espericueta et al. 2001
White shrimp (post larva, 7.13 mg), *Litopenaeus vannamei*	R, U	-	15	**1,070**	-	**1,632**	Wu and Chen 2004
Tiger shrimp (juvenile), *Penaeus monodon*	R, M	Cadmium chloride	28	**1,720**	-	**1,720**	Raj Kumar 2012

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Daggerblade grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	3,280	-	-	Khan et al. 1988
Daggerblade grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	1,830	-	-	Khan et al. 1988
Daggerblade grass shrimp (juvenile), *Palaemonetes pugio*	S, M	Cadmium chloride	10	1,300	1,983	1,983	Burton and Fisher 1990
Grass shrimp, *Palaemonetes vulgaris*	S, U	Cadmium chloride	-	420[i]	-	-	Eisler 1971
Grass shrimp, *Palaemonetes vulgaris*	F, M	Cadmium chloride	-	760	760	760	Nimmo et al. 1977b
Sand shrimp, *Crangon septemspinosa*	S, U	Cadmium chloride	-	320	320	320	Eisler 1971
American lobster (larva), *Homarus americanus*	S, U	Cadmium nitrate	-	78	78	78	Johnson and Gentile 1979
Longwrist hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	320	-	-	Eisler 1971
Longwrist hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	1,300	645.0	645.0	Eisler and Hennekey 1977
Rock crab (zoea), (formerly, *Cancer irroratus*) *Cancer plebejus*	F, M	Cadmium chloride	-	250	250	250	Johns and Miller 1982
Dungeness crab (zoeae), *Cancer magister*	S, U	Cadmium chloride	33.8	247	-	-	Martin et al. 1981
Dungeness crab (zoeae), *Cancer magister*	S, M	Cadmium chloride	30	200	222.3	222.3	Dinnel et al. 1989
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	35	11,600	-	-	Frank and Robertson 1979

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	15	4,700	-	-	Frank and Robertson 1979
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	1	320	2,594	2,594	Frank and Robertson 1979
Lesser blue crab (intermolt, 1-5 g), *Callinectes similis*	R, U	Cadmium chloride	30	**6,350**	-	**6,350**	Ramirez et al. 1989
Green shore crab, *Carcinus maenas*	S, U	Cadmium chloride	-	4,100	4,100	4,100	Eisler 1971
Mud crab (1 g), *Eurypanopeus depressus*	S, U	Cadmium chloride	25	**4,900**	-	**4,900**	Collier et al. 1973
Pacific sand crab (juvenile), *Emerita analoga*	R, U	Cadmium chloride	28	**2,110**	-	**2,110**	Boese et al. 1997
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	10 (20°C)	32,300	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	20 (20°C)	46,600	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	30 (20°C)	37,000	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	10 (30°C)	6,800	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	20 (30°C)	10,400	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	30 (30°C)	23,300	21,238	21,238	O'Hara 1973a
Fiddler crab (intermolt, males, 24-29 mm carapace), *Uca triangularis*	R, U	Cadmium chloride	25	**7,660**	-	**7,660**	Devi 1987
Common starfish, *Asterias forbesii*	S, U	Cadmium chloride	-	820	-	-	Eisler 1971

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Common starfish, *Asterias forbesii*	S, U	Cadmium chloride	-	7,100	2,413	2,413	Eisler and Hennekey 1977
Green sea urchin (embryo), *Strongylocentrotus droebachiensis*	S, M	Cadmium chloride	30	1,800	1,800	1,800	Dinnel et al. 1989
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M	Cadmium chloride	30	500	-	-	Dinnel et al. 1989
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M	Cadmium chloride	34	**342.3**	500	**413.7**	Phillips et al. 2003
Sand dollar (embryo), *Dendraster excentricus*	S, M	Cadmium chloride	30	7,400	7,400	7,400	Dinnel et al. 1989
Moon jellyfish (ephyra), *Aurelia aurita*	S, U	Cadmium nitrate	37	**61.75**	-	**61.75**	Faimali et al. 2013
Coho salmon (smolt), *Oncorhynchus kisutch*	F, M	Cadmium chloride	28.3	1,500	1,500	1,500	Dinnel et al. 1989
Sheepshead minnow (36 mm, 1.1 g), *Cyprinodon variegatus*	S, U	Cadmium chloride	-	50,000	-	-	Eisler 1971
Sheepshead minnow (25.8 mm, 0.27 g), *Cyprinodon variegatus*	S, M	Cadmium chloride	10	**15,900**	50,000	**28,196**	Roberts et al. 1982
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	49,000[i]	-	-	Eisler 1971
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	114,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	92,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	78,000[i]	-	-	Voyer 1975

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	73,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	73,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	63,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	31,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	30,000[i]	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	29,000[i]	-	-	Voyer 1975
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	22,000[i]	-	-	Eisler and Hennekey 1977
Mummichog (12-20 mm), *Fundulus heteroclitus*	F, M	Cadmium sulfate	14	18,200	18,200	18,200	Lin and Dunson 1993
Striped killifish (adult), *Fundulus majalis*	S, U	Cadmium chloride	-	21,000	21,000	21,000	Eisler 1971
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M	Cadmium sulfate	14	23,700[c]	-	-	Lin and Dunson 1993
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M	Cadmium sulfate	14	18,500[c]	-	-	Lin and Dunson 1993
Rivulus (adult, 120 d), *Rivulus marmoratus*	S, M	Cadmium chloride	10	32,200[c]	-	-	Park et al. 1994
Rivulus (juvenile, 30 d), *Rivulus marmoratus*	S, M	Cadmium chloride	10	18,800[c]	-	-	Park et al. 1994
Rivulus (larvae, 7 d), *Rivulus marmoratus*	S, M	Cadmium chloride	10	800	800	800	Park et al. 1994
Atlantic silverside (59.4 mm, 2.15 g), *Menidia menidia*	S, M	Cadmium chloride	10	**6,400[c]**	-	-	Roberts et al. 1982
Atlantic silverside (adult), *Menidia menidia*	S, U	Cadmium chloride	30	2,032[c]	-	-	Cardin 1985

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	30	28,532[c]	-	-	Cardin 1985
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	30	13,652[c]	-	-	Cardin 1985
Atlantic silverside (larva, 1d), *Menidia menidia*	S, U	Cadmium chloride	30.4	1,054	779.8	**1,054**	Cardin 1985
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	1	75.0	75.0	75.0	Palawski et al. 1985
Cabezon (larva), *Scorpaenichthys marmoratus*	S, M	Cadmium chloride	27	>200	>200	>200	Dinnel et al. 1989
Pinfish (subadult), *Lagodon rhomboides*	S, U	Cadmium	1	**1,000**	-	**1,000**	Sharp 1988
Shiner perch (adult, 87 mm), *Cymatogaster aggregata*	F, M	Cadmium chloride	30.1	11,000	11,000	11,000	Dinnel et al. 1989
Striped mullet (juvenile, 50 mm), *Mugil cephalus*	S, U	Cadmium chloride	37.3	28,000[c]	-	-	Hilmy et al. 1985
Striped mullet (fry, 10 mm), *Mugil cephalus*	S, U	Cadmium chloride	37.3	7,079	7,079	7,079	Hilmy et al. 1985
White mullet, *Mugil curema*	S, U	Cadmium chloride	36	**12,000**	-	**12,000**	Chung 1978
Mozambique tilapia (27 mm), *Oreochromis mossambicus*	S, U	Cadmium chloride	1	**>80,000**	-	**>80,000**	Chung 1983
Cunner (2-3 yr., 1 cm, 14-29 g), *Tautogolabrus adspersus*	R, U	Cadmium chloride	-	25,900	-	**25,900**	Robohm 1986

Species	Method[a]	Chemical	Salinity (g/kg)	Acute Value (µg/L)	2001 SMAV (µg/L)	2016 SMAV (µg/L)	Reference
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	-	14,297	14,297	14,297	Cardin 1985
Scorpionfish (287 g), *Scorpaena guttata*	R, M	Cadmium chloride	-	**62,000**	-	**62,000**	Brown et al. 1984

[a] S=static, R=renewal, F=flow-through, U=unmeasured, M=measured

[c] Data not used to calculate SMAV because more sensitive lifestage available.

[f] Study reported a dissolved value only and this value was converted to total cadmium with a conversion factor of 1.028, 1.059 and 1.093 for total hardness levels of 50, 100 and 200 mg/L, respectively for freshwater species and 1.006 for saltwater species.

[g] Not used to calculate SMAV because either a more definitive value available or value is considered an outlier.

[i] Data not used to calculate SMAV because flow-through measure test(s) available.

Appendix C Acceptable Freshwater Chronic Toxicity Data

Appendix Table C-1. Acceptable Freshwater Chronic Toxicity Data

(Values normalized to total hardness=100 mg/L as $CaCO_3$ using pooled hardness slope of 0.7977 and expressed as total cadmium).
(Underlined values are used in SMCV calculation and values in bold represent new/revised values since 2001 AWQC document).
(Species are organized phylogenetically).

Species	**Method^a**	**Test^a**	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Chronic Limits (µg/L)**	**MATC (µg/L)**	**EC_{20} (µg/L)**	**Normalized Chronic Value^b (µg/L)**	**2001 SMCV (µg/L)**	**2016 SMCV (µg/L)**	**Reference**
Oligochaete, *Aeolosoma headleyi*	R, M	LC	Cadmium chloride	175 (160-190)	32-50.2	40.08 (growth & reproduction)	57.35 (growth)	**36.70**	34.66	**36.70**	Niederlehner et al. 1984
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	R, M	28 d	-	140	86.9-107.6	96.70 (reproduction)	19.83 (reproduction)	**15.16**	-	-	Straus 2011
Oligochaete (adult), *Lumbriculus variegatus*	R, M	28 d	-	22	2.3->2.3	>2.3 (survival)	-	**>7.695^c**	-	**15.16**	Straus 2011
Snail (<24 hr, egg masses), *Aplexa hypnorum*	F, M	LC	Cadmium chloride	45.3	4.41-7.63	5.801 (-)	4.002 (reproduction)	7.525	-		Holcombe et al. 1984
Snail (<24 hr, egg masses), *Aplexa hypnorum*	F, M	LC	Cadmium chloride	45.3	2.50-4.79	3.460 (-)	0.8737 (survival)	1.643	8.055	3.516	Holcombe et al. 1984
Pond snail (5 mm), *Lymnaea stagnalis*	R, M	31 d	Cadmium chloride	135 (130-140)	9.43-28.3	16.34 (growth)	1.944 (survival)	**1.530**	-	-	Pais 2012
Pond snail (10 mm), *Lymnaea stagnalis*	R, M	31 d	Cadmium chloride	135 (130-140)	28.3-94.3	51.66 (survival)	35.56 (growth)	**27.99**	-	-	Pais 2012
Pond snail (15 mm), *Lymnaea stagnalis*	R, M	31 d	Cadmium chloride	135 (130-140)	94.3->94.3	>94.3 (growth)	28.68 (growth)	**22.57**	-	-	Pais 2012
Pond snail (5 mm), *Lymnaea stagnalis*	R, M	28 d	Cadmium chloride	90	5.20->5.20	>5.20 (survival & growth)	-	**>5.655^c**	-	**9.887**	Pais 2012
Mudsnail, *Potamopyrgus antipodarum*	R, M	28 d	Cadmium sulfate	-	0.806-3.44	1.665 (reproduction)	2.641 (reproduction)	-	-	**NA^f**	Sieratowicz et al. 2011

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Fatmucket (juvenile), *Lampsilis siliquoidea*	F, M	28 d	Cadmium nitrate	44 (40-48)	4.4-8.2	6.007 (survival & growth)	5.868 (growth)	**11.29**	-	**11.29**	Wang et al. 2010d
Cladoceran, *Ceriodaphnia dubia*	-	LC	-	100	-	2.20 (-)	-	**2.200**[c]	-	-	Spehar and Fiandt 1986
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	-	20	10-19	13.78 (-)	-	49.75[c]	-	-	Jop et al. 1995
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	5.304-9.934	7.259 (survival & reproduction)	6.129 (reproduction)	**2.775**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	1.073-2.391	1.602 (reproduction)	2.262 (reproduction)	**1.024**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	3.066-4.108	3.549 (reproduction)	3.029 (reproduction)	**1.371**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	5.457-7.174	6.257 (survival & reproduction)	3.376 (reproduction)	**1.528**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	R, M	LC	Cadmium chloride	270	1.748-2.391	2.044 (reproduction)	1.341 (reproduction)	**0.6071**	-	-	Southwest Texas State Univeristy 2000
Cladoceran, *Ceriodaphnia dubia*	-	LC	-	170	1.1-3.4	1.93 (reproduction)	-	**1.264**[c]	45.40	**1.293**	Brooks et al. 2004
Cladoceran, *Ceriodaphnia reticulata*	-	LC	-	44	3.6-7.5	5.20 (-)	-	**10.01**	-	**NA**[g]	Spehar and Carlson 1984a,b
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	53	0.08-0.29	0.1523 (reproduction)	-	0.2527[c]	-	-	Chapman et al. Manuscript, 1980
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	103	0.16-0.28	0.2117 (reproduction)	0.2118 (reproduction)	0.2068	-	-	Chapman et al. Manuscript, 1980

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L CaCO$_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	209	0.21-0.91	0.4371 (reproduction)	0.3545 (reproduction)	0.1969	-	-	Chapman et al. Manuscript, 1980
Cladoceran, *Daphnia magna*	R, M	LC	-	200	0.37-0.48	0.37 (EC$_{20}$)	0.37 (-)	**0.2128**	-	-	Canton and Slooff 1982
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium chloride	150	5.0-10	7.07 (reproduction)	6.166 (survival)	4.461	-	-	Bodar et al. 1988b
Cladoceran, *Daphnia magna*	R, M	LC	Cadmium	130	<1.86-1.86	<1.86 (reproduction)	1.677 (reproduction)	1.360	-	-	Borgmann et al. 1989a; b
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	170	0.6-2.0	1.10 (growth)	-	**0.7203**[c]	-	-	Baird et al. 1990
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	99	1.67-3.43	2.39 (reproduction)	2.496 (reproduction)	**2.516**	-	-	Chadwick Ecological Consultants 2003
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	51	1.97-3.43	2.60 (reproduction)	2.373 (reproduction)	**4.059**	-	-	Chadwick Ecological Consultants 2003
Cladoceran (<24 hr), *Daphnia magna*	R, M	LC	Cadmium chloride	-	0.328-0.656	0.46 (reproduction)	1.528 (survival)	**NA**[c]	<0.6340	**0.9150**	Jemec et al. 2008
Cladoceran, *Daphnia pulex*	R, M	LC	Cadmium chloride	65	5.5-10.2	7.49 (survival & reproduction)	6.214 (growth)	8.761	-	-	Niederlehner 1984
Cladoceran (<24 hr), *Daphnia pulex*	R, M	LC	Cadmium chloride	52	14.6->14.6	>14.6 (reproduction)	3.051 (reproduction)	**5.140**	-	-	Chadwick Ecological Consultants 2003
Cladoceran, *Daphnia pulex*	-	LC	-	52	-	-	1.45 (survival)	**2.443**	-	-	Chadwick Ecological Consultants 2004a

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Cladoceran, *Daphnia pulex*	-	LC	-	52	-	-	2.17 (reproduction)	**3.655**	10.30	**4.478**	Chadwick Ecological Consultants 2004a
Amphipod (7-8 d), *Hyalella azteca*	F, M	LC	Cadmium chloride	280	0.51-1.9	0.984 (growth & survival)	1.695 (reproduction)	0.7453	0.4590	0.7453	Ingersoll and Kemble 2001
Midge (larva, <24 hr), *Chironomus dilutus*	F, M	LC	Cadmium chloride	280	5.8-16.4	9.753 (growth)	4.548 (percent hatch)	2.000	4.686	2.000	Ingersoll and Kemble 2001
Rio Grande cutthroat trout (eyed egg), *Oncorhynchus clarkii virginalis*	F, M	ELS	Cadmium sulfate	44.9	1.48-3.37	2.296[e] (2.233 dissolved) (survival, growth & biomass)	1.871[e] (1.82 dissolved) (survival, growth & biomass)	**3.543**	-	**3.543**	Brinkman 2012
Coho salmon (Lake Superior), *Oncorhynchus kisutch*	-	ELS	Cadmium chloride	44	1.3-3.4	2.102 (-)	-	4.046	-	-	Eaton et al. 1978
Coho salmon (West Coast), *Oncorhynchus kisutch*	-	ELS	Cadmium chloride	44	4.1-12.5	7.159 (-)	-	13.78	7.127	**NA[g]**	Eaton et al. 1978
Rainbow trout (adult, female, 270 d), *Oncorhynchus mykiss*	-	LC	-	250	3.39-5.48	4.310 (-)	3.319 (reproduction)	1.598	-	-	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	F, M	PLC	-	46	1.25-1.74	1.47 (lethal to 1%)	2.473 (survival)	**4.593**	-	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	F, M	PLC	-	217	2.55-5.03	3.58 (lethal to 1%)	4.762 (survival)	**2.567**	-	-	Davies et al. 1993
Rainbow trout, *Oncorhynchus mykiss*	F, M	PLC	-	413.8	2.57-5.16	3.64 (lethal to 1%)	3.808 (survival)	**1.226**	-	-	Davies et al. 1993

Species	Method^{a}	Test^{a}	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	Normalized Chronic Value^{b} (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium sulfate	301	8.20-14.2	10.8 (survival)	9.508 (survival)	**3.947^{d}**	-	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium sulfate	282	1.48-2.24 (aged solution)	1.82 (survival)	-	**0.7962^{c}**	-	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium sulfate	29	1.02-1.89	1.39 (survival)	2.604 (survival)	**6.989^{d}**	-	-	Davies and Brinkman 1994b
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	-	103	1.3-2.7	1.87 (survival)	3.471 (survival)	**3.389^{d}**	-	-	Besser et al. 2007
Rainbow trout (4 hr post fert), *Oncorhynchus mykiss*	R, M	ELS	Cadmium chloride	6.8	0.25-2.5	0.79 (delayed hatch & growth)	-	**6.743^{c}**	-	-	Lizardo-Daudt and Kennedy 2008
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium chloride	19.7	0.6-1.3	0.905^{e} (0.88 dissolved) (survival)	1.312^{e} (1.276 dissolved) (survival)	**4.794^{d}**	-	-	Mebane et al. 2008
Rainbow trout, *Oncorhynchus mykiss*	F, M	ELS	Cadmium chloride	29.4	<0.16-0.16	<0.164^{e} (<0.16 dissolved) (growth)	2.386^{e} (2.321 dissolved) (survival)	**6.334^{d}**	-	-	Mebane et al. 2008
Rainbow trout (1 dph), *Oncorhynchus mykiss*	F, M	ELS	Cadmium chloride	100	-	-	5.613^{e} (5.3 dissolved) (survival)	**5.612^{d}**	2.186	**2.192**	Wang et al. 2014a
Chinook salmon (egg-fry), *Oncorhynchus tshawytscha*	F, M	ELS	Cadmium chloride	25	1.30-1.88	1.563 (survival)	1.465 (growth)	4.426	4.366	4.426	Chapman 1975
Atlantic salmon, *Salmo salar*	-	ELS (5°C)	Cadmium chloride	23.5	90-270	155.9 (survival & hatch)	19.37 (biomass)	61.47^{d}	-	-	Rombough and Garside 1982
Atlantic salmon, *Salmo salar*	-	ELS (8.9°C)	Cadmium chloride	24.5	300-800	489.9 (survival)	127.8 (biomass)	**392.5^{d}**	-	-	Rombough and Garside 1982

Species	Method[a]	Test[a]	Chemical	Hardness (mg/L CaCO$_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC$_{20}$ (µg/L)	Normalized Chronic Value[b] (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Atlantic salmon (alevin), *Salmo salar*	-	ELS (9.6°C)	Cadmium chloride	23.5	2.5-8.2	4.53 (survival)	0.7528 (biomass)	2.389	13.24	2.389	Rombough and Garside 1982
Brown trout, *Salmo trutta*	-	ELS	Cadmium chloride	44	3.8-11.7	6.668 (-)	-	12.83[c]	-	-	Eaton et al. 1978
Brown trout (adult, female), *Salmo trutta*	-	LC	Cadmium sulfate	250	9.34-29.1	16.49 (growth)	15.15 (survival)	7.294[d]	-	-	Brown et al. 1994
Brown trout, *Salmo trutta*	F, M	ELS	Cadmium sulfate	36.9	1.11-1.6	1.33 (survival)	1.368 (survival)	**3.030**	-	-	Davies and Brinkman 1994a
Brown trout (fingerling), *Salmo trutta*	F, M	ELS	Cadmium sulfate	37.6	<0.7-0.7	<0.7 (growth & survival)	0.624 (survival)	**1.361**	-	**-**	Davies and Brinkman 1994c
Brown trout (eggs), *Salmo trutta*	F, M	ELS	Cadmium sulfate	149	9.62-19.1	13.56 (survival)	16.02 (biomass)	**11.65**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (eggs), *Salmo trutta*	F, M	ELS	Cadmium sulfate	71.3	4.68-8.64	6.36 (survival)	5.187 (biomass)	**6.793**	-	-	Brinkman and Hansen 2004a; 2007
Brown trout (eggs), *Salmo trutta*	F, M	ELS	Cadmium sulfate	30.6	2.54-4.87	3.52 (survival)	2.807 (biomass)	**7.218**	8.360	**4.725**	Brinkman and Hansen 2004a; 2007
Brook trout, *Salvelinus fontinalis*	-	LC	Cadmium chloride	44	1.7-3.4	2.404 (growth of F3 juveniles)	1.224 (reproduction)	2.356	-	-	Benoit et al. 1976
Brook trout, *Salvelinus fontinalis*	-	ELS	Cadmium chloride	37	1-3	1.732 (growth)	2.187 (survival)	4.833[d]	-	-	Sauter et al. 1976
Brook trout, *Salvelinus fontinalis*	-	ELS	Cadmium chloride	188	7-12	9.165 (survival & growth)	9.172 (survival)	**5.543[d]**	-	-	Sauter et al. 1976
Brook trout, *Salvelinus fontinalis*	-	ELS	Cadmium chloride	44	1.1-3.8	2.045 (-)	-	3.935[c]	4.416	2.356	Eaton et al. 1978

Species	Method^a	Test^a	Chemical	Hardness (mg/L $CaCO_3$)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	Normalized Chronic Value^b (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Lake trout, *Salvelinus namaycush*	-	ELS	Cadmium chloride	44	4.4-12.3	7.357 (-)	-	14.16	13.51	**NA**^{g}	Eaton et al. 1978
Northern pike, *Esox lucius*	-	ELS	Cadmium chloride	44	4.2-12.9	7.361 (-)	-	14.17	13.52	14.17	Eaton et al. 1978
Fathead minnow (0.23 g), *Pimephales promelas*	-	LC	Cadmium sulfate	201	37-57	45.92 (-)	24.71 (reproduction)	14.16	-	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	-	ELS	-	44	9-18	12.73 (-)	-	**24.50**^{c}	-	-	Spehar and Carlson 1984a,b
Fathead minnow, *Pimephales promelas*	-	ELS	Cadmium nitrate	44	-	10.0 (-)	-	19.25^c	27.37	14.16	Spehar and Fiandt 1986
White sucker, *Catostomus commersoni*	-	ELS	Cadmium chloride	44	4.2-12.0	7.099 (-)	-	13.66	13.04	13.66	Eaton et al. 1978
Flagfish, *Jordanella floridae*	-	LC	Cadmium chloride	44	4.1-8.1	5.763 (-)	5.018 (reproduction)	9.659	-	-	Spehar 1976a,b
Flagfish, *Jordanella floridae*	-	LC	Cadmium chloride	47.5	3.0-6.5	4.416 (-)	6.274 (reproduction)	11.36	-	-	Carlson et al. 1982
Flagfish, *Jordanella floridae*	-	LC	Cadmium chloride	47.5	3.4-7.3	4.982 (-)	3.341 (reproduction)	6.050	8.886	8.723	Carlson et al. 1982
Bluegill, *Lepomis macrochirus*	-	LC	Cadmium sulfate	207	31-80	49.80 (-)	29.35 (survival)	16.43	29.05	16.43	Eaton 1974
Smallmouth bass, *Micropterus dolomieui*	-	ELS	Cadmium chloride	44	4.3-12.7	7.390 (-)	-	14.22	13.58	14.22	Eaton et al. 1978
Blue tilapia, *Oreochromis aurea*	-	LC	Cadmium nitrate	145	>52.0	>52.0 (-)	-	>38.66	>39.48	>38.66	Papoutsoglou and Abel 1988
Mottled sculpin, *Cottus bairdi*	F, M	ELS	Cadmium chloride	103	1.4-2.6	1.908 (survival)	1.762 (biomass)	**1.721**	-	-	Besser et al. 2007

Species	**Method[a]**	**Test[a]**	**Chemical**	**Hardness (mg/L $CaCO_3$)**	**Chronic Limits (µg/L)**	**MATC (µg/L)**	**EC_{20} (µg/L)**	**Normalized Chronic Value[b] (µg/L)**	**2001 SMCV (µg/L)**	**2016 SMCV (µg/L)**	**Reference**
Mottled sculpin, *Cottus bairdii*	F, M	ELS	Cadmium chloride	103	0.59-1.3	0.8758 (survival)	1.285 (survival)	**1.255**	-	**1.470**	Besser et al. 2007

[a] R=renewal, F=flow-through, U=unmeasured, M=measured, ELS=early life-cycle test, PLC=partial life-cycle test, LC=life-cycle test.

[b] Freshwater data normalized to a hardness of 100 mg/L using the pooled acute slope of 0.7977.

[c] Not used to calculate SMCV because other normalized data available or normalized EC20 values available.

[d] Not used to calculate SMCV because either a more definitive value available, value is considered an outlier, or preference was given to the more sensitive exposure scenario (LC versus ELS tests).

[e] Study reported a dissolved value only and was converted to total cadmium with a conversion factor of 1.028, 1.059, and 1.093 for hardness of 50, 100, and 200 mg/L, respectively for freshwater species and 1.006 for saltwater species.

[f] Freshwater data not normalized so no SMCV calculated.

[g] No SMCV calculated because normalized EC_{20} data available for the genus.

Appendix Table C-2. Chronic Values used to develop the Chronic Hardness Correction Slope

Species	Hardness (mg/L $CaCO_3$)	Chronic Value (µg/L)	Endpoint	Reference
Daphnia magna	53	0.1523	MATC	Chapman et al. Manuscript, 1980
Daphnia magna	103	0.2117	MATC	Chapman et al. Manuscript, 1980
Daphnia magna	209	0.4371	MATC	Chapman et al. Manuscript, 1980
Oncorhynchus mykiss	250	3.319	EC_{20}	Brown et al. 1994
Oncorhynchus mykiss	301	9.508	EC_{20}	Davies and Brinkman 1994b
Oncorhynchus mykiss	29	2.604	EC_{20}	Davies and Brinkman 1994b
Oncorhynchus mykiss	103	3.471	EC_{20}	Besser et al. 2007
Oncorhynchus mykiss	19.7	1.312	EC_{20}	Mebane et al. 2008
Oncorhynchus mykiss	29.4	2.386	EC_{20}	Mebane et al. 2008
Salmo trutta	250	15.15	EC_{20}	Brown et al. 1994
Salmo trutta	36.9	1.368	EC_{20}	Davies and Brinkman 1994a
Salmo trutta	37.6	0.624	EC_{20}	Davies and Brinkman 1994c
Salmo trutta	149.2	16.02	EC_{20}	Brinkman and Hansen 2004a; 2007
Salmo trutta	71.3	5.187	EC_{20}	Brinkman and Hansen 2004a; 2007
Salmo trutta	30.6	2.807	EC_{20}	Brinkman and Hansen 2004a; 2007
Salvelinus fontinalis	44	1.224	EC_{20}	Benoit et al. 1976
Salvelinus fontinalis	37	2.187	EC_{20}	Sauter et al. 1976
Salvelinus fontinalis	188	9.172	EC_{20}	Sauter et al. 1976

Appendix Table C-3. Chronic Freshwater Total to Dissolved Conversion Factors for Cadmium based on Hardness.

Hardness (mg/L as $CaCO_3$)	Conversion Factor[a]
25	0.9670
50	0.9380
75	0.9210
100	0.9090
150	0.8920
200	0.8800
250	0.8707
300	0.8630
350	0.8566
400	0.8510

[a] The conversion factor (CF) is calculated as: CF = 1.101672 - (ln (hardness) x 0.041838).

Appendix D Acceptable Estuarine/Marine Chronic Toxicity Data

Appendix Table D-1. Acceptable Estuarine/Marine Chronic Toxicity Data
(Underlined values are used in SMCV calculation and values in bold represent new/revised values since 2001 AWQC document).
(Species are organized phylogenetically).

Species	Method[a]	Test	Chemical	Salinity (g/kg)	Chronic Limits (µg/L)	MATC (µg/L)	EC_{20} (µg/L)	2001 SMCV (µg/L)	2016 SMCV (µg/L)	Reference
Mysid, *Americamysis bahia*	-	LC	Cadmium chloride	15-23	6.4-10.6	8.237	5.605	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	-	LC	Cadmium chloride	30	5.1-10	7.141	10.93	-	-	Gentile et al. 1982; Lussier et al. 1985
Mysid, *Americamysis bahia*	-	LC	Cadmium chloride	30	<4-4	<4[d]	5.833	6.173	6.149	Carr et al. 1985
Mysid, (formerly, *Mysidopsis bigelowi*) *Americamysis bigelowi*	-	LC	Cadmium chloride	-	5.1-10	7.141	11.61	7.141	11.61	Gentile et al. 1982

[a] S=static, R=renewal; F=flow-through, U=unmeasured, M=measured, ELS=early life-cycle test, LC=life-cycle test

Appendix E Acceptable Freshwater Plant Toxicity Data

Appendix Table E-1. Acceptable Freshwater Plant Toxicity Data

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Alga, *Euglena gracilis*	-	Cadmium chloride	-	-	Morphological abnormalities	-	5,000	Nakano et al. 1980
Alga, *Euglena gracilis anabaena*	-	Cadmium nitrate	-	-	Cell division inhibition	-	20,000	Nakano et al. 1980
Blue-green alga, *Anabaena doliolum*	R, U	-	-	12 d	EC_{50} (lethal)	-	75,000	Kaur et al. 2002
Blue-green alga, *Anabaena doliolum*	R, U	-	-	12 d	Algicidal	-	250,000	Kaur et al. 2002
Blue-green alga, *Anabaena flos-aquae*	-	Cadmium chloride	-	96 hr	EC_{50}	-	120	Rachlin et al. 1984
Blue-green alga (15 d), *Anabaena flos-aquae*	S, U	Cadmium nitrate	-	96 hr	EC_{50}	-	140	Heng et al. 2004
Blue-green alga, *Microcystis aeruginosa*	-	Cadmium nitrate	-	-	Incipient inhibition	-	70	Bringmann 1975
Blue-green alga, *Microcystis aeruginosa*	S, U	Cadmium chloride	-	14 d	Growth	56.21-112.41	79.49	Zhou et al. 2006
Blue-green alga, *Spirulina platensis*	S, U	Cadmium chloride	-	96 hr	EC_{50} (growth)	-	18,350	Rangsayatorn et al. 2002
Diatom, *Asterionella formosa*	-	-	-	-	Factor of 10 growth rate decrease	-	2	Conway 1978
Diatom, *Navicula incerta*	-	Cadmium chloride	-	96 hr	EC_{50}	-	310	Rachlin et al. 1982
Diatom, *Navicula pelliculosa*	S, M	Cadmium chloride	-	96 hr	EC_{50} (mat formation)	-	31	Irving et al. 2009
Diatom, *Nitzschia costerium*	-	Cadmium chloride	-	96 hr	EC_{50}	-	480	Rachlin et al. 1982

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Diatom, *Nitzschia palea*	S, U	Cadmium chloride	-	5 d	EC$_{50}$ (growth)	-	27.6	Branco et al. 2010
Green alga, *Ankistrodesmus falcatus*	-	Cadmium chloride	-	-	58% reduction in growth	-	2,500	Devi Prasad and Devi Prasad 1982
Green alga, *Chara vulgaris*	S, M	Cadmium sulfate	-	7 d	Lethal dose	-	56.2	Heumann 1987
Green alga, *Chara vulgaris*	S, M	Cadmium sulfate	-	14 d	EC$_{50}$ (growth)	-	9.5	Heumann 1987
Green alga, *Chlamydomonas sp.*	S, U	Cadmium chloride	-	12 d	EC$_{50}$ (growth)	-	22,482	Aguilera and Amils 2005
Green alga, *Chlamydomonas moewusii*	S, U	Cadmium chloride	-	96 hr	EC$_{50}$ (growth)	-	4,100	Suarez et al. 2010
Green alga, *Chlamydomonas reinhardii*	F, M	Cadmium chloride	24	96 hr	EC$_{50}$ (cell density)	-	203	Schafer et al. 1993
Green alga, *Chlamydomonas reinhardii*	F, M	Cadmium chloride	24	7 d	EC$_{50}$ (cell density)	-	130	Schafer et al. 1993
Green alga, *Chlamydomonas reinhardii*	F, M	Cadmium chloride	24	10 d	EC$_{50}$ (cell density)	-	99	Schafer et al. 1993
Green alga, *Chlamydomonas reinhardii*	S, U	Cadmium nitrate	-	96 hr	EC$_{50}$ (growth)	-	3,020	Li et al. 2012b
Green alga, *Chlamydomonas reinhardii*	S, U	Cadmium nitrate	-	96 hr	EC$_{50}$ (cell density)	-	2,690	Li et al. 2013
Green alga, *Chlamydomonas reinhardii*	S, U	Cadmium nitrate	-	96 hr	EC$_{50}$ (Chlorophyll a)	-	1,820	Li et al. 2013
Green alga, *Chlorella pyrenoidosa*	-	-	-	-	Reduction in growth	-	250	Hart and Scaife 1977
Green alga, *Chlorella pyrenoidosa*	S, U	Cadmium nitrate	-	96 hr	EC$_{50}$ (growth)	-	5,170	Li et al. 2012b

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Green alga, *Chlorella pyrenoidosa*	S, U	Cadmium chloride	-	96 hr	Reduced O_2 evolution	-	2,810	Wang et al. 2013
Green alga, *Chlorella saccharophila*	-	Cadmium chloride	-	96 hr	EC_{50}	-	105	Rachlin et al. 1984
Green alga, *Chlorella vulgaris*	-	-	-	-	EC_{50} (growth)	-	50	Hutchinson and Stokes 1975
Green alga, *Chlorella vulgaris*	-	Cadmium chloride	-	-	EC_{50} (growth)	-	60	Rosko and Rachlin 1977
Green alga, *Chlorella vulgaris*	-	Cadmium chloride	50	96 hr	EC_{50} (growth)	-	3,700	Canton and Slooff 1982
Green alga, *Chlorella vulgaris*	S, U	Cadmium sulfate	-	15 d	Growth	<17.99-17.99	<17.99	Awasthi and Das 2005
Green alga (South Laguna de Bay strain), *Chlorella vulgaris*	S, U	Cadmium chloride	-	12 d	EC_{50} (growth)	-	1,850	Nacorda et al. 2007
Green alga (West Laguna de Bay strain), *Chlorella vulgaris*	S, U	Cadmium chloride	-	12 d	EC_{50} (growth)	-	2,500	Nacorda et al. 2007
Green alga, *Chlorella vulgaris*	S, U	Cadmium chloride	-	7 d	Stimulated growth	<562.1-562.1	<562.1	Huang et al. 2009
Green alga, *Chlorococcum sp.*	-	Cadmium chloride	-	-	42% reduction in growth	-	2,500	Devi Prasad and Devi Prasad 1982
Green alga, *Chlorococcum sp.*	S, U	Cadmium chloride	-	10 d	Growth	1,000-5,000	2,236	Qiu et al. 2006
Green alga, *Gonium pectorale*	S, U	Cadmium chloride	-	96 hr	EC_{50} (growth)	-	109	Pereira et al. 2005
Green alga, *Parachlorell kessleri*	S, M	-	-	5 d	Growth and chlorophyll a content	2-8	4.000	Ngo et al. 2009

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Green alga, *Pseudokirchneriella subcapitata*	S, U	Cadmium chloride	171	96 hr	EC_{50} (growth)	-	130	Versteeg 1990
Green alga, *Pseudokirchneriella subcapitata*	-	Cadmium chloride	-	-	Reduction in growth	-	50	Bartlett et al. 1974
Green alga, *Pseudokirchneriella subcapitata*	-	Cadmium nitrate	-	-	Reduction in growth	-	255	Slooff et al. 1983a
Green alga, *Pseudokirchneriella subcapitata*	S, U	Cadmium chloride	-	96 hr	EC_{50} (growth)	-	10,500	Bozeman et al. 1989
Green alga, *Pseudokirchneriella subcapitata*	S, U	Cadmium chloride	-	96 hr	EC_{50} (growth)	-	23.2	Thellen et al. 1989
Green alga, *Pseudokirchneriella subcapitata*	S, M	Cadmium nitrate	-	96 hr	IC_{50} (growth rate)	-	67.44	Rodgher et al. 2012
Green alga, *Scenedesmus obliquus*	-	Cadmium chloride	-	-	39% reduction in growth	-	2,500	Devi Prasad and Devi Prasad 1982
Green alga, *Scenedesmus obliquus*	S, U	Cadmium nitrate	-	96 hr	EC_{50} (growth)	-	2,660	Li et al. 2012b
Green alga, *Scenedesmus quadricauda*	-	Cadmium chloride	-	-	Reduction in cell count	-	6.1	Klass et al. 1974
Green alga, *Scenedesmus quadricauda*	-	Cadmium nitrate	-	-	Incipient inhibition	-	310	Bringmann and Kuhn 1977a,c
Green alga, *Scenedesmus quadricauda*	S, U	Cadmium chloride	-	144 hr	Growth rate and chlorophyll a concentration	<50-50	<50	Mohammed and Markert 2006
Green alga, *Spirogyra decimina*	S, U	Cadmium chloride	-	96 hr	Growth	<1,124.1-1,124.1	<1,124.1	Pribyl et al. 2005
Duckweed, *Lemna gibba*	S, M	Cadmium nitrate	-	7 d	EC_{50} (growth)	-	800	Devi et al. 1996

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Duckweed, *Lemna gibba*	S, M	Cadmium chloride	-	96 hr	Growth	<1-1	<1	Megateli et al. 2009
Duckweed, *Lemna gibba*	S, U	Cadmium sulfate	-	96 hr	Total chlorophyll	100-500	223.6	Doganlar 2013
Duckweed, *Lemna gibba*	R, U	Cadmium nitrate	-	7 d	Reduced chlorophyll pigment	-	5,000	Uruc Parlak and Yilmaz 2013
Duckweed, *Lemna minor*	R, M	Cadmium chloride	39	96 hr	Reduced chlorophyll	-	54	Taraldsen and Norberg-King 1990
Duckweed, *Lemna minor*	S, U	-	-	96 hr	EC_{50} (growth)	-	200	Wang 1986
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	9 d	Chlorosis symptoms	<112.41-112.41	<112.41	Paczkowska et al. 2007
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	9 d	Growth	112.41-562.05	251.4	Paczkowska et al. 2007
Duckweed, *Lemna minor*	S, U	Cadmium sulfate	-	7 d	EC_{50} (growth)	-	<2,500	Uysal and Taner 2007
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	7 d	Growth rate, chlorosis	11.24-112.4	35.54	Razinger et al. 2008
Duckweed, *Lemna minor*	S, U	Cadmium chloride	-	7 d	EC_{20} (frond abscission)	-	56.0	Henke et al. 2011
Duckweed, *Lemna minor*	R, M	Cadmium chloride	-	7 d	EC_{50} (growth)	-	112.4	Basile et al. 2012
Duckweed, *Lemna minor*	S, U	Cadmium sulfate	-	96 hr	Total chlorophyll	500-1,500	866.0	Doganlar 2013
Duckweed, *Lemna triscula*	S, U	Cadmium sulfate	-	7 d	LOEC (Chl *a* reduction)	-	112.4	Malec et al. 2010
Duckweed, *Lemna valdiviana*	-	Cadmium nitrate	-	-	Reduction in number of fronds	-	10	Hutchinson and Czyrska 1972
Giant duckweed, *Spirodela polyrrhiza*	R, U	Cadmium sulfate	-	28 d	Growth	<7.63-7.63	<7.63	Sajwan and Ornes 1994
Giant duckweed, *Spirodela polyrrhiza*	S, U	Cadmium chloride	-	7 d	Multiplication rate and fresh weight	<1,000-1,000	<1,000	Singh et al. 2011

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Giant duckweed, *Spirodela polyrrhiza*	S, U	Cadmium sulfate	-	96 hr	Total chlorophyll	10-50	22.36	Doganlar 2013
Duckweed, *Wolffia arrhiza*	S, M	Cadmium nitrate	-	7 d	Fresh weight	112.41-1,124.1	355.5	Piotrowska et al. 2010
Duckweed, *Wolffia arrhiza*	S, M	Cadmium nitrate	-	14 d	Fresh weight	<112.41-112.41	<112.41	Piotrowska et al. 2010
Duckweed (3 wk), *Wolffia globosa*	S, U	Cadmium chloride	-	12 d	Algal lethal	-	8,000	Boonyapookana et al. 2002
Duckweed (3 wk), *Wolffia globosa*	S, U	Cadmium chloride	-	9 d	EC_{50} (biomass)	-	1,500	Boonyapookana et al. 2002
Duckweed (3 wk), *Wolffia globosa*	S, U	Cadmium chloride	-	9 d	EC_{50} (total chlorophyll content)	-	500	Boonyapookana et al. 2002
Pondweed, *Elodea canadensis*	R, M	Cadmium chloride	-	7 d	EC_{50} (growth)	-	112.4	Basile et al. 2012
Feathered fern, *Azolla pinnata*	S, U	-	-	96 hr	Decrease chlorophyll	100-500	223.6	Prasad and Singh 2011
Macrophyte, *Bacopa monnieri*	R, M	Cadmium nitrate	-	96 hr	Cysteine content in roots	1,124.1-5,620.5	2,514	Singh et al. 2006
Macrophyte, *Bacopa monnieri*	R, M	Cadmium nitrate	-	96 hr	TBARS content in leaves and roots	1,124.1-5,620.5	2,514	Singh et al. 2006
Macrophyte, *Bacopa monnieri*	R, M	Cadmium nitrate	-	96 hr	Cysteine content in leaves	<1,124.1-1,124.1	<1,124.1	Singh et al. 2006
Water hyacinth (mature), *Eichhornia crassipes*	S, U	Cadmium nitrate	-	16 d	Growth	2,500-4,000	3,162	Hasan et al. 2007
Moss, *Leptodictyum riparium*	R, M	Cadmium chloride	-	7 d	EC_{50} (growth)	-	562.5	Basile et al. 2012

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Crome sphagnum (young shorts), *Sphagnum squarrosum*	S, U	Cadmium chloride	-	25 d	LOEC (reduced chlorophyll)	-	1,124	Saxena and Saxena 2012
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	-	32 d	EC_{50} (root weigtht)	-	7,400	Stanley 1974
Water lettuce, *Pistia stratiotes*	R, U	Cadmium chloride	-	21 d	Growth	8.993-17.98	12.72	Wang et al. 2010b
Macrophyte, *Potamogeton crispus*	R, U	Cadmium chloride	-	7 d	Decreased chlorophyll a, b and carotenoid pigments in leaves	<2,248-2,248	<2,248	Xu et al. 2012
Sage pond weed, *Potamogeton pectinatus*	S, M	Cadmium chloride	-	96 hr	Chlorophyll a content	2,810-5,620	3,974	Rai et al. 2003
Aquatic fern, *Salvinia cucullata*	S, U	Cadmium chloride	-	8 d	% biomass, total chlorophyll content	<500-500	<500	Phetsombat et al. 2006
Fern, *Salvina natans*	-	Cadmium nitrate	-	-	Reduction in number of fronds	-	10	Hutchinson and Czyrska 1972
Macrophyte, *Vallisneria spiralis*	S, U	Cadmium chloride	-	14 d	Growth	4.496-8.993	6.359	Wang et al. 2009e

[a] S=static, R=renewal; F=flow-through, U=unmeasured, M=measured

Appendix F Acceptable Estuarine/Marine Plant Toxicity Data

Appendix Table F-1. Acceptable Estuarine/Marine Plant Toxicity Data

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Diatom, *Asterionella japonica*	-	Cadmium chloride	-	72 hr	EC_{50} (growth rate)	-	224.8	Fisher and Jones 1981
Diatom, *Chaetoceros calcitrans*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth)	-	50-70	Ismail et al. 2002
Diatom, *Ditylum brightwellii*	-	Cadmium chloride	-	5 d	EC_{50} (growth)	-	60	Canterford and Canterford 1980
Diatom, *Isochrysis galbana*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-well test)	-	50-70	Ismail et al. 2002
Diatom, *Isochrysis galbana*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-shaken flask)	-	60	Ismail et al. 2002
Diatom, *Phaeodactylum tricornutum*	S, U	Cadmium chloride	35	96 hr	EC_{50} (growth)	-	22,390	Torres et al. 1998
Diatom (3-5 d), *Phaeodactylum tricornutum*	S, U	Cadmium nitrate	-	96 hr	EC_{50} (growth)	-	15,720	Horvatic and Persic 2007
Diatom (3-5 d), *Phaeodactylum tricornutum*	S, U	Cadmium nitrate	-	336 hr	EC_{50} (growth)	-	7,560,000	Horvatic and Persic 2007
Dinoflagellate, *Prorocentrum minimum*	S, U	-	-	96 hr	EC_{50} (growth, nutrient rich medium)	-	674.5	Miao and Wang 2006
Dinoflagellate, *Prorocentrum minimum*	S, U	-	-	96 hr	EC_{50} (growth, P-starved medium)	-	113.5	Miao and Wang 2006
Diatom, *Skeletonema costatum*	-	Cadmium chloride	-	96 hr	EC_{50} (growth rate)	-	175	Gentile and Johnson 1982
Diatom, *Tetraselmis sp.*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-well test)	-	3,900-7,500	Ismail et al. 2002
Diatom, *Tetraselmis sp.*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-shaken flask)	-	5,199	Ismail et al. 2002

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Diatom, *Tetraselmis tetrahele*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-well test)	-	4,500-5,800	Ismail et al. 2002
Diatom, *Tetraselmis tetrahele*	S, U	Cadmium chloride	30	96 hr	EC_{50} (growth-shaken flask)	-	6,900	Ismail et al. 2002
Diatom, *Thalassiosira nordenskioeldii*	S, U	-	-	15 d	IC_{50} (growth)	-	67.00	Wang and Wang 2011
Diatom, *Thalassiosira pseudonana*	-	Cadmium chloride	-	96 hr	EC_{50} (growth rate)	-	160	Gentile and Johnson 1982
Green alga, *Cladophora rupestris*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009
Green alga, *Dunaliella viridis*	S, U	Cadmium chloride	35	10 d	Chlorophyll production	5-10	7.071	Marcano et al. 2009
Green alga, *Scenedesmus sp.*	S, U	Cadmium chloride	35	10 d	Chlorophyll production	5-10	7.071	Marcano et al. 2009
Green alga, *Ulva intestinalis*	R, U	Cadmium chloride	-	14 d	NOEC (growth)	>1,124.1	>1,124.1	Baumann et al. 2009
Green alga, *Ulva pertusa*	S, U	-	35	5 d	EC_{50} (growth)	-	326	Han and Choi 2005
Green alga, *Ulva pertusa*	S, U	-	35	5 d	Sporulation inhibition	63->63	>63	Han and Choi 2005
Green alga, *Ulva pertusa*	S, U	-	35	96 hr	EC_{50} (spore inhibition)	-	95	Han et al. 2008
Brown alga, *Ascophyllum nodosum*	R, U	Cadmium chloride	-	14 d	NOEC (growth)	>1,124.1	>1,124.1	Baumann et al. 2009
Brown alga, *Fucus vesiculosus*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Chronic Limits (µg/L)	Concentration (µg/L)	Reference
Kelp, *Laminana saccharina*	-	Cadmium chloride	-	8 d	EC_{50} (growth rate)	-	860	Markham et al. 1980
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporophyte growth	-	24.9	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporangia production	-	>189	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced female growth	-	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Stopped sexual production	-	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	R, U	Cadmium chloride	28-30	14 d	Sexual reproduction	77->77	>77	Thursby and Steele 1986
Red alga, *Chondrus crispus*	R, U	Cadmium chloride	-	14 d	NOEC (growth)	>1,124.1	>1,124.1	Baumann et al. 2009
Red alga, *Gracilaria lemaneiformis*	S, U	-	-	96 hr	Growth	5,620-11,241	7,948	Xia et al. 2004
Red alga, *Hypnea musciformis*	S, U	Cadmium chloride	34	7 d	LOEC (Chl *a*)	-	5,620	Bouzon et al. 2011
Red alga, *Palmaria palmata*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009
Red alga, *Polysiphonia lanosa*	R, U	Cadmium chloride	-	14 d	Growth	112.41-1,124.1	355.5	Baumann et al. 2009

[a] S=static, R=renewal; F=flow-through, U=unmeasured, M=measured

Appendix G Acceptable Bioaccumulation Data

Appendix Table G-1. Acceptable Bioaccumulation Data

(Species are organized phylogenetically).

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
FRESHWATER								
Aufwuchs (attached microscopic plants and animals)	Cadmium chloride	-	-	-	-	365	720	Giesy et al. 1979
Aufwuchs (attached microscopic plants and animals)	Cadmium chloride	-	-	-	-	365	580	Giesy et al. 1979
Duckweed, *Lemna valdiviana*	Cadmium nitrate	-	-	Whole plant	-	21	603	Hutchinson and Czyrska 1972
Fern, *Salvinia natans*	Cadmium nitrate	-	-	Whole plant	-	21	960	Hutchinson and Czyrska 1972
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	4.6	140	Whole body	51.3 (dry wt.)	87	2,230	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	32.4	140	Whole body	156.4 (dry wt.)	87	965	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	57.4	140	Whole body	533.1 (dry wt.)	87	1,857	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	86.9	140	Whole body	649.9 (dry wt.)	87	1,496	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	107.6	140	Whole body	739.2 (dry wt.)	87	1,374	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	153	140	Whole body	989.3 (dry wt.)	87	1,293	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	205.3	140	Whole body	1,620.6 (dry wt.)	87	1,579	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	0.3	22	Whole body	15.9 (dry wt.)	28	10,600	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	0.5	22	Whole body	21.6 (dry wt.)	28	8,640	Straus 2011
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	1.3	22	Whole body	45.5 (dry wt.)	28	7,000	Straus 2011

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Oligochaete (2-2.5 cm), *Lumbriculus variegatus*	-	2.3	22	Whole body	99.4 (dry wt.)	28	8,643	Straus 2011
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	0.35	20.5 (20-21)	Soft tissue	25 (dry wt.)	28 d	14,285	Pais 2012
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	0.53	20.5 (20-21)	Soft tissue	30 (dry wt.)	28 d	11,320	Pais 2012
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	1.41	20.5 (20-21)	Soft tissue	61 (dry wt.)	28 d	8,652	Pais 2012
Pond snail (juvenile, 4-5 mm), *Lymnaea stagnalis*	Cadmium chloride	2.51	20.5 (20-21)	Soft tissue	117 (dry wt.)	28 d	9,322	Pais 2012
Snail, *Physa integra*	Cadmium chloride	-	-	Whole body	-	28	1,750	Spehar et al. 1978
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	71	Tessier et al. 1994a
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	74	Tessier et al. 1994a
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	109	Tessier et al. 1994a
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	28	Tessier et al. 1994a
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	42	Tessier et al. 1994a
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	60	Tessier et al. 1994a
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	27	Tessier et al. 1994a
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	42	Tessier et al. 1994a

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	26	Tessier et al. 1994a
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	10	-	Soft tissue	-	60	6,910	Tessier et al. 1994b
Snail (1 yr), *Viviparus georgianus*	Cadmium chloride	50	-	Soft tissue	-	60	2,238	Tessier et al. 1994b
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	10	-	Soft tissue	-	60	1,758	Tessier et al. 1994b
Snail (2 yr), *Viviparus georgianus*	Cadmium chloride	50	-	Soft tissue	-	60	758	Tessier et al. 1994b
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	10	-	Soft tissue	-	60	1,258	Tessier et al. 1994b
Snail (3 yr), *Viviparus georgianus*	Cadmium chloride	50	-	Soft tissue	-	60	617	Tessier et al. 1994b
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	15	Tessier et al. 1994a
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	16	Tessier et al. 1994a
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	28	Tessier et al. 1994a
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	16	Tessier et al. 1994a
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	16	Tessier et al. 1994a
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	14	Tessier et al. 1994a
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	100	- (10ºC)	Soft tissue	-	20	8	Tessier et al. 1994a
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	100	- (15ºC)	Soft tissue	-	20	7	Tessier et al. 1994a
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	100	- (25ºC)	Soft tissue	-	20	8	Tessier et al. 1994a
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	10	-	Soft tissue	-	60	1,256	Tessier et al. 1994b

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Mussel (0-74 mm), *Elliptio complanata*	Cadmium chloride	50	-	Soft tissue	-	60	918	Tessier et al. 1994b
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	10	-	Soft tissue	-	60	945	Tessier et al. 1994b
Mussel (74-86 mm), *Elliptio complanata*	Cadmium chloride	50	-	Soft tissue	-	60	613	Tessier et al. 1994b
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	10	-	Soft tissue	-	60	574	Tessier et al. 1994b
Mussel (86-100 mm), *Elliptio complanata*	Cadmium chloride	50	-	Soft tissue	-	60	254	Tessier et al. 1994b
Zebra mussel (19-25 mm), *Dreissena polymorpha*	Cadmium chloride	2.2	-	Whole body	22 (dry wt.)	31	2,000	Voets et al. 2004
Zebra mussel (19-25 mm), *Dreissena polymorpha*	Cadmium chloride	7.3	-	Whole body	42.7 (dry wt.)	31	1,170	Voets et al. 2004
Zebra mussel (19-25 mm), *Dreissena polymorpha*	Cadmium chloride	23.9	-	Whole body	129.3 (dry wt.)	31	1,082	Voets et al. 2004
Asian clam, *Corbicula fluminea*	Cadmium sulfate	-	-	Whole body	-	28	3,770	Graney et al. 1983
Asian clam, *Corbicula fluminea*	Cadmium sulfate	-	-	Whole body	-	28	1,752	Graney et al. 1983
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	3	55.8	Whole body	175 (dry wt.)	28	11,667	Barfield et al. 2001
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	5	55.8	Whole body	227.4 (dry wt.)	28	9,096	Barfield et al. 2001
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	9.2	55.8	Whole body	175 (dry wt.)	28	3,804	Barfield et al. 2001
Asian clam (adult), *Corbicula fluminea*	Cadmium chloride	20.2	55.8	Whole body	175 (dry wt.)	28	1,733	Barfield et al. 2001
Cladoceran, *Daphnia magna*	Cadmium sulfate	-	-	Whole body	-	2-4	320	Poldoski 1979
Cladoceran, *Daphnia magna*	Cadmium sulfate	-	-	Whole body	-	7	484	Winner 1984

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Amphipod, *Hyalella azteca*	Cadmium sulfate	0.48	162.7	Whole body	0.59 (wet wt.)	28	1,229	Stanley et al. 2005
Amphipod, *Hyalella azteca*	Cadmium sulfate	5.09	162.7	Whole body	41.18 (wet wt.)	28	8,090	Stanley et al. 2005
Amphipod, *Hyalella azteca*	-	0.3	22	Whole body	98.4 (dry wt.)	28	65,600	Straus 2011
Amphipod, *Hyalella azteca*	-	0.5	22	Whole body	145.0 (dry wt.)	28	58,000	Straus 2011
Amphipod, *Hyalella azteca*	-	1.25	140	Whole body	82.4 (dry wt.)	21	13,184	Straus 2011
Amphipod, *Hyalella azteca*	-	2.5	140	Whole body	128.3 (dry wt.)	21	10,264	Straus 2011
Amphipod, *Hyalella azteca*	-	5	140	Whole body	106.7 (dry wt.)	21	4,268	Straus 2011
Amphipod (2-9 d, neonate), *Hyalella azteca*	Cadmium chloride	0.64	90	Whole body	15 (dry wt.)	28 d	4,688	Pais 2012
Amphipod (2-9 d, neonate), *Hyalella azteca*	Cadmium chloride	1.38	90	Whole body	110 (dry wt.)	28 d	15,942	Pais 2012
Amphipod (2-9 d, neonate), *Hyalella azteca*	Cadmium chloride	2.65	90	Whole body	145 (dry wt.)	28 d	10,943	Pais 2012
Crayfish, *Orconectes propinquus*	-	-	-	Whole body	-	8	184	Gillespie et al. 1977
Mayfly, *Ephemeroptera sp.*	Cadmium chloride	-	-	Whole body	-	365	1,630	Giesy et al. 1979
Mayfly, *Ephemeroptera sp.*	Cadmium chloride	-	-	Whole body	-	365	3,520	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Cadmium chloride	-	-	Whole body	-	365	736	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Cadmium chloride	-	-	Whole body	-	365	3,520	Giesy et al. 1979
Damselfly, *Ischnura sp.*	Cadmium chloride	-	-	Whole body	-	365	1,300	Giesy et al. 1979

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Damselfly, *Ischnura sp.*	Cadmium chloride	-	-	Whole body	-	365	928	Giesy et al. 1979
Stonefly, *Pteronarcys dorsata*	Cadmium chloride	-	-	Whole body	-	28	373	Spehar et al. 1978
Beetle, Dytiscidae	Cadmium chloride	-	-	Whole body	-	365	164	Giesy et al. 1979
Beetle, Dytiscidae	Cadmium chloride	-	-	Whole body	-	365	260	Giesy et al. 1979
Caddisfly, *Hydropsyche sp.*	Cadmium chloride	-	-	Whole body	-	2-8	228.2	Dressing et al. 1982
Caddisfly, *Hydropsyche betteni*	Cadmium chloride	-	-	Whole body	-	28	4,190	Spehar et al. 1978
Biting midge, Ceratopogonidae	Cadmium chloride	-	-	Whole body	-	365	936	Giesy et al. 1979
Biting midge, Ceratopogonidae	Cadmium chloride	-	-	Whole body	-	365	662	Giesy et al. 1979
Midge, Chironomidae	Cadmium chloride	-	-	Whole body	-	365	2,200	Giesy et al. 1979
Midge, Chironomidae	Cadmium chloride	-	-	Whole body	-	365	1,830	Giesy et al. 1979
Midge, *Chironomus riparius*	-	10,000	-	Whole body	-	28	1,370	Timmermans et al. 1992
Lake whitefish, *Coregonus clupeaformis*	Cadmium chloride	2.07	82.5	Whole body	-	72	42	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	-	-	-	Whole body	-	140	540	Kumada et al. 1973

Species	Chemical	Concentration in water (μg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (μg/g)	Duration (days)	BCF or BAF	Reference
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	-	-	Whole body	-	70	33	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	3.39	82.5	Whole body	-	72	55	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	1.8	250	Muscle	-	231	333	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	3.4	250	Muscle	-	231	294	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	5.5	250	Muscle	-	231	509	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	1.8	250	Muscle	-	455	89	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	3.4	250	Muscle	-	455	182	Brown et al. 1994
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	5.5	250	Muscle	-	455	127	Brown et al. 1994
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	0.87	- (pH=6.8)	Whole body	-	91	229	Peterson et al. 1985
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	1.74	- (pH=6.8)	Whole body	-	91	176	Peterson et al. 1985
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	1.01	- (pH=4.5)	Whole body	-	91	4	Peterson et al. 1985
Atlantic salmon (egg), *Salmo salar*	Cadmium chloride	2.09	- (pH=4.5)	Whole body	-	91	7	Peterson et al. 1985
Brookl trout, *Salvelinus fontinalis*	Cadmium chloride	-	-	Muscle	-	490	3	Benoit et al. 1976
Brook trout, *Salvelinusfontinalis*	Cadmium chloride	-	-	Muscle	-	84	151	Benoit et al. 1976
Bull trout, *Salvelinus confluentus*	Cadmium chloride	-	-	Muscle	-	93	22	Sangalang and Freeman 1979
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.052	30.6	Whole body	0.170 (dry wt.)	55	817	Hansen et al. 2002a

Species	**Chemical**	**Concentration in water (µg/L)**	**Hardness (mg/L as $CaCO_3$)**	**Tissue**	**Concentration (µg/g)**	**Duration (days)**	**BCF or BAF**	**Reference**
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.089	30.6	Whole body	0.204 (dry wt.)	55	573	Hansen et al. 2002a
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.197	30.6	Whole body	0.379 (dry wt.)	55	481	Hansen et al. 2002a
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.383	30.6	Whole body	0.572 (dry wt.)	55	373	Hansen et al. 2002a
Bull trout (juvenile, 30.5 mm, 212mg), *Salvelinus confluentus*	Cadmium chloride	0.786	30.6	Whole body	0.913 (dry wt.)	55	290	Hansen et al. 2002a
Mosquitofish, *Gambusia affinis*	Cadmium chloride	-	-	Whole body (estimated steady state)	-	180	2,213	Giesy et al. 1979
Mosquitofish, *Gambusia affinis*	Cadmium chloride	-	-	Whole body (estimated steady state)	-	180	1,891	Giesy et al. 1979
Guppy, *Poecilia reticulata*	-	-	-	Whole body	-	32	280	Canton and Sloof 1982
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	0.8	134	Whole body	-	28	113	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	1.8	134	Whole body	-	28	78	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	2.2	134	Whole body	-	28	86	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	2.8	134	Whole body	-	28	68	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	3.6	134	Whole body	-	28	67	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	4.4	134	Whole body	-	28	66	Cope et al. 1994

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as CaCO$_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	5.2	134	Whole body	-	28	69	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	6.2	134	Whole body	-	28	50	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	7.7	134	Whole body	-	28	48	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	8.4	134	Whole body	-	28	62	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	13.2	134	Whole body	-	28	55	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	16.1	134	Whole body	-	28	37	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	19.7	134	Whole body	-	28	34	Cope et al. 1994
Bluegill sunfish, *Lepomis macrochirus*	Cadmium chloride	32.3	134	Whole body	-	28	41	Cope et al. 1994
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	6.8	145	Muscle	-	112	17.6	Papoutsoglou and Abel 1988
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	14	145	Muscle	-	112	16.4	Papoutsoglou and Abel 1988
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	28	145	Muscle	-	112	25.7	Papoutsoglou and Abel 1988
Blue tilapia, *Tilapia aurea*	Cadmium nitrate	52	145	Muscle	-	112	17.7	Papoutsoglou and Abel 1988
African clawed frog, *Xenopus laevis*	-	-	-	Whole body	-	100	130	Canton and Sloof 1982
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	0.1	-	Whole body	2.5 (dry wt.)	47	6,250	Sharma and Patino 2008
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	0.8	-	Whole body	6.6 (dry wt.)	47	2,063	Sharma and Patino 2008

Species	Chemical	Concentration in water (µg/L)	Hardness (mg/L as $CaCO_3$)	Tissue	Concentration (µg/g)	Duration (days)	BCF or BAF	Reference
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	8	-	Whole body	8.4 (dry wt.)	47	263	Sharma and Patino 2008
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	84	-	Whole body	14 (dry wt.)	47	42	Sharma and Patino 2008
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	855	-	Whole body	100 (dry wt.)	47	29	Sharma and Patino 2008

Species	Chemical	Concentration in water (µg/L)	Salinity	Tissue	Concentration (µg/g)	Duration	BCF or BAF	Reference
ESTUARINE/MARINE WATER								
Polychaete worm, *Ophryotrocha diadema*	Cadmium chloride	-	-	Whole body	-	64	3,160	Klockner 1979
Common bay mussel, *Mytilus edulis*	Cadmium chloride	-	-	Soft parts	-	35	306	Phillips 1976
Common bay mussel, *Mytilus edulis*	Cadmium chloride	-	-	Soft parts	-	28	113	George and Coombs 1977
Common bay mussel (adult, 40-50 mm), *Mytilus edulis*	Cadmium chloride	3.3 (dissolved)	- (6ºC)	Whole body	8 (dry wt.)	28	485	Mubiana and Blust 2007
Common bay mussel (adult, 40-50 mm), *Mytilus edulis*	Cadmium chloride	3.1 (dissolved)	- (16ºC)	Whole body	16 (dry wt.)	28	1,032	Mubiana and Blust 2007
Common bay mussel (adult, 40-50 mm), *Mytilus edulis*	Cadmium chloride	3.2 (dissolved)	- (26ºC)	Whole body	21 (dry wt.)	28	1,313	Mubiana and Blust 2007
Common bay mussel (9.5 g, 43.2 cm), Mytilus edulis	Cadmium chloride	55.9	-	Soft tissue	85 (dry wt.)	14		Amachree et al. 2013

Species	Chemical	Concentration in water (µg/L)	Salinity	Tissue	Concentration (µg/g)	Duration	BCF or BAF	Reference
Bay scallop, *Argopecten irradians*	Cadmium chloride	-	-	Muscle	-	42	2,040	Pesch and Stewart 1980
Eastern oyster, *Crassostrea virginica*	Cadmium nitrate	-	-	Soft parts	-	98	1,220	Schuster and Pringle 1969
Eastern oyster, *Crassostrea virginica*	Cadmium chloride	-	-	Soft parts	-	280	2,150	Zaroogian and Cheer 1976
Eastern oyster, *Crassostrea virginica*	Cadmium chloride	-	-	Soft parts	-	280	1,830	Zaroogian 1979
Soft-shell clam, *Mya arenaria*	Cadmium nitrate	-	-	Soft parts	-	70	160	Pringle et al. 1968
Pink shrimp, *Penaeus duorarum*	Cadmium chloride	-	-	Whole body	-	30	57	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes pugio*	Cadmium chloride	-	-	Whole body	-	28	203	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes pugio*	Cadmium chloride	-	-	Whole body	-	42	22	Pesch and Stewart 1980
Grass shrimp, *Paleomonetes vulgaris*	Cadmium chloride	-	-	Whole body	-	28	307	Nimmo et al. 1977b
Green crab, *Carcinus maenas*	Cadmium chloride	-	-	Muscle	-	68	5	Wright 1977
Green crab, *Carcinus maenas*	Cadmium chloride	-	-	Muscle	-	40	7	Jennings and Rainbow 1979a

Appendix H Other Freshwater Toxicity Data

Appendix Table H-1. Other Freshwater Toxicity Data
(Species are organized phylogenetically).

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
FRESHWATER							
Mixed natural fungi and bacterial colonies on leaf litter	Cadmium chloride	196 d	10.7	Inhibition of leaf decomposition	5	Giesy 1978	Mixed community exposure
Mixed algal species	Cadmium chloride	-	11.1	Significant reduction in population	5	Giesy et al. 1979	Mixed community exposure
Mixed algal species	Cadmium chloride	10 d	-	Growth inhibition	50	Lasheen et al. 1990	Mixed community exposure
Phytoplankton community	-	7 week	-	Positive biodiversity-production relationship	120,000	Li et al. 2010b	Mixed community exposure
Stream microcosm	Cadmium nitrate	21 d	-	No effect on periphyton structure, but adverse effects on invertebrate grazers and collectors	22	Selby et al. 1985	Mixed community exposure
Mixed zooplankton community	-		14 d	60% reduced biomass	1	Lawrence and Holoka 1987	Mixed community exposure
Mixed macro-invertebrates	Cadmium chloride	52 wk	11.1	Reduced taxa	5	Giesy et al. 1979	Mixed community exposure
Blue-green alga, *Microcystis aeruginosa*	Cadmium chloride	24 hr	-	EC50 (growth)	0.56	Guanzon et al. 1994	Duration
Blue-green alga, *Microcystis aeruginosa*	-	48 hr	-	EC50 (growth, non-toxic strain)	19.78	Zeng et al. 2009	Duration
Blue-green alga, *Microcystis aeruginosa*	-	48 hr	-	EC50 (growth, toxic strain)	11.58	Zeng et al. 2009	Duration
Cyanobacteria, *Anacystis nidulans*	Cadmium chloride	14 d	-	No growth	50,000	Lee et al. 1992	
Cyanobacteria, *Synechococcus sp.*	-		-	EC50	5,400	Satoh et al. 2005	
Cyanobacteria, *Synechococcus sp.*	Cadmium chloride	72 hr	-	Reduced growth	562	Toth et al. 2012	

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Diatom, *Entomoneis* cf *punctulata*	Cadmium sulfate	24 hr	-	EC50 (fluorescence inhibition)	3,700	Adams and Stauber 2004	Duration
Diatom, *Entomoneis* cf *punctulata*	Cadmium sulfate	72 hr	-	EC50 (growth)	2,400	Adams and Stauber 2004	Duration
Green alga, *Acetabularia acetabulum*	Cadmium chloride	3 wk	-	Morphological deformities	100	Karez et al. 1989	
Green alga, *Chlamydomonas acidophila*	Cadmium sulfate	72 hr	-	EC50 (growth)	1,562	Nishikawa and Tominaga 2001	Duration
Green alga, *Chlamydomonas reinhardtii*	Cadmium chloride	72 hr	-	EC50 (growth)	789	Schafer et al. 1994	Duration
Green alga, *Chlamydomonas reinhardtii*	-	24 hr	-	NOEC-LOEC (specific growth rate)	2.248-4.496	Stoiber et al. 2010	Duration
Green alga, *Chlorella pyrenoidosa*	Cadmium chloride	24 hr	-	EC50 (growth-batch test)	170	Lin et al. 2007	Duration
Green alga, *Chlorella pyrenoidosa*	Cadmium chloride	24 hr	-	EC50 (growth-continuous test)	28	Lin et al. 2007	Duration
Green alga, *Chlorella vulgaris*	Cadmium nitrate	72 hr	-	EC50 (growth)	50,000	Wren and McCarroll 1990	Duration
Green alga, *Chlorella vulgaris*	Cadmium chloride	72 hr	-	Reduced progeny formation	100	Wilczok et al. 1994	Duration
Green alga, *Chlorella vulgaris*	Cadmium sulfate	72 hr	-	LOEC (reduced nitrate reductase activity)	17.99	Awasthi and Das 2005	Duration; Atypical endpoint
Green alga, *Chlorococcum sp.*	-	72 hr	-	EC50 (growth)	11,200	Satoh et al. 2005	Duration
Green alga, *Chlorococcum littorale*	-	72 hr	-	EC50 (growth)	9,700	Satoh et al. 2005	Duration
Green alga, *Prasinococcus sp.*	-	72 hr	-	EC50 (growth)	5,900	Satoh et al. 2005	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	Cadmium nitrate	5 d	-	LOEC (growth)	30	Thompson and Couture 1991	
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	24.2	EC50 (cell counts)	20.6	Radetski et al. 1995	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	24.2	EC50 (cell counts)	42.7	Radetski et al. 1995	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	72 hr	-	EC50 (cell number)	164	Van der Heever and Grobbelaar 1996	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	72 hr	-	EC50 (chlorophyll)	97	Van der Heever and Grobbelaar 1996	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	3.5	EC50 (growth rate)	31	Kallqvist 2009	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	13.5	EC50 (growth rate)	62	Kallqvist 2009	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	72 hr	43.5	EC50 (growth rate)	131	Kallqvist 2009	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	24 hr	-	EC50 (growth rate-total cell volume)	82	Chao and Chen 2001	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	24 hr	-	EC50 (growth rate-cell density)	13	Chao and Chen 2001	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	72 hr	-	EC50 (cell division)	15	Franklin et al. 2001	Duration too short; Lack of exposure details
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	24 hr	-	EC50 (growth)	15,370	Bascik-Remisiewicz and Tukaj 2002	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium nitrate	24 hr	-	EC50 (growth)	18,000	Bascik-Remisiewicz and Tukaj 2002	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium sulfate	24 hr	-	EC50 (growth)	16,440	Bascik-Remisiewicz and Tukaj 2002	Duration
Green alga, *Pseudokirchneriella subcapitata*	Cadmium chloride	60 min	-	EC50 (photosynthesis inhibition)	200	Koukal et al. 2003	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	48 hr	-	EC50 (growth)	35	Lin et al. 2005	Duration
Green alga, *Pseudokirchneriella subcapitata*	-	48 hr	-	EC50 (cell density)	25	Lin et al. 2005	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Green alga, *Pseudokirchneriella subcapitata*	-	48 hr	-	EC50 (D.O. production)	80	Lin et al. 2005	Duration
Green alga, *Scenedesmus dimorphus*	Cadmium nitrate	48 hr	11.3	LC50 (density)	63	Ghosh et al. 1990	Duration
Green alga, *Scenedesmus quadricauda*	Cadmium chloride	96 hr	-	Incipient inhibition (river water)	100	Bringmann and Kuhn 1959a;b	
Green alga, *Scenedesmus quadricauda*	Cadmium chloride	20 d	-	LC50	9	Fargasova 1993	
Green alga, *Scenedesmus quadricauda*	Cadmium chloride	24 hr	-	EC50 (growth)	1.9	Guanzon et al. 1994	Duration
Green alga, *Stichococcus bacillaris*	Cadmium chloride	96 hr	-	Reduced growth	5,000	Skowronski et al. 1985	
Duckweed, *Lemna minor*	-	10 d	-	EC50 (frond production)	191	Smith and Kwan 1989	
Duckweed, *Lemna minor*	Cadmium sulfate	48 hr	-	NOEC-LOEC (relative pigment concentration)	562,050-1,124,100	Prasad et al. 2001	Duration
Duckweed, *Lemna minor*	Cadmium chloride	24 hr	-	EC50 (growth)	57,000	Drinovec et al. 2004	Duration
Duckweed, *Lemna pavcicostata*	Cadmium chloride	48 hr	-	NOEC-LOEC (increase colony break-up)	44.96-89.93	Li and Xiong 2004	Duration
Giant duckweed, *Spirodela polyrrhiza*	-	12 d	-	NOEC-LOEC (inhibit chlorophyll synthesis)	100-500	Rolli et al. 2010	Lack of exposure details
Duckweed, *Spirodela punctata*	-	30 d	-	Reduced growth rate	25	Outridge 1992	
Fungi, *Cylindrotheca sp.*	-	72 hr	-	EC50 (growth)	9,300	Satoh et al. 2005	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Garden cress (seeds), *Lepidium sativum*	Cadmium chloride	72 hr	-	EC50 (growth)	33,723	Gianazza et al. 2007	Duration
Water fern, *Salvinia minima*	-	30 d	-	Reduced growth rate	10	Outridge 1992	
Bacteria, *Escherichia coli*	Cadmium chloride	-	-	Incipient inhibition	150	Bringmann and Kuhn 1959a,b	Bacteria
Bacteria, *Salmonella typhimurium*	Cadmium chloride	8 hr	50	EC50 (growth inhibition)	10,400	Canton and Slooff 1982	Bacteria
Bacteria, *Pseudomonas putida*	Cadmium chloride	16 hr	-	Incipient inhibition	80	Bringmann and Kuhn 1976; 1977a,c; 1979; 1980b	Bacteria
Bacteria, *Vibrio fischeri*	Cadmium chloride	30 min	-	EC50	14,240	Macken et al. 2009	Bacteria
Bacteria (6 species)	Cadmium chloride	18 hr	-	Reduced growth	5,000	Seyfreid and Horgan 1983	Bacteria
Protozoan community	Cadmium chloride	48 hr	70	EC50 (number of species)	4,600	Niederlehner et al. 1985	Protozoan
Protozoan community	Cadmium chloride	28 d	70	EC20 (colonization)	1	Niederlehner et al. 1985	Protozoan
Protozoan community	Cadmium chloride	10 d	-	Reduced biomass	1	Fernandez-Leborans and Novillo-Villajos 1993	Protozoan
Protozoan, *Chilomonas paramecium*	Cadmium nitrate	48 hr	-	Incipient inhibition	160	Bringmann et al. 1980	Protozoan
Ciliate, *Colpidium campylum*	Cadmium sulfate	24 hr	-	EC50 (growth)	75	Dive et al. 1989	Protozoan

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Protozoan, *Colpidium colpoda*	Cadmium chloride	24 hr	103	LC50	890	Madoni and Romeo 2006	Protozoan
Protozoan, *Colpoda steinii*	-	24 hr	-	LC50	500	Martin-Gonzalez et al. 2005	Protozoan
Protozoan, *Cyrtolophosis elongata*	-	24 hr	-	LC50	2,000	Martin-Gonzalez et al. 2005	Protozoan
Protozoan, *Dexiotricha granulosa*	Cadmium chloride	24 hr	103	LC50	300	Madoni and Romeo 2006	Protozoan
Protozoan, *Drepanomonas revoluta*	-	24 hr	-	LC50	2,000	Martin-Gonzalez et al. 2005	Protozoan
Protozoa, *Entosiphon sulcatum*	Cadmium nitrate	72 hr	-	Incipient inhibition	11	Bringmann 1978; Bringmann and Kuhn 1979; 1980b; 1981	Protozoan
Protozoa, *Euglena gracilis*	Cadmium nitrate	24 hr	-	EC50 (motility)	860	Ahmed and Hader 2010	Protozoan
Protozoa, *Euplotes aediculatus*	Cadmium chloride	24 hr	103	LC50	590	Madoni and Romeo 2006	Protozoan
Protozoan, *Halteria grandinella*	Cadmium chloride	24 hr	103	LC50	70	Madoni and Romeo 2006	Protozoan
Protozoan, *Microregma heterostoma*	Cadmium chloride	28 hr	-	Incipient inhibition	100	Brinmgmann and Kuhn 1959b	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium chloride	24 hr	28	LC50	78.1	Nalecz-Jawecki et al. 1993	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium chloride	24 hr	250	LC50	5,270	Nalecz-Jawecki et al. 1993	Protozoan

Species	Chemical	Duration	Hardness (mg/L CaCO$_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	-	LC50	168	Nalecz-Jawecki and Sawicki 1998	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	<10	LC50	160	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	<10	EC50 (deformity)	130	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	200	LC50	3,870	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum ambiguum*	Cadmium nitrate	48 hr	200	EC50 (deformity)	3,250	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Spirostomum teres*	Cadmium chloride	24 hr	-	LC50	1,950	Twagilimana et al. 1998	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	90 min	-	Reduced locomotor rate	750	Bergquist and Bovee 1976	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	60 min	-	Decrease in swimming rate	1,000	Bergquist and Bovee 1976	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	72 hr	-	Growth inhibition	3,372	Krawczynska et al. 1989	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium acetate	30 min	-	Complete mortality	56,205	Larsen and Svensmark 1991	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	96 hr	-	EC50 (growth)	1,045	Schafer et al. 1994	Protozoan
Ciliate, *Tetrahymena pyriformis*	Cadmium chloride	9 hr	-	IC50 (growth)	3,000	Sauvant et al. 1995	Protozoan
Protozoan, *Tetrahymena thermophila*	Cadmium chloride	24 hr	-	LC50	195	Gallego et al. 2007	Protozoan
Protozoan, *Tetrahymena thermophila*	Cadmium nitrate	24 hr	<10	EC50 (feeding inhibition)	130	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Tetrahymena thermophila*	Cadmium nitrate	24 hr	200	EC50 (feeding inhibition)	260	Nalecz-Jawecki and Sawicki 2005	Protozoan
Protozoan, *Uronema parduezi*	Cadmium nitrate	20 hr	-	Incipient inhibition	26	Bringmann and Kuhn 1980a; 1981	Protozoan

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Paramecium, *Paramecium caudatum*	Cadmium chloride	5 d	-	IC50 (growth)	94.40	Miyoshi et al. 2003	Protozoan
Paramecium, *Paramecium bursaria*	-	24 hr	-	LC50	640	Wanick et al. 2008	Protozoan
Paramecium, *Paramecium trichium*	Cadmium chloride	5 d	-	IC50 (growth)	11.71	Miyoshi et al. 2003	Protozoan
Heliozoon, *Raphidiophrys contractilis*	Cadmium chloride	20 min	-	LOEC (axopodial degradation)	11.24	Khan et al. 2006a	Protozoan
Hydra, *Hydra littoralis*	Cadmium chloride	12 d	70	Reduced growth	20	Santiago-Fandino 1983	Duration; Exposure methods unknown
Hydra, *Hydra oligactis*	Cadmium nitrate	48 hr	-	LC50	583	Slooff 1983; Slooff et al. 1983a	Duration
Green hydra, *Hydra viridissima*	Cadmium chloride	7 d	19-20	NOEC-LOEC (population growth rate)	0.4-0.8	Holdway et al. 2001	Duration; Unmeasured exposure
Green hydra (symbiotic, with algae), *Hydra viridissima*	Cadmium chloride	48 hr	207	LC50	160	Karntanut and Pascoe 2005	Duration
Green hydra (aposymbiotic, without algae), *Hydra viridissima*	Cadmium chloride	48 hr	207	LC50	140	Karntanut and Pascoe 2005	Duration
Pink hydra, *Hydra vulgaris*	Cadmium chloride	7 d	19-20	LOEC (population growth rate)	12.5	Holdway et al. 2001	Duration; Unmeasured exposure
Planarian, *Dendrocoelum lacteum*	Cadmium chloride	48 hr	122.8	LC50	46,000	Brown and Pascoe 1988	Duration
Planarian, *Dugesia lugubris*	Cadmium nitrate	48 hr	-	LC50	>20,000	Slooff 1983	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	24 hr	80-100	LC50	1,300	Snell et al. 1991a	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	48 hr	80-100	EC50	70	Snell and Moffat 1992	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	48 hr	80-100	Chronic value	60	Snell and Moffat 1992	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium sulfate	24 hr	250	EC50	120	Crisinel et al. 1994	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium chloride	35 min	170	NOEC (ingestion rate)	250.00	Juchelka and Snell 1994	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	72 hr	80-100	Chronic value (asexual reproduction)	20	Snell and Carmona 1995	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium nitrate	72 hr	80-100	Chronic value (sexual reproduction)	20	Snell and Carmona 1995	Duration
Rotifer (<2 hr), *Brachionus calyciflorus*	Cadmium nitrate	48 hr	80-100	EC50	10	Radix et al. 1999	Duration
Rotifer, *Brachionus calyciflorus*	Cadmium chloride	24 hr	-		180	Sarma et al. 2006	Duration
Rotifer, *Brachionus macracanthus*	Cadmium chloride	24 hr	-	LC50	118.9	Nandini et al. 2007	Duration
Rotifer, *Brachionus macracanthus*	Cadmium chloride	21 d	-	LOEC (population growth)	0.383	Nandini et al. 2007	Unmeasured chronic exposure
Rotifer, *Brachionus rubens*	Cadmium chloride	24 hr	80-100	LC50	810	Snell and Persoone 1989a	Duration
Rotifer, *Brachionus rubens*	Cadmium chloride	24 hr	80-100	NOEC (survival)	280	Snell and Persoone 1989a	Duration
Rotifer, *Philodina acuticornis*	Cadmium chloride	96 hr	Soft water	EC50 (death and immobility)	500	Buikema et al. 1973	Test species fed
Rotifer, *Philodina acuticornis*	Cadmium sulfate	96 hr	Soft water	EC50 (death and immobility)	200	Buikema et al. 1973	Test species fed
Rotifer, *Philodina acuticornis*	Cadmium sulfate	96 hr	Hard water	EC50 (death and immobility)	300	Buikema et al. 1973	Test species fed

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Rotifer, *Streptocephalus rubricaudatus*	Cadmium sulfate	24 hr	250	EC50	250	Crisinel et al. 1994	Duration
Rotifer, *Thamnocephalus platyurus*	Cadmium chloride	24 hr	80-100	LC50	400	Centeno et al. 1995	Duration
Parasite (embryo, blastula stage), *Chordodes nobilli*	Cadmium chloride	96 hr	162	Infective capacity of larva	630	Achiorno et al. 2010	Atypical endpoint
Parasite (larva), *Chordodes nobilli*	Cadmium chloride	48 hr	162	Infective capacity of larva	360	Achiorno et al. 2010	Atypical endpoint; Duration
Nematode, *Caenorhabditis elegans*	Cadmium chloride	96 hr	-	LC50	61	Williams and Dusenbery 1990	Test species fed
Nematode (adult), *Caenorhabditis elegans*	-	48 hr	-		2,000	Cressman and Williams 1997	Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	EC50 (growth)	16,524	Anderson et al. 2001	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	EC50 (movement)	18,772	Anderson et al. 2001	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	EC50 (feeding)	14,388	Anderson et al. 2001	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	72 hr	-	EC50 (reproduction)	16,973	Anderson et al. 2001	Test species fed; Duration
Nematode (L1 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	LC50	66,884	Chu and Chow 2002	Test species fed; Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	LC50	620,503	Chu and Chow 2002	Test species fed; Duration
Nematode (larva), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	LC50	169,920	Ura et al. 2002	Duration
Nematode (3 d), *Caenorhabditis elegans*	Cadmium chloride	24 hr	-	LC50	518,598	Roh et al. 2006	Duration
Nematode (L1-L4 larva), *Caenorhabditis elegans*	Cadmium chloride	4 hr	-	LOEC (reproduction)	11,240	Guo et al. 2009	Duration
Nematode (adult), *Caenorhabditis elegans*	Cadmium chloride	72 hr	-	LOEC (reproduction)	11,240	Guo et al. 2009	Duration
Nematode (L4 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	EC50 (number of offsprings)	20,906	Boyd et al. 2010	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Nematode (L4 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	EC50 (number of offsprings)	19,784	Boyd et al. 2010	Duration
Nematode (L4 larva), *Caenorhabditis elegans*	Cadmium chloride	48 hr	-	EC50 (number of offsprings)	21,583	Boyd et al. 2010	Duration
Polychaete worm (non-reproductive), *Aelosoma headleyi*	Cadmium chloride	48 hr	60-70	LC50	1,200	Niederlehner et al. 1984	Test species fed; Duration
Polychaete worm (non-reproductive), *Aelosoma headleyi*	Cadmium chloride	48 hr	160-190	LC50	4,980	Niederlehner et al. 1984	Test species fed; Duration
Oligochaete, *Aeolosoma headleyi*	Cadmium chloride	10 d	65 (60-70)	NOEC-LOEC (growth and reproduction)	17.2-36.9	Niederlehner et al. 1984	Duration
Oligochaete (adult) worm, *Lumbriculus variegatus*	Cadmium chloride	10 d	44-47	LC50	158	Phipps et al. 1995	Duration
Oligochaete worm, *Lumbriculus variegatus*	Cadmium chloride	48 hr	20	LC50	270	Penttinen et al. 2011	Duration
Oligochaete worm, *Lumbriculus variegatus*	Cadmium chloride	48 hr	50	LC50	410	Penttinen et al. 2011	Duration
Oligochaete worm, *Lumbriculus variegatus*	Cadmium chloride	48 hr	250.25	LC50	2,161	Penttinen et al. 2011	Duration
Oligochaete, *Pristina sp.*	Cadmium chloride	52 week	11.1	Population reduction	5	Giesy et al. 1979	Exposure methods unknown
Oligochate, *Prstina leidyi*	Cadmium chloride	48 hr	95	LC50	215	Smith et al. 1991	Duration
Tubificid worm, *Tubifex tubifex*	Cadmium chloride	48 hr	224	LC50	320,000	Qureshi et al. 1980	Duration
Tubificid worm, *Tubifex tubifex*	Cadmium chloride	96 hr	245	LC50	47,530	Khangarot 1991	
Tubificid worm (adult, 4 cm), *Tubifex tubifex*	Cadmium chloride	24 hr	-	LC50	4,900	Gerhardt 2009	Duration
Tubificid worm (adult, 4 cm), *Tubifex tubifex*	Cadmium chloride	24 hr	-	EC50 (locomotion)	1,100	Gerhardt 2009	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Spire snail, *Amnicola limosa*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	6,350	Mackie 1989	pH is artificially low as part of study
Spire snail, *Amnicola limosa*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	3,800	Mackie 1989	pH is artificially low as part of study
Spire snail, *Amnicola limosa*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	2,710	Mackie 1989	pH is artificially low as part of study
Snail (egg, strain BS90), *Biomphalaria glabrata*	Cadmium chloride	3 mo	-	LOEC (hatching success)	1.14	Salice and Miller 2003	Unmeasured chronic exposure
Snail (egg, strain NMRI), *Biomphalaria glabrata*	Cadmium chloride	3 mo	-	LOEC (hatching success)	2.81	Salice and Miller 2003	Unmeasured chronic exposure
Pond snail (6-9 mo., 10.32 mm), *Lymnaea palustris*	Cadmium chloride	28 d	-	LC50	>320	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail (6-9 mo., 10.32 mm), *Lymnaea palustris*	Cadmium chloride	28 d	-	EC50 (growth)	58.2	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail (6-9 mo., 10.32 mm), *Lymnaea palustris*	Cadmium chloride	28 d	-	NOEC-LOEC (reproduction)	40-80	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail, *Lymnaea stagnalis*	Cadmium chloride	48 hr	-	LC50	583	Slooff 1983; Slooff et al. 1983a	Duration
Pond snail (6-9 mo., 20.62 mm), *Lymnaea stagnalis*	Cadmium chloride	28 d	-	EC50 (growth)	142.2	Coeurdassier et al. 2003	Unmeasured chronic exposure
Pond snail (5 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	LC50	12.8 (dissolved)	Pais 2012	Duration
Pond snail (10 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	NOEC (length and weight)	94.3	Pais 2012	More sensitive endpoint available for this study
Pond snail (10 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	LC50	49.7 (dissolved)	Pais 2012	Duration
Pond snail (15 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	NOEC (length and weight)	94.3	Pais 2012	More sensitive endpoint available for this study
Pond snail (15 mm), *Lymnaea stagnalis*	Cadmium chloride	31 d	135 (130-140)	LC50	45.7 (dissolved)	Pais 2012	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Pond snail (juvenile, 7 mm), *Lymnaea stagnalis*	Cadmium chloride	28 d	20.5 (20-21)	LC50	7.3 (dissolved)	Pais 2012	Duration; Too few exposure concentrations
Pond snail (juvenile, 7 mm), *Lymnaea stagnalis*	Cadmium chloride	28 d	20.5 (20-21)	NOEC-LOEC (length and weight)	2.47-4.76	Pais 2012	Too few exposure concentrations
Snail, *Physa integra*	Cadmium chloride	28 d	44-58	LC50	10.4	Spehar et al. 1978	Exposure methods unknown; Duration
New Zealand mud snail (clone A, 3-4 mm), *Potamopyrgus antipodarum*	Cadmium chloride	48 hr	197	LC50	1,920	Jensen and Forbes 2001	Duration
New Zealand mud snail (clone B, 3-4 mm), *Potamopyrgus antipodarum*	Cadmium chloride	48 hr	197	LC50	1,290	Jensen and Forbes 2001	Duration
New Zealand mud snail (clone C, 3-4 mm), *Potamopyrgus antipodarum*	Cadmium chloride	48 hr	197	LC50	560	Jensen and Forbes 2001	Duration
New Zealand mudsnail, *Potamopyrgus antipodarum*	Cadmium sulfate	28 d	-	EC50 (reproduction)	11.5	Sieratowicz et al. 2011	Atypical endpoint
Snail, *Viviparus bengalensis*	Cadmium chloride	96 hr	140-190	LC50	1,550	Gadkari and Marathe 1983	
Mussel (glochidia), *Fusconia masoni*	Cadmium chloride	24 hr	88	LC50	168.1	Black 2001	Control mortality was not reported adequately to use for this lifestage
Fatmucket (juvenile), *Lampsilis siliquoidea*	Cadmium nitrate	28 d	40-48	LC50	8.1	Wang et al. 2010d	Atypical endpoint
Mussel, *Utterbackia imbecillis*	Cadmium chloride	48 hr	39	LC50	57	Keller and Zam 1991	Duration
Mussel, *Utterbackia imbecillis*	Cadmium chloride	48 hr	80-100	LC50	137	Keller and Zam 1991	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mussel (glochidia), *Utterbackia imbecillis*	Cadmium chloride	24 hr	88	LC50	56.76	Black 2001	Control mortality was not reported adequately to use for this lifestage
Zebra mussel (3.0-3.5 cm), *Dreissena polymorpha*	Cadmium chloride	8 hr	-	Caused valve closure	200-560	Slooff et al. 1983b	Atypical endpoint; Duration
Zebra mussel, *Dreissena polymorpha*	Cadmium chloride	77 d	268	LOEC (filtration rate)	9	Kraak et al. 1992b	Atypical endpoint
Zebra mussel, *Dreissena polymorpha*	Cadmium chloride	77 d	268	EC50	130	Kraak et al. 1992b	Duration
Zebra mussel, *Dreissena polymorpha*	Cadmium chloride	48 hr	150	EC50	388	Kraak et al. 1994a	Duration
Zebra mussel (18-25 mm), *Dreissena polymorpha*	Cadmium chloride	7 d	290	Increased metallothionein level	10	Ivankovic et al. 2010	Atypical endpoint; Duration
Asian clam (adult, 15-20 mm), *Corbicula fluminea*	Cadmium chloride	30 d	90	LOEC (reduced phagocytosis activity)	3	Champeau et al. 2007	Unmeasured chronic exposure; Atypical endpoint
Asian clam (adult, 15-20 mm), *Corbicula fluminea*	Cadmium chloride	30 d	90	NOEC-LOEC (decrease lysosomal value, surface, size and number)	21.5-46.5	Champeau et al. 2007	Unmeasured chronic exposure; Atypical endpoint
Bivalve, *Pisidium casertanum*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	1,370	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium casertanum*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	480	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium casertanum*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	700	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium compressum*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	2,080	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium compressum*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	700	Mackie 1989	pH is artificially low as part of study
Bivalve, *Pisidium compressum*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	360	Mackie 1989	pH is artificially low as part of study

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Cadmium nitrate	48 hr	100	LC50	27.3	Spehar and Fiandt 1986	High TOC; River dilution water not characterized
Cladoceran, *Ceriodaphnia dubia*	Cadmium sulfate	10 d	90	NOEC (reproduction)	0.5	Winner 1988	Duration; Unmeasured chronic exposure
Cladoceran, *Ceriodaphnia dubia*	Cadmium sulfate	7 d	169	Chronic value (reproduction)	<14	Masters et al. 1991	Duration; Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	-		290		120	Schubauer-Berigan et al. 1993	Test species fed
Cladoceran (<48 hr), *Ceriodaphnia dubia*	Cadmium nitrate	48 hr	280-300	LC50	560	Schubauer-Berigan et al. 1993	Test species fed
Cladoceran, *Ceriodaphnia dubia*	Cadmium chloride	1 hr	80-100	EC50 (feeding inhibition)	54	Bitton et al. 1996	Duration; Atypical endpoint
Cladoceran, *Ceriodaphnia dubia*	Cadmium chloride	1 hr	80-100	EC50 (feeding inhibition)	76.2	Lee et al. 1997	Duration; Atypical endpoint
Cladoceran (≤ 24hr), *Ceriodaphnia dubia*	Cadmium chloride	48 hr	17	LC50	63.1	Suedel et al. 1997	Test species fed
Cladoceran, *Ceriodaphnia dubia*	-	LC	17	NOEC-LOEC	1.0-4.0	Suedel et al. 1997	Static exposure
Cladoceran, *Ceriodaphnia dubia*	Cadmium chloride	7 d	80-100	Chronic value	1.4	Zuiderveen and Birge 1997	Duration; Unmeasured chronic exposure
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Cadmium sulfate	120 min	160-180	Reduced mobility	2,500 (dissolved)	Brent and Herricks 1998	Duration
Cladoceran (<24 hr), *Ceriodaphnia dubia*	Cadmium nitrate	48 hr	80-100	LC50	78.2	Nelson and Roline 1998	Test species fed
Cladoceran (neonate), *Ceriodaphnia dubia*	Cadmium chloride	1.5 hr	-	EC50	34.2	Jun et al. 2006	Duration
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	-	7 d	100	LOEC (reproduction)	5.22	Sofyan et al. 2007a	Duration
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	-	7 d	100	LOEC (reproduction)	5	Sofyan et al. 2007b	Duration; Unmeasured chronic exposure

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (neonate, <24 hr), *Ceriodaphnia dubia*	-	7 d	100	NOEC-LOEC (survival)	5-10	Sofyan et al. 2007b	Duration; Unmeasured chronic exposure
Cladoceran, *Ceriodaphnia reticulata*	-	48 hr	45	LC50	66	Mount and Norberg 1984	Test species fed
Cladoceran, *Ceriodaphnia reticulata*	Cadmium chloride	48 hr	55-79	LC50	129	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Cladoceran (< 6hr), *Ceriodaphnia reticulata*	Cadmium chloride	48 hr	200	LC50	79.4	Hall et al. 1986	Well water (not characterized)
Cladoceran, *Daphnia galeata mendotae*	Cadmium chloride	154 d	-	Reduced biomass	4.0	Marshall 1978a	Exposure methods unknown
Cladoceran, *Daphnia galeata mendotae*	Cadmium chloride	15 d	-	Reduced rate of increase	5.0	Marshall 1978b	Exposure methods unknown
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	-	EC50	100	Bringmann and Kuhn 1959a;b	River dilution water not characterized
Cladoceran, *Daphnia magna*	Cadmium chloride	21 d	45	Reproductive impairment	0.17	Biesinger and Christensen 1972	Exposure methods unknown
Cladoceran, *Daphnia magna*	Cadmium chloride	72 hr	163	LC50	15.8	Debelak 1975	Test species fed
Cladoceran, *Daphnia magna*	Cadmium nitrate	24 hr	-	LC50	600	Bringmann and Kuhn 1977b	Duration
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (10ºC)	LC50	224	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (15ºC)	LC50	224	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (25ºC)	LC50	12	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (3-5 d), *Daphnia magna*	Cadmium sulfate	72 hr	- (30ºC)	LC50	0.1	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (10ºC)	LC50	479	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (15ºC)	LC50	187	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (25ºC)	LC50	10.2	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran (adult), *Daphnia magna*	Cadmium sulfate	72 hr	- (30ºC)	LC50	2.4	Braginskly and Shcherban 1978	Duration; Atypical lifestage for species
Cladoceran, *Daphnia magna*	Cadmium nitrate	24 hr	200	EC50	160	Bellavere and Gorbi 1981	Duration
Cladoceran, *Daphnia magna*	Cadmium chloride	20 d	200	LC50	670	Canton and Sloof 1982	Other endpoints used
Cladoceran, *Daphnia magna*	-	48 hr	45	LC50	118	Mount and Norberg 1984	Test species fed
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	55-79	LC50	166	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	37	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	6.1	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	43	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	31	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	18	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	12	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	24	Lewis and Weber 1985	Mean control survial was >90% for 16 of 22 tests, but author did not present control survival for each test
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	200	LC50	49.0	Hall et al. 1986	Well water (not characterized)
Cladoceran (1 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	64	Nebeker et al. 1986a	Test species fed
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	55	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	306	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	41	LC50	98	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	307	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	37	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	94	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	277	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (2 d), *Daphnia magna*	Cadmium chloride	48 hr	71	LC50	135	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	17	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	40	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	41	LC50	30	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	131	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	38	LC50	92	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old; Test species fed
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	76	LC50	25	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	74	LC50	36	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	71	LC50	18	Nebeker et al. 1986a	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	34	LC50	33	Nebeker et al. 1986b	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	34	LC50	24	Nebeker et al. 1986b	Typically tests with cladocerans are <24 hr old
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	48 hr	34	LC50	40	Nebeker et al. 1986b	Typically tests with cladocerans are <24 hr old
Cladoceran, *Daphnia magna*	Cadmium sulfate	25 d	100 (20ºC)	NOEC (reproduction)	2.25	Winner and Whitford 1987	Unmeasured chronic exposure
Cladoceran, *Daphnia magna*	Cadmium sulfate	25 d	100 (25ºC)	NOEC (reproduction)	0.75	Winner and Whitford 1987	Unmeasured chronic exposure

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran, *Daphnia magna*	Cadmium chloride	25 d	150	NOEC-LOEC (reproduction)	5.0-10	Bodar et al. 1988b	More sensitive endpoint available from this study
Cladoceran, *Daphnia magna*	Cadmium sulfate	10 d	90	NOEC (reproduction)	2.5	Winner 1988	Duration; Unmeasured chronic exposure
Cladoceran (egg), *Daphnia magna*	Cadmium chloride	46 hr	150	Profound effect on egg development	>1,000	Bodar et al. 1989	Duration
Cladoceran, *Daphnia magna*	Cadmium sulfate	48 hr	240	LC50	1,880	Khangarot and Ray 1989a	Dilution water not fully characterized
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	24 hr	-	EC50	1,900	Kuhn et al. 1989	Duration
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	24 d	-	NOEC (reproduction)	0.6	Kuhn et al. 1989	
Cladoceran (small neonate), *Daphnia magna*	Cadmium chloride	48 hr	250	LC50	98	Enserink et al. 1990	Test species fed
Cladoceran (large neonate), *Daphnia magna*	Cadmium chloride	48 hr	250	LC50	294	Enserink et al. 1990	Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180 (20ºC)	LC50	38	Lewis and Horning 1991	Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	160-180 (26ºC)	LC50	9	Lewis and Horning 1991	Test species fed
Cladoceran (5 d), *Daphnia magna*	Cadmium chloride	21 d	225	LOEC (reproduction)	2.3	Enserink et al. 1993	
Cladoceran, *Daphnia magna*	Cadmium chloride	48 hr	-	LC50	48	Domal-Kwiatkowska et al. 1994	Test species fed
Cladoceran (14 d), *Daphnia magna*	Cadmium chloride	48 hr	160-180	LC50	80	Allen et al. 1995	
Cladoceran, *Daphnia magna*	Cadmium acetate	24 hr	-	EC50	980	Sorvari and Sillanpaa 1996	Duration
Cladoceran (≤ 24 hr) *Daphnia magna*	Cadmium chloride	48 hr	17	LC50	26.4	Suedel et al. 1997	Test species fed
Cladoceran (juvenile, 4-5 d), *Daphnia magna*	Cadmium sulfate	48 hr	160-180	EC50 (death and immobility)	30-219	Barata et al. 2000	Test species fed
Cladoceran (juvenile, 4-5 d), *Daphnia magna*	Cadmium sulfate	48 hr	160-180	EC50 (feeding inhibition)	9-41	Barata et al. 2000	Test species fed; Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (neonate, <48 hr), *Daphnia magna*	Cadmium chloride	17 d	-	NOEC-LOEC (reproduction)	1.7-3.7	Knops et al. 2001	Duration; Unmeasured chronic exposure
Cladoceran (4th instar, 4-5 d), *Daphnia magna*	-	24 hr	-	IC50 (feeding inhibition)	1.31	McWilliam and Baird 2002	Duration; Atypical endpoint; Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	96 hr	50	LC50	>3.43	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	96 hr	100	LC50	>6.85	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (adult, 12-15 d), *Daphnia magna*	Cadmium chloride	3 hr	-	LOEC (reduce phototactic index)	30	Yuan et al. 2003	Duration; Atypical endpoint
Cladoceran (neonate, >14 d, female), *Daphnia magna*	Cadmium nitrate	14 d	-	NOEC-LOEC (Survival-low food ration groups)	2.81-5.62	Smolders et al. 2005	Duration
Cladoceran (neonate, >14 d, female), *Daphnia magna*	Cadmium nitrate	14 d	-	NOEC-LOEC (Survival-high food ration groups)	1.12-2.81	Smolders et al. 2005	Duration
Cladoceran (<24 hr), *Daphnia magna*	Cadmium sulfate	48 hr	-	Reduced feeding and egg production	2.473	Barata et al. 2007	Atypical endpoint
Cladoceran (<24 hr), *Daphnia magna*	Cadmium sulfate	21 d	125-140	EC50 (survival)	0.64	Poynton et al. 2007	Unmeasured chronic exposure
Cladoceran (<24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	125-140	LC50	180	Poynton et al. 2007	Duration
Cladoceran (juvenile, 5 d), *Daphnia magna*	Cadmium chloride	4 hr	240	LOEC (ROS production)	>112.41	Xie et al. 2007	Duration; Atypical endpoint
Cladoceran (4th instar, 4-5 d), *Daphnia magna*	Cadmium chloride	24 hr	160-180	EC50 (feeding inhibition)	35.54	Ferreira et al. 2008a	Duration; Atypical endpoint
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	24 hr	-	50% reduced survival	36.79	Connon et al. 2008	Duration
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	21 d	-	NOEC-LOEC (ChE activities)	0.041-0.082	Jemec et al. 2008	Atypical endpoint
Cladoceran (juvenile, ≤24 hr), *Daphnia magna*	Cadmium chloride	48 hr	250	EC50 (respiration)	160	Zitova et al. 2009	Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L CaCO$_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	- (20ºC)	EC50 (immobility)	112 (dissolved)	Muyssen et al. 2010	Elevated DOC (3.7-5.74 mg/L) in dilution water
Cladoceran (<24 hr), *Daphnia magna*	Cadmium chloride	48 hr	- (24ºC)	EC50 (immobility)	64 (dissolved)	Muyssen et al. 2010	Elevated DOC (3.7-5.74 mg/L) in dilution water
Cladoceran (14 d), *Daphnia magna*	Cadmium chloride	24 hr	-	LC50	71	Taylor et al. 2010	Lack of exposure details; Duration
Cladoceran, *Daphnia magna*	Cadmium chloride	24 hr	90 (80-110) (20ºC)	EC50	6.34	Kim et al. 2012a	Duration
Cladoceran, *Daphnia magna*	Cadmium chloride	1 hr	90 (80-110) (36.5ºC)	EC50	26.9	Kim et al. 2012a	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=5.0)	EC50 (immobility)	1,210	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=6.0)	EC50 (immobility)	1,160	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=7.0)	EC50 (immobility)	420	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=8.0)	EC50 (immobility)	390	Qu et al. 2013	Duration
Cladoceran (6-24 hr), *Daphnia magna*	Cadmium sulfate	24 hr	135.5 (pH=9.0)	EC50 (immobility)	350	Qu et al. 2013	Duration
Cladoceran, *Daphnia pulex*	Cadmium chloride	140 d	57	Reduced reproduction	1	Bertram and Hart 1979	Lack of exposure details
Cladoceran, *Daphnia pulex*	Cadmium chloride	48 hr	57	LC50	104-127	Ingersoll and Winner 1982	Test species fed
Cladoceran, *Daphnia pulex*	Cadmium chloride	58 d	106	NOEC-LOEC	5-10	Ingersoll and Winner 1982	Lack of exposure details
Cladoceran, *Daphnia pulex*	-	48 hr	45	LC50	68	Mount and Nerberg 1984	Test species fed
Cladoceran, *Daphnia pulex*	Cadmium sulfate	72 hr	100	LC50	80-92	Winner 1984	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Test species fed

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	120	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	170	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	190	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	160	Lewis and Weber 1985	Test species fed
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	150	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	150	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	100	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	180	Lewis and Weber 1985	Mean control survial was >90% for 12 of 16 tests, but author did not present control survival for each test

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran (≤ 24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90	LC50	130	Lewis and Weber 1985	Mean control survival was >90% for 12 of 16 tests, but author did not present control survival for each test
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	200	LC50	100	Hall et al. 1986	Well water (not characterized)
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	58	NOEC (survival)	3.8	Winner 1986	
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	115	NOEC (brood size)	7.5	Winner 1986	
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	230	NOEC (brood size)	7.5	Winner 1986	
Cladoceran (adult), *Daphnia pulex*	Cadmium chloride	48 hr	124-130	LC50	87.9	Jindal and Verma 1990	Pond water (not characterized)
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90 (20ºC)	LC50	42	Lewis and Horning 1991	Test species fed
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	48 hr	80-90 (26ºC)	LC50	6	Lewis and Horning 1991	Test species fed
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	21 d	80-90	NOEC (reproduction)	<0.003	Roux et al. 1993	Static, unmeasured exposure
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	96 hr	50	LC50	>14.6	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (<24 hr), *Daphnia pulex*	Cadmium chloride	96 hr	100	LC50	>20	Chadwick Environmental Consultants 2003	Test species fed
Cladoceran (24 hr), *Macrothrix triserialis*	Cadmium chloride	24 hr	-	LC50	420	Garcia et al. 2004	Duration
Cladoceran, *Moina macrocopa*	Cadmium chloride	20 d	80-84	Reduced survival	0.2	Hatakeyama and Yasuno 1981b	Duration; Unknown exposure methods
Cladoceran, *Moina macrocopa*	Cadmium chloride	10 d	-	Reduced survival	10	Wong and Wong 1990	Duration
Cladoceran (24 hr), *Moina macrocopa*	Cadmium chloride	24 hr	-	LC50	680	Garcia et al. 2004	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Cladoceran, *Simocephalus serrulatus*	Cadmium chloride	48 hr	55-79	LC50	123	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Cladoceran, *Simocephalus vetulus*	-	48 hr	45	LC50	24	Mount and Norberg 1984	Test species fed
Cladoceran, *Simocephalus vetulus*	Cadmium chloride	48 hr	55-79	LC50	89.3	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Copepod, *Acanthocyclops viridis*	Cadmium sulfate	72 hr	-	LC50	0.5	Braginskly and Shcherban 1978	Duration
Copepod, *Eucyclops agilis*	Cadmium chloride	52 wk	11.1	Population reduction	5	Giesy et al. 1979	Lack of exposure details
Copepod, *Tropocyclops prasinus mexicanus*	Cadmium chloride	48 hr	10	LC50	149	Lalande and Pinel-Alloul 1986	Duration
Aquatic sowbug (3-6 mm, land population), *Asellus aquaticus*	-		176		76	Pascoe and Carroll 2004	Test species fed
Aquatic sowbug (3-6 mm, pond population), *Asellus aquaticus*	-		176		160	Pascoe and Carroll 2004	Test species fed
Aquatic sowbug (3-6 mm, canal population), *Asellus aquaticus*	-		176		233	Pascoe and Carroll 2004	Test species fed
Amphipod, *Diporeia sp.*	Cadmium chloride	96 hr	- (4ºC)	LC50	800	Gossiaux et al. 1992	Dilution water not fully characterized
Amphipod, *Diporeia sp.*	Cadmium chloride	96 hr	- (10ºC)	LC50	280	Gossiaux et al. 1992	Dilution water not fully characterized
Amphipod, *Diporeia sp.*	Cadmium chloride	96 hr	- (15ºC)	LC50	60	Gossiaux et al. 1992	Dilution water not fully characterized

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Amphipod (0-1 wk), *Gammarus fasciatus*	Cadmium	130	1.49-2.23	NOEC - LOEC (survival)	1.49-2.23	Borgmann et al. 1989b	Poor control survival (45%)
Amphipod, *Gammarus pseudolimnaeus*	Cadmium chloride	96 hr	55-79	LC50	54.4	Spehar and Carlson 1984a;b	River dilution water not characterized
Amphipod (adult, 9 mm), *Gammarus tigrinus*	Cadmium chloride	72 hr	116	LC50	146.5	Boets et al. 2012	Duration
Scud, *Gammarus sp.*	Cadmium	S, U	50		70	Rehwoldt et al. 1973	Lack of detail since other acceptable study available with specific species
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	55-79	LC50	285	Spehar and Carlson 1984a,b	High TOC; River dilution water not characterized
Amphipod (0-1 wk), *Hyalella azteca*	Cadmium	LC	130	NOEC-LOEC (survival)	0.57-0.92	Borgmann et al. 1989b	Low control weights and poor (64%) control survival
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	15.3 (pH=5.0)	LC50	12	Mackie 1989	pH is artificially low as part of study
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	15.3 (pH=5.5)	LC50	16	Mackie 1989	pH is artificially low as part of study
Amphipod, *Hyalella azteca*	Cadmium chloride	96 hr	15.3 (pH=6.0)	LC50	33	Mackie 1989	pH is artificially low as part of study
Amphipod, *Hyalella azteca*	Cadmium nitrate	6 wk	130	EC50 (survival)	0.53	Borgmann et al. 1991	Inadequate control performance
Amphipod, *Hyalella azteca*	Cadmium nitrate	96 hr	280-300	LC50	230	Schubauer-Berigan et al. 1993	Test species fed
Amphipod (0-2 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈13	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (2-4 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈7.5	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Amphipod (4-6 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈9.5	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (10-12 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈7	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (16-18 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈11.5	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod (24-26 d), *Hyalella azteca*	Cadmium chloride	96 hr	90	LC50	≈14	Collyard et al. 1994	Test species fed; Data graphed, could only get approximate value
Amphipod, *Hyalella azteca*	Cadmium chloride	10 d	44-47	LC50	2.8	Phipps et al. 1995	Duration
Amphipod, *Hyalella azteca*	-	JGS (juvenile growth and survival test	17	Chronic value (growth and survival)	0.16	Suedel et al. 1997	Static exposure
Amphipod (2-3 wk), *Hyalella azteca*	-	96 hr	17	LC50	2.8	Suedel et al. 1997	Did not meet specific acceptability criteria for this species
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50 (starved for 48 hr before test)	99.34	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50 (starved for 72 hr before test)	82.17	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50 (starved for 96 hr before test)	65.00	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50	107.3	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50	75.42	McNulty et al. 1999	Duration
Amphipod, *Hyalella azteca*	Cadmium chloride	24 hr	217-301	LC50	74.20	McNulty et al. 1999	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Amphipod (7-10 d), *Hyalella azteca*	-	96 hr	48	LC50	3.8	Jackson et al. 2000	Did not meet specific acceptability criteria for this species
Amphipod (7-10 d), *Hyalella azteca*	-	96 hr	118	LC50	12.1	Jackson et al. 2000	Did not meet specific acceptability criteria for this species
Amphipod (7-8 d), *Hyalella azteca*	Cadmium chloride	LC	153	NOEC-LOEC (survival)	0.8-1.3	Chadwick Ecological Consultants 2003	Low control weights; does not meet feeding recommendations for chronic test with this species
Amphipod (7-8 d), *Hyalella azteca*	Cadmium chloride	LC	126	NOEC-LOEC (survival)	0.5-1.1	Chadwick Ecological Consultants 2003	Low control weights; does not meet feeding recommendations for chornic test with this species
Amphipod (1-11 d), *Hyalella azteca*	-	7 d	18	LC50	0.15	Borgmann et al. 2005	Duration
Amphipod (1-11 d), *Hyalella azteca*	-	7 d	124	LC50	1.60	Borgmann et al. 2005	Duration
Amphipod, *Hyalella azteca*	Cadmium sulfate	LC	162.7	NOEC-LOEC (survival)	2.49-5.09	Stanley et al. 2005	Low control weights; does not meet feeding recommendations for chornic test with this species
Amphipod, *Hyalella azteca*	-	72 hr	-	LC50	1.9	Gust 2006	Duration
Amphipod (neonate 2-9 d), *Hyalella azteca*	-	21 d	140	NOEC-LOEC (survival)	5-10	Straus 2011	More sensitive endpoint available for this study
Amphipod (neonate 2-9 d), *Hyalella azteca*	-	21 d	140	NOEC-LOEC (growth)	<1.25-1.25	Straus 2011	Does not meet chronic test requirements for this species
Amphipod (neonate 2-9 d), *Hyalella azteca*	-	28 d	22	NOEC-LOEC (survival)	0.5-1.3	Straus 2011	Does not meet chronic test requirements for this species
Amphipod (neonate 2-9 d), *Hyalella azteca*	Cadmium chloride	7 d	90	LC50	4.6 (dissolved)	Pais 2012	Duration

Species	Chemical	Duration	Hardness (mg/L CaCO$_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Amphipod (neonate 2-9 d), *Hyalella azteca*	Cadmium chloride	28 d	90	LC50	0.70 (dissolved)	Pais 2012	Duration
Crayfish, *Cambarus latimanus*	Cadmium chloride	50 mo	11.1	Significant mortality	5	Thorp et al. 1979	Lack of exposure details
Crayfish, *Orconectes immunis*	Cadmium chloride	96 hr	50.3	LC50	>10,000	Thorp and Gloss 1986	Effect level based on nominal, but substantial loss per measured levels was observed
Crayfish (juvenile, 2 g), *Orconectes immunis*	Cadmium nitrate	5 d	-	LC50	7,000	Khan et al. 2006b	Duration; Test species fed
Crayfish (juvenile, 2 g), *Orconectes immunis*	Cadmium nitrate	2.51 d	-	LT50=2.51 d	22,000	Khan et al. 2006b	Duration; Test species fed
Fairy shrimp (2nd-3rd instar nauplii), *Streptocephalus proboscideus*	-	24 hr	-	-	460	Centeno et al. 1993	Duration
Fairy shrimp (2nd-3rd instar nauplii), *Streptocephalus proboscideus*	-	24 hr	-	-	510	Centeno et al. 1993	Duration
Fairy shrimp, *Streptocephalus proboscideus*	Cadmium sulfate	24 hr	250	-	250	Crisinel et al. 1994	Duration
Fairy shrimp, *Thamnocephalus platyurus*	Cadmium chloride	24 hr	80-100		400	Centeno et al. 1995	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (10ºC)	LC50	70,600	Braginskly and Shcherban 1978	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (15ºC)	LC50	28,600	Braginskly and Shcherban 1978	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (25ºC)	LC50	6,990	Braginskly and Shcherban 1978	Duration
Mayfly, *Cleon dipterum*	Cadmium sulfate	72 hr	- (30ºC)	LC50	930	Braginskly and Shcherban 1978	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mayfly, *Cleon dipterum*	Cadmium nitrate	48 hr	-	LC50	56,000	Slooff et al. 1983a	Duration
Mayfly, *Ephemerella sp.*	Cadmium chloride	28 d	44-48	LC50	<3.0	Spehar et al. 1978	Lack of exposure details
Mayfly, *Paraleptophlebia praepedita*	Cadmium chloride	96 hr	55-77	LC50	449	Spehar and Carlson 1984a;b	River dilution water not characterized
Mayfly, *Rhithrogena sp.*	Cadmium chloride	96 hr	25	LC50	157 (dissolved)	Mebane et al. 2012	Other data avilable for a specific species in the genus
Mayfly, *Rhithrogena sp.*	Cadmium chloride	96 hr	21	LC50	>50 (dissolved)	Mebane et al. 2012	Other data avilable for a specific species in the genus
Mayfly (nymph), *Rhithrogena hageni*	Cadmium sulfate	10 d	48	NOEC-LOEC (survival)	1,880-3,520	Brinkman and Johnston 2008	Duration
Mosquito, *Aedes aegypti*	Cadmium nitrate	48 hr	-	LC50	4,000	Slooff et al. 1983a	Duration
Mosquito, *Culex pipiens*	Cadmium nitrate	48 hr	-	LC50	765	Slooff et al. 1983a	Duration
Midge (2nd instar), *Chironomus riparius*	Cadmium chloride	96 hr	100-110	LC50	13,000	Williams et al. 1986	Test species fed
Midge (3rd instar), *Chironomus riparius*	Cadmium chloride	96 hr	100-110	LC50	22,000	Williams et al. 1986	Test species fed
Midge (4th instar), *Chironomus riparius*	Cadmium chloride	96 hr	100-110	LC50	54,000	Williams et al. 1986	Test species fed
Midge, *Chironomus riparius*	Cadmium chloride	5 d	98	LOEC (egg viability)	30,000	Williams et al. 1987	Duration; Static, unmeasured exposure
Midge, *Chironomus riparius*	Cadmium chloride	10 d	98	LOEC (number of eggs ovipositioned)	100,000	Williams et al. 1987	Duration; Static, unmeasured exposure

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Midge (1st instar), *Chironomus riparius*	-	17 d	98	LOEC (survival, development and growth)	150	Pascoe et al. 1989	Duration
Midge (1st instar), *Chironomus riparius*	-	1 hr	100	Reduced emergence	2,100	McCahon and Pascoe 1991	Duration
Midge (1st instar), *Chironomus riparius*	-	10 hr	100	Reduced emergence	210	McCahon and Pascoe 1991	Duration
Midge (4th instar), *Chironomus riparius*	-	1 hr	100	Reduced emergence	2,000	McCahon and Pascoe 1991	Duration
Midge (4th instar), *Chironomus riparius*	-	10 hr	100	Reduced emergence	200	McCahon and Pascoe 1991	Duration
Midge (1st instar larva, <24 hr), *Chironomus riparius*	Cadmium nitrate	24 hr	8	LC50	9,380	Bechard et al. 2008	Duration
Midge (4th instar), *Chironomus riparius*	Cadmium chloride	24 hr	-	LC50	212,230	Choi and Ha 2009	Duration
Midge (4th instar), *Chironomus riparius*	Cadmium chloride	72 hr	-	Downregulation of CrSTART1 mRNA	2,000	Nair and Choi 2012	Duration; Atypical endpoint
Midge, *Chironomus dilutus*	Cadmium chloride	48 hr	25	LC50	8,050	Khangarot and Ray 1989b	Dilution water (natural surface water) not characterized
Midge (2nd instar, 10-12 d), *Chironomus dilutus*	Cadmium chloride	96 hr	17	LC50	2,956	Suedel et al. 1997	Test species fed
Midge (4th instar larva), *Chironomus dilutus*	Cadmium chloride	24 hr	-	LOEC (increased HSP gene expression)	200	Lee et al. 2006b	Duration; Atypical endpoint
Midge (4th instar larva), *Chironomus dilutus*	Cadmium chloride	48 hr	-	NOEC (growth)	20,000	Lee et al. 2006b	Duration
Midge (4th instar larva), *Chironomus dilutus*	Cadmium chloride	24 hr	-	LC50	169,500	Ha and Choi 2008	Duration
Midge, *Tanytarsus dissimilis*	Cadmium chloride	10 d	47	LC50	3.8	Anderson et al. 1980	Duration
Damselfly, *Enallagma sp.*	Cadmium chloride	96 hr	15.3 (pH=3.5)	LC50	7,050	Mackie 1989	pH is artificially low as part of study

Species	Chemical	Duration	Hardness (mg/L CaCO$_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Damselfly, *Enallagma sp.*	Cadmium chloride	96 hr	15.3 (pH=4.0)	LC50	8,660	Mackie 1989	pH is artificially low as part of study
Damselfly, *Enallagma sp.*	Cadmium chloride	96 hr	15.3 (pH=4.5)	LC50	10,660	Mackie 1989	pH is artificially low as part of study
Rio Grande cutthroat trout (eyed egg), *Oncorhynchus clarkii virginalis*	Cadmium sulfate	ELS (53 d)	44.9	NOEC (hatch success)	8.03 (dissolved)	Brinkman 2012	More sensitive endpoint available for this study
Pink salmon (alevin), *Oncorhynchus gorbuscha*	Cadmium chloride	7 d	83.1	LC50	3,160	Servizi and Martens 1978	Duration
Pink salmon (fry), *Oncorhynchus gorbuscha*	Cadmium chloride	7 d	83.1	LC50	2,700	Servizi and Martens 1978	Duration
Pink salmon (alevin, newly hatched), *Oncorhynchus gorbuscha*	Cadmium chloride	7 d	83.1	LC50	3,600	Servizi and Martens 1978	Duration
Coho salmon (juvenile), *Oncorhynchus kisutch*	Cadmium chloride	217 hr	22	LC50	2.0	Chapman and Stevens 1978	Duration
Coho salmon (adult), *Oncorhynchus kisutch*	Cadmium chloride	215 hr	22	LC50	3.7	Chapman and Stevens 1978	Duration
Coho salmon (alevin), *Oncorhynchus kisutch*	Cadmium chloride	96 hr	41	LC50	6.0	Buhl and Hamilton 1991	
Rainbow trout, *Oncorhynchus mykiss*	-	7 d	290	LC50	8.944 (8-10)	Ball 1967	Lack of exposure details; Duration; Unmeasured exposure
Rainbow trout, *Oncorhynchus mykiss*	-	24 hr	290	LC50	30,000	Ball 1967	Lack of exposure details; Duration
Rainbow trout, *Oncorhynchus mykiss*	-	10 d	-	LC50	7	Kumada et al. 1973	Duration
Rainbow trout, *Oncorhynchus mykiss*	-	10 d	-	LC50	5	Kumada et al. 1973	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	96 hr	326	LC20	20	Davies 1976b	Atypical endpoint for this duration
Rainbow trout (embryo, larva), *Oncorhynchus mykiss*	Cadmium chloride	28 d	104	EC50 (death and deformity)	140	Birge 1978; Birge et al. 1980	Lack of exposure details

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (alevin), *Oncorhynchus mykiss*	Cadmium chloride	186 hr	23	LC10	>6	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (swim-up fry), *Oncorhynchus mykiss*	Cadmium chloride	200 hr	23	LC10	1.0	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (parr), *Oncorhynchus mykiss*	Cadmium chloride	200 hr	23	LC10	0.7	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (smolt), *Oncorhynchus mykiss*	Cadmium chloride	200 hr	23	LC10	0.8	Chapman 1978	Duration; Atypical endpoint
Rainbow trout (adult), *Oncorhynchus mykiss*	Cadmium chloride	17 d	54	LC50	5.2	Chapman and Stevens 1978	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium sulfate	243 d	240	Increased gill diffusion	2	Hughes et al. 1979	Lack of exposure details; Atypical endpoint
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	10 d	125 (18ºC)	LC50	10-30	Roch and Maly 1979	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	10 d	125 (12ºC)	LC50	30	Roch and Maly 1979	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	10 d	125 (6ºC)	LC50	10-30	Roch and Maly 1979	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	80 min	112	Significant avoidance	52	Black and Birge 1980	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium stearate	96 hr	-	LC50	6	Kumada et al. 1980	Inappropriate form of toxicant
Rainbow trout, *Oncorhynchus mykiss*	Cadmium acetate	96 hr	-	LC50	6.2	Kumada et al. 1980	Inappropriate form of toxicant
Rainbow trout, *Oncorhynchus mykiss*	-	18 mo	112	Reduced survival	0.2	Birge et al. 1981	Lack of exposure details
Rainbow trout (embryo, larva), *Oncorhynchus mykiss*	Cadmium sulfate	62 d	100	Reduced survival	<5	Dave et al. 1981	Lack of exposure details
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	4 mo	320	Physiological effects	10	Arillo et al. 1982; 1984	Lack of exposure details; Atypical endpoint
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	47 d	98.6	Reduced growth and survival	100	Woodworth and Pascoe 1982	Lack of exposure details
Rainbow trout (larva), *Oncorhynchus mykiss*	Cadmium chloride	7 d	89-107	LC50	700	Birge et al. 1983	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (larva), *Oncorhynchus mykiss*	Cadmium chloride	7 d	89-107	LC50	1,590	Birge et al. 1983	Duration; Acclimated to 5.9 ug/L for 24 days
Rainbow trout, *Oncorhynchus mykiss*	Cadmium nitrate	48 hr	-	LC50	55	Slooff et al. 1983a	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	11 d	82 (10ºC)	LC50	16.0	Majewski and Giles 1984	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	8 d	82 (15ºC)	LC50	16.6	Majewski and Giles 1984	Duration
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	178 d	82	Physiological effects	4.8	Majewski and Giles 1984	Atypical endpoint
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	96 hr	55-79	LC50	10.2	Spehar and Carlson 1984a;b	High TOC; River dilution water not characterized
Rainbow trout (egg, 0 hr), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	13,000	Van Leeuwen et al. 1985a	
Rainbow trout (egg, 24 hr), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	13,000	Van Leeuwen et al. 1985a	
Rainbow trout (eyed egg, 14 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	7,500	Van Leeuwen et al. 1985a	
Rainbow trout (eyed egg, 28 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	9,200	Van Leeuwen et al. 1985a	
Rainbow trout (sac fry, 42 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	30	Van Leeuwen et al. 1985a	
Rainbow trout (early fry, 77 d), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	50	LC50	10	Van Leeuwen et al. 1985a	
Rainbow trout (fry), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	9.2 (pH=4.7)	LC50	28	Cusimano et al. 1986	Exposure at low pH
Rainbow trout (fry), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	9.2 (pH=5.7)	LC50	0.7	Cusimano et al. 1986	Exposure at low pH
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	96 hr	63	LC50	1,300 (dissolved)	Pascoe et al. 1986	Test species fed
Rainbow trout, *Oncorhynchus mykiss*	Cadmium chloride	96 hr	300	LC50	2,600 (dissolved)	Pascoe et al. 1986	Test species fed
Rainbow trout (5 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	>100,000	Shazili and Pascoe 1986	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (10 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	3,300	Shazili and Pascoe 1986	Duration
Rainbow trout (15 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	7,200	Shazili and Pascoe 1986	Duration
Rainbow trout (22 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	8,000	Shazili and Pascoe 1986	Duration
Rainbow trout (29 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	12,500	Shazili and Pascoe 1986	Duration
Rainbow trout (36 d post fert.), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	16,500	Shazili and Pascoe 1986	Duration
Rainbow trout (alevin, 2 d post hatch), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	5,800	Shazili and Pascoe 1986	Duration
Rainbow trout (alevin, 7 d post hatch), *Oncorhynchus mykiss*	Cadmium chloride	48 hr	87.7	LC50	8,300	Shazili and Pascoe 1986	Duration
Rainbow trout (alevin), *Oncorhynchus mykiss*	Cadmium chloride	96 hr	41	LC50	37.9	Buhl and Hamilton 1991	
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Cadmium nitrate	96 hr	140	LC50	280	Hollis et al. 1999	Prior exposed to 3 ug/L for 30 d
Rainbow trout (juvenile), *Oncorhynchus mykiss*	Cadmium nitrate	96 hr	140	LC50	250	Hollis et al. 1999	Prior exposed to 10 ug/L for 30 d
Rainbow trout (33.3 mm, 263 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	30.7	LC50	0.53	Hansen et al. 2002b	Duration
Rainbow trout (33.6 mm, 289 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	89.3	LC50	2.07	Hansen et al. 2002b	Duration
Rainbow trout (34 mm, 299 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	30.0	LC50	0.84	Hansen et al. 2002b	Duration
Rainbow trout (42.6 mm, 659 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	29.3	LC50	0.35	Hansen et al. 2002b	Duration
Rainbow trout (49.4 mm, 1,150 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	31.7	LC50	0.36	Hansen et al. 2002b	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Rainbow trout (48.2 mm, 1,030 mg), *Oncorhynchus mykiss*	Cadmium chloride	5 d	30.2	LC50	0.35	Hansen et al. 2002b	Duration
Rainbow trout (larvae, 1 mo., 1.2-1.5 g), *Oncorhynchus mykiss*	Cadmium chloride	1 hr	210	NOEC (decrease oxygen consumption rates)	200	Jezierska and Sarnowski 2002	Duration; Atypical endpoint
Rainbow trout (swim-up fry, 4-5 wk), *Oncorhynchus mykiss*	-	96 hr	101	LC50	5.4	Besser et al. 2006; 2007	Test species fed
Rainbow trout (1 dph), *Oncorhynchus mykiss*	Cadmium chloride	21 d	100	EC20 (survival)	12	Wang et al. 2014a	Duration too short
Rainbow trout (juvenile, 26 dph), *Oncorhynchus mykiss*	Cadmium chloride	28 d	100	EC20 (biomass)	1.9	Wang et al. 2014a	Exposure started too late for true ELS test
Sockeye salmon (newly hatched alevin), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	4,500	Servizi and Martens 1978	Duration
Sockeye salmon (alevin), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	1,000	Servizi and Martens 1978	Duration
Sockeye salmon (alevin), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	500	Servizi and Martens 1978	Duration
Sockeye salmon (fry), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	30	Servizi and Martens 1978	Duration
Sockeye salmon (fry), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	8	Servizi and Martens 1978	Duration
Sockeye salmon (smolt), *Oncorhynchus nerka*	Cadmium chloride	7 d	83.1	LC50	360	Servizi and Martens 1978	Duration
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	18-26	Chapman 1978	Duration
Chinook salmon (swim-up fry), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	1.2	Chapman 1978	Duration
Chinook salmon (parr), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	1.3	Chapman 1978	Duration
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	Cadmium chloride	200 hr	23	LC10	1.5	Chapman 1978	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Atlantic salmon (alevin), *Salmo salar*	Cadmium chloride	92 d	28	Net water uptake inhibited	0.78	Rombough and Garside 1982	Atypical endpoint
Atlantic salmon, *Salmo salar*	Cadmium chloride	70 d	13	Reduced growth	2	Peterson et al. 1983	Lack of exposure details
Brown trout, *Salmo trutta*	Cadmium chloride	96 hr	55-79	LC50	15.1	Spehar and Carlson 1984a;b	River dilution water not characterized
Brown trout, *Salmo trutta*	Cadmium sulfate	96 hr	36.9	LC50	1.87	Davies and Brinkman 1994a	Test species fed
Brown trout, *Salmo trutta*	Cadmium sulfate	12 wk	37.6	Chronic value (growth and survival)	0.70	Davies and Brinkman 1994c	Per author chronic values does not have a clear effect level
Brown trout (fry), *Salmo trutta*	Cadmium sulfate	30 d	29.2	NOEC-LOEC (survival)	0.74-1.40	Brinkman and Hansen 2004a; 2007	Duration
Brown trout (fry), *Salmo trutta*	Cadmium sulfate	30 d	67.6	NOEC-LOEC (survival)	1.30-2.58	Brinkman and Hansen 2004a; 2007	Duration
Brown trout (fry), *Salmo trutta*	Cadmium sulfate	30 d	151	NOEC-LOEC (survival)	4.81-8.88	Brinkman and Hansen 2004a; 2007	Duration
Bull trout (juvenile, 30.5 mm, 212 mg), *Salvelinus confluentus*	Cadmium chloride	55 d	30.6	NOEC-LOEC (growth and survival)	0.383-0.786	Hansen et al. 2002a	Duration
Bull trout (23.8 mm, 76.1 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	30.7	LC50	0.83	Hansen et al. 2002b	Duration
Bull trout (23.4 mm, 72.7 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	89.3	LC50	5.23	Hansen et al. 2002b	Duration
Bull trout (26.0 mm, 84.2 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	30.0	LC50	2.41	Hansen et al. 2002b	Duration
Bull trout (30.2 mm, 200 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	29.3	LC50	0.83	Hansen et al. 2002b	Duration
Bull trout (32.0 mm, 221 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	31.7	LC50	0.88	Hansen et al. 2002b	Duration
Bull trout (31.8 mm, 218 mg), *Salvelinus confluentus*	Cadmium chloride	5 d	30.2	LC50	0.83	Hansen et al. 2002b	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Brook trout, *Salvelinus fontinalis*	Cadmium chloride	21 d	10	Testicular damage	10	Sangalang and O'Halloran 1972; 1973	Lack of exposure details; Atypical endpoint
Brook trout (8 mo.), *Salvelinus fontinalis*	-	10 d	20	NOEC-LOEC (survival)	8-18	Jop et al. 1995	Duration
Lake trout, *Salvelinus namaycush*	Cadmium chloride	8-9 mo	90	Decreased thyroid follicle epithelial cell height	5	Scherer et al. 1997	Atypical endpoint
Arctic grayling (alevin), *Thymallus arcticus*	Cadmium chloride	96 hr	41	LC50	6.1	Buhl and Hamilton 1991	Only acclimated to test water for 1 d
Arctic grayling (juvenile), *Thymallus arcticus*	Cadmium chloride	96 hr	41	LC50	4.0	Buhl and Hamilton 1991	Low D.O.
Goldfish, *Carassius auratus*	-	50 d	-	Reduced plasma sodium	44.5	McCarty and Houston 1976	Lack of exposure details; Atypical endpoint
Goldfish (embryo, larva), *Carassius auratus*	Cadmium chloride	7 d	195	EC50 (death and deformity)	170	Birge 1978	Duration
Common carp (embryo), *Cyprinus carpio*	Cadmium sulfate	-	360	EC50 (hatch)	2,094	Kapur and Yadav 1982	Duration unknown
Common carp (embryo, larva), *Cyprinus carpio*	Cadmium chloride	8 d	101.6	LC50	139	Birge et al. 1985	Multiple-species test; Duration
Common carp (fry), *Cyprinus carpio*	-	96 hr	100	LC50	4,260	Suresh et al. 1993a	
Common carp (fingerling), *Cyprinus carpio*	-	96 hr	100	LC50	17,050	Suresh et al. 1993a	
Common carp (30 g), *Cyprinus carpio*	Cadmium chloride	29 d	-	NOEC-LOEC (survival)	449.64-2,248	De Smet and Blust 2001	Duration
Common carp (30 g), *Cyprinus carpio*	Cadmium chloride	29 d	-	NOEC-LOEC (survival)	56.2-280.25	De Smet et al. 2001	Duration
Common carp (larva, 0.9-1.39 g), *Cyprinus carpio*	Cadmium chloride	1 hr	210	LOEC (decrease oxygen consumption rates)	200	Jezierska and Sarnowski 2002	Duration; Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Golden shiner (3 mo, 6.75 g), *Notemigonus crysoleucas*	Cadmium sulfate	96 hr	100-119	Elevated metabolic rate	200	Peles et al. 2012	Atypical endpoint
Common shiner (0.75-3.5 mg), *Notropis cornutus*	Cadmium chloride	7 d	48	67% reduced growth	200 (dissolved)	Borgmann and Ralph 1986	Duration; Atypical endpoint
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	12 d	200	LC50	100	Nguyen and Janssen 2001	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	12 d	200	NOEC-LOEC (survival)	50-150	Nguyen and Janssen 2001	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	48 hr	100	NOEC (enlarged edema)	753.1	Fraysse et al. 2006	Duration; Atypical endpoint
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	80 hr	100	NOEC (hatching time)	<22.48	Fraysse et al. 2006	Duration; Atypical endpoint
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	48 hr	-	EC50	3,372	Lahnsteiner 2008	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	48 hr	-	LC50	24,185	Notch et al. 2011	Duration
Zebrafish (embryo), *Danio rerio*	Cadmium chloride	72 hr	250	EC50 (deformation rate)	4,856	Sawle et al. 2010	Duration; Atypical endpoint
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	63	LC50	80.8	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	55	LC50	40.9	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	59	LC50	64.8	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	66	LC50	135	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	65	LC50	120	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	74	LC50	86.3	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	79	LC50	86.6	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	62	LC50	114	Spehar 1982	

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	63	LC50	80.8	Spehar 1982	
Fathead minnow, *Pimephales promelas*	Cadmium chloride	6.8 hr	103	LT50=6.8 hr	6,000	Birge et al. 1983	Atypical endpoint
Fathead minnow, *Pimephales promelas*	Cadmium chloride	3.7 hr	254-271	LT50=3.7 hr	16,00	Birge et al. 1983	Atypical endpoint
Fathead minnow (larva), *Pimephales promelas*	Cadmium chloride	7 d	89-107	LC50	200	Birge et al. 1983	Duration
Fathead minnow (larva), *Pimephales promelas*	Cadmium chloride	7 d	89-107	LC50	540	Birge et al. 1983	Duration; Acclimated to 5.6 ug/L for 4 d
Fathead minnow, *Pimephales promelas*	Cadmium nitrate	48 hr	-	LC50	2,200	Slooff et al. 1983a	Duration
Fathead minnow, *Pimephales promelas*	Cadmium nitrate	48 hr	209	LC50	802	Slooff et al. 1983a	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	-	Histological effects	12,000	Stromberg et al. 1983	Atypical endpoint
Fathead minnow (30 d), *Pimephales promelas*	Cadmium chloride	96 hr	55-79	LC50	3,390	Spehar and Carlson 1984a;b	River dilution water not characterized
Fathead minnow, *Pimephales promelas*	Cadmium chloride	96 hr	55-79	LC50	1,830	Spehar and Carlson 1984a;b	River dilution water not characterized
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (20.1ºC)	LC50	125	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (22.8ºC)	LC50	84	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (25.7ºC)	LC50	76	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6 (27.9ºC)	LC50	87	Birge et al. 1985	Duration
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6	LC50	41	Birge et al. 1985	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow (embryo, larva), *Pimephales promelas*	Cadmium chloride	8 d	101.6	LC50	107	Birge et al. 1985	Duration; Multiple-species test
Fathead minnow (14-30 d), *Pimephales promelas*	Cadmium chloride	96 hr	200	LC50	90	Hall et al. 1986	
Fathead minnow (1-7 d), *Pimephales promelas*	Cadmium chloride	48 hr	70-90	LC50	35.4	Diamond et al. 1997	Duration
Fathead minnow (2-4 d), *Pimephales promelas*	Cadmium chloride	96 hr	17	LC50	4.8	Suedel et al. 1997	Test species fed
Fathead minnow, *Pimephales promelas*	-	juvenile growth & survival test	17	NOEC-LOEC (growth and survival)	1.0-2	Suedel et al. 1997	Static exposure
Fathead minnow, *Pimephales promelas*	-	Juvenile growth & survival test	17	NOEC-LOEC (growth and survival)	2.0-3	Suedel et al. 1997	Static exposure
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	270	NOEC-LOEC (growth and survival)	10.7-21.9	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	261	NOEC-LOEC (growth and survival)	11.5-21.3	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	285	NOEC-LOEC (growth and survival)	8.5-11.3	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	272	NOEC-LOEC (growth and survival)	9.6-12.2	Southwest Texas State University 2000	Duration
Fathead minnow, *Pimephales promelas*	Cadmium chloride	7 d	292	NOEC-LOEC (growth and survival)	5.3-6.9	Southwest Texas State University 2000	Duration
Fathead minnow (larva, 96-144 hr), *Pimephales promelas*	Cadmium chloride	7 d	-	LC50	15.43	Southwest Texas State University 2000	Duration
Fathead minnow (larva, 96-144 hr), *Pimephales promelas*	Cadmium chloride	7 d	-	LC50	16.99	Southwest Texas State University 2000	Duration

Species	Chemical	Duration	Hardness (mg/L CaCO$_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Fathead minnow (adult pairs), *Pimephales promelas*	Cadmium chloride	21 d	169	NOEC-LOEC (spawning frequency)	24.3-39.7	Sellin and Kolok 2006a	Duration; Atypical endpoint
Fathead minnow (larva, 8 d), *Pimephales promelas*	Cadmium chloride	21 d	173	NOEC-LOEC (# of pairs to spawn per day)	25-50	Sellin and Kolok 2006b	Duration
Fathead minnow (larva, 8 d), *Pimephales promelas*	Cadmium chloride	21 d	173	NOEC (hatching success, offspring mortality)	50	Sellin and Kolok 2006b	Duration
Fathead minnow (adult), *Pimephales promelas*	Cadmium sulfate	96 hr	117.9	LOEC (increase metabolic rate)	250	Pistole et al. 2008	Atypical endpoint
Fathead minnow (29-55 mm), *Pimephales promelas*	Cadmium nitrate	96 hr	120	Increase in auditory threshold	2.1-2.9	Low 2009	Atypical endpoint
Fathead minnow (larva, <24 hr), *Pimephales promelas*	Cadmium chloride	48 hr	38-66	LC50	47.7	Robison 2011	Duration
White sucker (larva), *Catostomus commersoni*	Cadmium chloride	7 d	48	46% reduced growth	36 (dissolved)	Borgmann and Ralph 1986	Duration
Walking catfish (12-14 cm, 25 g), *Clarias batrachus*	Cadmium chloride	96 hr	250 (240-260)	LC50	315,000	Banerjee et al. 1978	Lack of exposure details
Walking catfish, *Clarias batrachus*	Cadmium chloride	14 d	-	60% mortality	8,993	Jana and Sahana 1989	Duration; Unmeasured exposure
Stickleback, *Gasterosteus aculeatus*	Cadmium sulfate	18 d	299	Kidney cell tissue breakdown	6,000	Oronsaye 1989	Duration; Atypical endpoint
Stickleback, *Gasterosteus aculeatus*	Cadmium sulfate	30 d	299	NOEC-LOEC (kidney cytological alteration)	4,000-6,000	Oronsaye 2001	Duration; Atypical endpoint
Brown bullhead, *Ictalurus nebulosus*	Cadmium chloride	2 hr	-	Affected gills and kidney	61,300	Blickens 1978; Garofano 1979	Duration; Atypical endpoint
Channel catfish, *Ictalurus punctatus*	Cadmium chloride	-	-	Increased albinism	0.5	Westerman and Birge 1978	Duration unknown; Atypical endpoint
Channel catfish, *Ictalurus punctatus*	Cadmium chloride	96 hr	55-79	LC50	7,940	Spehar and Carlson 1984a;b	River dilution water not characterized

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mosquitofish, *Gambusia affinis*	Cadmium sulfate	48 hr	45	LC50	7,260	Chagnon and Guttman 1989	Duration
Guppy (fry), *Poecilia reticulata*	Cadmium chloride	96 hr	140-190	LC50	2,500	Gadkari and Marathe 1983	
Guppy (male), *Poecilia reticulata*	Cadmium chloride	96 hr	140-190	LC50	12,750	Gadkari and Marathe 1983	
Guppy (female), *Poecilia reticulata*	Cadmium chloride	96 hr	140-190	LC50	16,000	Gadkari and Marathe 1983	
Guppy, *Poecilia reticulata*	Cadmium nitrate	48 hr	209	LC50	41,900	Slooff et al. 1983a	Duration
Striped bass (larva), *Morone saxatilis*	Cadmium chloride	72 hr	34.5	LC50	1	Hughes 1973	Duration
Striped bass (fingerling), *Morone saxatilis*	Cadmium chloride	72 hr	34.5	LC50	2	Hughes 1973	Duration
Bluegill, *Lepomis macrochirus*	Cadmium chloride	80 min	112	Significant avoidance	>41.1	Black and Birge 1980	Duration; Atypical endpoint
Bluegill, *Lepomis macrochirus*	Cadmium chloride	3 d	340-360	Increased cough rate	50	Bishop and McIntosh 1981	Duration; Atypical endpoint
Bluegill, *Lepomis macrochirus*	Cadmium chloride	96 hr	55-79	LC50	8,810	Spehar and Carlson 1984a;b	River dilution water not characterized
Bluegill (juvenile), *Lepomis macrochirus*	Cadmium chloride	32 d	134	NOEC (growth)	>32.3	Cope et al. 1994	
Bluegill (31.1 mm), *Lepomis macrochirus*	Cadmium chloride	22 d	174	LOEC (prey attack rate)	37.3	Bryan et al. 1995	Duration; Atypical endpoint
Largemouth bass (embryo, larva), *Micropterus salmoides*	Cadmium chloride	8 d	99	EC50 (death and deformity)	1,640	Birge et al. 1978	Duration
Largemouth bass, *Micropterus salmoides*	-	24 hr	-	Affected opercular activity	150	Morgan 1979	Duration; Atypical endpoint
Largemouth bass, *Micropterus salmoides*	Cadmium chloride	80 min	112	Significant avoidance	8.83	Black and Birge 1980	Duration; Atypical endpoint

Species	**Chemical**	**Duration**	**Hardness (mg/L $CaCO_3$)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Largemouth bass (embryo, larva), *Micropterus salmoides*	Cadmium chloride	8 d	101.6	LC50	244	Birge et al. 1985	Duration; Multiple-species test
Fountain darter (larva, 96-144 hr), *Etheostoma fonticola*	Cadmium chloride	96 hr	254-282	LC50	9.62 (reported-dissolved)	Southwest Texas State University 2000	Test species fed
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	270	NOEC-LOEC (growth and survival)	1.4-2.8	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	261	NOEC-LOEC (growth and survival)	5.5-11.5	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	285	NOEC-LOEC (growth and survival)	5.7-8.5	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	270	NOEC-LOEC (growth and survival)	6.6-9.6	Southwest Texas State University 2000	Duration
Fountain darter, *Etheostoma fonticola*	Cadmium chloride	7 d	292	NOEC-LOEC (growth and survival)	4-5.3	Southwest Texas State University 2000	Duration
Orangethroat darter (embryo), *Etheostoma spectabile*	Cadmium chloride	96 hr	180	LC50	>500	Sharp and Kaszubski 1989	River dilution water not characterized
Nile tilapia (adult, 13.1 cm, 77.2 g), *Oreochromis niloticus*	Cadmium chloride	96 hr	36.17	Reduction in plasma Ca 2+ concentration	5,000	Garcia-Santos et al. 2006	Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	LOEC (increase CAT activity)	562	Atli and Canli 2007	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	LOEC (decrease intestine Na, K-ATPase activity)	562	Atli and Canli 2007	Unmeasured chronic exposure; Duration; Atypical endpoint

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	NOEC-LOEC (decrease muscle Na, K-ATPase activity)	562-1,124	Atli and Canli 2007	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	NOEC (gill, blood, and muscle and GSH level)	>2,248	Atli and Canli 2008	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (15.7 cm, 61.5 g), *Oreochromis niloticus*	Cadmium chloride	14 d	324	LOEC (increase liver MT level)	562	Atli and Canli 2008	Unmeasured chronic exposure; Duration; Atypical endpoint
Nile tilapia (fingerling, 4-6 cm), *Oreochromis niloticus*	Cadmium chloride	28 d	-	NOEC (brain and muscle ChE activity)	30	Silva and Pathiratne 2008	Atypical endpoint
Mozambique tilapia (12-14 cm, 25 g), *Oreochromis mossambica*	Cadmium chloride	96 hr	250 (240-260)	LC50	200,000	Banerjee et al. 1978	Lack of exposure details
Mozambique tilapia (larva, <1 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	205	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 1 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	83	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 2 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	33	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 3 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	22	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (larva, 7 d), *Oreochromis mossambica*	Cadmium chloride	96 hr	-	LC50	29	Hwang et al. 1995	Dilution water not characterized
Mozambique tilapia (72 hr), *Oreochromis mossambica*	Cadmium chloride	96 hr	28	LC50	21.4	Chang et al. 1998	
Mummichog, *Fundulus heteroclitus*	Cadmium chloride	96 hr	5	TL50	12.2	Gill and Epple 1992	Atypical endpoint
White sturgeon (embryo), *Acipenser transmontanus*	Cadmium chloride	66 d	70	NOEC-LOEC (mortality)	1.1-8.3	Vardy et al. 2011	No true control group - control water had Cd level similar to lowest exposure group

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
White sturgeon (embryo), *Acipenser transmontanus*	Cadmium chloride	66 d	70	LC20	1.5	Vardy et al. 2011	No true control group
White sturgeon (larva, 2 dph), *Acipenser transmontanus*	Cadmium chloride	14 d	100	EC20 (survival)	>11	Wang et al. 2014a	Duration too short
White sturgeon (juvenile, 28 dph), *Acipenser transmontanus*	Cadmium chloride	28 d	100	EC20 (biomass)	3.2	Wang et al. 2014a	Exposure started too late for true ELS test
Southern gray treefrog (embryo), *Hyla chrysoscelis*	Cadmium chloride	72 hr	90	LC50	49.9	Westerman 1977	Duration
Southern gray treefrog (embryo), *Hyla chrysoscelis*	Cadmium chloride	7 d	90	LC50	40.3	Westerman 1977	Duration
Pipfrog (embryo), *Rana grylio*	Cadmium chloride	6 d	90	LC50	81.8	Westerman 1977	Duration
Pipfrog (embryo), *Rana grylio*	Cadmium chloride	10 d	90	LC50	69.3	Westerman 1977	Duration
River frog (embryo), *Rana heckscheri*	Cadmium chloride	6 d	90	LC50	69.2	Westerman 1977	Duration
River frog (embryo), *Rana heckscheri*	Cadmium chloride	10 d	90	LC50	60.5	Westerman 1977	Duration
Leopard frog (embryo), *Rana pipiens*	Cadmium chloride	6 d	90	LC50	56.1	Westerman 1977	Duration
Leopard frog (embryo), *Rana pipiens*	Cadmium chloride	10 d	90	LC50	50.1	Westerman 1977	Duration
Southern leopard frog (tadpole, GS 25), *Rana sphenocephala*	Cadmium chloride	48 hr	130.8	NOEC-LOEC (decreased tadpole activity)	750-1,200	Moyer 2012	Duration; Atypical endpoint
American toad (tadpoles, Gosner stage 25), *Bufo americanus*	Cadmium chloride	60 d	51.2	LOEC (metamorph wet weight and days to tail resorption)	5	James and Little 2003	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
American toad (tadpoles, Gosner stage 25), *Bufo americanus*	Cadmium chloride	60 d	51.2	NOEC-LOEC (survival)	54-540	James and Little 2003	Duration
Red-spotted toad (embryo), *Bufo punctatus*	Cadmium chloride	72 hr	90	LC50	9,800	Westerman 1977	Duration
Red-spotted toad (embryo), *Bufo punctatus*	Cadmium chloride	7 d	90	LC50	6,781	Westerman 1977	Duration
Narrow-mouthed toad (embryo, larva), *Gastrophyryne carolinensis*	Cadmium chloride	7 d	195	EC50 (death and deformity)	40	Birge 1978	Duration
Narrow-mouthed toad (embryo), *Gastrophyryne carolinensis*	Cadmium chloride	72 hr	90	LC50	47.9	Westerman 1977	Duration
Narrow-mouthed toad (embryo), *Gastrophyryne carolinensis*	Cadmium chloride	7 d	90	LC50	41.5	Westerman 1977	Duration
African clawed frog, *Xenopus laevis*	Cadmium nitrate	48 hr	209	LC50	11,700	Slooff and Baerselman 1980; Slooff et al. 1983a	Duration
African clawed frog, *Xenopus laevis*	Cadmium chloride	48 hr	170	LC50	3,200	Canton and Slooff 1982	Duration
African clawed frog, *Xenopus laevis*	Cadmium chloride	100 d	170	Inhibited development	650	Canton and Slooff 1982	Lack of exposure details
African clawed frog (stage 40), *Xenopus laevis*	Cadmium chloride	24 hr	-	LC50	1,000	Herkovits et al. 1997	Duration
African clawed frog (stage 40), *Xenopus laevis*	Cadmium chloride	72 hr	-	LC50	0.2	Herkovits et al. 1998	Duration
African clawed frog (stage 47), *Xenopus laevis*	Cadmium chloride	72 hr	-	LC50	1.6	Herkovits et al. 1998	Duration
African clawed frog (adult, female), *Xenopus laevis*	Cadmium chloride	30 d	-	NOEC-LOEC (total egg count)	500-1,000	Fort et al. 2001	Duration
African clawed frog (adult, male), *Xenopus laevis*	Cadmium chloride	30 d	-	NOEC-LOEC (total sperm count)	2,500-5,000	Fort et al. 2001	Duration

Species	Chemical	Duration	Hardness (mg/L $CaCO_3$)	Effect	Concentration (µg/L)	Reference	Reason Other Data
African clawed frog (stage 50), *Xenopus laevis*	Cadmium chloride	6 d	-	40% mortality	5,000	Mouchet et al. 2007	Duration; Test species fed
African clawed frog (stage 50), *Xenopus laevis*	Cadmium chloride	6 d	-	60% mortality	10,000	Mouchet et al. 2007	Duration; Test species fed
African clawed frog, *Xenopus laevis*	Cadmium chloride	96 hr	-	Increased toxicity and teratogenicity	562	Boga et al. 2008	Atypical endpoint
African clawed frog (embryo), *Xenopus laevis*	Cadmium chloride	47 d	-	NOEC-LOEC (delayed development and forelimb emergence)	84-855	Sharma and Patino 2008	Duration
African clawed frog (embryo,<24 hr), *Xenopus laevis*	Cadmium chloride	86 d	-	NOEC-LOEC (survival)	85-860	Sharma and Patino 2009	Duration
African clawed frog (embryo,<24 hr), *Xenopus laevis*	Cadmium chloride	86 d	-	NOEC-LOEC (growth)	8-85	Sharma and Patino 2009	Duration
Marbled salamander (embryo, larva), *Ambystoma gracile*	Cadmium chloride	8 d	99	EC50 (death and deformity)	150	Birge et al. 1978	Duration
Northwestern salamander, *Ambystoma gracile*	Cadmium chloride	10 d	45	LOEC (limb regeneration)	44.6	Nebeker et al. 1994	Duration
Northwestern salamander, *Ambystoma gracile*	Cadmium chloride	10 d	45	LOEC (growth)	227	Nebeker et al. 1995	Duration

Appendix I Other Estuarine/Marine Toxicity Data

Appendix Table I-1. Other Estuarine/Marine Toxicity Data

(Species are organized phylogenetically).

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
				ESTUARINE/MARINE WATER			
Bacterium, *Vibrio fischeri*	Cadmium nitrate	22 hr	35	EC50	214	Radix et al. 1999	Bacteria
Bacteria, *Vibrio fischeri*	Cadmium chloride	15 min	35	EC50 (luminescence)	56,800	Rosen et al. 2008	Bacteria
Phytoplankton population	Cadmium nitrate	4 d	-	Reduced biomass	112	Hollibaugh et al. 1980	Mixed community exposure
Phytoplankton community	-	-	-	LC50	0.23-498.7	Echeveste et al. 2012	Mixed community exposure, exposure duration not well defined
Phytoflagellate, *Olisthodiscus luteus*	Cadmium chloride	192 hr	-	27% biovolume reduction	500	Fernandez-Leborans and Novillo 1996	
Dinoflagellate, *Alexandrium catenella*	Cadmium sulfate	30 d	-	30% decreased growth	5.83	Herzi et al. 2013	Duration
Dinoflagellate, *Ceratocorys horrida*	Cadmium chloride	24 hr	35	EC50 (bioluminescence)	1,710	Rosen et al. 2008	Duration
Dinoflagellate, *Heterocapsa sp.*	-	72 hr	-	EC50 (growth)	13,800	Satoh et al. 2005	Duration
Dinoflagellate, *Lingulodinium polyedrum*	Cadmium chloride	24 hr	35	EC50 (bioluminescence)	843	Rosen et al. 2008	Duration
Dinoflagellate, *Prorocentrum minimum*	Cadmium chloride	2 hr	20	LC50 (growth)	12,000	Roberts et al. 1982	Duration
Dinoflagellate, *Prorocentrum minimum*	-	72 hr	-	IC50 (cell-specific growth rate)	116.9	Wang 2010	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Dinoflagellate (4 wk), *Pyrocystis lunula*	-	48 hr	35	EC50 (bioluminescence)	750	Heimann et al. 2002	Duration
Dinoflagellate, *Pyrocystis noctiluca*	Cadmium chloride	24 hr	35	EC50 (bioluminescence)	1,130	Rosen et al. 2008	Duration
Haptophyte, *Pseudoisochrysis paradoxa*	Cadmium chloride	2 hr	20	LC50 (growth)	167,000	Roberts et al. 1982	Duration
Diatom, *Chaetoceros gracilis*	Cadmium chloride	72 hr	-	EC50 (growth)	8,500	Koutsaftis and Aoyama 2006	Duration
Diatom, *Isochrysis galbana*	-	72 hr	-	EC50 (growth)	2,900	Satoh et al. 2005	Duration
Diatom, *Minutocellus polymorphus*	Cadmium chloride	48 hr	-	EC50	66	Walsh et al. 1988	Duration
Diatom, *Skeletonema costatum*	Cadmium chloride	2 hr	20	LC50 (growth)	681,000	Roberts et al. 1982	Duration
Diatom, *Skeletonema costatum*	-	10 d	-	EC50 (growth)	450	Govindarajan et al. 1993	
Diatom, *Skeletonema costatum*	Cadmium chloride	72 hr	-	EC50	144	Walsh et al. 1988	Duration
Diatom, *Tetraselmis gracilis*	-	96 hr	-	EC50 (survival)	1,800	Okamoto et al. 1996	
Diatom, *Tetraselmis tetrahele*	-	72 hr	-	EC50 (growth)	9,800	Satoh et al. 2005	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- (18ºC)	EC50 (growth)	291.1	Wang and Wang 2008; Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- (24ºC)	EC50 (growth)	210.2	Wang and Wang 2008; Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- (30.5ºC)	EC50 (growth)	33.72	Wang and Wang 2008; Wang 2010	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- High irradiance	IC50 (cell-specific growth rate)	77.56	Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- Low irradiance	IC50 (cell-specific growth rate)	303.5	Wang 2010	Duration
Diatom, *Thalassiosira nordenskioeldii*	-	72 hr	- Med. irradiance	IC50 (cell-specific growth rate)	236.1	Wang 2010	Duration
Diatom, *Thalassiosira pseudonana*	-	72 hr	-	IC50 (cell-specific growth rate)	7.862	Wang 2010	Duration
Diatom, *Thalassiosira weissflogii*	-	48 hr	-	EC50 (growth-nutrient rich medium)	157.4	Miao and Wang 2006	Duration
Diatom, *Thalassiosira weissflogii*	-	48 hr	-	EC50 (growth-N-starved medium)	22.48	Miao and Wang 2006	Duration
Diatom, *Thalassiosira weissflogii*	-	48 hr	-	EC50 (growth-P-starved medium)	73.07	Miao and Wang 2006	Duration
Green alga, *Acetabularia acetabulum*	Cadmium chloride	3 wk	-	Morphological deformities	100	Karez et al. 1989	
Green alga, *Acetabularia acetabulum*	Cadmium chloride	3 wk	-	Decreased cell elongation	1	Karez et al. 1989	
Green alga, *Chlorella autotrophica*	-	72 hr	-	IC50 (cell-specific growth rate)	1,248	Wang 2010	Duration
Green alga, *Ulva pertusa*	Cadmium chloride	72-120 hr	35	EC50 (reproduction)	217	Han et al. 2007	Duration not specifically identified
Red alga, *Champia parvula*	Cadmium chloride	48 hr	28-30	NOEC (sexual reproduction)	>100	Thursby and Steele 1986	Duration
Hydroid, *Campanularia flexuosa*	-	-	-	Enzyme inhibition	40-75	Moore and Stebbing 1976	Duration not specifically identified

Species	**Chemical**	**Duration**	**Salinity (g/kg)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Hydroid, *Campanularia flexuosa*	-	11 d	-	Growth rate	110-280	Stebbing 1976	
Starlet sea anemone (adult, female), *Nematostella vectensis*	Cadmium chloride	21 d	12	NOEC-LOEC (survival)	50-250	Harter and Matthews 2005	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	15	LC50	54,900	Snell and Personne 1989b	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	30	LC50	56,800	Snell and Personne 1989b	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	15	LC50	>39,000	Snell et al. 1991b	Duration
Rotifer, *Brachionus plicatilis*	Cadmium chloride	24 hr	-	LC50	490.6	Arulvasu et al. 2010	Duration
Rotifer, *Brachionus plicatilis*	Cadmium nitrate	7 d	-	No survival	429.2	Arulvasu et al. 2010	Unmeasured chronic exposure; Duration
Polychaete, *Capitella capitata*	Cadmium chloride	28 d	-	LC50	630	Reish et al. 1976	Duration
Polychaete, *Capitella capitata*	Cadmium chloride	28 d	-	LC50	700	Reish et al. 1976	Duration
Polychaete, *Neanthes arenaceodentata*	Cadmium chloride	28 d	-	LC50	3,000	Reish et al. 1976	Duration
Polychaete worm, *Nereis virens*	Cadmium chloride	144 hr	-	LC50	170	McLeese and Ray 1986	Duration
Sea squirt (sperm), *Ciona intestinalis*	Cadmium chloride	30 min	33	NOEC-LOEC (% fertilization)	4,096-16,384	Bellas et al. 2001	Duration
Sea squirt (gamete), *Ciona intestinalis*	Cadmium chloride	1 hr	33	LOEC (% fertilization)	>16,384	Bellas et al. 2001	Duration
Sea squirt (embryo), *Ciona intestinalis*	Cadmium chloride	20 hr	33	EC50 (development)	809.4	Bellas et al. 2001	Duration
Sea squirt (larva), *Ciona intestinalis*	Cadmium chloride	48 hr	33	EC50 (attachmnet)	>16,366	Bellas et al. 2001	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Sea squirt (egg/sperm), *Ciona intestinalis*	Cadmium chloride	20 hr	33	EC50 (embryonic development)	721	Bellas et al. 2004	Duration
Sea squirt (egg/sperm), *Ciona intestinalis*	Cadmium chloride	70 hr	33	EC50 (larva attachment)	752	Bellas et al. 2004	Duration
Gastropod (larva), *Crepidula fornicata*	Cadmium chloride	48 hr	-	LOEC (% larval mortality)	2,189	Pechenik et al. 2001	Duration; Test species fed
Mud snail (0.24-1.14 g), *Nassarius obsoletus*	Cadmium chloride	72 hr	25	Increased O_2 consumption	500	MacInnes and Thurberg 1973	Atypical endpoint
Mussel, *Mytilus edulis*	Cadmium chloride	9.5 d	28	LT50 = 9.5 d (anoxic conditions)	47	Veldhuizen-Tsoerkan et al. 1991	Atypical endpoint
Bay scallop, *Argopecten irradians*	Cadmium chloride	42 d	-	EC50 (growth)	78	Pesch and Stewart 1980	
Scallop (juvenile, 3 mm), *Argopecten ventricosus*	Cadmium chloride	30 d	36	LOEC (growth)	10	Sobrino-Figueroa et al. 2007	Unmeasured chronic exposure; Duration
Pacific oyster (larva, 6 d), *Crassostrea gigas*	Cadmium chloride	96 hr	-	EC50 (growth)	75	Watling 1982	Atypical endpoint
Pacific oyster (larva, 16 d), *Crassostrea gigas*	Cadmium chloride	96 hr	-	EC50 (growth)	120	Watling 1982	Atypical endpoint
Pacific oyster, *Crassostrea gigas*	Cadmium chloride	6 d	-	50 % reduction in settlement	20-25	Watling 1983b	Duration
Pacific oyster, *Crassostrea gigas*	Cadmium chloride	14 d	-	Growth reduction	10	Watling 1983b	Duration
Pacific oyster, *Crassostrea gigas*	Cadmium chloride	23 d	-	LC50	50	Watling 1983b	Duration
Pacific oyster (1 yr, 112 mm, 20.3 g), *Crassostrea gigas*	Cadmium chloride	11 d	35	LOEC (increase expression of MT mRNA in digestive gland and gills)	10	Choi et al. 2008	Duration; Unmeasured chronic exposure; Atypical endpoint

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Pacific oyster (1 yr, 112 mm, 20.3 g), *Crassostrea gigas*	Cadmium chloride	11 d	35	LOEC (increase expression of HSP90 mRNA in digestive gland and gills)	10	Choi et al. 2008	Duration; Unmeasured chronic exposure; Atypical endpoint
American or virginia oyster, *Crassostrea virginica*	Cadmium chloride	48 hr	-	Reduction in embryonic development	15	Zaroogian and Morrison 1981	Duration
Brown mussel (20-24 mm), *Perna perna*	Cadmium acetate	96 hr	32	LC50	877.5	Baby and Menon 1987	Inappropriate form of toxicant
Clam, *Macoma balthica*	Cadmium chloride	6 d	-	LC50	1,710	McLeese and Ray 1986	Duration
Hard clam (juvenile), *Mercenaria mercenaria*	Cadmium chloride	7 d	25	EC50 (growth)	86.7	Keppler and Ringwood 2002	Duration; Test species fed
Hard clam (juvenile, 212-350 mm), *Mercenaria mercenaria*	-	24 hr	32	LC50	420	Chung et al. 2007	Duration
Japanese carpet shell (6.7-7.1 mm), *Ruditapes philippinarum*	-	5 d	-	LC50	3,114	Figueira et al. 2012	Duration
Sand gaper, *Mya arenaria*	Cadmium chloride	7 d	-	LC50	150	Eisler 1977	Duration
Sand gaper, *Mya arenaria*	Cadmium chloride	7 d	-	LC50	700	Eisler and Hennekey 1977	Duration
Calanoid copepod (newly hatched nauplii), *Eurytemora affinis*	Cadmium chloride	24 hr	-	Reduction in swimming speed	130	Sullivan et al. 1983	Duration
Calanoid copepod (newly hatched nauplii), *Eurytemora affinis*	Cadmium chloride	48 hr	-	Reduction in development rate	116	Sullivan et al. 1983	Duration
Calanoid copepod, *Eurytemora affinis*	Cadmium chloride	96 hr	5	LC50	51.6	Hall et al. 1995	Test species fed

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Calanoid copepod, *Eurytemora affinis*	Cadmium chloride	96 hr	15	LC50	213	Hall et al. 1995	Test species fed
Harpacticoid copepod, *Nitokra spinipes*	Cadmium sulfate	96 hr	30	NOEC (survival)	500	Ward et al. 2011	Atypical endpoint
Copepod, *Tisbe holothurlae*	Cadmium chloride	48 hr	-	LC50	970	Moraitou-Apostolopoulou and Verriopoulos 1982	Duration
Barnacle (larva, stage 2 nauplii), *Balanus improvisus*	Cadmium chloride	96 hr	15	LC50	>100.5	Lang et al. 1981	According to the author no attempt was made to determine a LC50; Test species fed
Barnacle (larva, stage 2 nauplii), *Balanus improvisus*	Cadmium chloride	96 hr	30	LC50	>201.8	Lang et al. 1981	According to the author no attempt was made to determine a LC50; Test species fed
Mysid, *Americamysis bahia*	Cadmium chloride	17 d	15-23	LC50	11.3	Nimmo et al. 1977a	Duration
Mysid, *Americamysis bahia*	Cadmium chloride	16 d	30	LC50	28	Gentile et al. 1982	Duration
Mysid, *Americamysis bahia*	Cadmium chloride	8 d	-	LC50	60	Gentile et al. 1982	Duration
Mysid, *Americamysis bahia*	-	28 d	13-29	NOEC (survival, growth and reproduction)	4-5	Voyer and McGovern 1991	
Mysid (8 d), *Americamysis bahia*	Cadmium chloride	7 d	25	NOEC (survival and growth)	5	Khan et al. 1992	Duration; Unmeasured exposure
Mysid (8 d), *Americamysis bahia*	Cadmium chloride	96 hr	25	NOEC (survival and growth)	5	Khan et al. 1992	
Mysid, *Americamysis bahia*	-	24 hr	12	Reduced serum osmolality	3.62	De Lisle and Roberts 1994	Duration; Atypical endpoint

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mysid, *Mysidopsis bigelowi*	Cadmium chloride	28 d	-	LC50	18	Gentile et al. 1982	Duration
Mysid, *Mysidopsis bigelowi*	Cadmium chloride	8 d	-	LC50	70	Gentile et al. 1982	Duration
Mysid (adult, 18 mm), *Praunus flexuosus*	Cadmium chloride	6 d	10	LC50	83.11	Roast et al. 2001b	Duration
Isopod, *Idotea baltica*	Cadmium chloride	5 d	3	LC50	10,000	Jones 1975	Duration
Isopod, *Idotea baltica*	Cadmium chloride	3 d	21	LC50	10,000	Jones 1975	Duration
Isopod, *Idotea baltica*	Cadmium chloride	1.5 d	14	LC50	10,000	Jones 1975	Duration
White shrimp (0.02 cm, 0.1 g), *Litopenaeus vannamei*	Cadmium sulfate	28 d	15	LOEC (growth)	100	Wu and Chen 2005a	Unmeasured chronic exposure
White shrimp (0.22 cm, 0.49 g), *Litopenaeus vannamei*	Cadmium sulfate	28 d	15	NOEC-LOEC (food consumption)	100-200	Wu and Chen 2005a	Unmeasured chronic exposure; Atypical endpoint
Pink shrimp, *Penaeus duorarum*	Cadmium chloride	30 d	-	LC50	720	Nimmo et al. 1977b	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	29 d	-	LC50	120	Nimmo et al. 1977b	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	5	LC25	50	Vernberg et al. 1977	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	10	LC10	50	Vernberg et al. 1977	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	20	LC5	50	Vernberg et al. 1977	Lack of exposure details
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	21 d	-	BCF = 140	-	Vernberg et al. 1977	Steady state not documented
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	6 d	10	LC75	300	Middaugh and Floyd 1978	Duration

Species	**Chemical**	**Duration**	**Salinity (g/kg)**	**Effect**	**Concentration (µg/L)**	**Reference**	**Reason Other Data**
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	6 d	15	LC50	300	Middaugh and Floyd 1978	Duration
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	6 d	30	LC25	300	Middaugh and Floyd 1978	Duration
Daggerblade grass shrimp, *Palaemonetes pugio*	Cadmium chloride	42 d	-	LC50	300	Pesch and Stewart 1980	Duration
Daggerblade grass shrimp (juvenile), *Palaemonetes pugio*	Cadmium chloride	48 hr	10	LC50	1,300	Burton and Fisher 1990	Duration too short for juvenile shrimp
Daggerblade grass shrimp (25-35 mg), *Palaemonetes pugio*	Cadmium chloride	8 hr	20	NOEC-LOEC (increase GSH)	562.05-5,620.5	Downs et al. 2001a	Duration; Atypical endpoint
Daggerblade grass shrimp (25-35 mg), *Palaemonetes pugio*	Cadmium chloride	8 hr	20	LOEC (increase LPO and ubiquitin)	112.41	Downs et al. 2001a	Duration; Atypical endpoint
Shrimp, *Palaemon sp.*	-	5 d	-		2,300	Ahsanullah 1976	Duration
Spot shrimp, *Pandalus platyceros*	-	-	-		4,970	Cardwell et al. 1979	Unknown duration
Pink shrimp, *Pandalus montagui*	Cadmium chloride	6 d	-	LC50	1,280	McLeese and Ray 1986	Duration
Common shrimp (post-molt), *Crangon crangon*	-	5.3 d	-		350	Price and Uglow 1979	Duration
Bay shrimp, *Crangon septemspinosa*	Cadmium chloride	6 d	-	LC50	1,160	McLeese and Ray 1986	Duration
American lobster, *Homarus americanus*	Cadmium chloride	21 d	-	BCF = 25	-	Eisler et al. 1972	Steady state not documented
American lobster, *Homarus americanus*	Cadmium chloride	30 d	-	Increase in ATPase activity	6	Tucker 1979	Atypical endpoint

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Longwrist hermit crab, *Pagurus longicarpus*	Cadmium chloride	7 d	-	25% mortality	270	Eisler and Hennekey 1977	Duration
Longwrist hermit crab, *Pagurus longicarpus*	Cadmium chloride	60 d	-	LC56	70	Pesch and Stewart 1980	Lack of exposure details; Atypical endpoint
Yellow crab, *Cancer anthonyi*	Cadmium chloride	7 d	34	28% mortality	1,000	MacDonald et al. 1988	Duration
Rock crab, *Cancer irroratus*	Cadmium chloride	96 hr	-	Enzyme activity	1,000	Gould et al. 1976	Atypical endpoint
Rock crab (larva), *Cancer irroratus*	Cadmium chloride	28 d	-	Delayed development	50	Johns and Miller 1982	Lack of exposure details
Blue crab, *Callinectes sapidus*	Cadmium nitrate	7 d	10	LC50	50	Rosenberg and Costlow 1976	Duration
Blue crab, *Callinectes sapidus*	Cadmium nitrate	7 d	30	LC50	150	Rosenberg and Costlow 1976	Duration
Blue crab, *Callinectes sapidus*	Cadmium chloride	21 d	2.5	LC50	19	Guerin and Stickle 1995	Duration
Blue crab, *Callinectes sapidus*	Cadmium chloride	21 d	25	LC50	186	Guerin and Stickle 1995	Duration
Blue crab, *Callinectes sapidus*	Cadmium chloride	6-8 d	28	EC50 (hatching)	0.25	Lee et al. 1996	Duration
Shore crab (45.6 g), *Carcinus maenas*	Cadmium chloride	10 d	32	NOEC-LOEC (osmotic pressure)	3.4-34	Burke et al. 2003	Duration; Only two exposure concentrations
Shore crab (45.6 g), *Carcinus maenas*	Cadmium chloride	10 d	10.5	LOEC (osmotic pressure)	3.4	Burke et al. 2003	Duration; Only two exposure concentrations
Mud crab (larva), *Eurypanopeus depressus*	Cadmium chloride	8 d	-	LC50	10	Mirkes et al. 1978	Duration; Lack of exposure details
Mud crab (larva), *Eurypanopeus depressus*	Cadmium chloride	44 d	-	Delay in metamorphysis	10	Mirkes et al. 1978	Lack of exposure details

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mud crab, *Rhithropanopeus harrisil*	Cadmium nitrate	11 d	10	LC80	50	Rosenberg and Costlow 1976	Duration; Atypical endpoint
Mud crab, *Rhithropanopeus harrisil*	Cadmium nitrate	11 d	20	LC75	50	Rosenberg and Costlow 1976	Duration; Atypical endpoint
Mud crab, *Rhithropanopeus harrisil*	Cadmium nitrate	11 d	30	LC40	50	Rosenberg and Costlow 1976	Duration; Atypical endpoint
Fiddler crab, *Uca pugilator*	-	10 d	-	LC50	2,900	O'Hara 1973a	Duration
Fiddler crab, *Uca pugilator*	Cadmium chloride	-	-	Effect on respiration	1.0	Vernberg et al. 1974	Duration not provided
Northern Pacific seastar (egg/sperm), *Asterias amurensis*	Cadmium chloride	60 min	32	Fertilization rate	154,000	Lee et al. 2004	Duration
Common starfish, *Asterias forbesii*	Cadmium chloride	7 d	-	25% mortality	270	Eisler and Hennekey 1977	Duration
Sea urchin (sperm cell), *Arbacia punctulata*	Cadmium chloride	1 hr	30	EC50 (sperm cell)	38,000	Nacci et al. 1986	Duration
Sea urchin (embryo), *Arbacia punctulata*	Cadmium chloride	4 hr	30	EC50 (embryo growth)	13,900	Nacci et al. 1986	Duration
Green sea urchin (sperm), *Strongylocentrotus droebachiensis*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	26,000	Dinnel et al. 1989	Duration
Green sea urchin (embryo), *Strongylocentrotus droebachiensis*	Cadmium chloride	120 hr	30	EC50 (development)	1,800	Dinnel et al. 1989	Duration
Red sea urchin (sperm), *Strongylocentrotus franciscanus*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	12,000	Dinnel et al. 1989	Duration
Purple sea urchin (sperm), *Strongylocentrotus purpuratus*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	18,000	Dinnel et al. 1989	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	Cadmium chloride	120 hr	30	EC50 (development)	500	Dinnel et al. 1989	Duration
Purple sea urchin, *Strongylocentrotus purpuratus*	Cadmium chloride	40 min	30	NOEC (sperm fertilization)	>67	Bailey et al. 1995	Duration
Sand dollar (sperm), *Dendraster excentricus*	Cadmium chloride	80 min	30	EC50 (sperm fertilization)	8,000	Dinnel et al. 1989	Duration
Sand dollar, *Dendraster excentricus*	Cadmium chloride	40 min	30	NOEC (sperm fertilization)	>67	Bailey et al. 1995	Duration
Herring (larvae), *Clupea harengus*	Cadmium chloride	-	-	100% embryonic survival	5,000	Westernhagen et al. 1979	Duration not provided
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	<24 hr	-	17% reduction in volume	10,000	Alderdice et al. 1979a	Duration; Atypical endpoint
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	96 hr	-	Decrease in capsule strength	1,000	Alderdice et al. 1979b	Atypical endpoint
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	48 hr	-	Reduced osmolality of periviteline fluid	1,000	Alderdice et al. 1979c	Duration; Atypical endpoint
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	34-35	LC50	1,230	Hutchinson et al. 1994	Test species fed
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	7 d	34-35	NOEC (survival and growth)	560	Hutchinson et al. 1994	Duration
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	5	LC50	180 (dissolved)	Hall et al. 1995	Test species fed
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	15	LC50	312 (dissolved)	Hall et al. 1995	Test species fed
Sheepshead minnow, *Cyprinodon variegatus*	Cadmium chloride	96 hr	25	LC50	496 (dissolved)	Hall et al. 1995	Test species fed
Mummichog, *Fundulus heteroclitus*	Cadmium chloride	21 d	-	BCF = 48	-	Eisler et al. 1972	Steady state not documented
Mummichog (adult), *Fundulus heteroclitus*	Cadmium chloride	48 hr	20	LC50	60,000	Middaugh and Dean 1977	Duration
Mummichog (adult), *Fundulus heteroclitus*	Cadmium chloride	48 hr	30	LC50	43,000	Middaugh and Dean 1977	Duration

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Mummichog (larva), *Fundulus heteroclitus*	Cadmium chloride	48 hr	20	LC50	32,000	Middaugh and Dean 1977	Duration
Mummichog (larva), *Fundulus heteroclitus*	Cadmium chloride	48 hr	30	LC50	7,800	Middaugh and Dean 1977	Duration
Mummichog (<23 d), *Fundulus heteroclitus*	Cadmium chloride	48 hr	10	LC50	44,400	Burton and Fisher 1990	Duration
Atlantic silverside (adult), *Menidia menidia*	Cadmium chloride	48 hr	20	LC50	13,000	Middaugh and Dean 1977	Duration
Atlantic silverside (adult), *Menidia menidia*	Cadmium chloride	48 hr	30	LC50	12,000	Middaugh and Dean 1977	Duration
Atlantic silverside (larva), *Menidia menidia*	Cadmium chloride	48 hr	20	LC50	2,200	Middaugh and Dean 1977	Duration
Atlantic silverside (larva), *Menidia menidia*	Cadmium chloride	48 hr	30	LC50	1,600	Middaugh and Dean 1977	Duration
Atlantic silverside, *Menidia menidia*	Cadmium chloride	19 d	12	LC50	<160	Voyer et al. 1979	Duration
Atlantic silverside, *Menidia menidia*	Cadmium chloride	19 d	20	LC50	540	Voyer et al. 1979	Duration
Atlantic silverside, *Menidia menidia*	Cadmium chloride	19 d	30	LC50	>970	Voyer et al. 1979	Duration
Striped bass (juvenile), *Morone saxatilis*	Cadmium chloride	90 d	-	Significant decrease in enzyme activity	5	Dawson et al. 1977	Atypical endpoint
Striped bass (juvenile), *Morone saxatilis*	Cadmium chloride	30 d	-	NOEC-LOEC (significant decrease in oxygen consumption)	0.5-5	Dawson et al. 1977	Atypical endpoint
Cunner (adult), *Tautogolabrus adspersus*	Cadmium chloride	96 hr	-	Decreased enzyme activity	3,000	Gould and Karolus 1974	Atypical endpoint
Cunner (adult), *Tautogolabrus adspersus*	Cadmium chloride	60 d	-	37.5% mortality	100	MacInnes et al. 1977	Lack of exposure details
Cunner (adult), *Tautogolabrus adspersus*	Cadmium chloride	30 d	-	Depressed gill tissue oxygen consumption	50	MacInnes et al. 1977	Atypical endpoint

Species	Chemical	Duration	Salinity (g/kg)	Effect	Concentration (µg/L)	Reference	Reason Other Data
Winter flounder, *Pseodopleuronectes americanus*	Cadmium chloride	60 d	-	Increase gill tissue respiration	5	Calabrese et al. 1975	Atypical endpoint
Winter flounder, *Pseudopleuronectes americanus*	Cadmium chloride	8 d	-	50% viable hatch	300	Voyer et al. 1977	Duration
Winter flounder, *Pseodopleuronectes americanus*	Cadmium chloride	17 d	-	Reduction of viable hatch	586	Voyer et al. 1982	Lack of exposure details
Spot (larva), *Leiostomus xanthurus*	Cadmium chloride	9 d	-	Incipient LC50	200	Middaugh and Dean 1977	Duration

Appendix J Unused Studies

Appendix Table J-1. Unused Studies

Authors	Title	Year	Reason Unused
Abbasi and Soni	An examination of environmentally safe levels of zinc (II), cadmium (II) and lead (II) with reference to impact on channelfish *Nuria denricus*	1986	Not North American species
Abbasi and Soni	Relative toxicity of seven heavy metals with respect to impact towards larvae of amphibian *Rana tigrina*.	1989	The materials, methods or results were insufficiently described
Abdallah	Trace Element Levels in Some Commercially Valuable Fish Species from Coastal Waters of Mediterranean Sea, Egypt	2008	Bioaccumulation: steady state not documented
AbdAllah and Moustafa	Accumulation of lead and cadmium in the marine prosobranch *Nerita saxtilis*, chemical analysis, light and electron microscopy	2002	Non-applicable
Abdel-Baky et al.	Seasonal variations of some heavy metals accumulated in the organs of *Clarias gariepinus* (Burchell, 1822) in Lake Manzala, Egypt	1998	Non-applicable
Abel and Barlocher	Uptake of cadmium by *Gammarus fossarum* (Amphipoda) from food and water.	1988	Not North American species
Abel and Garner	Comparisons of median survival times and median lethal exposure times for *Gammarus pulex* exposed to cadmium, permethrin and cyanide.	1986	Not North American species
Abel and Papoutsoglou	Lethal toxicity of cadmium to *Cyprinus carpio* and *Tilapia aurea*.	1986	Not North American species
Abrahim et al.	Distribution and Assessment of Sediment exposure Toxicity in Tamaki Estuary, Auckland, New Zealand	2007	Sediment exposure
Abtahi et al.	Study of Histopathological Effect of Environmental Factors of Caspian Sea on Sturgeon Fishes	2007	Mixture
Adam et al.	Impact of Cadmium and Zinc Prior Exposure on 110mSilver, 58+60Cobalt and 137Cesium Uptake by Two Freshwater Bivalves During a Brief Field Experiment	2002	Bioaccumulation: steady state not documented
Adami et al.	Levels of cadmium and zinc in hepatopancreas of reared *Mytilus galloprovincialis* from the Gulf of Trieste (Italy)	2002	Non-applicable
Adams et al.	The Impact of an Industrially Contaminated Lake on Heavy Metal Levels in Its Effluent Stream	1980	Bioaccumulation: steady state not documented
Adeyemi and Deaton	The effect of cadmium exposure on digestive enzymes in the Eastern oyster *Crassostrea virginica*	2012	Only two exposure concentrations
Adham et al.	Impaired Functions in Nile Tilapia, *Oreochromis niloticus* (Linnaeus, 1757), from Polluted Waters	2002	Mixture
Adhikari et al.	Effect of calcium hardness on toxicity and accumulation of water-borne lead, cadmium and chromium to *Labeo rohita* (Hamilton)	2007	Bioaccumulation: steady state not documented (only 14 day exposure); not North American speciess
Adhikari et al.	Combined effects of water pH and alkalinity on the accumulation of lead, cadmium and chromium to *Labeo rohita* (Hamilton)	2006	Bioaccumulation: steady state not documented (only 14 day exposure); not North American species

Authors	**Title**	**Year**	**Reason Unused**
Adiele	Involvement of mitochondria in cadmium toxicity in rainbow trout (*Oncorhynchus mykiss*)	2012	Excised tissue/cells
Adiele et al.	Reciprocal Enhancement of Uptake and Toxicity of Cadmium and Calcium in Rainbow Trout (*Oncorhynchus Mykiss*) Liver Mitochondria.	2010	In vitro
Adiele et al.	Cadmium- and calcium-mediated toxicity in rainbow trout (*Oncorhynchus mykiss*) *in vivo*: interactions on fitness and mitochondrial endpoints.	2011	Only two exposure concentrations
Adiele et al.	Differential inhibition of electron transport chain enzyme complexes by cadmium and calcium in isolated rainbow trout (*Oncorhynchus mykiss*) hepatic mitochondria.	2012a	In vitro
Adiele et al.	Features of Cadmium and Calcium Uptake and Toxicity in Rainbow Trout (*Oncorhynchus mykiss*) Mitochondria.	2012b	In vitro
Afonso et al.	Contaminant metals in black scabbard fish (*Aphanopus carbo*) caught off Madeira and the Azores	2007	Bioaccumulation: steady state not documented
Agnello et al.	Cadmium induces an apoptotic response in sea urchin embryos	2007	Not North American species, only one exposure concentration, duration too short
Agrahari and Gopal	Fate and toxicity of cadmium and lead accumulation in different tissues (gills, liver, kidney, brain) of a freshwater fish *Channa punctatus*	2007	Not North American species, lack of exposure details
Ahmad et al.	Effect of cadmium chloride on the histoarchitecture of liver and kidney of a freshwater catfish, *Clarias batrachus*	2011	Only two exposure concentrations
Ahmed et al.	Measurements of genotoxic potential of cadmium in different tissues of fresh water climbing perch Anabas testudineus (Bloch), using the comet assay	2010	Excised tissue/cells
Ahn et al.	The effect of body size on metal accumulations in the bivalve *Laternula elliptica*	2001	Non-applicable
Ahn et al.	Spatial Variations of Heavy Metal Accumulation in Manila Clam *Ruditapes philippinarum* From Some Selected Intertidal Flats of Korea	2006	Bioaccumulation: steady state not documented
Ahsanullah and Arnott	Acute toxicity of copper, cadmium, and zinc to larvae of the crab *Paragrapsus quadridentatus* (H. Milne Edwards), and implications for water quality criteria	1978	Not North American species
Ahsanullah and Williams	Sublethal effects and bioaccumulation of cadmium, chromium, copper and zinc in the marine amphipod *Allorchestes compressa*	1991	Not North American species
Ahsanullah et al.	Toxicity of zinc, cadmium, and copper to the shrimp *Callianassa australiensis*	1981	Not North American species
Ai et al.	Effects of Heavy Metal and Pollutants on the Non-Special Immunity of the Shrimp and Crab.	2008	Non-applicable
Airas et al.	Copper, Zinc, Arsenic, Cadmium, Mercury, and Lead in Blue Mussels (*Mytilus edulis*) in the Bergen Harbor Area, Western Norway	2004	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Akinola and Ekiyoyo	Accumulation of Lead, Cadmium and Chromium in Some Plants Cultivated Along the Bank of River Ribila at Odo-Nla Area of Ikorodu, Lagos State, Nigeria	2006	Bioaccumulation: steady state not documented
Aktac et al.	The effects of short-term exposure to cadmium and copper on sialic acid in carp (*Cyprinus carpio*) tissues	2010	Only three exposure concentrations, too few organisms per concentration; Bioaccumulation: steady state not documented
Albers and Camardese	Effects of Acidification on Metal Accumulation by Aquatic Plants and Invertebrates. 1. Constructed Wetlands	1993a	Bioaccumulation: steady state not documented
Albers and Camardese	Effects of Acidification on Metal Accumulation by Aquatic Plants and Invertebrates. 2. Wetlands, Ponds and Small Lake.	1993b	Bioaccumulation: steady state not documented
Albrecht et al.	Heavy Metal Levels in Ribbon Snakes (*Thamnophis sauritus*) and Anuran Larvae From the Mobile-Tensaw River Delta, Alabama, USA	2007	Bioaccumulation: steady state not documented
Albright et al.	Technique for Measuring Metallic Salt Effects Upon the Indigenous Heterotrophic Microflora of Natural Water.	1972	Bacteria
Alhashemi et al.	Bioaccumulation of trace elements in trophic levels of wetland plants and waterfowl birds.	2011	Bioaccumulation: steady state not documented
Al-Homaidan	Heavy Metal Concentrations in Three Species of Green Algae from the Saudi Coast of the Arabian Gulf	2007	Bioaccumulation: steady state not documented
Allen	Accumulation profiles of lead and the influence of cadmium and mercury in *Oreochromis aureus* (Steindachner) during chronic exposure	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Allen	Soft-tissue accumulation of lead in the blue tilapia, *Oreochromis aureus* (Steindachner), and the modifying effects of cadmium and mercury	1995a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Allen	Accumulation profiles of lead and cadmium in the edible tissues of *Oreochromis aureus* during acute exposure	1995b	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Allen et al.	Development and Application of Long-Term Sublethal Whole Sediment exposure Tests With *Arenicola marina* and *Corophium volutator* Using Ivermectin as the Test Compound	2007	Sediment exposure
Al-Madfa	Metals accumulation in the marine ecosystem around Qatar (Arabian Gulf)	2002	Bioaccumulation: steady state not documented
Almaguer-Cantu et al.	Biosorption of Lead (II) and Cadmium (II) Using *Escherichia coli* Genetically Engineered With Mice Metallothionein I.	2011	Bacteria
Almeida et al.	Environmental cadmium exposure and metabolic responses of the Nile tilapia, *Oreochromis niloticus*	2001	Dilution water not characterized, duration too short, unmeasured chronic exposure
Almli et al.	Hepatic and renal concentrations of 10 trace elements in crocodiles (*Crocodylus niloticus*) in the Kafue and Luangwa rivers in Zambia	2005	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Alonso et al.	Development of a feeding behavioural bioassay using the freshwater amphipod *Gammarus pulex* and the multispecies freshwater biomonitor.	2009	Not North American species, duration too short, a typical endpoint
Alonso et al.	Contrasting sensitivities to toxicants of the freshwater amphipods *Gammarus pulex* and *G. fossarum*	2010a	Not North American species
Alonso et al.	Effects of animal starvation on the sensitivity of the freshwater amphipod *Gammarus pulex* to cadmium	2010b	Not North American species, atypical endpoint
Alquezar et al.	Metal Accumulation in the Smooth Toadfish, *Tetractenos glaber*, in Estuaries Around Sydney, Australia	2006a	Bioaccumulation: steady state not documented
Alquezar et al.	Effects of Metals on Condition and Reproductive Output of the Smooth Toadfish in Sydney Estuaries, South-Eastern Australia	2006b	Non-applicable
Alquezar et al.	Comparative Accumulation of 109Cd and 75Se from Water and Food by an Estuarine Fish (*Tetractenos glaber*)	2008	Bioaccumulation: steady state not documented
Al-Shami et al.	Genotoxicity of heavy metals to the larvae of *Chironomus kiiensis* Tokunaga after short-term exposure	2012	Only three exposure concentrations
Al-Shwafi and Rushdi	Heavy Metal Concentrations in Marine Green, Brown, and Red Seaweeds From Coastal Waters of Yemen, the Gulf of Aden	2008	Bioaccumulation: steady state not documented
AltIndag and Yigit	Assessment of heavy metal concentrations in the food web of lake Beysehir, Turkey	2005	Bioaccumulation: steady state not documented
Alvarado et al.	Cellular biomarkers of exposure and biological effect in hepatocytes of turbot (*Scophthalmus maximus*) exposed to Cd, Cu and Zn and after depuration	2005	Dilution water not characterized, only two exposure concentrations, duration too short, not North American species
Alvarez-Legorreta et al.	Thiol peptides in the seagrass *Thalassia testudinum* (Banks ex Konig) in response to cadmium exposure	2008	Bioaccumulation: steady state not documented
Alves de Oliveira et al.	Sulphate uptake and metabolism in water hyacinth and salvinia during cadmium stress	2009	Only one exposure concentration, duration too short
Amado-Filho et al.	Heavy Metals in Benthic Organisms From Todos Os Santos Bay, Brazil	2008	Bioaccumulation: steady state not documented
Amenu	A comparative study of water quality conditions between heavily urbanized and less urbanized watersheds of Los Angeles Basin	2011	Not applicable (no cadmium toxicity information)
Amiard et al.	Influence of some ecological and biological factors on metal bioaccumulation in young oysters (*Crassostrea gigas* Thunberg) during their spat rearing	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Amiard et al.	Influence of ploidy and metal-metal interactions on the accumulation of Ag, Cd, and Cu in oysters *Crassostrea gigas* Thunberg	2005	Bioaccumulation: steady state not documented (only 15 day exposure)
Amiard et al.	Relationship Between the Liability of Sediment exposure-Bound Metals (Cd, Cu, Zn) and Their Bioaccumulation in Benthic Invertebrates	2007	Sediment exposure

Authors	Title	Year	Reason Unused
Amiard-Triquet et al.	Contribution to the ecotoxicological study of cadmium, copper and zinc in the mussel *Mytilus edulis*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Amiard-Triquet et al.	Etudes *in situ* et experimentales de leotoxicologie de quatre metaux (Cd, Pb, Cu, Zn) chez des algues et des mollusques gasteropodes brouteurs	1987	Not North American species
Amiard-Triquet et al.	Field and experimental study of the bioaccumulation of some trace metals in a coastal food chain: seston, oyster (*Crassostrea gigas*), drill (*Ocenebra erinacea*)	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Amin et al.	Toxicity of cadmium, lead, and zinc to larval stages of *Lithodes santolla* (Decapoda, Anomura)	2003	Dilution water not characterized, not North American species
Amin et al.	Heavy Metal Concentrations in Sediment exposure and Intertidal Gastropod *Nerita lineata* From Two Opposing Sites in the Straits of Malacca	2008	Bioaccumulation: steady state not documented
Amutha and Subramanian	Cadmium alters the reproductive endocrine disruption and enhancement of growth in the early and adult stages of *Oreochromis mossambicus*	2013	Only two exposure concentrations
Amweg and Weston	Whole-Sediment exposure Toxicity Identification Evaluation Tools for Pyrethroid Insecticides: I. Piperonyl Butoxide Addition	2007	Sediment exposure
An et al.	Heavy Metals Contents in Haplocladium and Their Relationships With Shanghai City Environment	2006	Bioaccumulation: steady state not documented
Anadu	Fish acclimation and the development of tolerance to zinc as a modifying factor in toxicity	1983	Mixture, prior exposure to zinc
Anadu et al.	Effect of zinc exposure on subsequent acute tolerance to heavy metals in rainbow trout	1989	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Anajjar et al.	Monitoring of Trace Metal Contamination in the Souss Estuary (South Morocco) Using the Clams *Cerastoderma edule* and *Scrobicularia plana*	2008	Bioaccumulation: steady state not documented
Anan et al.	Subcellular distribution of trace elements in the liver of sea turtles	2002	Bioaccumulation: steady state not documented
Anderson	Concentration of Cadmium, Copper, Lead, and Zinc in Thirty-Five Genera of Freshwater Macroinvertebrates From the Fox River, Illinois and Wisconsin.	1977	Bioaccumulation: steady state not documented
Anderson et al.	The distribution of Cd, Cu, Pb and Zn in the biota of two freshwater sites with different trace metal inputs	1978	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Anderson et al.	A Comparison of in Situ and Laboratory Toxicity Tests With the Estuarine Amphipod *Eohaustorius estuarius*	2004	Non-applicable
Anderson et al.	DNA- and RNA-derived assessments of fungal community composition in soil amended with sewage sludge rich in cadmium, copper and zinc	2008	Sludge

Authors	**Title**	**Year**	**Reason Unused**
Andosch et al.	A freshwater green alga under cadmium stress: Ameliorating calcium effects on ultrastructure and photosynthesis in the unicellular model Micrasterias	2012	No control group, only two exposure concentrations
Andreji et al.	Heavy Metals Content and Microbiological Quality of Carp (*Cyprinus carpio*, L.) Muscle From Two Southwestern Slovak Fish Farms	2006a	Bioaccumulation: steady state not documented
Andreji et al.	Accumulation of Some Metals in Muscles of Five Fish Species from Lower Nitra River	2006b	Bioaccumulation: steady state not documented
Andres et al.	Field transplantation of the freshwater bivalve *Corbicula fluminea* along a polymetallic contamination gradient (River Lot, France): I. Geochemical characteristics of sampling sites and cadmium and zinc bioaccumulation kinetics	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Ankley et al.	Evaluation of the Toxicity of Marine Sediments and Dredge Spoils With the Microtox Bioassay.	1989	Bacteria
Annabi et al.	Cadmium accumulation and histological lesion in mosquitofish (*Gambusia affinis*) tissues following acute and chronic exposure	2011	Bioaccumulation: exposure not measured
Annabi et al.	Influence of cadmium exposure on growth and fecundity of freshwater mosquitofish *Gambusia affinis*: In situ and in vivo studies	2012	Only one exposure concentration
Annune et al.	Acute toxicity of cadmium to juveniles of *Clarias gariepinus* (Teugels) and *Oreochromis niloticus* (Trewavas). J.	1994	Not North American species
Ansaldo et al.	Effect of cadmium, lead and arsenic on the oviposition, hatching and embryonic survival of *Biomphalaria glabrata*	2009	Only two exposure concentration, test species fed, unmeasured chronic exposure
Anu et al.	Monitoring of Heavy Metal Partitioning in Reef Corals of Lakshadweep Archipelago, Indian Ocean	2007	Bioaccumulation: steady state not documented
Anushia et al.	Heavy metal induced enzyme response in *Tilapia mossambicus*	2012	Dilution water not characterized
Apeti et al.	Cadmium Distribution in Coastal Sediment exposures and Mollusks of the US	2009	Bioaccumulation: steady state not documented
Aramphongphan et al.	Snakehead-Fish Cell Line, Ssn-1 (*Ophicephalus striatus*) as a Model for Cadmium Genotoxicity Testing	2009	In vitro
Aravind and Prasad	Zinc Alleviates Cadmium-Induced Oxidative Stress in *Ceratophyllum demersum* L.: A Free Floating Freshwater Macrophyte	2003	Mixture
Aravind and Prasad	Zinc Protects Chloroplasts and Associated Photochemical Functions in Cadmium Exposed *Ceratophyllum demersum* L., a Freshwater Macrophyte	2004	Mixture
Aravind and Prasad	Zinc Mediated Protection to the Conformation of Carbonic Anhydrase in Cadmium Exposed *Ceratophyllum demersum* L.	2005	Mixture
Aravind et al.	Zinc Protects *Ceratophyllum demersum* L. (Free-Floating Hydrophyte) Against Reactive Oxygen Species Induced by Cadmium	2009	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Arias-Almeida and Rico-Martinez	Inhibition of Two Enzyme Systems in Euchlanis dilatata (Rotifera: *Monogononta*) as Biomarker of Effect of Metals and Pesticides.	2011a	In vitro
Arias-Almeida and Rico-Martinez	Toxicity of cadmium, lead, mercury and methyl parathion on *Euchlanis dilatata* Ehrenberg 1832 (Rotifera: *Monogononta*).	2011b	Duration too short, not North American species
Arikpo et al.	Cadmium uptake by the green alga *Chlorella emersonii*	2004	Adsorption not absorption study
Arini et al.	Field Translocation of Diatom Biofilms Impacted by Cd and Zn to Assess Decontamination and Community Restructuring Capacities.	2012	Mixture
Arnac and Lassus	Heavy metal accumulation (Cd, Cu, Pb and Zn) by smelt (*Osmerus mordax*) from the north shore of the St. Lawrence estuary	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Arshaduddin et al.	Effect of two heavy metals (lead and cadmium) on growth in the rotifer *Asplanchna intermedia*	1989	Not North American species
Arts et al.	Sensitivity of submersed freshwater macrophytes and endpoints in laboratory toxicity tests	2008	No cadmium toxicity information
Asagba et al.	Bioaccumulation of cadmium and its biochemical effect on selected tissues of the catfish (*Clarias gariepinus*)	2008	Bioaccumulation: steady state not documented (only 21 day exposure); not North American species
Asagba et al.	Oxidative enzymes in tissues of the catfish (*Clarias gariepinus*) exposed to varying levels of cadmium	2010	Dilution water not characterized, not North American species, only three exposure concentrations
Asato and Reish	The effects of heavy metals on the survival and feeding of *Holmesimysis costata* (Crustacea: Mysidacea)	1988	High control mortality reported
Ashraf	Accumulation of heavy metals in kidney and heart tissues of *Epinephelus microdon* fish from the Arabian Gulf	2005	Bioaccumulation: steady state not documented
Ashraf et al.	Seasonal Variation of Metal Concentration in Barnacles (*Balanus spp*.) Of Cochin Estuary, South West Coast of India	2007	Bioaccumulation: steady state not documented
Askary Sary et al.	Cadmium, Iron, Lead and Mercury Bioaccumulation in Abu mullet, *Liza abu*, Different Tissues From Karoun and Karkheh Rivers, Khozestan, Iran	2012	Bioaccumulation: steady state not documented
Atici et al.	Sensitivity of freshwater microalgal strains (*Chlorella vulgaris* Beijernick and *Scenedesmus obliquus* (Turpin) Kutzing) to heavy metals	2008	Excessive EDTA
Attar and Maly	Acute toxicity of cadmium, zinc, and cadmium-zinc mixtures to *Daphnia magna*	1982	Prior exposure (1.0 ug/L Cd in city water used for culturing organisms)
Au et al.	Reproductive impairment of sea urchins upon chronic exposure to cadmium. Part I: effects on gamete quality	2001a	Dilution water not characterized, only two exposure concentrations, Not North American species
Au et al.	Reproductive impairment of sea urchin upon chronic exposure to cadmium. Part II: effects on sperm development	2001b	Dilution water not characterized, only two exposure concentrations, Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Audet and Couture	Seasonal variations in tissue metabolic capacities of yellow perch (*Perca flavescens*) from clean and metal-contaminated environments	2003	Bioaccumulation: steady state not documented
Augier et al.	Variation of heavy metal contents of the green alga *Caulerpa taxifolia* (Vahl) C. agardh in its area of expansion in the French Mediterranean Sea	1999	Bioaccumulation: steady state not documented
Auslander et al.	Pollution-affected fish hepatic transcriptome and its expression patterns on exposure to cadmium	2008	Dietary and injected exposure; not North American species
Austen and McEvoy	The use of offshore meiobenthic communities in laboratory microcosm experiments: response to heavy metal contamination	1997	Sediment, no species name given, only one exposure concentration
Austin and Deniseger	Periphyton Community Changes Along a Heavy Metals Gradient in a Long Narrow Lake. Environ.	1985	Bioaccumulation: steady state not documented
Avery et al.	The detection of pollutant impact in marine environments: condition index, oxidative DNA damage, and their associations with metal bioaccumulation in the Sydney rock oyster *Saccostrea commercialis*	1996	Not North American species
Awasthi and Rai	Toxicity of Nickel, Zinc, and Cadmium to Nitrate Uptake in Free and Immobilized Cells of *Scenedesmus quadricauda*	2005	Mixture
Awasthi and Rai	Interactions Between Zinc and Cadmium Uptake by Free and Immobilized Cells of *Scenedesmus quadricauda* (Turp.)	2006	Mixture
Ayas et al.	Heavy Metal Accumulation in Water, Sediment exposures and Fishes of Nallihan Bird Paradise, Turkey	2007	Bioaccumulation: steady state not documented
Azeez and Banerjee	Influence of light on chlorophyll, a content of blue-green algae treated with heavy metals	1987	Not North American species
Baas et al.	Modeling the Effects of Binary Mixtures on Survival in Time	2007	Modeling
Babich and Stotzky	Influence of chloride ions on the toxicity of cadmium to fungi	1982	Non-aquatic species, only one exposure concentration
Babich et al.	In Vitro Cytotoxicity of Metals to Bluegill (Bf-2) Cells	1986	In vitro
Backor et al.	Response to Copper and Cadmium Stress in Wild-Type and Copper Tolerant Strains of the Lichen Alga *Trebouxia erici*: Metal Accumulation, Toxicity and Non-Protein Thiols	2007	Mixture
Badr and Fawzy	Bioaccumulation and Biosorption of Heavy Metals and Phosphorous by *Potamogeton pectinatus* L. And *Ceratophyllum demersum* L. In Two Nile Delta Lakes	2008	Bioaccumulation: steady state not documented
Bagwe	Effect of cadmium and seasonality on critical temperatures of aerobic metabolism in eastern oysters, *Crassostrea virginica* Gmelin 1791	2012	Only one exposure concentration, unmeasured chronic exposure
Bagy et al.	Effect of pH and organic matter on the toxicity of heavy metals to growth of some fungi	1991	Only three exposure concentrations
Bah et al.	Comparative proteomic analysis of *Typha angustifolia* leaf under chromium, cadmium and lead stress	2010	Soil exposure
Bai et al.	Effect of H2O2 pretreatment on Cd tolerance of different rice cultivars	2011	Not applicable (non-aquatic plant)

Authors	**Title**	**Year**	**Reason Unused**
Baillieul and Blust	Analysis of the swimming velocity of cadmium-stressed *Daphnia magna*	1999	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Baines and Fisher	Modeling the Effect of Temperature on Bioaccumulation of Metals by a Marine Bioindicator Organism, *Mytilus edulis*	2008	Modeling
Baines et al.	Effects of Temperature on Uptake of Aqueous Metals by Blue Mussels *Mytilus edulis* From Arctic and Temperate Waters	2006	Bioaccumulation: steady state not documented
Baird and Van den Brink	Using Biological Traits to Predict Species Sensitivity to Toxic Substances	2007	Modeling
Bajguz	An enhancing effect of exogenous brassinolide on the growth and antioxidant activity in *Chlorella vulgaris* cultures under heavy metals stress	2010	Only three exposure concentrations
Bajguz	Suppression of *Chlorella vulgaris* growth by cadmium, lead, and copper stress and its restoration by endogenous brassinolide	2011	Mixture
Bakhmet et al.	Effect of copper and cadmium ions on heart function and calpain activity in blue mussel *Mytilus edulis*	2012	Dilution water not characterized
Bako and Daudu	Trace Metal Contents of the Emergent Macrophytes *Polygonum sp*. And *Ludwigia sp*. In Relation to the Sediment exposures of Two Freshwater Lake Ecosystems in the Nigerian Savanna	2007	Bioaccumulation: steady state not documented
Baldisserotto et al.	Effects of Dietary exposure Calcium and Cadmium on Cadmium Accumulation, Calcium and Cadmium Uptake from the Water, and Their Interactions in Juvenile Rainbow Trout	2005	Dietary exposure
Baldisserotto et al.	Acute and waterborne cadmium uptake in rainbow trout is reduced by Dietary exposure calcium carbonate	2004a	Bioaccumulation: steady state not documented (only 3 hour exposure); lack of exposure details
Baldisserotto et al.	A protective effect of Dietary exposure calcium against acute waterborne cadmium uptake in rainbow trout	2004b	Bioaccumulation: steady state not documented; lack of exposure details
Ball	The toxicity of cadmium to rainbow trout (*Salmo gairdnerii* Richardson)	1967	The materials, methods or results were insufficiently described
Ball et al.	Toxicity of a cadmium-contaminated diet to *Hyalella azteca*	2006	Dietary exposure
Balog and Shalanki	Crustacean Zooplankton as Indicators of Lake Balaton Pollution With Heavy Metals (Ispol'zovanie Rachkovogo Zooplanktons (Crustacea) Dlya Otsenki Zagryazneniya Oz. Balaton Tyazhelymi Metallami)	1984	Bioaccumulation: steady state not documented
Balogh and Salanki	The dynamics of mercury and cadmium uptake into different organs of *Anodonta cygnea* L	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bambang et al.	Effect of cadmium on survival and osmoregulation of various developmental stages of the shrimp *Penaeus japonicus* (Crustacea: Decapoda)	1994	Not North American species

Authors	Title	Year	Reason Unused
Banni et al.	Mixture toxicity assessment of cadmium and benzo[a]pyrene in the sea worm *Hediste diversicolor*	2009	Mixture
Banni et al.	Mechanisms Underlying the Protective Effect of Zinc and Selenium Against Cadmium-Induced Oxidative Stress in Zebrafish *Danio rerio*	2011	Mixture
Baraj et al.	Assessing the effects of Cu, Cd, and exposure period on metallothionein production in gills of the Brazilian brown mussel *Perna perna* by using factorial design	2011	Bioaccumulation: unmeasured exposure
Barata et al.	Toxicity of Binary Mixtures of Metals and Pyrethroid Insecticides to *Daphnia magna* Straus. Implications for Multi-Substance Risks Assessment	2006	Mixture
Barata et al.	Among- and within-population variability in tolerance to cadmium stress in natural populations of *Daphnia magna*: implications for ecological risk assessment	2002a	Lack of detail
Barata et al.	Genetic variability in sublethal tolerance to mixtures of cadmium and zinc in clones of *Daphnia magna* straus	2002b	Water and dietary exposure simultaneously
Barata et al.	Demographic responses of a tropical cladoceran to cadmium: effects of food supply and density	2002c	Dietary exposure
Barbieri	Use of oxygen consumption and ammonium excretion to evaluate the sublethal toxicity of cadmium and zinc on *Litopenaeus schmitti* (Burkenroad, 1936, Crustacea)	2007	Not North American species, dilution water not characterized
Barbieri	Effects of Zinc and Cadmium on Oxygen Consumption and Ammonium Excretion in Pink Shrimp (*Farfantepenaeus paulensis*, Perez-Farfante, 1967, Crustacea)	2009	Mixture, Not North American species
Bargagli et al.	Elevated cadmium accumulation in marine organisms from Terra Nova Bay (Antarctica)	1996	Bioaccumulation: steady state not documented
Barhoumi et al.	Cadmium Bioaccumulation in Three Benthic Fish Species, *Salaria basilisca*, *Zosterisessor ophiocephalus* and *Solea vulgaris* Collected From the Gulf of Gabes in Tunisia	2009	Bioaccumulation: steady state not documented
Barjaktarovic and Bendell-Young	Accumulation of 109Cd by Second-Generation Chironominae Propagated from Wild Populations Sampled from Low-, Mid-, and high-Saline Environments	2001	Bioaccumulation: steady state not documented
Barjhoux et al.	Effects of Copper and Cadmium Spiked-Sediments on Embryonic Development of Japanese Medaka (*Oryzias latipes*)	2012	Sediment
Barka	Insoluble Detoxification of Trace Metals in a Marine Copepod *Tigriopus brevicornis* Exposed to Copper, Zinc, Nickel, Cadmium, Silver and Mercury	2007	Mixture

Authors	Title	Year	Reason Unused
Barka et al.	Metal distributions in *Tigriopus brevicornis* (Crustacea, Copepoda) exposed to copper, zinc, nickel, cadmium, silver, and mercury, and implication for subsequent transfer in the food web	2010	Bioaccumulation: unmeasured exposure
Barnthouse et al.	Estimating responses of fish populations to toxic contaminants	1987	Review of previously published data
Barrento et al.	Influence of Season and Sex on the Contents of Minerals and Trace Elements in Brown Crab (*Cancer pagurus*, Linnaeus, 1758)	2009	Bioaccumulation: steady state not documented
Barrera-Escorcia and Wong	Lipid Peroxidation and Metallothionein Induction by Chromium and Cadmium in Oyster *Crassostrea virginica* (Gmelin) From Mandinga Lagoon, Veracruz	2010	Bioaccumulation: steady state not documented.
Barrera-Escorcia et al.	Mean Lethal Body Concentration of Cadmium in *Crassostrea virginica* from a Mexican Tropical Coastal Lagoon	2005	Bioaccumulation: steady state not documented
Barrera-Escorcia et al.	Filtration rate, assimilation and assimilation efficiency in *Crassostrea virginica* (Gmelin) fed with *Tetraselmis suecica* under cadmium exposure	2010	Only two exposure concentrations
Bartsch et al.	Effects of cadmium-spiked sediment on cadmium accumulation and bioturbation by nymphs of the burrowing mayfly *Hexagenia bilineata*	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Barwick and Maher	Biotransferance and biomagnification of selenium copper, cadmium, zinc, arsenic and lead in a temperate seagrass ecosystem from Lake Macquarie Estuary, NSW, Australia	2003	Bioaccumulation: steady state not documented
Basha and Rani	Cadmium-induced antioxidant defense mechanism in freshwater teleost *Oreochromis mossambicus* (Tilapia)	2003	Dilution water not characterized, only one exposure concentration, exposure methods unknown
Basic et al.	Cadmium hyperaccumulation and genetic differentiation of *Thlaspi caerulescens* populations	2006	Non-aquatic plant
Batista et al.	Impacts of warming on aquatic decomposers along a gradient of cadmium stress	2012	Dilution water not characterized, unmeasured exposure
Battaglini et al.	The effects of cadmium on the gills of the goldfish *Carassius auratus* L.: metal uptake and histochemical changes	1993	No useable data on cadmium toxicity or bioconcentration
Baudrimont et al.	Bioaccumulation and metallothionein response in the asiatic clam (*Corbicula fluminea*) after experimental exposure to cadmium and inorganic mercury	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Baudrimont et al.	The Key Role of Metallothioneins in the Bivalve *Corbicula fluminea* During the Depuration Phase, After In Situ Exposure to Cd and Zn	2003	Mixture
Baudrimont et al.	Geochemical survey and metal bioaccumulation of three bivalve species (*Crassostrea gigas*, *Cerastoderma edule* and *Ruditapes philippinarum*) in the Nord Medoc salt marshes (Gironde estuary, France)	2005	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Baumann and Fisher	Relating the sediment phase speciation of arsenic, cadmium, and chromium with their bioavailability for the deposit-feeding polychaete *Nereis succinea*	2011a	Mixture
Baumann and Fisher	Modeling metal bioaccumulation in a deposit-feeding polychaete from labile sediment fractions and from pore water	2011b	Dilution water not characterized, mixture, sediment
Baunemann and Hofner	Influence of Cd, Cu, Ni and Zn on the Synthesis of Metalloproteins by *Scenedesmus subspicatus* (Einfluss Von Cd, Cu, Ni and Zn Auf Die Synthese Metallothionein-Ahnlicher Substanzen in Scenedesmus Subspicatus).	1991	Text in foreign language
Bay et al.	Status and applications of echinoid (*Phylum echinodermata*) toxicity test methods	1993	Review of previously published data
Bazzaz and Govindjee	Effects of cadmium nitrate on spectral characteristics and light reactions of chloroplasts	1974	Not applicable
Beattie and Pascoe	Cadmium uptake by rainbow trout, *Salmo gairdneri* eggs and alevins	1978	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Beauvais et al.	Cholinergic and behavioral neurotoxicity of carbaryl and cadmium to larval rainbow trout (*Oncorhynchus mykiss*).	2001	Only two exposure concentrations
Bednarz and Warkowska-Dratnal	Toxicity of zinc, cadmium, lead, copper, and their mixture for *Chlorella pyrenoidosa* Chick	1983/ 1984	Not North American species
Beiras and Albentosa	Inhibition of embryo development of the commercial bivalves *Ruditapes decussatus* and *Mytilus galloprovincialis* by trace metals; implications for the implementation of seawater quality criteria.	2004	Not North American species
Beiras et al.	Effects of storage temperature and duration on toxicity of sediments assessed by *Crassostrea gigas* oyster embryo bioassay	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bektas et al.	Inhibition effect of cadmium on carbonic anhydrase in rainbow trout (*Oncorhynchus mykiss*)	2008	Dietary exposure
Belabed et al.	Toxicity study of some heavy metals with daphnia test	1994	The materials, methods or results were insufficiently described
Beltrame et al.	Cadmium and zinc in Mar Chiquita Coastal Lagoon (Argentina): salinity effects on lethal toxicity in juveniles of the burrowing crab *Chasmagnathus granulatus*	2008	Not North American species
Benaduce et al.	Toxicity of cadmium for silver catfish *Rhamdia quelen* (Heptapteridae) embryos and larvae at different alkalinities	2008	Lack of detail; not North American species
Bendell	Cadmium in Shellfish: the British Columbia, Canada Experience--a Mini-Review	2010	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Bendell and Feng	Spatial and Temporal Variations in Cadmium Concentrations and Burdens in the Pacific Oyster (*Crassostrea gigas*) Sampled From the Pacific North-West. Marine Pollution Bulletin	2009	Bioaccumulation: steady state not documented
Bendell-Young	Comparison of metal concentrations in the fore and hindguts of the crayfish *Cambarus bartoni* and *Orconectes virilis* and implications regarding metal absorption efficiencies	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bendell-Young	Application of a kinetic model of bioaccumulation across a pH and salinity gradient for the prediction of cadmium uptake by the sediment dwelling chironomidae	1999	The materials, methods or results were insufficiently described
Bendell-Young et al.	Accumulation of cadmium by white suckers (*Catostomus commersoni*) in relation to fish growth and lake acidification	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bender	Trace Metal Levels In Beach Dipterans And Amphipods	1975	Bioaccumulation: steady state not documented
Bennett et al.	Pilot Sampling For Heavy Metals In Fish Flesh From Killarney Lake, Coeur D'alene River System, Idaho	1996	Bioaccumulation: steady state not documented
Bentley	Accumulation of cadmium by channel catfish (*Ictalurus punctatus*): Influx from environmental solutions	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bere and Tundisi	Toxicity and sorption kinetics of dissolved cadmium and chromium III on tropical freshwater phytoperiphyton in laboratory mesocosm experiments	2011	Only two exposure concentrations
Bere and Tundisi	Cadmium and lead toxicity on tropical freshwater periphyton communities under laboratory-based mesocosm experiments	2012a	Mixture, Mixed species exposure
Bere and Tundisi	Effects of cadmium stress and sorption kinetics on tropical freshwater periphytic communities in indoor mesocosm experiments	2012b	Dilution water not characterized
Berglind	The effects of cadmium on ala-d activity, growth and haemoglobin content in the water flea, *Daphnia magna*	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Berglind	Combined and separate effects of cadmium, lead and zinc on ala-d activity, growth and hemoglobin content in *Daphnia magna*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bernds	Bioaccumulation of trace metals in polychaetes from the German Wadden Sea: evaluation and verification of toxicokinetic models	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Berntssen and Lundebye	Energetics in Atlantic Salmon (*Salmo salar* L.) Parr fed Elevated Dietary exposure Cadmium	2001	Dietary exposure

Authors	Title	Year	Reason Unused
Berntssen et al.	Tissue Metallothionein, Apoptosis and Cell Proliferation Responses in Atlantic Salmon (*Salmo salar* L.) Parr Fed Elevated Dietary exposure Cadmium	2001	Dietary exposure
Berntssen et al.	Effects of dietary exposure cadmium on calcium homeostasis, Ca mobilization and bone deformities in Atlantic salmon (*Salmo salar* L.) Parr	2003	Dietary exposure
Bervoets et al.	The uptake of cadmium by the midge larvae *Chironomus riparius* as a function of salinity	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bervoets et al.	Effect of temperature on cadmium and zinc uptake by the midge larvae *Chironomus riparius*	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bervoets et al.	Accumulation of Metals in the Tissues of Three Spined Stickelback (*Gasterosteus aculeatus*) From Natural Fresh Waters	2001	Bioaccumulation: steady state not documented
Bervoets et al.	Comparison of Accumulation of Micropollutants Between Indigenous and Transplanted Zebra Mussels (*Dreissena polymorpha*)	2004	Non-applicable
Besser and Rabeni	Bioavailability and toxicity of metals leached from lead-mine tailings to aquatic invertebrates	1987	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Besser et al.	Bioavailability of Metals in Stream Food Webs and Hazards to Brook Trout (*Salvelinus fontinalis*) in the Upper Animas River Watershed, Colorado	2001	Bioaccumulation: steady state not documented
Besser et al.	Ecological Impacts of Lead Mining on Ozark Streams: Toxicity of Sediment and Pore Water	2009	Mixture
Besson et al.	NO contributes to cadmium toxicity in *Arabidopsis thaliana*	2007	Mixture
Besson-Bard and Wendehenne	NO Contributes to Cadmium Toxicity in *Arabidopsis thaliana* by Mediating an Iron Deprivation Response	2009	Mixture
Besson-Bard et al.	Nitric Oxide Contributes to Cadmium Toxicity in Arabidopsis by Promoting Cadmium Accumulation in Roots and by up-Regulating Genes Related to Iron Uptake	2009	Mixture
Beyrem et al.	Individual and combined effects of cadmium and diesel on a nematode community in a laboratory microcosm experiment	2007	Sediment exposure
Bhamre et al.	Effects of cadmium intoxication on the gills of freshwater mussel *Parreysia favidens*	2010	Only one exposure concentration
Bhamre and Desai	Impact of heavy metal compounds on oxygen consumption of freshwater mussel *Lamellidens consobrinus* (Lea)	2012	Only one exposure concentration

Authors	**Title**	**Year**	**Reason Unused**
Bhattacharya et al.	Heavy Metals Accumulation in Water, Sediment exposure and Tissues of Different Edible Fishes in Upper Stretch of Gangetic West Bengal	2008	Bioaccumulation: steady state not documented
Bhilave et al.	Biochemical changes in the fish cirrhinus mrigala after acute and chronic exposure of heavy metals	2008	Dilution water not characterized, lack of exposure details, not North American species
Bicho et al.	Accumulation in Livers and Excretion Through Eggs of Heavy Metals in a Nesting Population of Green Turtles, *Chelonia mydas*, in the NW Indian Ocean	2008	Bioaccumulation: steady state not documented
Biddinger and Gloss	The Importance of Trophic Transfer in the Bioaccumulation of Chemical Contaminants in Aquatic Ecosystems	1984	Review
Biesinger et al.	Effects of metal salt mixtures on *Daphnia magna* reproduction	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bigelow and Lasenby	Particle size selection in cadmium uptake by the opossum shrimp, *Mysis relicta*	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bigot et al.	Early defense responses in the freshwater bivalve *Corbicula fluminea* exposed to copper and cadmium: Transcriptional and histochemical studies	2011	Only three exposure concentrations, dilution water not characterized
Billoir et al.	Integrating the lethal and sublethal effects of toxic compounds into the population dynamics of *Daphnia magna*: a combination of the DEBtox and matrix population models	2007	No original data; modeling
Billoir et al.	Bayesian modeling of daphnid responses to time-varying cadmium exposure in laboratory aquatic microcosms	2011	Mixed species exposure
Billoir et al.	Comparison of bioassays with different exposure time patterns: the added value of dynamic modeling in predictive ecotoxicology	2012	Mixed species exposure
Bird et al.	To What Extent Are Hepatic Concentrations of Heavy Metals in *Anguilla anguilla* at a Site in a Contaminated Estuary Related to Body Size and Age and Reflected in the Metallothionein Concentrations?	2008	Bioaccumulation: steady state not documented
Birge and Black	In Situ Acute/Chronic Toxicological Monitoring of Industrial Effluents for the NPDES Biomonitoring Program Using Fish and Amphibian Embryo-Larval Stages as Test Organisms	1981	Effluent
Birmelin et al.	The mysid *Siriella armata* as a test organisms in toxicology: effects of cadmium	1995	Not North American species
Bisova et al.	Cell growth and division processes are differentially sensitive to cadmium in *Scenedesmus quadricauda*	2003	Excessive EDTA in growth media (18,000 ug/L), duration too short
Biswas and Kaviraj	Size dependent tolerance of indian cat fish *Heteropneustes fossilis* (Bloch) to toxicity of cadmium and composted vegetation	2002	Dilution water not characterized, not North American species
Bitton et al.	Evaluation of a microplate assay specific for heavy metal toxicity	1994	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Bitton et al.	Short-term toxicity assay based on daphnid feeding behavior	1995	The materials, methods or results were insufficiently described
Bjerregaard	Accumulation of cadmium and selenium and their mutual interaction in the shore crab *Carcinus maenas*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bjerregaard	Effect of selenium on cadmium uptake in the shore crab *Carcinus maenas* (L.)	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bjerregaard	Relationship between physiological condition and cadmium accumulation in *Carcinus maenas* (L.)	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Bjerregaard and Depledge	Cadmium accumulation in *Littorina littorea*, *Mytilus edulis* and *Carcinus maenas*: the influence of salinity and calcium ion concentrations	1994	The materials, methods or results were insufficiently described
Bjerregaard and Depledge	Trace metal concentrations and contents in the tissues of the shore crab *Carcinus maenas*: effects of size and tissue hydration	2002	Bioaccumulation: steady state not documented
Bjerregaard et al.	Cadmium in the Shore Crab *Carcinus maenas*: Seasonal Variation in Cadmium Content and Uptake and Elimination of Cadmium After Administration via Food	2005	Bioaccumulation: steady state not documented
Blackmore and Wang	Uptake and Efflux of Cd and Zn by the Green Mussel *Perna viridis* After Metal Preexposure	2002	Mixture
Blinova	Use of freshwater algae and duckweeds for phytotoxicity testing	2004	Review
Block and Glynn	Influence of xanthates on the uptake of ^{109}Cd by Eurasian dace (*Phoxinus phoxinus*) and rainbow trout (*Oncorhynchus mykiss*)	1992	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Block and Part	Uptake of ^{109}Cd by cultured gill epithelial cells from rainbow trout (*Oncorhynchus mykiss*)	1992	No interpretable concentration, time, response data or examined only a single exposure concentration
Block et al.	Xanthate effects on cadmium uptake and intracellular distribution in rainbow trout (*Oncorhynchus mykiss*) gills	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Blondin et al.	An in vitro submitochondrial bioassay for predicting acute toxicity in fish	1989	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Bocchetti et al.	Trace Metal Concentrations and Susceptibility to Oxidative Stress in the Polychaete *Sabella spallanzanii* (Gmelin) (Sabellidae): Potential Role of Antioxidants in Revealing Stressful Environmental Conditions in the Mediterranean	2004	Bioaccumulation: steady state not documented
Bochenek et al.	Concentrations of Cd, Pb, Zn, and Cu in Roach, *Rutilus rutilis* (L.) From the Lower Reaches of the Oder River, and Their Correlation With Concentrations of Heavy Metals in Bottom Sediment exposures Collected in the Same Area	2008	Bioaccumulation: steady state not documented
Bodar et al.	Effects of cadmium on consumption, assimilation and biochemical parameters of *Daphnia magna*: possible implications for reproduction	1988a	Organisms were exposed to cadmium in food or by injection or gavage
Bodar et al.	Ecdysteroids in *Daphnia magna*: their role in moulting and reproduction and their levels upon exposure to cadmium	1990a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bodar et al.	Cadmium resistance in *Daphnia magna*	1990b	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Bohn and Mcelroy	Trace metals arsenic cadmium copper iron and zinc in arctic cod *Boreogadus saida* and selected zoo plankton from Strathcona Sound Northern Baffin Island	1976	Bioaccumulation: steady state not documented
Boisson et al.	Comparative radiotracer study of cadmium uptake, storage, detoxification and depuration in the oyster *Crassostrea gigas*: potential adaptive mechanisms	2003	Bioaccumulation: steady state not documented (only 15 day exposure)
Bolanos et al.	Differential toxicological response to cadmium in *Anabaena* strain PCC 7119 grown with NO_3^- or NH_4^+ as nitrogen source	1992	The materials, methods or results were insufficiently described
Bonneris et al.	Sub-cellular Partitioning of Cd, Cu and Zn in Tissues of Indigenous Unionid Bivalves Living Along a Metal Exposure Gradient and Links to Metal-Induced Effects	2005	Bioaccumulation: steady state not documented
Borane et al.	Ascorbate effect on the cadmium induced alterations in the behavior of the fresh water fish *Channa orientalis* (Schneider)	2008	Only one exposure concentration, not North American species
Borchardt	Influence of food quantity on the kinetics of cadmium uptake and loss via food and seawater in *Mytilus edulis*	1983	No useable data on cadmium toxicity or bioconcentration
Borchardt	Biological monitoring in the central and southern north sea heavy metal contamination of mussels *Mytilus edulis*	1988	Bioaccumulation: steady state not documented
Borcherding and Wolf	The influence of suspended particles on the acute toxicity of 2-chloro-4-nitro-aniline, cadmium, and pentachlorophenol on the valve movement response of the zebra mussel (*Dreissena polymorpha*)	2001	Only one exposure concentration, duration too short, concentration decreased over time
Bordajandi et al.	Study on PCBs, PCDD/Fs, organochlorine pesticides, heavy metals and arsenic content in freshwater fish species from the River Turia (Spain)	2003	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Borgmann et al.	Relative Contribution of Food and Water to 27 Metals and Metalloids Accumulated by Caged *Hyalella azteca* in Two Rivers Affected by Metal Mining	2007	Mixture
Boscher et al.	Chemical contaminants in fish species from rivers in the North of Luxembourg: Potential impact on the Eurasian otter (*Lutra lutra*)	2010	Bioaccumulation: steady state not documented
Bouallam and Nejmeddine	Effects of Heavy Metals - Cu, Hg, Cd - on Three Species of Mosquitoes Larvae (Diptera: Culicidae)	2001	Mixture
Boughammoura et al.	Effects of cadmium and high temperature on some parameters of calcium metabolism in the killifish (*Aphanius fasciatus*)	2013	Only one exposure concentration; not North American species
Boullemant et al.	Uptake of lipophilic cadmium complexes by three green algae: influence of humic acid and its pH dependence	2011	Bioaccumulation: steady state not achieved (only 40 minute exposure)
Bouquegneau and Martoja	La teneur en cuivre et son degre de complexation chez quatre gasteropodes marins. Donnees sur le cadmium et zinc	1982	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Bouraoui et al.	Acute effects of cadmium on liver phase I and phase II enzymes and metallothionein accumulation on sea bream *Sparus aurata*	2008	Injected toxicant, not North American species
Bourgeault et al.	Modeling the effect of water chemistry on the bioaccumulation of waterborne cadmium in zebra mussels	2010	Bioaccumulation: steady state not achieved
Bourret et al.	Evolutionary Ecotoxicology of Wild Yellow Perch (*Perca flavescens*) Populations Chronically Exposed to a Polymetallic Gradient	2008	Mixture
Bovee	Effects of certain chemical pollutants on small aquatic plants	1975	Lack of exposure details; cannot determine effect concentration
Bowen and Engel	Effects of protracted cadmium exposure on gametes of the purple sea urchin, *Arbacia punctulata*	1996	No interpretable concentration, time, response data or examined only a single exposure concentration
Bowmer et al.	The Detection of Chronic Biological Effects in the Marine Intertidal Bivalve *Cerastoderma edule*, in Model Ecosystem Studies With Pulverised Fuel Ash: Reproduction and Histopathology	1994	Mixture
Boyden	Effect of size upon metal content of shellfish	1977	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Boyer	Trace Elements In The Water Sediment exposures And Fish Of The Upper Mississippi River Twin Cities Metropolitan Area USA	1984	Bioaccumulation: steady state not documented
Boyle et al.	Natural Arsenic Contaminated Diets Perturb Reproduction in Fish	2008	Dietary exposure
Bozcaarmutlu and Arinc	Effect of Mercury, Cadmium, Nickel, Chromium and Zinc on Kinetic Properties of NADPH-Cytochrome P450 Reductase Purified From Leaping Mullet (*Liza saliens*)	2007	Mixture

Authors	Title	Year	Reason Unused
Bradac et al.	Kinetics of cadmium accumulation in periphyton under freshwater conditions	2009	Mixed species exposure
Bradac et al.	Cadmium Speciation and Accumulation in Periphyton in a Small Stream With Dynamic Concentration Variations	2010	Bioaccumulation: steady state not documented
Brand et al.	Reduction of marine phytoplankton reproduction rates by copper and cadmium.	1986	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Brandao et al.	Correlation between the in vitro cytotoxicity to cultured fathead minnow fish cells and fish lethality data for 50 chemicals	1992	Not applicable per ECOTOX Duluth; in vitro
Brauwers	Algae and Heavy Metal Pollution	1985	Review
Bresler and Yanko	Acute toxicity of heavy metals for benthic epiphytic foraminifera *Pararotalia spinigera* (Le Calvez) and influence of seaweed-derived DOC	1995	Not North American species
Bressan and Brunetti	The effects of nitriloacetic acid, Cd and Hg on the marine algae *Dunaliella tertiolecta* and *Isochrysis galbana*	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Bringmann and Kuhn	Results of toxic action of water pollutants on *Daphnia magna* Straus tested by an improved standardized procedure	1982	Cultured daphnids in one dilution water and tested them in another one
Brinke et al.	Using Meiofauna to Assess Pollutants in Freshwater Sediments: a Microcosm Study With Cadmium	2011	Sediment
Brinkhurst et al.	Comparative study of respiration rates of some aquatic oligochaetes in relation to sublethal stress	1983	Only two exposure concentrations
Brinkman and Vieira	Water pollution studies	2008	Scientific name not given, just common name
Brinza et al.	Cadmium Tolerance and Adsorption by the Marine Brown Alga *Fucus vesiculosus* From the Irish Sea and the Bothnian Sea	2009	Bioaccumulation: steady state not documented
Brix et al.	Effects of Copper, Cadmium, and Zinc on the Hatching Success of Brine Shrimp (*Artemia franciscana*)	2006	Mixture
Brix et al.	The Sensitivity of Aquatic Insects to Divalent Metals: a Comparative Analysis of Laboratory and Field Data	2011	Review
Brkovic-Popovic and Popovic	Effects of heavy metals on survival and respiration rate of tubificid worms: Part I-effects on survival	1977a	The dilution water or medium used was open to questions because of its origin or content
Brkovic-Popovic and Popovic	Effects of heavy metals on survival and respiration rate of tubificid worms: Part II-effects on respiration rate	1977b	The dilution water or medium used was open to questions because of its origin or content
Brooks et al.	Sublethal Effects and Predator-Prey Interactions: Implications for Ecological Risk Assessment	2009	Multiple species exposed
Brooks et al.	A simple indoor artificial stream system designed to study the effects of toxicant pulses on aquatic organisms	1996	Not North American species
Brouwer et al.	In vivo magnetic resonance imaging of the blue crab, *Callinectes sapidus*: effect of cadmium accumulation in tissues on proton relaxation properties	1992	Organisms were exposed to cadmium in food or by injection or gavage
Brown	Effects of Polluting Substances on Enzymes of Aquatic Organisms	1976	In vitro

Authors	Title	Year	Reason Unused
Brown and Ahsanullah	Effect of heavy metals on mortality and growth	1971	Brine shrimp
Brown et al.	A comparison of the differential accumulation of cadmium in the tissues of three species of freshwater fish, *Salmo Gairdneri*, *Rutilus rutilus* and *Noemacheilus barbatulus*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Brucka-Jastrzebska and Protasowicki	Elimination Dynamics of Cadmium, Administered by a Single Intraperitoneal Injection, in Common Carp, *Cyprinus carpio* L	2004	In vitro
Brumbaugh et al.	Concentrations of cadmium, lead, and zinc in fish from mining-influenced waters of northeastern Oklahoma: sampling of blood, carcass, and liver for aquatic biomonitoring	2005	Bioaccumulation: steady state not documented
Brunelli et al.	Ultrastructural and immunohistochemical investigation on the gills of the teleost, *Thalassoma pavo* L., exposed to cadmium	2011	Not North American species
Brunetti et al.	Effects of the chelating agent nitrilotriacetic acid (NTA) on the toxicity of metals (Cd, Cu, Zn and Pb) in the sea urchin *Paracentrotus lividus* LMK	1991	Not North American species
Brunham and Bendell	The effect of temperature on the accumulation of cadmium, copper, zinc, and lead by *Scirpus acutus* and *Typha latifolia*: a comparative analysis	2011	Sediment exposure
Bryan	The effects of heavy metals (other than mercury) on marine and estuarine organisms	1971	Questionable treatment of test organisms or inappropriate test conditions or methodology
Bryan and Langston	Bioavailability, Accumulation and Effects of Heavy Metals in Sediments With Special Reference to United Kingdom Estuaries: a Review.	1992	Review
Bryan et al.	An assessment of the gastropod, *Littorina littorea*, as an indicator of heavy metal contamination in United Kingdom estuaries	1983	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Bryson et al.	Roxboro Steam Electric Plant Preliminary Hyco Bioassay Report for 1983	1984a	Effluent
Bryson et al.	Roxboro Steam Electric Plant 1982 Environmental Monitoring Studies Volume II Hyco Reservoir Bioassay Studies	1984b	Mixture
Buchwalter et al.	Using Biodynamic Models to Reconcile Differences Between Laboratory Toxicity Tests and Field Biomonitoring With Aquatic Insects	2007	Modeling
Buckley et al.	Toxicities of total and chelex-labile cadmium to salmon in solutions of natural water and diluted sewage with potentially different cadmium complexing capacities	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Budambula and Mwachiro	Metal Status of Nairobi River Waters and Their Bioaccumulation in *Labeo cylindricus*	2006	Bioaccumulation: steady state not documented
Buikema et al.	Rotifer sensitivity to combinations of inorganic water pollutants	1977	The 96 hour values reported were subject to error because of possible reproductive interactions
Buikema et al.	Rotifers as monitors of heavy metal pollution in water	1974a	The 96 hour values reported were subject to error because of possible reproductive interactions

Authors	Title	Year	Reason Unused
Buikema et al.	Evaluation of *Philodina acuticornis* (Rotifera) as a bioassay organism for heavy metals	1974b	The 96 hour values reported were subject to error because of possible reproductive interactions
Bulus Rossini and Ronco	Sensitivity of *Cichlasoma facetum* (Cichlidae, Pisces) to metals	2004	Not North American species
Bunluesin et al.	Influences of Cadmium and Zinc Interaction and Humic Acid on Metal Accumulation in *Ceratophyllum demersum*	2007	Mixture
Bu-Olayan and Thomas	Trace metals toxicity and bioaccumulation in mudskipper *Periophthalmus waltoni* Koumans 1941 (Gobiidae: Perciformes)	2008	Dilution water not characterized, not North American species
Bu-Olayan et al.	Trace metals toxicity to the body structures of mullet *Liza klunzingeri* (Mugilidae: Perciformes)	2008	Mixture, dilution water not characterized
Burdin and Bird	Heavy metal accumulation by carrageenan and agar producing algae	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Burger	Assessment and Management of Risk to Wildlife From Cadmium	2008	Review
Burger and Campbell	Species differences in contaminants in fish on and adjacent to the Oak Ridge Reservation, Tennessee	2004	Bioaccumulation: steady state not documented
Burger and Gochfeld	Heavy metals in commercial fish in New Jersey	2005	Bioaccumulation: steady state not documented
Burger et al.	Exposure Assessment for Heavy Metal Ingestion From a Sport Fish in Puerto Rico: Estimating Risk for Local Fishermen.	1992	Bioaccumulation: steady state not documented
Burger et al.	Metal Levels in Fish from the Savannah River: Potential Hazards to Fish and Other Receptors	2002a	Bioaccumulation: steady state not documented
Burger et al.	Metal levels in horseshoe crabs (*Limulus polyphemus*) from Maine to Florida	2002b	Bioaccumulation: steady state not documented
Burger et al.	Metal levels in tissues of Florida gar (*Lepisosteus platyrhincus*) from Lake Okeechobee	2004	Bioaccumulation: steady state not documented
Burger et al.	Metal Levels in Blood, Muscle and Liver of Water Snakes (*Nerodia spp.*) from New Jersey, Tennessee and South Carolina	2007a	Bioaccumulation: steady state not documented
Burger et al.	Metal Levels in Flathead Sole (*Hippoglossoides elassodon*) and Great Sculpin (*Myoxocephalus polyacanthocephalus*) From Adak Island, Alaska: Potential Risk to Predators and Fishermen	2007b	Bioaccumulation: steady state not documented
Burger et al.	Heavy Metals in Pacific Cod (*Gadus macrocephalus*) From the Aleutians: Location, Age, Size, and Risk	2007c	Bioaccumulation: steady state not documented
Burgos and Rainbow	Availability of Cadmium and Zinc from Sewage Sludge to the Flounder, *Platichthys flesus*, via a Marine Food Chain	2001	Sludge
Burnison et al.	Toxicity of cadmium to freshwater algae	1975	The materials, methods or results were insufficiently described
Burnison et al.	Cadmium accumulation in zebrafish (*Danio rerio*) eggs in modulated by dissolved organic matter (DOM)	2006	Bioaccumulation: steady state not documented (only 5 hour exposure)

Authors	**Title**	**Year**	**Reason Unused**
Burrell and Weihs	Uptake of cadmium by marine bacteria and transfer to a deposit feeding clam	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Burt et al.	The Accumulation of Zn, Se, Cd, and Pb and Physiological Condition of *Anadara trapezia* Transplanted to a Contamination Gradient in Lake Macquarie, New South Wales, Australia	2007	Bioaccumulation: steady state not documented
Burton and Pinkney	Yellow Perch Larval Survival in the Zekiah Swamp Watershed (Wicomico River, Maryland) Relative to the Potential Effects of a Coal Ash Storage Facility	1994	Effluent
Busch et al.	Effects of changing salt concentrations and other physical-chemical parameters on bioavailability and bioaccumulation of heavy metals in exposed *Dreissena polymorpha* (Pallas, 1771)	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Bustamante et al.	Biokinetics of zinc and cadmium accumulation and depuration at different stages in the life cycle of the cuttlefish *Sepia officinalis*	2002	Mixture; not North American species
Bustamante et al.	Distribution of trace elements in the tissues of benthic and pelagic fish from the Kerguelen Islands	2003	Bioaccumulation: steady state not documented
Byzitter et al.	Acute Combined Exposure to Heavy Metals (Zn, Cd) blocks memory formation in a freshwater snail.	2012	Only one exposure concentration, duration too short
Cadena-Cardenas et al.	Heavy Metal Levels in Marine Mollusks From Areas With, or Without, Mining Activities Along the Gulf of California, Mexico	2009	Bioaccumulation: steady state not documented
Cain et al.	Linking metal bioaccumulation of aquatic insects to their distribution patterns in a mining-impacted river	2004	Bioaccumulation: steady state not documented
Cain et al.	Influence of metal exposure history on the bioaccumulation and subcellular distribution of aqueous cadmium in the insect *Hydropsyche californica*	2006	Bioaccumulation: steady state not documented (only 6 day exposure)
Cain et al.	Bioaccumulation dynamics and exposure routes of Cd and Cu among species of aquatic mayflies	2011	Bioaccumulation: steady state not documented, not renewal or flow-through
Cairns et al.	The effects of temperature upon the toxicity of chemicals to aquatic organisms	1975	Not applicable per ECOTOX Duluth; review
Cairns et al.	A simple, cost-effective multispecies toxicity test using organisms with a cosmopolitan distribution	1986	Review of previously published data
Calabro et al.	Survey on the Presence of Heavy Metals in *Patella caerulea* Specimens Collected Along Coastlines in Messina Province (Italy)	2006	Bioaccumulation: steady state not documented
Calevro et al.	Tests of toxicity and teratogenicity in biphasic vertebrates treated with heavy metals (Cr^{3+}, Al^{3+}, Cd^{2+})	1998a	Not North American species
Calevro et al.	Toxic effects of aluminum, chromium and cadmium in intact and regenerating freshwater planarians	1998b	The materials, methods or results were insufficiently described

Authors	**Title**	**Year**	**Reason Unused**
Caliceti et al.	Heavy metal contamination in the seaweeds of the Venice Lagoon	2002	Bioaccumulation: steady state not documented
Call et al.	Variation of acute toxicity with water source	1983	Report appears to be missing data tables and LC50 values
Cambier et al.	Cadmium-induced genotoxicity in zebrafish at environmentally relevant doses	2010	Only two exposure concentrations
Campbell and Evans	Cadmium concentrations in the freshwater mussel (*Elliptio complanata*) and their relationship to water chemistry	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Campbell et al.	Cadmium-Handling Strategies in Two Chronically Exposed Indigenous Freshwater Organisms-The Yellow Perch (*Perca flavescens*) and the Floater Mollusc (*Pyganodon grandis*)	2005	Non-applicable
Campos	Heavy Metal Concentrations In Some Oyster Species Of The Caribbean Coast Of Columbia	1985	Bioaccumulation: steady state not documented
Camusso et al.	Bioconcentration of trace metals in rainbow trout: a field study	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Canli and Furness	Toxicity of heavy metals dissolved in sea water and influences of sex and size on metal accumulation and tissue distribution in the Norway lobster *Nephrops norvegicus*	1993	Not North American species
Canli and Furness	Mercury and cadmium uptake from seawater and from food by the Norway lobster *Nephrops norvegicus*	1995	Not North American species
Canli and Kargin	A Comparative Study on Heavy Metal (Cd, Cr, Pb and Ni) Accumulation in the Tissue of the Carp *Cyprinus carpio* and the Nile Fish *Tilapia nilotica*	1995	Mixture
Canli et al.	The induction of metallothionein in tissues of the Norway lobster *Nephrops norvegicus* following exposure to cadmium, copper and zinc: the relationships between metallothionein and the metals	1997	Mixture
Canli et al.	Metal (Cd, Pb, Cu, Zn, Fe, Cr, Ni) Concentrations in Tissues of a Fish *Sardina pilchardus* and a Prawn *Penaeus japonicus* from Three Stations on the Mediterranean Sea	2001	Bioaccumulation: steady state not documented
Cannicci et al.	Effects of Urban Wastewater on Crab and Mollusc Assemblages in Equatorial and Subtropical Mangroves of East Africa	2009	Mixture
Canton and Slooff	A proposal to classify compounds and to establish water quality based on laboratory data	1979	The materials, methods or results were insufficiently described
Cao et al.	Cadmium toxicity to embryonic-larval development and survival in red sea bream *Pagrus major*	2009	Not North American species
Cao et al.	Accumulation and oxidative stress biomarkers in japanese flounder larvae and juveniles under chronic cadmium exposure	2010	Not North American species, usually Unused data
Cao et al.	Tissue-specific accumulation of cadmium and its effects on antioxidative responses in japanese flounder juveniles	2012	Not North American species, lack of exposure details

Authors	Title	Year	Reason Unused
Capelli et al.	Distribution of Trace Elements in Organs of Six Species of Cetaceans From the Ligurian Sea (Mediterranean), and the Relationship With Stable Carbon and Nitrogen Ratios	2008	Bioaccumulation: steady state not documented
Caplat et al.	Comparative toxicities of aluminum and zinc from sacrificial anodes or from sulfate salt in sea urchin embryos and sperm	2010	Not applicable, not cadmium toxicity information
Carattino et al.	Effects of Long-Term Exposure to Cu2+ and Cd2+ on the Pentose Phosphate Pathway Dehydrogenase Activities in the Ovary of Adult *Bufo arenarum*: Possible Role as Biomarker for Cu2+ Toxicity	2004	Mixture
Cardwell et al.	Metal accumulation in aquatic macrophytes from southeast Queensland, Australia	2002	Bioaccumulation: steady state not documented
Carline et al.	Long-Term Effects of Treated Domestic Wastewater on Brown Trout	1987	Effluent
Carlisle and Clements	Sensitivity and variability of metrics used in biological assessments of running waters	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Carmichael and Fowler	Cadmium accumulation and toxicity in the kidney of the bay scallop *Argopecten irradians*	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Carpene and Boni	Effects of heavy metals on the algae *Nitzschia closterium* and *Prorocentrum micans*	1992	The materials, methods or results were insufficiently described
Carpene et al.	Cadmium-binding proteins from the mantle of *Mytilus edulis* (L.) after exposure to cadmium	1980	Exposure concentration not measured
Carr and Neff	Biochemical indices of stress in the sandworm *Neanthes virens* (Sars). II. sublethal responses to cadmium	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured, No pertinent adverse effects reported
Carranza-Alvarez et al.	Accumulation and Distribution of Heavy Metals in *Scirpus americanus* and *Typha latifolia* from an Artificial Lagoon in San Luis Potosi, Mexico	2008	Bioaccumulation: steady state not documented
Carriquiriborde and Ronco	Sensitivity of the neotropical teleost *Odonthestes bonariensis* (Pisces, Atherinidae) to chromium(VI), copper(II), and cadmium(II)	2002	Not North American species, duration too short, test species fed
Carriquiriborde and Ronco	Distinctive Accumulation Patterns of Cd(II), Cu(II), and Cr(VI) in Tissue of the South American Teleost, Pejerrey (*Odontesthes bonariensis*)	2008	Bioaccumulation: steady state not documented
Carroll et al.	Influences of hardness constituents on the acute toxicity of cadmium to brook trout (*Salvelinus fontinalis*)	1979	Authors noted that the Cd measured conc in the control water was greater than the LC50 value of 1.5 ug/L and had 100% survival
Casado-Martinez et al.	Biodynamic Modeling and the Prediction of Accumulated Trace Metal Concentrations in the Polychaete *Arenicola marina*	2009	Modeling
Casas et al.	Relation between metal concentration in water and metal content of marine mussels (*Mytilus galloprovincialis*): impact of physiology	2008	Bioaccumulation: steady state not documented; not North American species

Authors	**Title**	**Year**	**Reason Unused**
Casini and Depledge	Influence of copper, zinc, and iron on cadmium accumulation in the Talitrid amphipod, *Platorchestia platensis*	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Casiot et al.	Hydrological and Geochemical Control of Metals and Arsenic in a Mediterranean River Contaminated by Acid Mine Drainage (the Amous River, France) Preliminary Assessment of Impacts on Fish (*Leuciscus cephalus*)	2009	Mixture
Cassini et al.	Cadmium bioaccumulation studies in the freshwater molluscs *Anodonta cygnea* and *Unio elongatulus*	1986	Not North American species
Cassis et al.	The Role of Phytoplankton in the Modulation of Dissolved and Oyster Cadmium Concentrations in Deep Bay, British Columbia, Canada	2011	Bioaccumulation: steady state not documented
Castano et al.	Correlations between the RTG-2 cytotoxicity test EC50 and *in vivo* LC50 rainbow trout bioassay	1996	No interpretable concentration, time, response data or examined only a single exposure concentration
Castille and Lawrence	The effects of EDTA (ethylenedinitrotetraacetic acid) on the survival and development of shrimp nauplii (*Penaeus stylirostris* Stimpson) and the interactions of EDTA and the toxicities of cadmium, calcium, and phenol	1981	Not North American species
Cavas et al.	Induction of micronuclei and binuclei in blood, gill and liver cells of fishes subchronically exposed to cadmium chloride and copper sulphate	2005	Mixture
Cearley and Coleman	Cadmium toxicity and accumulation in southern naiad	1973	The dilution water or medium used was open to questions because of its origin or content
Cearley and Coleman	Cadmium toxicity and bioconcentration in largemouth bass and bluegill	1974	The dilution water or medium used was open to questions because of its origin or content
Cebrian and Uriz	Contrasting effects of heavy metals and hydrocarbons on larval settlement and juvenile survival in sponges	2007	Not North American species, only one exposure concentration, duration too short
Celik et al.	Determination of the lead and cadmium burden in some northeastern Atlantic and Mediterranean fish species by DPSAV	2004	Bioaccumulation: steady state not documented
Cesar et al.	Sensitivity of mediterranean amphipods and sea urchins to reference toxicants	2002	Not North American species, duration too short
Cevik et al.	Assessment of Metal Element Concentrations in Mussel (*M. galloprovincialis*) in Eastern Black Sea, Turkey	2008	Bioaccumulation: steady state not documented
Chadwick Ecological Consultants	U.S. EPA Cadmium water quality criteria document-technical review and criteria update	2004b	Review
Chadwick Ecological Consultants	Addendum to U.S. EPA Cadmium water quality criteria document-technical review and criteria update	2004c	Review
Chaharlang et al.	Assessment of Cadmium, Copper, Lead and Zinc Contamination Using Oysters (*Saccostrea cucullata*) as Biomonitors on the Coast of the Persian Gulf, Iran	2012	Bioaccumulation: steady state not documented
Chan and Cheng	Cadmium-induced ectopic apoptosis in zebrafish embryos	2003	Lack of details

Authors	Title	Year	Reason Unused
Chan et al.	Effects of polyethylene glycol on growth and cadmium accumulation of *Chlorella salina* CU-1	1981	Questionable treatment of test organisms or inappropriate test conditions or methodology
Chan et al.	Uptake of zinc and cadmium by two populations of shore crabs *Carcinus maenas* at different salinities	1992	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chan et al.	The Uptake of Cd, Cr, and Zn by the Macroalga *Enteromorpha crinita* and Subsequent Transfer to the Marine Herbivorous Rabbitfish, *Siganus canaliculatus*	2003	Bioaccumulation: steady state not documented
Chander et al.	Response of *Pithophora oedogonia* to cadmium	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chandini	Changes in food (*Chlorella*) levels and the acute toxicity of cadmium to *Daphnia carinata* (daphnidae) and *Echinisca triserialis* (macrothricidae) (Crustacea: cladocera)	1988a	Not North American species, dilution water not characterized
Chandini	Effects of different food (*Chlorell*a) concentrations on the chronic toxicity of cadmium to survivorship, growth and reproduction of *Echinisca triserialis* (crustacea: cladocera)	1988b	Not North American species
Chandini	Survival, growth and reproduction of *Daphnia carinata* (crustacea: cladocera) exposed to chronic cadmium stress at different food (*Chlorella*) levels	1989	Not North American species
Chandini	Reproductive value and the cost of reproduction in *Daphnia carinata* and *Echinisca triserialis* (crustacea: cladocera) exposed to food and cadmium stress	1991	Not North American species
Chandra and Garg	Absorption and toxicity of chromium and cadmium in *Limnanthemum cristatum* Griseb	1992	Not North American species
Chandra and Khuda-Bukhsh	Genotoxic effects of cadmium chloride and azadirachtin treated singly and in combination in fish	2004	Injected pollutant
Chandrudu and Radhakrishnaiah	Effect of cadmium on the histology of hepatopancreas and foot of the freshwater mussels *Lamellidens marginalis* (Lam.)	2008	Lack of detail, not North American species
Chandrudu et al.	Effect of subacute concentration of cadmium on the energetics of freshwater mussel *Lamellidens marginalis* (Lam.) and fish *Labeo rohita* (Ham.)	2007	Only one exposure concentration, not North American species
Chandurvelan et al.	Impairment of green-lipped mussel (*Perna canaliculus*) physiology by waterborne cadmium: relationship to tissue bioaccumulation and effect of exposure duration	2012	Not North American species
Chandurvelan et al.	Waterborne cadmium impacts immunocytotoxic and cytogenotoxic endpoints in green-lipped mussel, *Perna canaliculus*	2013a	Not North American species; only two exposure concentrations

Authors	**Title**	**Year**	**Reason Unused**
Chandurvelan et al.	Biochemical biomarker responses of green-lipped mussel, *Perna canaliculus*, to acute and subchronic waterborne cadmium toxicity	2013b	Not North American species; only two exposure concentrations
Chang et al.	Element concentrations in shell of *Pinctada margaritifera* from French Polynesia and evaluation for using as a food supplement	2007	Field bioaccumulation: steady state not documented, exposure concentration unknown
Chang et al.	Effects of cadmium on respiratory burst, intracellular Ca2+ and DNA damage in the white shrimp *Litopenaeus vannamei*.	2009	Dilution water not characterized, duration too short
Chang et al.	Influence of Divalent Metal Ions on E2-Induced ER Pathway in Goldfish (*Carassius auratus*) Hepatocytes	2011	In vitro
Chapman et al.	Global Geographic Differences in Marine Metals Toxicity	2006	Non-applicable
Charpentier et al.	Toxicity and bioaccumulation of cadmium in experimental cultures of duckweed, *Lemna polyrrhiza* L.	1987	Not North American species
Chassard-Bouchaud	Ultrastructural Study of Cadmium Concentration by the Digestive Gland of the Crab *Carcinus maenas* (Crustacea Decapoda).	1982	Bioaccumulation: steady state not documented
Chattopadhyay et al.	Bioassay evaluation of acute toxicity levels of mercuric chloride and cadmium chloride on the early growing stages of *Labeo rohita*	1995	Not North American species
Chaumot et al.	Additive vs non-additive genetic components in lethal cadmium tolerance of Gammarus (Crustacea): novel light on the assessment of the potential for adaptation to contamination	2009	Only one exposure concentration, dilution water not characterized, not North American species
Chawla et al.	Effect of pH and temperature on the uptake of cadmium by *Lemna minor* L.	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chelomin et al.	An in vitro study of the effect of reactive oxygen species on subcellular distribution of deposited cadmium in digestive gland of mussel *Crenomytilus grayanus*	2005	In vitro
Chen and Fang	Safety assessment and acute toxicity of copper, zinc and cadmium to the embryo and larval fish of *Tanichthys albonubes*	2011	Not North American species; text in foreign language, abstract only in English
Chen et al.	Comparison of the relative toxicity relationships based on batch and continuous algal toxicity tests	1997	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Chen et al.	Use of Japanese Medaka (*Oryzias latipes*) and Tilapia (*Oreochromis mossambicus*) in Toxicity Tests on Different Industrial Effluents in Taiwan	2001	Effluent
Chen et al.	Expression Pattern of Metallothionein, MTF-1 Nuclear Translocation, and Its DNA-Binding Activity in Zebrafish (Danio rerio) Induced by Zinc and Cadmium	2007	Mixture
Chen et al.	Accumulation and Release Characteristics of Heavy Metals in *Crassostrea rivalaris* Under Mixed Exposure	2008	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Chen et al.	Effects of Cd and Zn on Oxygen Consumption and Ammonia Excretion in Sipuncula (*Phascolosoma esculenta*)	2009	Mixture
Chen et al.	Accumulation and Elimination Characteristics of Heavy Metal Cadmium in *Bullacta exarata* from Intertidal Zone of Tianjin, China.	2010	Bioaccumulation: steady state not documented
Chen et al.	Toxicity Assessment of Simulated Urban Runoff Containing Polycyclic Musks and Cadmium in Carassius auratus Using Oxidative Stress Biomarkers	2012	Mixture
Chen et al.	Assessing abalone growth inhibition risk to cadmium and silver by linking toxicokinetics/toxicodynamics and subcellular partitioning	2011a	Analyzed data from another study
Chen et al.	Molecular cloning, characterization and expression analysis of receptor for activated C kinase 1 (RACK1) from pearl oyster (*Pinctada martensii*) challenged with bacteria and exposed to cadmium	2011b	Mixture
Chen et al.	Differential effect of waterborne cadmium exposure on lipid metabolism in liver and muscle of yellow catfish *Pelteobagrus fulvidraco*	2013	Only two exposure concentrations
Cherkasov et al.	Effects of acclimation temperature and cadmium exposure on cellular energy budgets in the marine mollusk *Crassostrea virginica*: linking cellular and mitochondrial responses	2006	Only one exposure concentration
Cherkasov et al.	Combined effects of temperature and cadmium exposure on haemocyte apoptosis and cadmium accumulation in the eastern oyster *Crassostrea virginica* (Gmelin)	2007	Bioaccumulation: not whole body or muscle content
Cherkasov et al.	Seasonal variation in mitochondrial responses to cadmium and temperature in eastern oysters *Crassostrea virginica* (Gmelin) from different latitudes	2010	Bioaccumulation: not renewal or flow-through; Excised cells
Chernova and Sergeeva	Metal Concentrations in Sargassum Algae From Coastal Waters of Nha Trang Bay (South China Sea)	2008	Bioaccumulation: steady state not documented
Cherry and Guthrie	Toxic Metals in Surface Waters From Coal Ash	1977	Bioaccumulation: steady state not documented
Cherry et al.	Coal Ash Basin Effects (Particulates, Metals, Acidic Ph) Upon Aquatic Biota: an Eight-Year Evaluation	1984	Effluent
Cheung and Lam	Effect of cadmium on the embryos and juveniles of a tropical freshwater snail, *Physa acuta* (Draparnaud, 1805)	1998	Not North American species
Cheung and Wong	Risk Assessment of Heavy Metal Contamination in Shrimp Farming in Mai Po Nature Reserve, Hong Kong	2006	Bioaccumulation: steady state not documented
Cheung et al.	Effects of heavy metals on the survival and feeding behaviour of the sandy shore scavenging gastropod *Nassarius festivus* (Powys)	2002	Not North American species
Cheung et al.	Metal Concentrations of Common Freshwater and Marine Fish From the Pearl River Delta, South China	2008	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Chevreuil et al.	Evaluation of the Pollution by Organochlorinated Compounds (Polychlorobiphenyls and Pesticides) and Metals (Cd, Cr, Cu and Pb) in the Water and in the Zebra Mussel (*Dreissena polymorpha* Pallas) of the River Seine	1996	Bioaccumulation: steady state not documented
Chiarelli et al.	Sea urchin embryos as a model system for studying autophagy induced by cadmium stress	2011	Lack of exposure details
Chiarelli et al.	Sea urchin embryos exposed to cadmium as an experimental model for studying the relationship between autophagy and apoptosis	2013	Only one exposure concentration\
Chigbo et al.	Uptake of Arsenic, Cadmium, Lead and Mercury Form Polluted Waters by the Water Hyacinth *Eichornia crassipes*	1982	Bioaccumulation: steady state not documented
Chiodi Boudet et al.	Lethal and sublethal effects of cadmium in the white shrimp *Palaemonetes argentinus*: A comparison between populations from contaminated and reference sites	2013	Not North American species; dilution water not characterized
Chishty et al.	Evaluation of acute toxicity of zinc, lead and cadmium to zooplanktonic community in upper Berach river system, Rajasthan, India	2012	Mixture (lead, zinc and cadmium)
Chitguppa et al.	Reusability of seaweed biosorbent in multiple cycles of cadmium adsorption and desorption	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Choi et al.	Cadmium bioaccumulation and detoxification in the gill and digestive gland of the Antarctic bivalve *Laternula elliptica*	2007a	Bioaccumulation: steady state not documented; not North American species
Choi et al.	Cadmium affects the expression of metallothionein (MT) and glutathione peroxidase (GPX) mRNA in goldfish, *Carassius auratus*	2007b	Injected pollutant
Choi et al.	Biosorption of heavy metals and uranium by starfish and *Pseudomonas putida*	2009	Bioaccumulation: steady state not documented
Chojnacka et al.	Biosorption of Cr3+, Cd2+ and Cu2+ Ions by Blue-Green Algae *Spirulina sp.*: Kinetics, Equilibrium and the Mechanism of the Process	2005	Mixture
Chora et al.	Effect of cadmium in the clam *Ruditapes decussatus* assessed by proteomic analysis	2009	Bioaccumulation: steady state not documented
Chou and Uthe	Effect of starvation on trace metal levels in blue mussels (*Mytilus edulis*)	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Chou et al.	Effect of dietary cadmium on growth, survival, and tissue concentrations of cadmium, zinc, copper, and silver in juvenile american lobster (*Homarus americanus*)	1987	Organisms were exposed to cadmium in food or by injection or gavage

Authors	**Title**	**Year**	**Reason Unused**
Chou et al.	Cadmium, Copper, Manganese, Silver, and Zinc in Rock Crab (*Cancer irroratus*) from Highly Copper Contaminated Sites in the Inner Bay of Fundy, Atlantic Canada	2002	Bioaccumulation: steady state not documented
Chou et al.	Effect of magnesium deficiency on antioxidant status and cadmium toxicity in rice seedlings.	2011	Only one exposure concentration
Chouchene et al.	Cadmium-induced ovarian pathophysiology is mediated by change in gene expression pattern of zinc transporters in zebrafish (*Danio rerio*).	2011	Only one exposure concentrations
Chowdhury et al.	Gastrointestinal Uptake and Fate of Cadmium in Rainbow Trout Acclimated to Sublethal Dietary exposure Cadmium	2004	Dietary exposure
Christoffers and Ernst	The *in-vivo* fluorescence of *Chlorella fusca* as a biological test for the inhibition of photosynthesis	1983	No interpretable concentration, time, response data or examined only a single exposure concentration
Ciardullo et al.	Bioaccumulation Potential of Dietary exposure Arsenic, Cadmium, Lead, Mercury, and Selenium in Organs and Tissues of Rainbow Trout (*Oncorhyncus mykiss*) as a Function of Fish Growth	2008	Dietary exposure
Cicik et al.	Effects of lead and cadmium interactions on the metal accumulation in tissue and organs of the Nile tilapia (*Oreochromis niloticus*)	2004	Bioaccumulation: steady state not documented (only 15 day exposure); not renewal or flow-through exposure
Cid et al.	Determination of trace metals in fish species of the Ria de Aveiro (Portugal) by electrothermal atomic absorption spectrometry	2001	Bioaccumulation: steady state not documented
Ciliberti et al.	The Nile Monitor (*Varanus niloticus*, Squamata: Varanidae) as a Sentinel Species for Lead and Cadmium Contamination in Sub-Saharan Wetlands	2011	Bioaccumulation: steady state not documented
Cincinelli et al.	Organochlorine Pesticide Air-Water Exchange and Bioconcentration in Krill in the Ross Sea	2009	Bioaccumulation: steady state not documented
Ciocan and Rotchell	Cadmium induction of metallothionein isoforms in juvenile and adult mussels (*Mytilus edulis*)	2004	Bioaccumulation: steady state not documented; dilution water not characterized
Cirillo et al.	Cadmium accumulation and antioxidant responses in *Sparus aurata* exposed to waterborne cadmium	2012	Bioaccumulation: steady state not documented (only 11 day exposure)
Ciutat and Boudou	Bioturbation Effects on Cadmium and Zinc Transfers from a Contaminated Sediment exposure and on Metal Bioavailability to Benthic Bivalves	2003	Sediment exposure
Ciutat et al.	Cadmium bioaccumulation in Tubificidae from the overlying water source and effects on bioturbation	2005	Sediment exposure
Clason et al.	Bioaccumulation of Trace Metals in the Antarctic Amphipod *Paramoera walkeri* (Stebbing, 1906): Comparison of Two-Compartment and Hyperbolic Toxicokinetic Models	2003	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Clausen et al.	Passive and active cadmium uptake in the isolated gills of the shore crab, *Carcinus maenas* (L.)	1993	No interpretable concentration, time, response data or examined only a single exposure concentration
Coban et al.	Heavy Metals in Livers, Gills and Muscle of *Dicentrarchus labrax* (Linnaeus, 1758) Fish Species Grown in the Dardanelles	2009	Bioaccumulation: steady state not documented
Cogun et al.	Accumulation of copper and cadmium in small and large Nile tilapia *Oreochromis niloticus*	2003	Bioaccumulation: unmeasured exposure, dilution water not characterized
Cogun et al.	Metal Concentrations in Fish Species from the Northeast Mediterranean Sea	2006	Bioaccumulation: steady state not documented
Cohen et al.	Trace Metals in Fish and Invertebrates of Three California Coastal Wetlands	2001	Bioaccumulation: steady state not documented
Collado et al.	Heavy Metals (Cd, Cu, Pb and Zn) in Two Species of Limpets (*Patella rustica* and *Patella candei crenata*) in the Canary Islands, Spain	2006	Bioaccumulation: steady state not documented
Collard and Matagne	Cd^{2+} resistance in wild-type and mutant strains of *Chlamydomonas reinhardtii*	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Company et al.	Effect of Cadmium, Copper and Mercury on Antioxidant Enzyme Activities and Lipid Peroxidation in the Gills of the Hydrothermal Vent Mussel *Bathymodiolus azoricus*	2004	Mixture
Company et al.	Sub-lethal effects of cadmium on the antioxidant defense system of the hydrothermal vent mussel *Bathymodiolus azoricus*	2010	Bioaccumulation: steady state not documented
Conti and Cecchetti	A biomonitoring study: trace metals in algae and molluscs from Tyrrhenian coastal areas	2003	Bioaccumulation: steady state not documented
Conway	Ecological Impact of Cadmium on Aquatic Organisms	1981	Review
Conway and Williams	Sorption and desorption of cadmium by *Asterionella formosa* and *Fragilaria crotonensis*	1977	Bioaccumulation: steady state not documented
Cooke et al.	Biological Availability of Sediment-Bound Cadmium to the Edible Cockle, *Cerastoderma edule*	1979	Sediment
Cooper and De	Reducing the Toxicity of Cadmium Sulphate to Rainbow Trout (*Salmo gairdneri*) by Preliminary Exposure of Fish to Zinc Sulphate, With and Without Intermittent Exposure to Cadmium	1978	Mixture
Cooper et al.	The Effects of Dietary exposure Iron Concentration on Gastrointestinal and Branchial Assimilation of both Iron and Cadmium in Zebrafish (*Danio rerio*)	2006	Dietary exposure
Cooper et al.	Subcellular partitioning of cadmium in the freshwater bivalve, *Pyganodon grandis*, after separate short-term exposures to waterborne or diet-borne metal	2010a	Bioaccumulation: not renewal or flow-through

Authors	**Title**	**Year**	**Reason Unused**
Cooper et al.	Modeling cadmium uptake from water and food by the freshwater bivalve *Pyganodon grandis*	2010b	Bioaccumulation: steady state not documented (only 60 hour exposure)
Cope et al.	Differential exposure, duration, and sensitivity of unionoidean bivalve life stages to environmental contaminants	2008	Dilution water not characterized, lack of details, duration too short
Copes et al.	Uptake of Cadmium From Pacific Oysters (*Crassostrea gigas*) in British Columbia Oyster Growers	2008	Bioaccumulation: steady state not documented
Coppellotti	Effects of cadmium on *Uronema marinum* (Ciliophora, Scuticociliatida) from Antarctica	1994	Not North American species
Corami et al.	Complexation of Cadmium and Copper by Fluvial Humic Matter and Effects on Their Toxicity	2007	Mixture
Cordero et al.	Effect of Heavy Metals on the Growth of the Tropical Microalgae *Tetrasermis chuii* (Prasinophyceae)	2005	Non-applicable
Cornellier	Cinetique De Bioaccumulation Et Distribution Tissulaire Du Cadmium-109 Par La Nourriture Et Par L'eau Chez Le Petoncle Geant (*Placopecten magellanicus*) Et Le Petoncle D'islande (*Chlamys islandica*)	2010	Text in foreign language
Costa et al.	Biochemical Endpoints on Juvenile *Solea senegalensis* Exposed to Estuarine Sediment exposures: the Effect of Contaminant Mixtures on Metallothionein and Cyp1a Induction	2009a	Sediment exposure
Costa et al.	Histological Biomarkers in Liver and Gills of Juvenile *Solea senegalensis* Exposed to Contaminated Estuarine Sediment exposures: a Weighted Indices Approach	2009b	Sediment exposure
Costa et al.	Multi-organ histological observations on juvenile *Senegalese soles* exposed to low concentrations of waterborne cadmium	2013	Not North American species, only three exposure concentrations
Coteur et al.	Alteration of Cellular Immune Responses in the Seastar *Asterias rubens* Following Dietary Exposure to Cadmium	2005	Dietary exposure
Couch	Ultrastructural study of lesions in gills of a marine shrimp exposed to cadmium	1977	Only one exposure concentration
Couillard	Acute toxicity of six metals to the rotifer *Brachionus calyciflorus*, with comparisons to other freshwaer organisms	1989	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Couture and Kumar	Impairment of Metabolic Capacities in Copper and Calcium Contaminated Wild Yellow Perch (*Perca flavescens*)	2003	Mixture
Cox	Interactions of Cadmium, Zinc, and Phosphorus in Marine *Synechococcus*: Field Uptake, Physiological and Proteomic Studies.	2011	Bioaccumulation: steady state not documented
Craig et al.	Effect of exposure regime on the internal distribution of cadmium in *Chironomus staegeri* larvae (insecta, diptera)	1998	No useable data on cadmium toxicity or bioconcentration

Authors	**Title**	**Year**	**Reason Unused**
Craig et al.	Experimental evidence for cadmium uptake via calcium channels in the aquatic insect *Chironomus staegeri*	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Cravo et al.	Metal concentrations in the shell of *Bathymodiolus azoricus* from contrasting hydrothermal vent fields on the mid-Atlantic ridge	2008	Bioaccumulation: steady state not documented
Creighton and Twining	Bioaccumulation from food and water of cadmium, selenium and zinc in an estuarine fish, *Ambassis jacksoniensis*	2010	Bioaccumulation: steady state not documented
Crichton et al.	Assessing Stream Grazer Response to Stress: A Post-Exposure Feeding Bioassay Using the Freshwater Snail *Lymnaea peregra* (Muller)	2004	Dietary exposure
Croisetiere et al.	A Field Experiment to Determine the Relative Importance of Prey and Water as Sources of As, Cd, Co, Cu, Pb, and Zn for the Aquatic Invertebrate *Sialis velata*	2006	Mixture
Croteau and Luoma	A Biodynamic Understanding of Dietborne Metal Uptake by a Freshwater Invertebrate	2008	Dietary exposure
Croteau et al.	Differences in Cd Accumulation Among Species of the Lake-Dwelling Biomonitor Chaoborus	2001	Bioaccumulation: steady state not documented
Cruz et al.	Kinetic modeling and equilibrium studies during cadmium biosorption by dead *Sargassum sp*. biomass	2004	Modeling
Cruz Rodriguez	Heat Shock Protein (HSP70) Response in the Eastern Oyster, *Crassostrea virginica*, Exposed to Various Contaminants (PAHs, PCBs and Cadmium)	2002	Mixture
Cubadda et al.	Size-dependent concentrations of trace metals in four Mediterranean gastropods	2001	Bioaccumulation: steady state not documented
Culshaw et al.	Concentrations of Cd, Zn and Cu in Sediment exposures and brown shrimp (*Crangon crangon* L.) from the Severn Estuary and Bristol Channel, UK	2002	Bioaccumulation: steady state not documented
Cunha et al.	Effects of Copper and Cadmium on Cholinesterase and Glutathione S-Transferase Activities of Two Marine Gastropods (*Monodonta lineata* and *Nucella lapillus*)	2007	Mixture
Cunningham	The effect of cadmium exposure on repeat swimming performance and recovery in rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and lake whitefish (*Coregonus clupeaformis*)	2012	Only one exposure concentration
Currie et al.	Influence of nutrient additions on cadmium bioaccumulation by aquatic invertebrates in littoral enclosures	1998	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Cuthbert et al.	Toxicity of cadmium to *Bullia digitalis* (prosobranchiata: nassaridae)	1976	Not North American species, dilution water not characterized
Cuvin-Aralar	Survival and heavy metal accumulation of two *Oreochromis niloticus* (L.) strains exposed to mixtures of zinc, cadmium and mercury	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Cuvin-Aralar and Aralar	Effects of long-term exposure to a mixture of cadmium, zinc, and inorganic mercurey on two strains of Tilapia *Oreochromis niloticus* (L.)	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Cyrille et al.	Cadmium accumulation in tissues of *Sarotherodon melanotheron* (Ruppel, 1852) from the Aby Lagoon system in Cote d'Ivoire	2012	Bioaccumulation: steady state not documented
D'Agostino and Finney	The effect of copper and cadmium on the development of *Tigriopus japonicas*	1974	Not North American species
D'Aniello et al.	Effect of mercury, cadmium and copper on the development and viability of *Loligo vulgaris* and *Sepia officinalis* embryos	1990	The materials, methods or results were insufficiently described
da Cruz et al.	Estimation of the critical effect level for pollution prevention based on oyster embryonic development toxicity test: The search for reliability	2007	Not North American species, duration too short
da Silva et al.	Relative contribution of food and water to the Cd burden in *Balanus amphitrite* in an urban tidal creek discharging into the Great Barrier Reef lagoon	2004	Bioaccumulation: steady state not documented
da Silva et al.	Can body burden in the barnacle *Balanus amphitrite* indicate seasonal variation in cadmium concentrations?	2005	Bioaccumulation: steady state not documented
Dabas et al.	Assessment of tissue-specific effect of cadmium on antioxidant defense system and lipid peroxidation in freshwater murrel, *Channa punctatus*	2012	Not North American species
Daka and Hawkins	Interactive Effects of Copper, Cadmium and Lead on Zinc Accumulation in the Gastropod Mollusc *Littorina saxatilis*	2006	Mixture
Daka et al.	Tolerance to Heavy Metals in *Littorina saxatilis* from a Metal Contaminated Estuary in the Isle of Man	2004	Bioaccumulation: steady state not documented
Dallinger and Kautzky	The Importance of Contaminated Food for the Uptake of Heavy Metals by Rainbow Trout (*Salmo gairdneri*): a Field Study	1985	Bioaccumulation: steady state not documented
Dallinger et al.	Effects of cadmium on *Murex trunculus* from the Adriatic Sea. I. Accumulation of metal and binding to a metallothionein-like protein	1989	Not North American species
Dallinger et al.	The role of metallothionein in cadmium accumulation of Arctic char (*Salvelinus alpinus*) from high alpine lakes	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Damiens et al.	Metal bioaccumulation and metallothionein concentrations in larvae of *Crassostrea gigas*	2006	Prior exposure, dilution water not characterized
Dang and Wang	Assessment of tissue-specific accumulation and effects of cadmium in a marine fish fed contaminated commercially produced diet	2009	Dietary exposure
Dang et al.	Metallothionein and Cortisol Receptor Expression in Gills of Atlantic Salmon, *Salmo salar*, Exposed to Dietary exposure Cadmium	2001	Dietary exposure
Dangre et al.	Effects of Cadmium on Hypoxia-Induced Expression of Hemoglobin and Erythropoietin in Larval Sheepshead Minnow, *Cyprinodon variegatus*	2010	In vitro
Darmono	Uptake of cadmium and nickel in banana prawn (*Penaeus merguiensis* de Man)	1990	Not North American species

Authors	Title	Year	Reason Unused
Darmono et al.	The pathology of cadmium and nickel toxicity in the banana shrimp (*Penaeus merguiensis* de Man)	1990	Not North American species
Das and Gupta	Effects of cadmium chloride on oxygen consumption and gill morphology of Indian flying barb, *Esomus danricus*	2012	Not North American species, only three exposure concentrations
Das and Khagarot	Bioaccumulation and toxic effects of cadmium on feeding and growth of an Indian pond snail *Lymnaea luteola* L. under laboratory conditions	2010	Dilution water not characterized
Das and Maiti Subodh	Metal Accumulation in *A. baccifera* Growing Naturally on Abandoned Copper Tailings Pond	2007	Bioaccumulation: steady state not documented
Das et al.	The temperature dependence of the acute toxicity of heavy metals (cadmium, copper and mercury) to a freshwater pond snail, *Lymnae aluteola* L	2012	Not North American species
Datta et al.	Estimation of acute toxicity of cadmium, a heavy metal, in a carnivorous freshwater teleost, *Mystus vittatus* (Bloch)	1987	Not North American species
Dautremepuit et al.	Gill and Head Kidney Antioxidant Processes and Innate Immune System Responses of Yellow Perch (*Perca flavescens*) Exposed to Different Contaminants in the St. Lawrence River, Canada	2009	Mixture
Dauvin	Effects of Heavy Metal Contamination on the Macrobenthic Fauna in Estuaries: the Case of the Seine Estuary	2008	Mixture
Daverat et al.	Otolith Microchemistry Interrogation of Comparative Contamination by Cd, Cu and PCBs of Eel and Flounder, in a Large SW France Catchment.	2011	Bioaccumulation: steady state not documented
Davies and Woodling	Importance of laboratory-derived metal toxicity results in predicting in-stream response of resident salmonids	1980	Not applicable per ECOTOX Duluth; effluent, survey
Davies et al.	Field and experimental studies on cadmium in the edible crab *Cancer pagurus*	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Davies et al.	The influence of particle surface characteristics on pollutant metal uptake by cells	1997	Organisms were exposed to cadmium in food or by injection or gavage
Davis et al.	Bioaccumulation of Arsenic, Chromium and Lead in Fish: Constraints Imposed by Sediment Geochemistry	1996	Bioaccumulation: steady state not documented
Davis et al.	Cadmium biosorption by *S. fluitans*: treatment, resilience and uptake relative to other *Saragassum spp*. and brown algae	2004	Lack of details, not renewal or flow-through accumulation study
Dayeh et al.	Cytotoxicity of metals common in mining effluent to rainbow trout cell lines and to the ciliated protozoan, *Tetrahymena thermophila*	2005	Excised tissue/cells
De Boeck et al.	Metal accumulation and metallothionein induction in the spotted dogfish *Scyliorhinus canicula*	2010	Bioaccumulation: steady state not documented (only 7 day exposure)

Authors	**Title**	**Year**	**Reason Unused**
De Coninck et al.	An investigation of the inter-clonal variation of the interactive effects of cadmium and *Microcystis aeruginosa* on the reproductive performance of *Daphnia magna*	2013	Only one exposure concentration
De Conto Cinier et al.	Cadmium bioaccumulation in carp (*Cyprinus carpio*) tissues during long-term high exposure: analysis by inductively coupled plasma-mass spectrometry	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
De Conto Cinier et al.	Cadmium accumulation and metallothionein biosynthesis in *Cyprinus carpio* tissues	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
de March	Acute toxicity of binary mixtures of five cations (Cu^{2+}, Cd^{2+}, Zn^{2+}, Mg^{2+} and K^{+}) to the freshwater amphipod *Gammarus lacustris* (Sars): alternative descriptive models	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
de Mora et al.	Distribution of heavy metals in marine bivalves, fish and coastal Sediment exposures in the Gulf and Gulf of Oman	2004	Bioaccumulation: steady state not documented
De Nicola Guidici and Guarino	Effects of cadmium on survival, bioaccumulation, histopathology, and PGM polymorphism in the marine isopod *Idotea baltica*.	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
De Nicola Guidici and Migliore	Ecotoxicological Assessment of Pollutants by Chemico-Biological Analysis: a Mini review	1996	Review
De Nicola et al	Effects of chronic exposure to cadmium or copper on *Idothea baltica* (crustacea, isopoda)	1989	Not North American species
De Nicola et al	Long term effect of cadmium of copper on *Asellus aquaticus* (L.) (Crustacea, isopoda)	1988	Not North American species
De Vries et al.	Critical Soil Concentrations of Cadmium, Lead, and Mercury in View of Health Effects on Humans and Animals	2007	Review
De Wolf and Rashid	Heavy Metal Accumulation in *Littoraria scabra* Along Polluted and Pristine Mangrove Areas of Tanzania	2008	Bioaccumulation: steady state not documented
De Wolf et al.	Sensitivity to cadmium along a salinity gradient in populations of the periwinkle, *Littorina littorea*, using time-to-death analysis	2004	Prior exposure
Decho and Luoma	Humic and fulvic acids: ink or source in the availability of metals to the marine bivalves *Macoma balthica* and *Potamocorbula amurensis*?	1994	Organisms were exposed to cadmium in food or by injection or gavage
DeFilippis et al.	The effects of sublethal concentrations of zinc, cadmium and mercury on *Euglena*. II. Respiration, photosynthesis and photochemical activities	1981	No pertinent adverse effects reported
Defo et al.	Evidence for Metabolic Imbalance of Vitamin A2 in Wild Fish Chronically Exposed to Metals	2012	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Dekker et al.	Life History Changes in the Benthic Cladoceran *Chydorus piger* Induced by Low Concentrations of Sediment exposure-Bound Cadmium	2002	Bioaccumulation: steady state not documented
Dekker et al.	Development and Application of a Sediment exposure Toxicity Test Using the Benthic Cladoceran *Chydorus sphaericus*	2006	Sediment exposure
Del Castillo Arias and Robinson	Nuclear and Cytosolic Distribution of Metallothionein in the Edible Blue Mussel, *Mytilus edulis* Linnaeus Exposed to Cadmium and Benzo[a]Pyrene and in Gill Tissue from Three Natural Populations Along the Massachusetts Coast	2009	Bioaccumulation: steady state not documented
Delmail et al.	Physiological, anatomical and phenotypical effects of a cadmium stress in different-aged chlorophyllian organs of *Myriophyllum alterniflorum* DC (Haloragaceae)	2011	Only one exposure concentration
Delmotte et al.	Cadmium Transport in Sediment exposures by Tubificid Bioturbation: an Assessment of Model Complexity	2007	Modeling
Delval et al.	Responses of a Flat Fish, the Flounder (*Platichtys flesus* L.) To Metal Pollutions by Elaborating Metallothioneins. Competition Between Zinc, Copper (Responses D'un Poisson Plat: Le Flet (Platichtys Flesus L.) Aux Pollutions Metalliques Par Elaboration De Metallothioneines: Competition Entre Zinc, Cuivre Et Cadmium)	1988	Text in foreign language
Demirak et al.	Heavy Metals in Water, Sediment exposure and Tissues of *Leuciscus cephalus* From a Stream in Southwestern Turkey	2006	Bioaccumulation: steady state not documented
Demon et al.	The influence of pre-treatment, temperature and calcium ions on trace element uptake by an alga (*Scenedesmus pannonicus* subsp. Berlin) and fungus (*Aureobasidium pullulans*)	1989	Not North American species
Den Besten et al.	Effects of cadmium and PCBs on reproduction of the sea star *Asterias rubens*: aberrations in the early development	1989	Not North American species
Den Besten et al.	Effects of cadmium on gametogenesis in the sea star *Asterias rubens* L	1991	Not North American species
Deng et al.	Trace Metal Concentration in Great Tit (*Parus major*) and Greenfinch (*Carduelis sinica*) at the Western Mountains of Beijing, China	2007	Bioaccumulation: steady state not documented
Deniseger et al.	Periphyton Communities in a Pristine Mountain Stream Above and Below Heavy Metal Mining Operations	1986	Effluent
Denton and Burdon-Jones	Influence of temperature and salinity on the uptake, distribution, and depuration of mercury, cadmium, and lead by the black-lip oyster *Saccostrea echinata*	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Denton and Burdon-Jones	Trace Metals In Corals From The Great Barrier Reef	1986a	Bioaccumulation: steady state not documented
Denton and Burdon-Jones	Environmental effects on toxicity of heavy metals to two species of tropical marine fish from northern Australia.	1986b	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Department of the Environment		1973	The materials, methods or results were insufficiently described
Desouky	Metallothionein is up-regulated in molluscan responses to cadmium, but not aluminum, exposure.	2012	Only one exposure concentration
Desouky et al.	Effect of orthosilic acid on the accumulation of trace metals by the pond snail *Lymnaea stagnalis*	2003	Bioaccumulation: not whole body or muscle content
Desrosiers et al.	Relationships Among Total Recoverable and Reactive Metals and Metalloid in St. Lawrence River Sediment exposure: Bioaccumulation by Chironomids and Implications for Ecological Risk Assessment	2008	Bioaccumulation: steady state not documented
Dethlefsen	Uptake, retention and loss of cadmium by brown shrimp (*Crangon crangon*)	1978	Dilution water not characterized
Deveau	Use of the Edible Seaweed Taqq'astan (*Porphyra abbottiae* Krishnamurthy: Bangiaceae) and Metal Bioaccumulation at Traditional Harvesting Sites in Queen Charlotte Strait and Broughton Strait	2011	Bioaccumulation: steady state not documented
Devi	Bioaccumulation and metabolic effects of cadmium on marine fouling dressinid bivalve, *Mytilopsis sallei* (Recluz)	1996	Not North American species; prior exposure (collected from a polluted harbor)
Devi and Kumaraguru	Toxicity of Heavy Metals Copper and Cadmium on the Brown Macroalgal Species of Pudumadam Coast, Gulf of Mannar	2008	Mixture
Devi and Rao	Cadmium accumulation in fiddler crabs *Uca annulipes* latelle and *Uca triangularis* (Milne Edwards)	1989	Not North American species
Devier et al.	One-Year Monitoring Survey of Organic Compounds (PAHs, PCBs, TBT), Heavy Metals and Biomarkers in Blue Mussels from the Arcachon Bay, France	2005	Bioaccumulation: steady state not documented
Devineau and Triquet	Patterns of bioaccumulation of an essential trace element (zinc) and a pollutant metal (cadmium) in larvae of the prawn *Palaemon serratus*	1985	Not North American species
Dhamotharan et al.	Bioremediation of Tannery Effluent Using Cyanobacterium	2009	Effluent
Diamond et al.	Effects of pulsed contaminant exposures on early life stages of the fathead minnow	2005	Pulsed exposure
Dickson et al.	The effect of chronic cadmium exposure on phosphoadenylate concentrations and adenylate energy charge of gills and dorsal muscle tissue of crayfish	1982	No pertinent adverse effects reported
Dierickx and Bredael-Rozen	Correlation between the *in vitro* cytotoxicity of inorganic metal compounds to cultured fathead minnow fish cells and the toxicity to *Daphnia magna*	1996	Review of previously published data
Dierking et al.	Spatial patterns in PCBs, pesticides, mercury and cadmium in the common sole in the NW Mediterranean Sea, and a novel use of contaminants as biomarkers	2009	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Dietrich et al.	Exposure of rainbow trout milt to mercury and cadmium alters sperm motility parameters and reproductive success	2010	In vitro
Dietrich et al.	Carp transferrin can protect spermatozoa against toxic effects of cadmium ions	2011	Only one exposure concentration, dilution water not characterized
Dixon et al.	Cadmium Uptake by Marine Micro-Organisms in the English Channel and Celtic Sea	2006	Bioaccumulation: steady state not documented
Dobrovoljc et al.	Uptake and elimination of cadmium in *Rana dalmatina* (Anura, amphibia) tadpoles	2003	Bioaccumulation: steady state not documented; dilution water not characterized; not North American species
Dong et al.	Concentrations of Heavy Metals and Safe Assessments of Fishes in Main Lakes From Wuhan City	2006	Bioaccumulation: steady state not documented
Dorfman	Tolerance of *Fundulus heteroclitus* to different metals in salt waters	1977	Questionable treatment of test organisms or inappropriate test conditions or methodology
Dorgelo et al.	Effects of diet and heavy metals on growth rate and fertility in the deposit-feeding snail *Potamopyrgus jenkinsi* (Smith) (Gastropoda: Hydrobiidae)	1995	Not North American species
Dorts et al.	Sub-lethal cadmium toxicity in bullhead *Cottus gobio*. Biochemical and proteomic approaches	2009	Lack of detail
Dorts et al.	Proteomic response to sublethal cadmium exposure in a sentinel fish species, *Cottus gobio*	2011	Not North American species
Dorts et al.	Proteasome and antioxidant responses in *Cottus gobio* during a combined exposure to heat stress and cadmium	2012	Not North American species, only two exposure concentrations
Douben	Uptake and elimination of waterborne cadmium by the fish *Noemacheilus barbatulus* L. (stone loach)	1989	Not North American species
Dovzhenko et al.	Cadmium-induced oxidative stress in the bivalve mollusk *Modiolus modiolus*	2005	Bioaccumulation: steady state not documented
Downs et al.	A molecular biomarker system for assessing the health of gastropods (*Ilyanassa obsoleta*) exposed to natural and anthropogenic stressors	2001b	Duration too short, only two exposure concentrations
Dragun et al.	The Influence of the Season and the Biotic Factors on the Cytosolic Metal Concentrations in the Gills of the European Chub (*Leuciscus cephalus* L.)	2007	Bioaccumulation: steady state not documented
Dragun et al.	Assessment of low-level metal contamination using the Mediterranean mussel gills as the indicator tissue	2010	Bioaccumulation: steady state not documented
Drastichova et al.	Effect of cadmium on hematological indices of common carp (*Cyprinus carpio* L.)	2004a	Dilution water not characterized, not definitive value, usually Unused data
Drastichova et al.	Effect of cadmium on blood plasma biochemistry in carp (*Cyprinus carpio* L.)	2004b	Dilution water not characterized, only one exposure concentration
Drava et al.	Trace elements in the muscle of red shrimp *Aristeus antennatus* (Risso, 1816) (Crustacea, Decapoda) from Ligurian sea (NW Mediterranean): variations related to the reproductive cycle	2004	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Drazkiewicz and Baszynaski	Calcium Protection of Ps2 Complex of *Phaseolus coccineus* From Cadmium Toxicity: in Vitro Study	2008	In vitro
Drbal et al.	Toxicity and accumulation of copper and cadmium in the alga *Scenedesmus obliquus* LH.	1985	Not North American species
Dressing	The effect of chemical speciation on the equilibrium, whole-body cadmium content of larvae of the caddisfly, *Hydropsyche sp.*	1980	Chelator present in test media (NTA (nitrilotriacetic acid))
Drost et al.	Heavy metal toxicity to *Lemna minor*: Studies on the time dependence of growth inhibition and the recovery after exposure	2007	Excessive EDTA in the medium (1,177 ug/L)
Du Laing et al.	Factors Affecting Metal Concentrations in Reed Plants (*Phragmites australis*) of Intertidal Marshes in the Scheldt Estuary	2009	Bioaccumulation: steady state not documented
Duan et al.	Differential survivorship among allozyme genotypes of *Hyalella azteca* exposed to cadmium, zinc or low pH	2001	Only one exposure concentration, duration too short
Dugmonits et al.	Major distinctions in the antioxidant responses in liver and kidney of Cd^{2+}-treated common carp (*Cyprinus carpio*)	2013	Only one exposure concentration
Dulymamode et al.	Evaluation of *Padina boergesenii* (Phaeophyceae) as a bioindicator of heavy metals: some preliminary results from Mauritius	2001	Bioaccumulation: not renewal or flow-through
Duman et al.	Bioaccumulation of nickel, copper, and cadmium by *Spirodela polyrhiza* and *Lemna gibba*	2009	Bioaccumulation: steady state not documented (only 10 day duration); unmeasured exposure
Duman and Kar	Temporal variation of metals in water, sediment and tissues of the European chup (*Squalius cephalus* L.)	2012	Field survey
Duman et al.	Seasonal Changes of Metal Accumulation and Distribution in Common Club Rush (*Schoenoplectus lacustris*) and Common Reed (*Phragmites australis*)	2007	Bioaccumulation: steady state not documented
Duman et al.	Effects of exogenous glycinebetaine and trehalose on cadmium accumulation and biological responses of an aquatic plant (*Lemna gibba* L.)	2011	No control group; only three exposure concentrations
Duong et al.	Seasonal Effects of Cadmium Accumulation in Periphytic Diatom Communities of Freshwater Biofilms	2008	Bioaccumulation: steady state not documented
Duong et al.	Experimental toxicity and bioaccumulation of cadmium in freshwater periphytic diatoms in relation with biofilm maturity	2010	Only one exposure concentration, mixed species exposure
Duquesne and Coll	Metal accumulation in the clam *Tridacna crocea* under natural and experimental conditions	1995	Not North American species
Duquesne et al.	Sub-lethal effects of metal exposure: physiological and behavioural responses of the estuarine bivalve *Macoma balthica*	2004	Lack of details, not North American species
Dural et al.	Bioaccumulation of some heavy metals in different tissues of *Dicentrarchus labrax* L, 1758, *Sparus aurata* L, 1758 and *Mugil cephalus* L, 1758 from the Camlik Lagoon of the eastern coast of Mediterranean (Turkey)	2006	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Dutta and Kaviraj	Acute Toxicity of Cadmium to Fish *Labeo rohita* and Copepod *Diaptomus forbesi* Pre-Exposed to CaO and KMnO4	2001	Mixture
Dutton and Fisher	Salinity effects on the bioavailability of aqueous metals for the estuarine killifish *Fundulus heteroclitus*	2011a	Bioaccumulation: not renewal or flow-through
Dutton and Fisher	Bioaccumulation of As, Cd, Cr, Hg(II), and MeHg in killifish (*Fundulus heteroclitus*) from amphipod and worm prey	2011b	Dietary exposure
Dutton and Fisher	Influence of humic acid on the uptake of aqueous metals by the killifish *Fundulus heteroclitus*	2012	Bioaccumualtion: steady state not documented
Dyer et al.	An initial evaluation of the use of Euro/North American fish species for tropical effects assessments	1997	Review of previously published data
Eaton	Chronic Toxicity Of A Copper, Cadmium And Zinc Mixture To The Fathead Minnow (*Pimephales promelas* Rafinesque)	1973	Non-applicable
Ebau et al.	Toxicity of cadmium and lead on tropical midge larvae, *Chironomus kiiensis* Tokunaga and *Chironomus javanus* Kieffer (Diptera: Chironomidae)	2012	Not North American species; test species fed
Ebrahimi	Using Computer Assisted Sperm Analysis (CASA) to Monitoring the Effects of Zinc and Cadmium Pollution on Fish Sperm	2005	Mixture
Ebrahimi	Effects of in Vivo and in Vitro Zinc and Cadmium Treatment on Sperm Steroidogenesis of the African Catfish *Clarias gairepinus*	2007	Mixture
Ebrahimi and Taherianfard	Concentration of Four Heavy Metals (Cadmium, Lead, Mercury, and Arsenic) in Organs of Two Cyprinid Fish (*Cyprinus carpio* and *Capoeta sp.*) From the Kor River (Iran)	2010	Bioaccumulation: steady state not documented
Ebrahimpour and Mushrifah	Heavy Metal Concentrations (Cd, Cu and Pb) in Five Aquatic Plant Species in Tasik Chini, Malaysia	2008	Bioaccumulation: steady state not documented
Ebrahimpour and Mushrifah	Seasonal Variation of Cadmium, Copper, and Lead Concentrations in Fish From a Freshwater Lake	2010	Bioaccumulation: steady state not documented
Edema and Egborge	Heavy metal content of crabs from Warri River, Nigeria	2001	Bioaccumulation: steady state not documented
Edge et al.	Indicators of environmental stress: cellular biomarkers and reproductive responses in the Sydney rock oyster (*Saccostrea glomerata*)	2012	Mixture
EIFAC Working Party on Water Quality Criteria for European Freshwater Fish	Report on cadmium and freshwater fish	1978	Review
Eimers et al.	Cadmium accumulation in the freshwater isopod *Asellus racovitzai*: the relative importance of solute and particulate sources at trace concentrations	2001	Sediment exposure
Eisler	Radio cadmium exchange with seawater by *Fundulus heteroclitus* (L.) (Pisces: Cyprinodontidae)	1974	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination

Authors	**Title**	**Year**	**Reason Unused**
Eisler	Trace metal concentrations in marine organisms	1981	Review of previously published data
Eisler and Gardner	Acute toxicology to an estuarine teleost of mixtures of cadmium, copper, and zinc salts	1973	Questionable treatment of test organisms or inappropriate test conditions or methodology
Eisler et al.	Metal Survey of the Marine Clam *Pitar morrhauna* Collected Near a Rhode Island (USA) Electroplating Plant	1978	Bioaccumulation: steady state not documented
Eissa et al.	Behavioral alterations in juvenile *Cyprinus carpio* (Linnaeus, 1758) exposed to sublethal waterborne cadmium	2006	Only two exposure concentrations, test species fed, usually Unused data
Eissa et al.	Quantitative behavioral parameters as toxicity biomarkers: fish responses to waterborne cadmium	2010	Dilution water not characterized
Elder and Mattraw	Accumulation of Trace Elements, Pesticides, and Polychlorinated Biphenyls in Sediments and the Clam *Corbicula manilensis* of the Apalachicola River, Florida.	1984	Sediment
Eletta et al.	Determination of concentration of heavy metals in two common fish species from Asa River, Ilorin, Nigeria	2004	Bioaccumulation: steady state not documented
Elliott et al.	The influence of cyclic exposure on the accumulation of heavy metals by *Mytilus edulis planulatus* (Lamarck)	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Elliott et al.	Metal interaction during accumulation by the mussel *Mytilus edulis planulatus*	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Engel	Accumulation and cytosolic partitioning of metals in the american oyster *Crassostrea virginica*	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Engel and Fowler	Copper and cadmium induced changes in the metabolism and structure of molluscan gill tissue	1979	Excised tissue/cells
Enserink et al.	Combined effects of metals; an ecotoxicological evaluation	1991	Review of previously published data
Erdogrul and Ates	Determination of Cadmium and Copper in Fish Samples From Sir and Menzelet Dam Lake Kahramanmaras, Turkey	2006	Bioaccumulation: steady state not documented
Erickson et al.	Effects of copper, cadmium, lead, and arsenic in a live diet on juvenile fish growth	2010	Dietary exposure
Errecalde et al.	Influence of a low molecular weight metabolite (citrate) on the toxicity of cadmium and zinc to the unicellular green alga *Selenastrum capricornutum*: and exception to the free-ion model	1998	The materials, methods or results were insufficiently described
Escobedo-Fregoso et al.	Assessment of Metallothioneins in Tissues of the Clam *Megapitaria squalida* as Biomarkers for Environmental Cadmium Pollution From Areas Enriched in Phosphorite	2010	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Eslami et al.	Trace element level in different tissues of *Rutilus frisii* kutum collected from Tajan River, Iran	2011	Bioaccumulation: steady state not documented
Espana et al.	Manganese, nickel, selenium and cadmium in molluscs from the Magellan Strait, Chile	2004	Bioaccumulation: steady state not documented
Espinoza et al.	Effect of cadmium on glutathione s-transferase and metallothionein gene expression in coho salmon liver, gill and olfactory tissues	2012	Only two exposure concentrations
Esposito et al.	Effects of heavy metals on ultrastructure and HSP70s induction in the aquatic moss *Leptodictyum riparium* Hedw	2012	Lack of exposure details (duration), effect concentration not clear
Essumang	Analysis and Human Health Risk Assessment of Arsenic, Cadmium, and Mercury in *Manta birostris* (Manta Ray) Caught Along the Ghanaian Coastline	2009	Bioaccumulation: steady state not documented
Estabrook et al.	Comparison of Heavy Metals in Aquatic Plants on Charity Island, Saginaw Bay, Lake Huron, USA, With Plants Along the Shoreline of Saginaw Bay	1985	Bioaccumulation: steady state not documented
Esvelt et al.	Toxicity Removal From Municipal Wastewaters. Volume IV of a Study of Toxicity and Biostimulation in San Francisco Bay-Delta Waters	1971	Effluent
Etnier et al.	Update of Acute and Chronic Aquatic Toxicity Data for Heavy Metals and Organic Chemicals Found at Hazardous Waste Sites	1987	Review
Eustace	Zinc, cadmium, copper and manganese in species of finfish and shellfish caught in the Derwent estuary, Tashmania	1974	Bioaccumulation: steady state not documented
Evans et al.	Simultaneous measurements of uptake and elimination of cadmium by caddisfly (Trichoptera: hydropsychidae) larvae using stable isotope tracers	2002	Dilution water not characterized
Everaarts	Uptake and release of cadmium in various organs of the common mussel, *Mytilus edulis* (L.)	1990	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Everaarts and Fischer	Micro Contaminants In Surface Sediment exposures And Macrobenthic Invertebrates Of The North Sea	1991	Bioaccumulation: steady state not documented
Everard and Swain	Isolation, charaterization and induction of metallothionein in the stonefly *Eusthenia spectabilis* following exposure to cadmium	1983	Not North American species, dilution water not characterized
EVS Environment Consultants	Site-Specfic Toxicity Testing Methods for the South Fork Coeur D'Alene River-Results and Recommendations	1996	Dilution water not characterized
Evtushenko et al.	Cadmium accumulation in organs of the scallop *Mizuhopecten yessoensis* - I. activities of phosphatases and composition and amount of lipids	1986	Not North American species
Evtushenko et al.	Cadmium bioaccumulation in organs of the scallop *Mizuhopecten yessoensis*	1990	Not North American species
Ezemonye and Enuneku	Evaluation of acute toxicity of cadmium and lead to amphibian tadpoles (toad: *Bufo Maculatus* and frog: *Ptychadena Birroni*)	2005	Lack of exposure details, not North American species

Authors	**Title**	**Year**	**Reason Unused**
Fabacher	Hepatic Microsomes From Freshwater Fish - I. In Vitro Cytochrome P-450 Chemical Interactions	1982	In vitro
Fabris et al.	Trace Metal Concentrations in Edible Tissue of Snapper, Flathead, Lobster, and Abalone from Coastal Waters of Victoria, Australia	2006	Bioaccumulation: steady state not documented
Fair and Sick	Accumulations of naphthalene and cadmium after simultaneous ingestion by the Black Sea Bass, *Centropristis striata*	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Falfushynska et al.	Population-related molecular responses on the effect of pesticides in *Carassius auratus gibelio*	2012	Mixture
Fan et al.	Metal accumulation and biomarker responses in *Daphnia magna* following cadmium and zinc exposure	2009	Mixture
Fang	Comparative studies on uptake pathway of cadmium by *Perna viridis*	2006	Bioaccumulation: steady state not documented
Fang et al.	Heavy Metals in Oysters, Mussels and Clams Collected From Coastal Sites Along the Pearl River Delta, South China	2003	Bioaccumulation: steady state not documented
Fang et al.	Trace Metals in Seawater and Copepods in the Ocean Outfall Area off the Northern Taiwan Coast	2006	Bioaccumulation: steady state not documented
Fang et al.	Metal Concentrations in Green-Lipped Mussels (*Perna viridis*) and Rabbitfish (*Siganus oramin*) From Victoria Harbour, Hong Kong After Pollution Abatement	2008	Bioaccumulation: steady state not documented
Fang et al.	Metallothionein and superoxide dismutase responses to sublethal cadmium exposure in the clam *Mactra veneriformis*.	2010	Not North American species, only three exposure concentrations
Farag et al.	Physiological changes and tissue metal accumulation in rainbow trout exposed to foodborne and waterborne metals	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Farag et al.	Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River basin, Idaho	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Farag et al.	Characterizing Aquatic Health Using Salmonid Mortality, Physiology, and Biomass Estimates in Streams with Elevated Concentrations of Arsenic, Cadmium, Copper, Lead, and Zinc in the Boulder River Watershed, Montana	2003	Mixture
Farag et al.	Concentrations of Metals in Water, Sediment exposure, Biofilm, Benthic Macroinvertebrates, and Fish in the Boulder River Watershed, Montana, and the Role of Colloids in Metal Uptake	2007	Bioaccumulation: steady state not documented
Fargasova	Comparative toxicity of five metals on various biological subjects	1994b	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Faria et al.	In situ and laboratory bioassays with *Chironomus riparius* larvae to assess toxicity of metal contamination in rivers: the relative toxic effect of sediment versus water contamination	2007	Mixture
Faria et al.	Contaminant accumulation and multi-biomarker responses in field collected zebra mussels (*Dreissena polymorpha*) and crayfish (*Procambarus clarkii*), to evaluate toxicological effects of industrial hazardous dumps in the Ebro river (NE Spain).	2010	Bioaccumulation: steady state not documented
Farkas et al.	Age- and size-specific patterns of heavy metals in the organs of freshwater fish *Abramis brama* L. populating a low-contaminated site	2003	Bioaccumulation: steady state not documented
Fattorini et al.	Seasonal, Spatial and Inter-Annual Variations of Trace Metals in Mussels From the Adriatic Sea: a Regional Gradient for Arsenic and Implications for Monitoring the Impact of Off-Shore Activities	2008	Bioaccumulation: steady state not documented
Faucher et al.	Impact of acute cadmium exposure on the trunk lateral line neuromasts and consequences on the "C-Start" response behaviour of the sea bass (*Dicentrarchus labrax* L.; Teleostei, Moronidae).	2006	Dilution water not characterized, not North American species, duration too short
Faucher et al.	Impact of cadmium exposure at environmental dose on escape behaviour in sea bass (*Dicentrarchus labrax* L.; Teleostei, Moronidae)	2008	Pulsed exposure, not North American species
Faupel and Traunspurger	Secondary Production of a Zoobenthic Community Under Metal Stress	2012	Mixture
Faupel et al.	The functional response of a freshwater benthic community to cadmium pollution	2012	Sediment; only two exposure concentrations
Fava et al.	Comparative Toxicity of Whole and Liquid Phase Sewage Sludges to Marine Organisms	1985	Sludge
Favorito et al.	Bioaccumulation of cadmium and its cytotoxic effect on zebrafish brain	2011	Bioaccumulation: steady state not documented
Fayed and Abdel-Shafy	Accumulation of Cu, Cd, and Pb by algae	1986	Bioaccumulation: unmeasured exposure
Fdil et al.	Valve movement response of the mussel *Mytilus galloprovincialis* to metals (Cu, Hg, Cd and Zn) and phosphate industry effluents from moroccan Atlantic coast	2006	Duration unknown, dilution water not characterized, not North American species
Felten et al.	Physiological and behavioural responses of *Gammarus pulex* (Crustacea: Amphipoda) exposed to cadmium	2008	Not North American species, test species fed, usually Unused data
Feng et al.	Exploring spatial and temporal variations of cadmium concentrations in Pacific oysters from British Columbia	2011	Bioaccumulation: steady state not documented
Feng et al.	Indication function of aquatic algae for environment	2012	Review of previously published data
Fennikoh et al.	Cadmium toxicity in planktonic organisms of a freshwater food web	1978	The materials, methods or results were insufficiently described
Fernandez and Beiras	Combined Toxicity of Dissolved Mercury with Copper, Lead and Cadmium on Embryogenesis and Early Larval Growth of the Paracentrotus lividus Sea-Urchin	2001	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Fernandez et al.	Assessment of the mechanisms of detoxification of chemical compounds and antioxidant enzymes in the digestive gland of mussels, *Mytilus galloprovincialis*, from Mediterranean coastal sites.	2012	Bioaccumulation: steady state not documented
Fernandez Severini et al.	Spatial and temporal distribution of cadmium and copper in water and zooplankton in the Bahia Blanca estuary, Argentina	2009	Bioaccumulation: steady state not documented
Fernandez-Leborans and Antonio-Garcia	Effects of lead and cadmium in a community of protozoans	1988	The materials, methods or results were insufficiently described
Fernandez-Pinas et al.	Cadmium toxicity in *Nostoc* UAM208: protection by calcium	1995	No interpretable concentration, time, response data or examined only a single exposure concentration
Ferrari et al.	Selective protection of temperature against cadmium acute toxicity to *Bufo arenarum* tadpoles	1993	Not North American species
Ferrari et al.	Energy balance of juvenile *Cyprinus carpio* after a short-term exposure to sublethal water-borne cadmium	2011	Only one exposure concentration
Ferreira da Silva et al.	Heavy Metal Pollution Downstream the Abandoned Coval Da Mo Mine (Portugal) and Associated Effects on Epilithic Diatom Communities	2009	Mixture
Ferreira et al.	Metal Accumulation and Oxidative Stress Responses in, Cultured and Wild, White Seabream from Northwest Atlantic	2008b	Bioaccumulation: steady state not documented
Ferrer et al.	Acute toxicities of four metals on the early life stages of the crab *Chasmagnathus granulata* from Bahia Blanca Estuary, Argentina	2006	Not North American species
Fialkowski et al.	Seasonal variation in trace metal concentrations in three talitrid amphipods from the Gulf of Gdansk, Poland	2003	Bioaccumulation: steady state not documented
Filazi et al.	Metal concentrations in tissues of the Black Sea fish Mugil auratus from Sinop-Icliman, Turkey	2003	Bioaccumulation: steady state not documented
Filosto et al.	Environmentally relevant cadmium concentrations affect development and induce apoptosis of *Paracentrotus lividus* larvae cultured *in vitro*	2008	Not North American species, unmeasured chronic exposure
Finger and Bulak	Toxicity of Water From Three South Carolina Rivers to Larval Striped Bass	1988	Mixture
Finlayson et al.	Toxicity of metal-contaminated Sediment exposures from Keswick Reservoir, California, USA	2000	Sediment exposure
Firat and Kargin	Biochemical alterations induced by Zn and Cd individually or in combination in the serum of *Oreochromis niloticus*	2010a	Only one exposure concentration
Firat and Kargin	Effects of zinc and cadmium on erythrocyte antioxidant systems of a freshwater fish *Oreochromis niloticus*	2010b	Only one exposure concentration
Firat and Kargin	Individual and combined effects of heavy metals on serum biochemistry of Nile *Tilapia oreochromis* Niloticus	2010c	Only one exposure concentration

Authors	**Title**	**Year**	**Reason Unused**
Firat and Kargin	Protein intensity changes in the hemoglobin and plasma electrophoretic patterns of *Oreochromis niloticus* in response to single and combined Zn and Cd exposure	2010d	Only two exposure concentrations
Fisher and Fabris	Complexation of Cu, Zn and Cd by metabolites excreted from marine diatoms	1982	No pertinent adverse effects reported
Fisher et al.	Accumulation and retention of metals in mussels from food and water: a comparison under field and laboratory conditions	1996	Not North American species
Fitzsimons et al.	Occurrence of a Swim-up Syndrome in Lake Ontario Lake Trout in Relation to Contaminants and Cultural Practices	1995	Bioaccumulation: steady state not documented
Flament et al.	Effect of cadmium on gonadogenesis and metamorphosis in *Pleurodeles waltl* (Urodele Amphibian)	2003	Not North American species, duration too short
Fleeger et al.	Does Bioturbation by a Benthic Fish Modify the Effects of Sediment exposure Contamination on Saltmarsh Benthic Microalgae and Meiofauna?	2006	Sediment exposure
Flegal	Trace Element Concentrations of the Rough Limpet, *Acmaea scabra*, in California	1978	Bioaccumulation: steady state not documented
Florence et al.	Determination of trace element speciation and the role of speciation in aquatic toxicity	1992	Review of previously published data
Food and Agriculture Organization of the United Nations	Report on Cadmium and Freshwater Fish	1977	Review
Foran et al.	Influence of parental and developmental cadmium exposure on endocrine and reproductive function in Japanese medaka (*Oryzias latipes*)	2002	Prior exposure, not North American species
Foran et al.	A survey of metals in tissues of farmed Atlantic and wild Pacific salmon	2004	Bioaccumulation: steady state not documented
Forbes	Response of *Hydrobia ventrosa* (Montagu) to environmental stress: Effects of salinity fluctuations and cadmium exposure on growth	1991	Not North American species
Forget et al.	Joint action of pollutant combinations (pesticides and metals) on survival (LC50 values) and acetylcholinesterase activity of *Tigriopus brevicornis* (Copepoda, Harpacticoida)	1999	Mixture
Formicki et al.	Combined effects of cadmium and ultraviolet radiation on mortality and mineral content in common frog (*Rana temporaria*) larvae	2008	Not North American species, duration too short
Formicki et al.	Cadmium Availability to Freshwater Mussel (*Unio tumidus*) in the Presence of Organic Matter and UV Radiation	2009	Mixture
Foster	Metal resistances of chlorophyta from rivers polluted by heavy metals	1982	Organisms were not exposed to cadmium in water
Fowler et al.	Levels of Toxic Metals in Marine Organisms Collected From Southern California Coastal Waters	1975	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Fracacio et al.	In situ and laboratory evaluation of toxicity with *Danio rerio* Buchanan (1822) and *Poecilia reticulata* Peters (1859)	2009	Mixture
France	Calcium and Trace Metal Composition of Crayfish (*Orconectes virilis*) in Relation to Experimental Lake Acidification	1987	Bioaccumulation: steady state not documented
Francesconi	Distribution of cadmium in the pearl oyster, *Pinctada albina albina* (Lamarck), following exposure to cadmium in seawater	1989	Not North American species
Francesconi et al.	Cadmium uptake from seawater and food by the western rock lobster *Panulirus Cygnus*	1994	Not North American species
Francesconi et al.	Cadmium in the saucer scallop, *Amusium balloti*, from Western Australian waters: Concentrations in adductor muscle and redistribution following frozen storage	1993	Bioaccumulation: steady state not documented
Franchi et al.	Bioconcentration of Cd and Pb by the river crab *Trichodactylus fluviatilis* (Crustacea: Decapoda)	2011	Dilution water not characterized
Frankenne et al.	Isolation and characterization of metallothioneins from cadmium-loaded mussel *Mytilus edulis*	1980	Dilution water not characterized
Franklin et al.	Toxicity of Metal Mixtures to a Tropical Freshwater Alga (*Chlorella sp*.): The Effect of Interactions Between Copper, Cadmium, and Zinc on Metal Cell Binding and Uptake	2002	Mixture
Franzellitti et al.	Heavy metals in tissues of loggerhead turtles (*Caretta caretta*) from the northwestern Adriatic Sea	2004	Bioaccumulation: steady state not documented
Franzin and McFarlane	An Analysis of the Aquatic Macrophyte, *Myriophyllum exalbescens*, as an Indicator of Metal Contamination of Aquatic Ecosystems Near a Base Metal Smelter	1980	Bioaccumulation: steady state not documented
Fraser et al.	Spatial and Temporal Distribution of Heavy Metal Concentrations in Mussels (*Mytilus edulis*) From the Baie Des Chaleurs, New Brunswick, Canada	2011	Bioaccumulation: steady state not documented
Frazier	Bioaccumulation of cadmium in marine organisms	1979	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Frazier and George	Cadmium kinetics in oyster - a comparative study of *Crassostrea gigas* and *Ostrea edulis*	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Freeman	Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress	1978	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	Title	Year	Reason Unused
Freeman	Accumulation of cadmium, chromium, and lead by bluegill sunfish (*Lepomis macrochirus* Rafinesque) under temperature and oxygen stress	1980	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Freitas and Rocha	Acute toxicity tests with the tropical cladoceran *Pseudosida ramosa*: The importance of using native species as test organisms	2011	Not North American species
Frias-Espericueta et al.	Heavy Metals in the Tissues of the Sea Turtle *Lepidochelys olivacea* From a Nesting Site of the Northwest Coast of Mexico	2006	Bioaccumulation: steady state not documented
Frias-Espericueta et al.	Metal Content of the Gulf of California Blue Shrimp *Litopenaeus stylirostris* (Stimpson)	2007	Bioaccumulation: steady state not documented
Frias-Espericueta et al.	Histological effects of a combination of heavy metals on Pacific white shrimp *Litopenaeus vannamei*	2008a	Mixture
Frias-Espericueta et al.	The Metal Content of Bivalve Molluscs of a Coastal Lagoon of NW Mexico	2008b	Bioaccumulation: steady state not documented
Frias-Espericueta et al.	Cadmium, copper, lead, and zinc in Mugil cephalus from seven coastal lagoons of NW Mexico	2011	Bioaccumulation: steady state not documented
Fridman et al.	Estradiol uptake, toxicity, metabolism, and adverse effects on cadmium-treated amphibian embryos	2004	Mixture, not North American species
Friedrich and Halden	Determining exposure history of northern pike and walleye to tailings effluence using trace metal uptake in otoliths	2010	Bioaccumulation: steady state not documented
Fritioff and Greger	Uptake and distribution of Zn, Cu, Cd, and Pb in an aquatic plant, *Potamogeton natans*	2006	Bioaccumulation: steady state not documented (only 5 day exposure); unmeasured exposure
Fritioff et al.	Influence of Temperature and Salinity on Heavy Metal Uptake by Submersed Plants	2005	Non-applicable
Fujii and Sugiyama	Toxic effect of cadmium to early life stages of fishes and a simple method for toxicity evaluation of environmental pollutants	1983	Not applicable per ECOTOX Duluth; text in foreign language
Fulladosa et al.	Study on the Toxicity of Binary Equitoxic Mixtures of Metals Using the Luminescent Bacteria *Vibrio fischeri* as a Biological Target	2005	Mixture
Fulladosa et al.	Stress proteins induced by exposure to sublethal levels of heavy metals in sea bream (*Sparus sarba*) blood levels	2006	Excised tissue/cells
Gaal et al.	The Heavy Metal Content Of Fish In Lake Balaton The Danube And The Tisza From 1979-1982	1984	Bioaccumulation: steady state not documented
Gachter	Heavy Metal Toxicity and Synergism to Natural Phytoplankton (Untersuchungen Uber Die Beeinflussung Der Planktischen Photosynthese Durch Anorganische Metallsalze Im Eutrophen Alpnachersee Und Der Mesotrophen Horwer Bucht)	1976	Text in foreign language
Gachter and Geiger	Melimex, an Experimental Heavy Metal Pollution Study: Behaviour of Heavy Metals in an Aquatic Food Chain	1979	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Gachter and Mares	Melimex, an Experimental Heavy Metal Pollution Study: Effects of Increased Heavy Metal Loads on Phytoplankton Communities	1979	Mixture
Gaete and Paredes	Toxicity of chemical pollutant mixtures towards *Daphnia magna*	1996	Non-applicable
Gagnaire et al.	In vitro effects of cadmium and mercury on Pacific oyster, *Crassostrea gigas* (Thunberg), haemocytes	2004	In vitro
Gagne et al.	Biomarker study of a municipal effluent dispersion plume in two species of freshwater mussels	2002	Effluent
Gagne et al.	Immunocompetence and Alterations in Hepatic Gene Expression in Rainbow Trout Exposed to Cds/Cdte Quantum Dots.	2010	Inappropriate toxicant
Gagnon et al.	Exposure of Caged Mussels to Metals in a Primary-Treated Municipal Wastewater Plume	2006	Effluent
Gale et al.	Aquatic Organisms and Heavy Metals in Missouri's New Lead Belt.	1973	Bioaccumulation: steady state not documented
Gale et al.	Lead, Zinc, Copper, and Cadmium in Fish and Sediment exposures from the Big River and Flat River Creek of Missouri's Old Lead Belt	2004	Bioaccumulation: steady state not documented
Gale et al.	Chronic Sublethal Sediment exposure Toxicity Testing Using the Estuarine Amphipod, *Melita plumulosa* (Zeidler): Evaluation Using Metal-Spiked and Field-Contaminated Sediment exposures	2006	Sediment exposure
Galic et al	Toxicity of cadmium and nitrilotriacetic acid in sea water to the photobacteria *Vibrio fisheri*	1987	The materials, methods or results were insufficiently described
Gallo et al.	The impact of metals on the reproductive mechanisms of the ascidian *Ciona intestinalis*	2011	Excised tissue/cells
Galvao et al.	Sudden Cadmium Increases in the Digestive Gland of Scallop, *Nodipecten nodosus* L., Farmed in the Tropics	2010	Bioaccumulation: steady state not documented
Gama-Flores et al.	Exposure time-dependent cadmium toxicity to *Moina macrocopa* (Cladocera): a life table demographic study	2007a	Pulsed exposure
Gama-Flores et al.	Effect of Pulsed Exposure to Heavy Metals (Copper and Cadmium) on Some Population Variables of *Brachionus calyciflorus* Pallas (Rotifera: Brachionidae: Monogononta)	2007b	Pulsed exposure
Gama-Flores et al.	Prey (*Brachionus calyciflorus* and *Brachionus havanaensis*) Exposed to Heavy Metals (Cu and Cd) for Different Durations and Concentrations Affect Predator's (*Asplanchna brightwellii*) Population Growth	2007c	Pulsed exposure
Gao et al.	Expression of metallothionein cDNA in a freshwater crab, *Sinopotamon yangtsekiense*, exposed to cadmium	2012	Dilution water not characterized
Garceau et al.	Inhibition of Goldfish Mitochondrial Metabolism by in Vitro Exposure to Cd, Cu and Ni	2010	In vitro
Garcia et al.	Comparative sensitivity of a tropical mysid metamysidopsis insularis and the temperate species *Americamysis bahia* to six toxicants	2008	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Garcia et al.	Age-related differential sensitivity to cadmium in *Hyalella curvispina* (Amphipoda) and implications in ecotoxicity studies	2010	Not North American species; test species fed
Garcia et al.	Age differential response of *Hyalella curvispina* to a cadmium pulse: Influence of sediment particle size	2012	Pulsed exposures; sediment present in test chambers
Garcia-Fernandez et al.	Heavy Metals in Tissues From Loggerhead Turtles (*Caretta caretta*) From the Southwestern Mediterranean (Spain)	2009	Bioaccumulation: steady state not documented
Garcia-Hernandez et al.	Concentrations of heavy metals in Sediment exposure and organisms during a harmful algal bloom (HAB) at Kun Kaak Bay, Sonora, Mexico	2005	Bioaccumulation: steady state not documented
Garcia-Santos et al.	Metabolic and osmoregulatory alterations and cell proliferation in gilthead seam bream (*Sparus aurata*) exposed to cadmium	2008	Injected toxicant
Garg and Chandra	The duckweed *Wolffia globosa* as an indicator of heavy metal pollution: sensitivity to Cr and Cd	1994	Excessive EDTA (>200 ug/L FeEDTA)
Garg et al.	Sublethal effects of heavy metals on biochemical composition and their recovery in Indian major carps	2009	Not North American species, unmeasured chronic exposure
Gargiulo et al.	Action of cadmium on the gills of *Carassius auratus* L. in the presence of catabolic NH_3	1996	No useable data on cadmium toxicity or bioconcentration
Gauley and Heikkila	Examination of the expression of the heat shock protein gene, hsp110, in *Xenopus laevis* cultured cells and embryos	2006	Cannot determine effect concentration, lack of details
Gaur et al.	Relationship between heavy metal accumulation and toxicity in *Spirodela polyrhiza* (L.) Schleid. and *Azolla pinnata* R	1994	Not North American species
Gauthier et al.	Metal effects on fathead minnows (*Pimephales promelas*) under field and laboratory conditions	2006	Mixture
Gauthier et al.	Condition and Pyloric Caeca as Indicators of Food Web Effects in Fish Living in Metal-Contaminated Lakes	2009	Bioaccumulation: steady state not documented
Geffard et al.	Relationships between metal bioaccumulation and metallothionein levels in larvae of *Mytilus galloprovincialis* exposed to contaminated estuarine Sediment exposure elutriate	2002	Sediment exposure
Geffard et al.	Bioaccumulation of Metals in Sediment exposure Elutriates and Their Effects on Growth, Condition Index, and Metallothionein Contents in Oyster Larvae	2007	Mixture
Geffard et al.	Effects of chronic dietary and waterborne cadmium exposures on the contamination level and reproduction of *Daphnia magna*	2008	Cannot determine effect concentration, lack of details
Geffard et al.	Ovarian cycle and embryonic development in *Gammarus fossarum*: Application for reproductive toxicity assessment	2010	Not North American species, only three exposure concentrations
George et al.	Effects of cadmium exposure on metal-containing amoebocytes of the oyster *Ostrea edulis*	1983	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	**Title**	**Year**	**Reason Unused**
Geret and Cosson	Induction of specific isoforms of metallothionein in mussel tissues after exposure to cadmium and mercury	2002	Bioaccumulation: steady state not documented; dilution water not characterized
Geret et al.	Effect of cadmium on antioxidant enzyme activities and lipid peroxidation in the gills of the clam *Ruditapes decussatus*	2002a	Dilution water not characterized, not North American species
Geret et al.	Influence of metal exposure on metallothionein synthesis and lipid peroxidation in two bivalve mollusks: The oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*)	2002b	Dilution water not characterized, only one exposure concentration
Gerhardt	Effects of subacute doses of cadmium on pH-stressed *Leptophlebia marginata* (L.) And *Baetis rhodani* Pictet (Insecta: Ephemeroptera)	1990	Dilution water not characterized, mixture, sediment
Gerhardt	Acute toxicity of Cd in stream invertebrates in relation to pH and test design	1992	Not North American species
Gerhardt	Review of Impact of Heavy Metals on Stream Invertebrates With Special Emphasis on Acid Conditions	1993	Review
Gerhardt	Joint and single toxicity of Cd and Fe related to metal uptake in the mayfly *Leptophlebia marginata* (L.) (Insecta)	1995	Not North American species
Gharbi-Bouraoui et al.	Field Study of Metal Concentrations and Biomarker Responses in the Neogastropod, *Murex trunculus*, From Bizerta Lagoon (Tunisia)	2008	Bioaccumulation: steady state not documented
Ghedira et al.	Metallothionein and metal levels in liver, gills and kidney of *Sparus aurata* exposed to sublethal doses of cadmium and copper	2010	Injected toxicant
Ghiasi et al.	Effects of low concentration of cadmium on the level of lysozyme in serum, leukocyte count and phagocytic index in *Cyprinus carpio* under the wintering conditions	2010	Only one exposure concentration
Ghidini et al.	Cd, Hg and As Concentrations in Fish Caught in the North Adriatic Sea	2003	Bioaccumulation: steady state not documented
Ghnaya et al.	Cd-induced growth reduction in the halophyte *Sesuvium portulacastrum* is significantly improved by NaCl	2007	Lack of details
Ghosh and Chakrabarti	Toxicity of arsenic and cadmium to a freshwater fish	1990	Not North American species
Giarratano et al.	Heavy metal toxicity in *Exosphaeroma gigas* (Crustacea, Isopoda) from the coastal zone of beagle channel	2007	Not North American species
Giesy and Wiener	Frequency Distributions of Trace Metal Concentrations in Five Freshwater Fishes	1977	Bioaccumulation: steady state not documented
Giguere et al.	Influence of lake chemistry and fish age on cadmium, copper, and zinc concentrations in various organs of indigenous yellow perch (*Perca flavescens*)	2004	Bioaccumulation: steady state not documented
Giguere et al.	Metal bioaccumulation and oxidative stress in yellow perch (*Perca flavescens*) collected from eight lakes along a metal contamination gradient (Cd, Cu, Zn, Ni)	2005	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Gil et al.	Heavy metal concentrations in the general population of Andalusia, South of Spain: A comparison with the population within the area of influence of Aznalcóllar mine spill (SW Spain)	2006	Bioaccumulation: steady state not documented
Giles	Accumulation of cadmium by rainbow trout, *Salmo gairdneri*, during extended exposure	1988	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Gillis et al.	Cadmium-Induced Production of a Metallothioneinlike Protein in *Tubifex tubifex* (Oligochaeta) and *Chironomus riparius* (Diptera): Correlation with Reproduction and Growth	2002	Non-applicable
Gillis et al.	Uptake and Depuration of Cadmium, Nickel, and Lead in Laboratory-Exposed *Tubefix tubifex* and Corresponding Changes in the Concentration of a Metallothionein-Like Protein	2004	Non-applicable
Gillis et al.	Metallothionein-Like Protein and Tissue Metal Concentrations in Invertebrates (Oligochaetes and Chironomids) Collected From Reference and Metal Contaminated Field Sediment exposures	2006a	Bioaccumulation: steady state not documented
Gillis et al.	Bioavailability of Sediment exposure-Associated Cu and Zn to *Daphnia magna*	2006b	Sediment exposure
Gingrich et al.	Zinc and cadmium metabolism in *Euglena gracilis*: metal distribution in normal and zinc-deficient cells	1984	No control group; only one exposure concentration
Gismondi et al.	Microsporidia parasites disrupt the responses to cadmium exposure in a gammarid	2012a	Multiple stressors (Cd and parasite)
Gismondi et al.	Acanthocephalan parasites: Help or burden in gammarid amphipods exposed to cadmium?	2012b	Not North American species
Gismondi et al.	Do male and female gammarids defend themselves differently during chemical stress?	2013	Not North American species, only two exposure concentrations
Giusto et al.	Cadmium toxicity assessment in juveniles of the Austral South America amphipod *Hyalella curvispina*.	2012	Not North American species; only 3 exposure concentrations, duration too long
Glubokov	Growth of three species of fish during early ontogeny under normal and toxic conditions	1990	The materials, methods or results were insufficiently described
Glynn	The concentration dependency of branchial intracellular cadmium distribution and influx in the zebrafish (*Brachydanio rerio*)	1996	Not North American species
Glynn	The Influence of Zinc on Apical Uptake of Cadmium in the Gills and Cadmium Influx to the Circulatory System in Zebrafish (*Danio rerio*)	2001	Mixture
Glynn et al.	Chronic toxicity and metabolism of Cd and Zn in juvenile minnows (*Phoxinus phoxinus*) exposed to a Cd and Zn mixture.	1992	Not North American species
Glynn et al.	Differences in uptake of inorganic mercury and cadmium in the gills of the zebrafish, *Brachydanio rerio*	1994	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Gnandi et al.	The Impact of Phosphate Mine Tailings on the Bioaccumulation of Heavy Metals in Marine Fish and Crustaceans from the Coastal Zone of Togo	2006	Bioaccumulation: steady state not documented
Goatcher et al.	Evaluation and Refinement of the Spirillum volutans Test for Use in Toxicity Screening	1984	Bacteria
Gold et al.	Effects of cadmium stress on periphytic diatom communities in indoor artificial streams	2003	No specific species
Golding et al.	Cadmium bioavailability to *Hyalella azteca* from a periphyton diet compared to an artificial diet and application of a biokinetic model	2013	Dietary exposure
Golding et al.	Validation of a chronic dietary cadmium bioaccumulation and toxicity model for *Hyalella azteca* exposed to field-contaminated periphyton and lake water	2011a	Prior exposure
Golding et al.	Modeling chronic dietary cadmium bioaccumulation and toxicity from periphyton to *Hyalella azteca*	2011b	Water and dietary exposure simultaneously
Gomez-Mendikute and Cajaraville	Comparative Effects of Cadmium, Copper, Paraquat and Benzo[a]pyrene on the Actin Cytoskeleton and Production of Reactive Oxygen Species (ROS) in Mussel Haemocytes	2003	In vitro
Gomot	Toxic effects of cadmium on reproduction, development, and hatching in the freshwater snail *Lymnaea stagnalis* for water quality monitoring	1998	No useable data on cadmium toxicity or bioconcentration
Gonzalez et al.	Comparative effects of direct cadmium contamination on gene expression in gills, liver, skeletal muscles and brain of zebrafish (*Danio rerio*)	2006	Bioaccumulation: steady state not documented
Gopal and Devi	Influence of nutritional status on the median tolerance limits (LC50) of *Ophiocephalus striatus* for certain heavy metal and pesticide toxicants	1991	Not North American species
Gopalakrishnan et al.	Comparison of heavy metal toxicity in life stages (spermiotoxicity, egg toxicity, embryotoxicity and larval toxicity) of *Hydroides elegans*	2008	Not North American species
Gordon et al.	*Mytilus californianus* as a bioindicator of trace metal pollution: Variability and statistical considerations	1980	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Gorman and Skogerboe	Speciation of cadmium in natural waters and their effect on rainbow trout	1987	The materials, methods or results were insufficiently described
Gorski and Nugegoda	Sublethal toxicity of trace metals to larvae of the blacklip abalone, *Haliotis rubra*.	2006a	Dilution water not characterized, high control mortality (<13%), not North American species
Gorski and Nugegoda	Toxicity of trace metals to juvenile abalone, *Haliotis rubra* following short-term exposure	2006b	Dilution water not characterized, not North American species
Gosselin and Hare	Effect of Sedimentary exposure Cadmium on the Behavior of a Burrowing Mayfly (Ephemeroptera, Hexagenia limbata)	2004	Sediment exposure
Goto and Wallace	Interaction of Cd and Zn During Uptake and Loss in the Polychaete *Capitella capitata*: Whole Body and Subcellular Perspectives	2007	Mixture

Authors	Title	Year	Reason Unused
Goto and Wallace	Relevance of intracellular partitioning of metals in prey to differential metal bioaccumulation among populations of mummichogs (*Fundulus heteroclitus*)	2009a	Bioaccumulation: steady state not documented
Goto and Wallace	Influences of prey- and predator-dependent processes on cadmium and methylmercury trophic transfer to mummichogs (*Fundulus heteroclitus*)	2009b	Dietary exposure
Gottofrey and Tjalve	Axonal transport of cadmium in the olfactory nerve of the pike	1991	Organisms were exposed to cadmium in food or by injection or gavage
Gottofrey et al.	Effect of sodium isopropylxanthate, potassium amylxanthate and sodium diethyldithiocarbamate or the uptake and distribution of cadmium in the brown trout (*Salmo trutta*)	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Goulet et al.	Dynamic multipathway modeling of Cd bioaccumulation in *Daphnia magna* using waterborne and dietary exposures	2007	Dietary exposure
Grabowski and Trybus	Some Results on Toxicity of Heavy Metals, Fly Ash and Chemical Solvents as Measured by the Method of a Substrate (FDA) With Fluorogenic Product (Badania Toksycznosci Metali Ciezkich, Pylu Lotnego I Rozpuszczalnikow Chemicznych Metoda Substratu Z Fluorogennym Produktem)	2001	Text in foreign language
Grajeda Y Ortega et al.	Cadmium, iron, and zinc uptake individually and as a mixture by *Limnodrillus hoffmeisteri* and impact on adenosine triphosphate content	2008	Sediment exposure
Graney et al.	The influence of substrate, pH, diet and temperature upon cadmium accumulation in the asiatic clam (*Corbicula fluminea*) in laboratory artificial streams	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Green and Williams	A continuous flow toxicity testing apparatus for macroinvertebrates	1983	Cannot determine effect concentration; testing methodology; no cadmium toxicity information
Green et al.	The acute and chronic toxicity of cadmium to different life history stages of the freshwater crustacean *Asellus aquaticus* (L)	1986	Not North American species
Greenwood and Fielder	Acute toxicity of zinc and cadmium to zoeae of three species of portnid crabs (Crustacea: Brachyura)	1983	Not North American species
Greichus et al.	Insecticides, Polychlorinated Biphenyls and Metals in African Lake Ecosystems. II. Lake Mcilwaine, Rhodesia	1978	Bioaccumulation: steady state not documented
Greig	Trace metal uptake by three species of mollusks	1979	Questionable treatment of test organisms or inappropriate test conditions or methodology
Greig and Wenzloff	Metal accumulation and depuration by the american oyster, *Crassostrea virginica*	1978	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water

Authors	Title	Year	Reason Unused
Griscom and Fisher	Uptake of Dissolved Ag, Cd, and Co by the Clam, *Macoma balthica*: Relative Importance of Overlying Water, Oxic Pore Water, and Burrow Water	2002	Mixture
Griscom et al.	Effects of Gut Chemistry in Marine Bivalves on the Assimilation of Metals from Ingested Sediment exposure Particles	2002a	Sediment exposure
Griscom et al.	Kinetic modeling of Ag, Cd and Co bioaccumulation in the clam *Macoma balthica*: quantifying Dietary exposure and dissolved sources	2002b	Modeling
Gross et al.	Lethal and sublethal effects of chronic cadmium exposure on northern leopard frog (*Rana pipiens*) tadpoles	2007	High control mortality (60%)
Gross et al.	Critical period of sensitivity for effects of cadmium on frog growth and development	2009	Only two exposure concentrations
Gstoettner and Fisher	Accumulation of cadmium, chromium, and zinc by the moss *Sphagnum papillosum* Lindle	1997	Bioaccumulation: not renewal or flow-through
Gu et al.	The toxic effect of Hg2+ and Cd2+ combined pollution on *Myriophyllum verticillatum* Linn	2001	Text in foreign language
Guan and Wang	Multipahse biokinetic modeling of cadmium accumulation in *Daphnia magna* from dietary and aqueous sources	2006c	Bioaccumulation: steady state not documented, dietary exposure
Guan and Wang	Cd and Zn uptake kinetics in *Daphnia magna* to Cd exposure history	2004a	Dietary exposure and prior exposure
Guan and Wang	Dietary assimilation and elimination of Cd, Se, and Zn by *Daphnia magna* at different metal concentrations	2004b	Dietary exposure
Guan and Wang	Multigenerational cadmium acclimation and biokinetics in *Daphnia magna*	2006a	Dietary exposure
Guan and Wang	Comparison between two clones of *Daphnia magna*: effects of multigenerational cadmium exposure on toxicity, individual fitness, and biokinetics	2006b	Lack of detail
Guardiola et al.	Accumulation, histopathology and immunotoxicological effects of waterborne cadmium on gilthead seabream (*Sparus aurata*)	2013	Only two exposure concentrations
Gueguen et al.	Competition Between Alga (*Pseudokirchneriella subcapitata*), Humic Substances and EDTA for Cd and Zn Control in the Algal Assay Procedure (AAP) Medium	2003	Mixture
Guerin et al.	Effects of cadmium on survival, osmoregulatory ability and bioenergetics of juvenile blue crabs *Callinectes sapidus* at different salinities.	1994	The materials, methods or results were insufficiently described
Guilhermino et al.	Inhibition of acetylcholinesterase activity as effect criterion in acute tests with juvenile *Daphnia magna*.	1997	Review of previously published data
Gul et al.	Investigation of Zinc, Copper, Lead and Cadmium Accumulation in the Tissues of *Sander lucioperca* (L., 1758) Living in Hirfanli Dam Lake, Turkey.	2011	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Gully and Mason	Cytosolic redistribution and enhanced accumulation of Cu in gill tissue of *Littorina littorea* as a result of Cd exposure	1993	Mixture (Cu and Cd), Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Guner	Effects of Copper and Cadmium Interaction on Total Protein Levels in Liver of *Carassius carassius*	2008	Mixture
Gunkel et al.	A Fish Test on the Basic of the Avoidance Reaction (Die Fluchtreaktion Von Fischen Als Grundlage Eines Fischtests).	1983	Text in foreign language
Guo et al.	Effect of dissolved organic matter on the uptake of trace metals by American oysters	2001	Mixture
Guo et al.	Levels and Bioaccumulation of Organochlorine Pesticides (OCPS) and Polybrominated Diphenyl Ethers (PBDES) in Fishes From the Pearl River Estuary and Daya Bay, South China	2008	Bioaccumulation: steady state not documented
Gupta and Devi	Uptake and toxicity of cadmium in aquatic ferns	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Gupta and Rajbanshi	Toxicity of copper and cadmium to *Heteropneustes fossilis* (Bloch)	1991	Not North American species
Gupta et al.	Effects of long-term low-dose exposure to cadmium during the entire life cycle of *Ceratopteris thalictroides*, a water fern	1992	Not North American species
Gupta et al.	Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad	2009	Bioaccumulation: steady state not documented
Gust and Fleeger	Exposure-related effects on Cd bioaccumulation explain toxicity of Cd-phenanthrene mixtures in *Hyalella azteca*	2005	Bioaccumulation: steady state not documented (only 96 hour exposure)
Gust and Fleeger	Exposure to Cadmium-Phenanthrene Mixtures Elicits Complex Toxic Responses in the Freshwater Tubificid Oligochaete, *Ilyodrilus templetoni*	2006	Non-applicable
Guthrie and Cherry	Trophic Level Accumulation of Heavy Metals in a Coal Ash Basin Drainage System	1979	Bioaccumulation: steady state not documented
Guven and De Pomerai	Differential Expression of Hsp70 Proteins in Response to Heat and Cadmium in *Caenorhabditis elegans*	1995	Mixture
Guven et al.	Heavy Metals Concentrations in Marine Algae From the Turkish Coast of the Black Sea	2007	Bioaccumulation: steady state not documented
Guzman-Garcia et al.	Effects of heavy metals on the oyster (*Crassostrea virginica*) at Mandinga Lagoon, Veracruz, Mexico.	2009	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Hackstein	Changes in the Population Dynamics of *Gammarus tigrinus* Sexton (Crustacea: Amphipoda) as Expression of Sublethal Effects by Reciprocal Interactions of Temperature and Cadmium Enriched Food (Die Veranderung Populations Dynamischer Parameter Bei Gammarus Tigrinus Sexton (Crustacea: Amphipoda) Ala Ausdruck Subletaler Effekte Durch Die Wechselwirkung Von Temperatur Und Cadmium Kontaminiertem Futter)	1988	Text in foreign language
Hader et al.	The Erlanger flagellate test (EFT): photosynthetic flagellates in biological dosimeters	1997	Not North American species
Hadjispyrou et al.	Toxicity, Bioaccumulation, and Interactive Effects of Organotin, Cadmium, and Chromium on Artemia franciscana	2001	Mixture
Haines and Brumbaugh	Metal concentration in the gill, gastrointestinal tract, and carcass of white suckers (*Catostomus commersoni*) in relation to lake acidity	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hakanson	Metals in Fish and Sediments From the River Kolbacksan Water System, Sweden	1984	Sediment
Hall	Studies of Striped Bass in Three Chesapeake Bay Spawning Habitats	1988	Mixture
Hall and Brown	Copper and Manganese Influence the Uptake of Cadmium in Marine Macroalgae	2002	Mixture
Hall et al.	Effects of organic and inorganic chemical contaminants on fertilization, hatching success, and prolarval survival of striped bass	1984	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hall et al.	Survival of Striped Bass Larvae and Yearlings in Relation to Contaminants and Water Quality in the Upper Chesapeake Bay	1987a	Mixture
Hall et al.	*In situ* striped bass (*Morone saxatilis*) contaminant and water quality studies in the Potomac River	1987b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hall et al.	Concurrent mobile on-site and *in situ* striped bass contaminant and water quality studies in the Choptank River and upper Chesapeake Bay	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hall et al.	Ambient Toxicity Testing in the Chesapeake Bay Watershed Using Freshwater and Estuarine Water Column Tests	1992	Mixture
Hall et al.	A ten-year summary of concurrent ambient water column and Sediment exposure toxicity tests in the Chesapeake Bay watershed: 1990-1999	2002	Review
Hamed and Emara	Marine Molluscs as Biomonitors for Heavy Metal Levels in the Gulf of Suez, Red Sea	2006	Bioaccumulation: steady state not documented
Hameed and Muthukumaravel	Impact of cadmium on the biochemical constituents of fresh water fish *Oreochromis mossambicus*.	2006	Lack of exposure details, dilution water not characterized
Hammock et al.	The effect of humic acid on the uptake of mercury(II), cadmium(II), and zinc(II) by Chinook salmon (*Oncorhynchus tshawytscha*) eggs	2003	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Hanafy and Soltan	Comparative changes in absorption, distribution and toxicity of copper and cadmium chloride in toads during the hibernation and the role of vitamin C against their toxicity	2007	Dietary exposure, not North American species
Handy	The effect of acute exposure to dietary Cd and Cu organ toxicant concentrations in rainbow trout, *Oncorhynchus mykiss*	1993	Organisms were exposed to cadmium in food or by injection or gavage
Handy	Dietary Exposure to Toxic Metals in Fish	1996	Review
Hannam et al.	Immune Modulation in the Blue Mussel *Mytilus edulis* Exposed to North Sea Produced Water	2009	Mixture
Hannas et al.	Regulation and Dysregulation of Vitellogenin MRNA Accumulation in Daphnids (*Daphnia magna*).	2011	In vitro
Hansen et al.	Accumulation of copper, zinc, cadmium and chromium by the marine sponge *Halichondria panicea* Pallas and the implications for biomonitoring	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hansen et al.	Behavioral Avoidance: Possible Mechanism for Explaining Abundance and Distribution of Trout Species in a Metal-Impacted River	1999	Mixture
Hansen et al.	Gill Metal Binding and Stress Gene Transcription in Brown Trout (*Salmo trutta*) Exposed to Metal Environments: the Effect of Pre-Exposure in Natural Populations	2007a	Pre-exposure
Hansen et al.	Induction and activity of oxidative stress-related proteins during waterborne Cd/Zn exposure in brown trout (*Salmo trutta*)	2007b	Mixture
Hanson and Evans	Metal Contaminant Assessment For The Southeast Atlantic And Gulf Of Mexico Coasts: Results Of The National Benthic Surveillance Project Over The First Four Years 1984-87	1992	Review
Hansten et al.	Viability of glochidia of *Anodonta anatina* (Unionidae) exposed to selected metals and chelating agents	1996	Not North American species
Harada et al.	Shortened Lifespan of Nematode *Caenorhabditis elegans* After Prolonged Exposure to Heavy Metals and Detergents	2007	Mixture
Hardy and O'Keeffe	Cadmium uptake by the water hyacinth: Effects of root mass, solution volume, complexers and other metal ions	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hardy and Raber	Zinc uptake by the water hyacinth: Effect of solution factors	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hare	Aquatic insects and trace metals: bioavailability, bioaccumulation, and toxicity	1992	Review of previously published data
Hare et al.	Trace Element Distributions in Aquatic Insects: Variations Among Genera, Elements, and Lakes	1991a	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Hare et al.	Dynamics of cadmium, lead, and zinc exchange between nymphs of the burrowing mayfly *Hexagenia rigida* (Ephemeroptera) and the environment	1991b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hare et al.	A field study of metal toxicity and accumulation by benthic invertebrates; implications for the acid-volatile sulfide (AVS) model	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hare et al.	Cadmium Accumulation by Invertebrates Living at the Sediment exposure-Water Interface	2001	Sediment exposure
Haritonidis et al.	Trace metal interactions in the macroalga *Enteromorpha prolifera* (O.F. Muller) grown in water of the Scheldt estuary (Belgium and SW Netherlands), in response to cadmium exposure	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Harper et al.	Effects of Acclimation on the Toxicity of Stream Water Contaminated with Zinc and Cadmium to Juvenile Cutthroat Trout	2008	Mixture
Harper et al.	Trout Density and Health in a Stream With Variable Water Temperatures and Trace Element Concentrations: Does a Cold-Water Source Attract Trout to Increased Metal Exposure?	2009	Mixture
Hartmann	Synergistic Effects of Heavy Metal Ions on the Activity of Bacteria and Other Aquatic Microorganisms	1980	Bacteria
Hartmann et al.	Algal Testing of Titanium Dioxide Nanoparticles - Testing Considerations, Inhibitory Effects and Modification of Cadmium Bioavailability	2010	Mixture
Hartmann et al.	The Potential of Tio2 Nanoparticles as Carriers for Cadmium Uptake in *Lumbriculus variegatus* and *Daphnia magna*	2012	Mixture
Hartwell	Demonstration of a toxicological risk ranking method to correlate measures of ambient toxicity and fish community diversity	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hartwell et al.	Avoidance Responses of Schooling Fathead Minnows (Pimephales Promelas) to a Blend of Metals During a 9-Month Exposure.	1987	Mixture
Hartwell et al.	Fish Behavioral Assessment of Pollutants.	1988	Mixture
Harvey and Luoma	Separation of solute and particulate vectors of heavy metal uptake in controlled suspension-feeding experiments with *Macoma balthica*	1985a	No useable data on cadmium toxicity or bioconcentration
Harvey et al.	Contaminant Concentrations in Whole-Body Fish and Shellfish From US Estuaries	2008	Bioaccumulation: steady state not documented
Hashemi et al.	Copper resistance in *Anabaena variabilis*: effects of phosphate nutrition and polyphosphate bodies	1994	Not applicable; No cadmium toxicity information
Hashim and Chu	Biosorption by brown, green, and red seaweeds	2004	Not in vivo study
Hashim et al.	Adsorption equilibria of cadmium on algal biomass	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	Title	Year	Reason Unused
Has-Schon et al.	Heavy Metal Profile in Five Fish Species Included in Human Diet, Domiciled in the End Flow of River Neretva (Croatia)	2006	Bioaccumulation: steady state not documented
Has-Schon et al.	Heavy Metal Concentration in Fish Tissues Inhabiting Waters of "Busko Blato" Reservoir (Bosnia and Herzegovina)	2008a	Bioaccumulation: steady state not documented
Has-Schon et al.	Heavy Metal Distribution in Tissues of Six Fish Species Included in Human Diet, Inhabiting Freshwaters of the Nature Park (Bosnia and Herzegovina)	2008b	Bioaccumulation: steady state not documented
Hatakeyama	Chronic effects of Cd on reproduction of *Polypedilum nubifer* (Chironomidae) through water and food	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hatakeyama and Yasuno	The effects of cadmium-accumulated *Chlorella* on the reproduction of *Moina macrocopa* (Cladocera)	1981a	Organisms were not exposed to cadmium in water
Hatakeyama et al.	Flora and Fauna in Heavy Metal Polluted Rivers. I. Density of *Epeorus latifolium* (Ephemeroptera) and Heavy Metal Concentrations of *Baetis spp*. (Ephemeroptera) Relating to Cd, Cu and Zn Concentrations.	1986	Text in foreign language
Hatano and Shoji	Toxicity of Copper and Cadmium in Combinations to Duckweed Analyzed by the Biotic Ligand Model	2008	Mixture
Hattink et al.	The toxicokinetics of cadmium in carp under normoxic and hypoxic conditions	2005	Species tested is a hybrid of wild and domestic populations
Haye et al.	Protective Role of Alginic Acid Against Metal Uptake by American Oyster (*Crassostrea virginica*)	2006	Mixture
Haynes et al.	Gender-dependent problems in toxicity tests with *Ceriodaphnia dubia*	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hazen and Kneip	Biogeochemical cycling of cadmium in a marsh ecosystem	1980	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Hedouin et al.	Allometric Relationships in the Bioconcentration of Heavy Metals by the Edible Tropical Clam *Gafrarium tumidum*	2006	Bioaccumulation: steady state not documented
Hedouin et al.	Trends in Concentrations of Selected Metalloid and Metals in Two Bivalves From the Coral Reefs in the SW Lagoon of New Caledonia	2009	Bioaccumulation: steady state not documented
Heininger et al.	Nematode Communities in Contaminated River Sediment exposures	2006	Sediment exposure
Heinis et al.	Short-term sublethal effects of cadmium on the filter feeding chironomid larva *Glyptotendipes pallens* (Meigen) (Diptera)	1990	Not North American species
Heit and Klusek	Trace Element Concentrations in the Dorsal Muscle of White Suckers and Brown Bullheads From Two Acidic Adirondack Lakes	1985	Bioaccumulation: steady state not documented
Heit et al.	Trace Element, Radionuclide, and Polynuclear Aromatic Hydrocarbon Concentrations in Unionidae Mussels From Northern Lake George.	1980	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Hendriks	Modelling equilibrium concentrations of microcontaminants in organisms of the Rhine delta: Can average field residues in the aquatic food chain be predicted from laboratory accumulation?	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hendrix et al.	Microcosms as test systems for the ecological effects of toxic substances: an appraisal with cadmium	1981	Mixed species exposure, only three exposure concentrations
Henebry and Ross	Use of Protozoan Communities to Assess the Ecotoxicological Hazard of Contaminated Sediments.	1989	Mixture
Henry et al.	Contamination accidentelle par le cadmium d'un mollusque *Rudifapes decussatus*: bioaccumulation et toxicite	1984	Not North American species
Henry et al.	Heavy metals in four fish species from the French coast of the Eastern English Channel and Southern Bight of the North Sea	2004	Bioaccumulation: steady state not documented
Herkovits and Perez-Coll	Stage -dependent susceptibility of *Bufo arenarum* embryos to cadmium	1993	Not North American species
Herkovits and Perez-Coll	Zinc protection against delayed development produced by cadmium	1990	Not North American species, only one exposure concentration
Herkovits and Perez-Coll	Increased resistance against cadmium toxicity by means of pretreatment with low cadmium-zinc concentrations in *Bufo arenarum* embryos	1995	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Hermesz et al.	Tissue-specific expression of two metallothionein genes in common carp during cadmium exposure and temperature shock	2001	No control exposure, dilution water not characterized
Hernandez et al.	Accumulation of toxic metals (Pb and Cd) in the sea urchin *Diadema aff. antillarum* Philippi, 1845, in an oceanic island (Tenerife, Canary Islands)	2010	Bioaccumulation: steady state not documented
Herve-Fernandez et al.	Cadmium bioaccumulation and retention kinetics in the Chilean blue mussel *Mytilus chilensis*: seawater and food exposure pathways	2010	Not North American species
Herwig et al.	Bioaccumulation and histochemical localization of cadmium in *Dreissena polymorpha* exposed to cadmium chloride	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Heugens et al.	Population growth of *Daphnia magna* under multiple stress conditions: joint effects of temperature, food, and cadmium	2006	Excessive EDTA (testing used Elendt M7 medium which complexes the metal)
Heugens et al.	Temperature-dependent effects of cadmium on *Daphnia magna*: accumulation versus sensitivity	2003	Excessive EDTA (testing used Elendt M7 medium which complexes the metal)
Hewitt et al.	Influence of water quality and associated contaminants on survival and growth of the endangered Cape Fear shiner (*Notropis mekistocholas*)	2006	Mixture
Heydari et al.	Cadmium and Lead Concentrations in Muscles and Livers of Stellate Sturgeon (*Acipenser stellatus*) From Several Sampling Stations in the Southern Caspian Sea.	2011	Bioaccumulation: steady state not documented
Hickey and Clements	Effects of heavy metals on benthic macroinvertebrate communities in New Zealand streams	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Hickey and Martin	Relative sensitivity of five benthic invertebrate species to reference toxicants and resin-acid contaminated sediments	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hickey and Roper	Acute toxicity of cadmium to two species of infaunal marine amphipods (tube-dwelling and burrowing) from New Zealand	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hildebrand et al.	The Potential Toxicity and Bioaccumulation in Aquatic Systems of Trace Elements Present in Aqueous Coal Conversion Effluents	1976	Effluent
Hinck et al.	Chemical Contaminants, Health Indicators, and Reproductive Biomarker Responses in Fish From the Colorado River and Its Tributaries	2007	Bioaccumulation: steady state not documented
Hinrichsen and Tran	A Circadian Clock Regulates Sensitivity to Cadmium in *Paramecium tetraurelia*	2010	Bacteria
Hiraoka	Reduction of Heavy Metal Content in Hiroshima Bay Oysters (*Crassostrea gigas*) by Purification	1991	Bioaccumulation: steady state not documented
Hiraoka et al.	Acute toxicity of 14 different kinds of metals affecting medaka (*Oryzias latipes*) fry	1985	Not North American species
Hoang and Klaine	Influence of organism age on metal toxicity to *Daphnia magna*	2007	No cadmium toxicity information
Hockett and Mount	Use of metal chelating agents to differentiate among sources of acute aquatic toxicity	1996	Only 5 organisms per concentration and excessive chelant used
Hockner et al.	Coping with cadmium exposure in various ways: the two helicid snails *Helix pomatia* and *Cantareus aspersus* share the metal transcription factor-2, but differ in promoter organization and transcription of their Cd-metallothionein genes	2009	Dietary exposure
Hofer et al.	Organochlorine and Metal Accumulation in Fish (*Phoxinus phoxinus*) Along a North-South Transect in the Alps	2001	Bioaccumulation: steady state not documented
Hofslagare et al.	Cadmium effects on photosynthesis and nitrate assimilation in *Scenedesmus obliquus*. A potentiometric study in an open CO_2-system	1985	The materials, methods or results were insufficiently described
Hogstrand et al.	The importance of metallothionein for the accumulation of copper, zinc and cadmium in environmentally exposed perch, *Perca fluviatilis*	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hollis et al.	Does the age of metal-dissolved organic carbon complexes influence binding of metals to fish gills?	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hollis et al.	Influence of dissolved organic matter on copper binding, and calcium on cadmium binding by gills of rainbow trout	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Hollis et al.	Tissue-specific cadmium accumulation, metallothionein induction, and tissue zinc and copper levels during chronic sublethal cadmium exposure in juvenile rainbow trout	2001	Dietary exposure
Hollis et al.	Protective Effects of Calcium Against Chronic Waterborne Cadmium Exposure to Juvenile Rainbow Trout	2000b	Prior exposure

Authors	**Title**	**Year**	**Reason Unused**
Holmes et al.	Trace-Metal Content in Antipatharian Corals From the Jacksonville Lithoherm, Florida	2006	Bioaccumulation: steady state not documented
Hongve et al.	Effect of heavy metals in combination with NTA, humic acid, and suspended sediment on natural phytoplankton photosynthesis	1980	Lack of exposure details; mixed species exposure
Hook and Fisher	Reproductive toxicity of metals in calanoid copepods	2001	Dietary exposure
Hook and Fisher	Relating the Reproductive Toxicity of Five Ingested Metals in Calanoid Copepods with Sulfur Affinity	2002	Dietary exposure
Hook and Lee	Interactive Effects of UV, Benzo(a)Pyrene, and Cadmium on DNA Damage and Repair in Embryos of the Grass Shrimp *Paleomonetes pugio*	2004	Mixture
Hooten and Carr	Development and application of a marine sediment pore-water toxicity test using *Ulva fasciata* zoospores	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Hopkins et al.	Responses of benthic fish exposed to contaminants in outdoor microcosms--examining the ecological relevance of previous laboratory toxicity tests	2004	Non-applicable
Horike et al.	Usefulness of flagellar regeneration in *Dunaliella sp*. as an endpoint for the bioassay of seawater pollution	2002	Text in foreign language
Horng et al.	Effects of Sediment exposure-Bound Cd, Pb, and Ni on the Growth, Feeding, and Survival of *Capitella sp*.	2009	Sediment exposure
Hornstrom	Toxicity test with algae - a discussion on the batch method	1990	Review of previously published data
Hoss et al.	Toxicity of cadmium to *Caenorhabditis elegans* (nematoda) in whole sediment and pore water-the ambiguous role of organic matter	2001	Sediment exposure
Hsiao et al.	The Bioconcentration of Trace Metals in Dominant Copepod Species Off the Northern Taiwan Coast	2006	Bioaccumulation: steady state not documented
Hsu et al.	Sublethal levels of cadmium down-regulate the gene expression of DNA mismatch recognition protein MutS homolog 6 (MSH6) in zebrafish (*Danio rerio*) embryos	2010	Dilution water not characterized
Hu et al.	Cadmium accumulation by several seaweeds	1996	Not North American species
Hu et al.	Bioaccumulation and chemical forms of cadmium, copper and lead in aquatic plants	2010	Bioaccumulation: steady state not documented
Hu et al.	Combined Effects of Titanium Dioxide and Humic Acid on the Bioaccumulation of Cadmium in Zebrafish	2011a	Mixture
Hu et al.	Root-induced changes to cadmium speciation in the rhizosphere of two rice (*Oryza sativa* L.) genotypes	2011b	Sediment (soil) exposure
Huang et al.	Bioaccumulation of silver, cadmium and mercury in the abalone Haliotis diversicolor from water and food sources	2008	Bioaccumulation: steady state not documented (only 7 day exposure)
Huang et al.	Cadmium and copper accumulation and toxicity in the macroalga *Gracilaria tenuistipitata*	2010a	Bioaccumulation: unmeasured exposure

Authors	**Title**	**Year**	**Reason Unused**
Huang et al.	Responses of abalone *Haliotis diversicolor* to sublethal exposure of waterborne and dietary silver and cadmium	2010b	Not North American species, dilution water not characterized, only one exposure concentration
Huang et al.	Differential protein expression of kidney tissue in the scallop *Patinopecten yessoensis* under acute cadmium stress	2011a	Dilution water not characterized; Not North American species
Huang et al.	Alteration of heart tissue protein profiles in acute cadmium-treated scallops *Patinopecten yessoensis*	2011b	Dilution water not characterized; Not North American species
Huebert and Shay	The effect of cadmium and its interaction with external calcium in the submerged aquatic macrophyte *Lemna trisulca* L.	1991	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebert and Shay	Zinc toxicity and its interaction with cadmium in the submerged aquatic macrophyte *Lemna trisulca* L.	1992	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebert and Shay	The response of *Lemna trisulca* L. to cadmium	1993	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebert et al.	The effect of EDTA on the assessment of Cu toxicity in the submerged aquatic macrophyte, *Lemna trisulca* L	1993	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Huebner and Pynnonen	Viability of glochidia of two species of *Anodonta* exposed to low pH and selected metals	1992	Not North American species
Huelya	Seasonal Variations of Heavy Metals in Water, Sediment exposures, Pondweed (P. Pectinatus L.) And Freshwater Fish (C. C. Umbla) of Lake Hazar (Elazig-Turkey)	2009	Bioaccumulation: steady state not documented
Huiskes and Nieuwenhuize	Uptake Of Heavy Metals From Contaminated Sediment exposures By Salt-Marsh Plants	1990	Sediment exposure
Hung	Effects of temperature and chelating agents on cadmium uptake in the American oyster	1982	Questionable treatment of test organisms or inappropriate test conditions or methodology
Hung et al.	Trace metals in different species of mollusca, water and Sediment exposures from Taiwan coastal area	2001	Bioaccumulation: steady state not documented
Hungspreugs et al.	Heavy Metals and Polycyclic Hydrocarbon Compounds in Benthic Organisms of the Upper Gulf of Thailand.	1984	Bioaccumulation: steady state not documented
Husaini et al.	Cadmium toxicity to photosynthesis and associated electron transport system of *Nostoc linckia*	1991	Not North American species
Hutcheson	The effects of temperature and salinity on cadmium uptake by the blue crab, *Callinectes sapidus*	1975	Questionable treatment of test organisms or inappropriate test conditions or methodology
Hutchins et al.	Transcriptomic Signatures in *Chlamydomonas reinhardtii* as Cd Biomarkers in Metal Mixtures	2010	Mixture
Hutchinson and Collins	Effect of H+ Ion Activity and Ca2+ on the Toxicity of Metals in the Environment	1978	Review
Hylland et al.	Interactions between eutrophication and contaminants. IV. Effects on sediment-dwelling organisms	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Iannacone and Alvarino	Acute ecotoxicity of heavy metals using juveniles of freshwater snail *Physa venustula* (Gould, 1847)	1999	Not applicable per ECOTOX Duluth; text in foreign language
Idardare et al.	Metal Concentrations in Sediment exposure and *Nereis diversicolor* in Two Moroccan Lagoons: Khnifiss and Oualidia	2008	Bioaccumulation: steady state not documented
Ieradi et al.	Mutagenicity test and heavy metals in teleost fish from Tiber River (Rome, Italy)	1996	Bioaccumulation: steady state not documented
Iftode et al.	Action of a heavy ion, Cd^{2+}, and the antagonistic effect of Ca^{2+}, on two ciliates *Tetrahymena pyriformis* and *Euplotes vannus*.	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Ikemoto et al.	Biomagnification of Trace Elements in the Aquatic Food Web in the Mekong Delta, South Vietnam Using Stable Carbon and Nitrogen Isotope Analysis	2008	Bioaccumulation: steady state not documented
Ikuta	A Comparison On Heavy Metal Contents Between *Batillus cornutus* And *Babylonia japonica*	1985a	Bioaccumulation: steady state not documented
Ikuta	Distribution And Localization Of Some Heavy Metals In Female And Male Of A Herbivorous Gastropod *Haliotis discus*	1985b	Bioaccumulation: steady state not documented
Ikuta	Distribution Of Heavy Metals In Female And Male Of A Herbivorous Gastropod *Batillus cornutus*	1985c	Bioaccumulation: steady state not documented
Ikuta	Distribution Of Heavy Metals In Female And Male Of A Scallop *Patinopecten yessoensis*	1985d	Bioaccumulation: steady state not documented
Ikuta	Cadmium accumulation by a top shell *Batillus cornutus*	1987	Not North American species
Ilangovan et al.	Effect of cadmium and zinc on respiration and photosynthesis in suspended and immobilized cultures of *Chlorella vulgaris* and *Scenedesmus acutus*	1998	No interpretable concentration, time, response data or examined only a single exposure concentration
Iliopoulou-Georgudaki and Kotsanis	Toxic effects of cadmium and mercury in rainbow trout (*Oncorhynchus mykiss*): a short-term bioassay	2001	Injected pollutant
Illuminati et al.	Cadmium bioaccumulation and metallothionein induction in the liver of the Antarctic teleost *Trematomus bernacchii* during an on-site short-term exposure to the metal via seawater	2010	Bioaccumulation: steady state not documented
Ingersoll et al.	Toxicity of Sediment exposure Cores Collected From the Ashtabula River in Northeastern Ohio, USA, to the Amphipod *Hyalella azteca*	2009	Sediment exposure
Inza et al.	Dynamics of cadmium and mercury compounds (inorganic mercury or methylmercury): uptake and depuration in *Corbicula fluminea*. Effects of temperature and pH	1998	Sediment; mixture (Hg and Cd)
Ip et al.	Heavy metal and Pb isotopic compositions of aquatic organisms in the Pearl River Estuary, South China	2005	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Irato and Piccinni	Effects of cadmium and copper on *Astasia longa*: Metal uptake and glutathione levels	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Irving et al.	Ecotoxicological responses of the mayfly *Baetis tricaudatus* to dietary and waterborne cadmium: Implications for toxicity testing	2003	High control mortality (19%)
Isani et al.	Cadmium accumulation and biochemical responses in *Sparus aurata* following sub-lethal Cd exposure	2009	Bioaccumulation: steady state not documented; not North American species
Ismail and Yusof	Effect of mercury and cadmium on early life stages of java medaka (*Oryzias javanicus*): A potential tropical test fish	2011	Not North American species, unmeasured chronic exposure
Issa et al.	Abolition of heavy metal toxicity on *Kirchneriella lunaris* (Chlorophyta) by calcium	1995	No interpretable concentration, time, response data or examined only a single exposure concentration
Issartel et al.	Cellular and molecular osmoregulatory responses to cadmium exposure in *Gammarus fossarum* (Crustacea, Amphipoda)	2010	Not North American species, only one exposure concentration
Ivanina and Sokolova	Effects of cadmium exposure on expression and activity of p-glycoprotein in eastern oysters, *Crassostrea virginica* Gmelin	2008	Unmeasured, non-renewal or flow-through chronic exposure, only one exposure concentration
Ivanina et al.	Interactive effects of cadmium and hypoxia on metabolic responses and bacterial loads of eastern oysters *Crassostrea virginica* Gmelin	2011	Mixture (Cd and hypoxia)
Ivanina et al.	Effects of cadmium on anaerobic energy metabolism and mrna expression during air exposure and recovery of an intertidal mollusk *Crassostrea virginica*	2010a	Only one exposure concentration
Ivanina et al.	Effects of cadmium exposure and intermittent anoxia on nitric oxide metabolism in eastern oysters, *Crassostrea virginica*	2010b	Only one exposure concentration
Ivanina and Sokolova	Interactive effects of pH and metals on mitochondrial functions of intertidal bivalves *Crassostrea virginica* and *Mercenaria mercenaria*	2013	Only one exposure concentration
Ivorra et al.	Metal-induced tolerance in the freshwater microbenthic diatom Gomphonema parvulum	2002a	No cadmium toxicity information
Ivorra et al.	Responses of Biofilms to Combined Nutrient and Metal Exposure	2002b	Mixture
Iwasaki and Ormerod	Estimating safe concentrations of trace metals from inter-continental field data on river macroinvertebrates.	2012	Bioaccumulation: steady state not documented
Jaafarzadeh et al.	Cadmium Determination in Two Flat Fishes From Two Fishery Regions in North of the Persian Gulf.	2011	Bioaccumulation: steady state not documented
Jak et al.	Evaluation of laboratory derived toxic effect concentrations of a mixture of metals by testing freshwater plankton communities in enclosure	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Jamers et al.	An omics based assessment of cadmium toxicity in the green alga *Chlamydomonas reinhardtii*	2012	Only two exposure concentrations

Authors	**Title**	**Year**	**Reason Unused**
James et al.	Metamorphosis of two amphibian species after chronic cadmium exposure in outdoor aquatic mesocosms	2005	Duration too short, non-renewal or flow-through chronic exposure
Jana and Sahana	Effects of copper, cadmium and chromium cations on the freshwater fish *Clarias batrachus* L.	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Janati-Idrissi et al.	Effect of cadmium on reproduction of daphnids in a small aquatic microcosm	2001	Dietary exposure, lack of details
Jankovska et al.	Concentrations of Zn, Mn, Cu and Cd in different tissues of perch (*Perca fluviatilis*) and in perch intestinal parasite (*Acanthocephalus lucii*) from the stream near Prague (Czech Republic).	2012	Bioaccumulation: steady state not documented
Janssen and Persoone	Rapid toxicity screening tests for aquatic biota. I. Methodology and experiments with *Daphnia magna*	1993	The materials, methods or results were insufficiently described
Janssens de Bisthoven et al.	The concentration of cadmium, lead, copper and zinc in *Chironomus thummi* larvae (Diptera, Chironomidae) with deformed versus normal menta	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Janssens De Bisthoven et al.	Morphological deformities in Chironomus riparius meigen larvae after exposure to cadmium over several generations	2001	Dietary exposure
Jara-Marini et al.	Trophic Relationships and Transference of Cadmium, Copper, Lead and Zinc in a Subtropical Coastal Lagoon Food Web From SE Gulf of California	2009	Bioaccumulation: steady state not documented
Javanshir et al.	Impact of water hardness on cadmium absorption by four freshwater mollusks *Physa fontinalis*, *Anodonta cygnea*, *Corbicula fluminea* and *Dreissena polymorpha* from south Caspian Sea region	2011	Mixture, only one exposure concentration
Javed and Greger	Cadmium triggers *Elodea canadensis* to change the surrounding water pH and thereby Cd uptake	2011	Sediment exposure
Jaworska et al.	Effect of metal ions on the entomopathogenic nematode *Heterorhabditis bacteriophora poinar* (Nematoda: Heterohabditidae) under laboratory conditions	1997	The materials, methods or results were insufficiently described
Jay and Muncy	Toxicity to Channel Catfish of Wastewater From an Iowa Coal Beneficiation Plant	1979	Mixture
Jebali et al.	Effects of malathion and cadmium on acetylcholinesterase activity and metallothionein levels in the fish *Seriola dumerilli*	2006	Injected toxicant
Jeitner and Burger	Metal Concentrations (Arsenic, Cadmium, Chromium, Lead, Mercury and Selenium) in Dolly Varden (*Salvelinus malma*) From the Aleutian Islands, Alaska	2009	Bioaccumulation: steady state not documented
Jenkins and Mason	Relationships between subcellular distributions of cadmium and perturbations in reproduction in the polychaete *Neanthes arenaceodentata*	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies

Authors	**Title**	**Year**	**Reason Unused**
Jenkins and Sanders	Relationships between free cadmium ion activity in seawater, cadmium accumulation and subcellular distibution, and growth in polychaetes	1986	Not North American species, Inappropriate medium of medium contained too much of a complexing agent for algal studies
Jenner and Bowmer	The Accumulation of Metals and Their Toxicity in the Marine Intertidal Invertebrates *Cerastoderma edule*, *Macoma balthica*, and *Arenicola marina* Exposed to Pulverized Fuel Ash in Mesocosms.	1990	Mixture
Jenner and Janssen-Mommen	Phytomonitoring of Pulverized Fuel Ash Leachates by the Duckweed (*Lemna minor*)	1989	Mixture
Jenner and Janssen-Mommen	Duckweed *Lemna minor* as a tool for testing toxicity of coal residues and polluted sediments	1993	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Jennett et al.	Some Effects of Century Old Abandoned Lead Mining Operations on Streams in Missouri, USA	1981	Bioaccumulation: steady state not documented
Jennings and Rainbow	Accumulation of cadmium by *Dunaliella tertiolecta* Butcher	1979b	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
Jensen et al.	Variation in cadmium uptake, feeding rate, and life-history effects in the gastropod Potamopyrgus antipodarum: linking toxicant effects on individuals to the population level	2001	Sediment exposure
Jerez et al.	Accumulation and tissue distribution of heavy metals and essential elements in loggerhead turtles (*Caretta caretta*) from Spanish Mediterranean coastline of Murcia	2010	Bioaccumulation: steady state not documented
Jezierska et al.	The effect of temperature and heavy metals on heart rate changes in common carp *Cyprinus carpio* L. and grass carp *Ctenopharyngodon idella* (Val.) during embryonic development	2002	Duration too short, only one exposure concentration
Jia et al.	Low Levels of Cadmium Exposure Induce DNA Damage and Oxidative Stress in the Liver of Oujiang Colored Common Carp *Cyprinus carpio* var. color	2011	In vitro
Jiang et al.	Heavy Metal Exposure Reduces Hatching Success of *Acartia pacifica* Resting Eggs in the Sediment exposure	2007	Sediment exposure
Jing et al.	Acute effect of copper and cadmium exposure on the expression of heat shock protein 70 in the Cyprinidae fish *Tanichthys albonubes*	2013	Excised tissue/cells
Jiraungkoorskul et al.	Micronucleus test: the effect of ascorbic acid on cadmium exposure in fish (*Puntius altus*)	2007a	Lack of detail, Mixture
Jiraungkoorskul et al.	The effect of ascorbic acid on cadmium exposure in the gills of *Puntius altus*	2007b	Not North American species, only one exposure concentration
Jiraungkoorskul et al.	Micronucleus Test: the Effect of Ascorbic Acid on Cadmium Exposure in Fish (*Puntius altus*)	2010	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Jofre et al.	Lead and Cadmium Accumulation in Anuran Amphibians of a Permanent Water Body in Arid Midwestern Argentina	2011	Bioaccumulation: steady state not documented
John et al.	Influence of aquatic humus and pH on the uptake and depuration of cadmium by the Atlantic salmon (*Salmo salar* L.)	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured, Bioaccumulation: not renewal or flow-through
Johns	Spatial Distribution of Total Cadmium, Copper, and Zinc in the Zebra Mussel (*Dreissena polymorpha*) Along the Upper St. Lawrence River	2001	Bioaccumulation: steady state not documented
Johns	Trends of Total Cadmium, Copper, and Zinc in the Zebra Mussel (*Dreissena Polymorpha*) Along the Upper Reach of the St. Lawrence River: 1994-2005.	2012	Bioaccumulation: steady state not documented
Johnson et al.	The Use of Periphyton as a Monitor of Trace Metals in Two Contaminated Indiana Lakes	1978	Bioaccumulation: steady state not documented
Jones et al.	Silver and Other Metals in Some Aquatic Bryophytes From Streams in the Lead Mining District of Mid-Wales, Great Britain	1985	Bioaccumulation: steady state not documented
Jones et al.	Cadmium delays growth hormone expression during rainbow trout development	2001	Bioaccumulation: steady state not documented (duration unknown)
Jonker et al.	Toxicity of Binary Mixtures of Cadmium-Copper and Carbendazim-Copper to the Nematode *Caenorhabditis elegans*	2004	Mixture
Jonnalagadda and Rao	Toxicity, bioavailability and metal speciation	1993	Review of previously published data
Jop	Concentration of metals in various larval stages of four *Ephemeroptera* species	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Jop et al.	Analysis of Metals in Blue Crabs, *Callinectes sapidus*, From Two Connecticut Estuaries	1997	Bioaccumulation: steady state not documented
Jost and Zauke	Trace Metal Concentrations in Antarctic Sea Spiders (*Pycnogonida, Pantopoda*)	2008	Bioaccumulation: steady state not documented
Juarez-Franco et al.	Effect of cadmium and zinc on the population growth *of Brachionus havanaensis* (Rotifera: Brachionidae)	2007	Not North American species, duration too short
Juhasza et al.	Comparative Study on the Expression of Glutathione Peroxidase, Glutathione Reductase, Glutathione Synthetase and Metallothionein Genes in Common Carp During Cadmium Exposure	2012	Abstract only
Julshamn et al.	Trace Elements Intake in the Faroe Islands. I. Element Levels in Edible Parts of Pilot Whales (*Globicephalus meleanus*)	1987	Bioaccumulation: steady state not documented
Julshamn et al.	Cadmium, lead, copper and zinc in blue mussels (*Mytilus edulis*) sampled in the Hardangerfjord, Norway	2001	Bioaccumulation: steady state not documented
Julshamn et al.	Concentrations of mercury and other toxic elements in orange roughy, *Hoplostethus atlanticus*, from the Mid-Atlantic Ridge.	2011	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Jung and Zauke	Bioaccumulation of Trace Metals in the Brown Shrimp *Crangon crangon* (Linnaeus, 1758) from the German Wadden Sea	2008	Bioaccumulation: steady state not documented
Jung et al.	Spatial Distribution of Heavy Metal Concentrations and Biomass Indices in *Cerastoderma edule* Linnaeus (1758) From the German Wadden Sea: an Integrated Biomonitoring Approach	2006	Bioaccumulation: steady state not documented
Jurewa and Blanuwa	Mercury, arsenic, lead and cadmium in fish and shellfish from the Adriatic Sea	2003	Bioaccumulation: steady state not documented
Kadioglu and Ozbay	Effects of heavy metals on chlorophyll content and cell colony number in *Chlamydomonas reinhardii*	1995	Lack of exposure details; cannot determine effect concentration
Kahle	Bioaccumulation of trace metals in the copepod *Calanoides acutus* from the Weddell Sea (Antarctica): comparison of two-compartment and hyperbolic toxicokinetic models	2002	Bioaccumulation: steady state not documented
Kahle and Zauke	Bioaccumulation of trace metals in the calanoid copepod *Metridia gerlachei* from the Weddell Sea (Antarctica)	2002	Bioaccumulation: steady state not documented
Kahle and Zauke	Bioaccumulation of Trace Metals in the Antarctic Amphipod *Orchomene plebs*: Evaluation of Toxicokinetic Models	2003a	Bioaccumulation: steady state not documented
Kahle and Zauke	Trace metals in Antarctic copepods from the Weddell Sea (Antarctica)	2003b	Bioaccumulation: steady state not documented
Kaitala et al.	The Effect of Copper, Cadmium, Zinc and Pentachlorophenolate on Heterotrophic Activity and Primary Production	1983	Abstract only
Kalafatic et al.	The impairments of neoblast division in regenerating planarian *Polycelis felina* (Daly.) caused by in vitro treatment with cadmium sulfate	2004	In vitro
Kalman et al.	Comparative Toxicity of Cadmium in the Commercial Fish Species *Sparus aurata* and *Solea senegalensis*	2010a	Injected toxicant
Kalman et al.	Biodynamic Modelling of the Accumulation of Ag, Cd and Zn by the Deposit-Feeding Polychaete *Nereis diversicolor*: Inter-Population Variability and a Generalised Predictive Model	2010b	Modeling
Kamala-Kannan et al.	Assessment of Heavy Metals (Cd, Cr and Pb) in Water, Sediment exposure and Seaweed (*Ulva lactuca*) in the Pulicat Lake, South East India	2008	Bioaccumulation: steady state not documented
Kamunde	Early subcellular partitioning of cadmium in gill and liver of rainbow trout (*Oncorhynchus mykiss*) following low-to-near-lethal waterborne cadmium exposure	2009	Bioaccumulation: steady state not documented
Kamunde and MacPhail	Subcellular interactions of dietary cadmium, copper and zinc in rainbow trout (*Oncorhynchus mykiss*)	2011a	Dietary exposure
Kamunde and MacPhail	Metal-metal interactions of dietary cadmium, copper and zinc in rainbow trout, *Oncorhynchus mykiss*	2011b	Dietary exposure
Kamunde et al	Effect of humic acid during concurrent chronic waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium and zinc	2011	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Kangwe et al.	Heavy metal inhibition of calcification and photosynthetic rates of the geniculate calcareous alga *Amphiroa tribulus*	2001	Lack of details
Kaonga et al.	Accumulation of Lead, Cadmium, Manganese, Copper and Zinc by Sludge Worms *Tubifex tubifex* in Sewage Sludge	2010	Effluent
Kaoud and Rezk	Effect of exposure to cadmium on the tropical freshwater prawn *Macrobrachium rosenbergii*	2011	Dilution water not characterized
Kapauan et al.	Cadmium, Lead, Copper And Zinc In Philippine Aquatic Life	1982	Bioaccumulation: steady state not documented
Kaplan et al.	Cadmium toxicity and resistance in *Chlorella sp*	1995	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Kar and Aditya	Impact of heavy metal and pesticide on total protein content in intact and regenerating *Hydra*	2010	Only one exposure concentration
Kara	Physiological and toxicological effects of lead plus cadmium mixtures on rainbow trout (*Oncorhynchus mykiss*) in soft acidic water	2010	Only two exposure concentrations; dilution water not characterized
Kara and Zeytunluoglu	Bioaccumulation of Toxic Metals (Cd and Cu) by *Groenlandia densa* (L.) Fourr	2007	Non-applicable
Karadede-Akin and Unlu	Heavy Metal Concentrations in Water, Sediment exposure, Fish and Some Benthic Organisms from Tigris River, Turkey	2007	Bioaccumulation: steady state not documented
Karasov et al.	Field Exposure of Frog Embryos and Tadpoles Along a Pollution Gradient in the Fox River and Green Bay Ecosystem in Wisconsin, USA	2005	Mixture
Karayakar et al.	Seasonal Variation in Copper, Zinc, Chromium, Lead and Cadmium Levels in Hepatopancreas, Gill and Muscle Tissues of the Mussel (*Ibrachidontes pharaonis*) Fischer, Collected Along the Mersin Coast, Turkey	2007	Bioaccumulation: steady state not documented
Kargin et al.	Distribution of Heavy Metals in Different Tissues of the Shrimp *Penaeus semiculatus* and *Metapenaeus monocerus* from the Iskenderun Gulf, Turkey: Seasonal Variations	2001	Bioaccumulation: steady state not documented
Karlsson-Norrgren and Runn	Cadmium dynamics in fish: Pulse studies with ^{109}Cd in female zebrafish, *Brachydanio rerio*	1985	Not North American species
Karouna-Renier et al.	Accumulation of Organic and Inorganic Contaminants in Shellfish Collected in Estuarine Waters Near Pensacola, Florida: Contamination Profiles and Risks to Human Consumers	2007	Bioaccumulation: steady state not documented
Karthik et al.	Synergistic effect of cadmium in combination with UV-B radiations in PS II photochemistry of the cyanobacterium *Spirulina platensis*	2011	Only three exposure concentrations
Karuppasamy et al.	Haematological responses to exposure to sublethal concentration of cadmium in air breathing fish, *Channa punctatus* (Bloch)	2005	Dilution water not characterized, only one exposure concentration, not North American species

Authors	Title	Year	Reason Unused
Kasherwani et al.	Cadmium induced skeletal deformities in freshwater catfish, *Heteropneustes fossilis* (Bloch)	2007	Unmeasured chronic exposure, not North American species, only one exposure concentration
Kasherwani et al.	Cadmium toxicity to freshwater catfish, *Heteropneustes fossilis* (Bloch)	2009	Not North American species
Kaska and Furness	Heavy metals in marine turtle eggs and hatchlings in the Mediterranean	2001	Bioaccumulation: steady state not documented
Kasuga	Sexual differences of medaka, *Oryzias latipes* in the acute toxicity test of cadmium	1980	Not North American species
Kato	Studies on Toxicity of Chemical Substances (Heavy Metals Etc.) To Fish and Animal	1973	Text in foreign language
Katsikatsou et al.	Field studies on the relation between the accumulation of heavy metals and metabolic and HSR in the bearded horse mussel *Modiolus barbatus*	2011	Bioaccumulation: steady state not documented
Katsumiti et al.	An Assessment of Acute Biomarker Responses in the Demersal Catfish *Cathorops spixii* After the Vicuna Oil Spill in a Harbour Estuarine Area in Southern Brazil	2009	Mixture
Katti and Sathyanesan	Chronic effects of lead and cadmium on the testis of the catfish *Clarias batrachus*	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kavun	Content of Microelements in the Grass Shrimp *Pandalus kessleri* (Decapoda: Pandalidae) From Coastal Waters of the Lesser Kurilskaya Ridge	2008	Bioaccumulation: steady state not documented
Kavun et al.	Metal accumulation in mussels of the Kuril Islands, North-west Pacific Ocean	2002	Bioaccumulation: steady state not documented
Kawamata et al.	Contents of Heavy Metals in Fishes in Nagano Prefecture	1983	Bioaccumulation: steady state not documented
Kay et al.	Cadmium accumulation and protein binding patterns in tissues of the rainbow trout, *Salmo gairdneri*	1986	The materials, methods or results were insufficiently described
Kayhan et al.	Cadmium (Cd) and Lead (Pb) Levels of Mediterranean Mussel (*Mytilus galloprovincialis* Lamarck, 1819) From Bosphorus, Istanbul, Turkey	2007	Bioaccumulation: steady state not documented
Kayser	Cadmium effects in food chain experiments with marine plankton algae (Dinophyta) and benthic filter-feeders (Tunicata)	1982	Lack of exposure details; dilution water not characterized
Ke and Wang	Trace Metal Ingestion and Assimilation by the Green Mussel *Perna viridis* in a Phytoplankton and Sediment exposure Mixture	2002	Sediment exposure
Ke and Wang	Bioaccumulation of Cd, Se, and Zn in an estuarine oyster (*Crassostrea rivularis*) and a coastal oyster (*Saccostrea glomerata*)	2001	Bioaccumulation: steady state not documented (only 2 hour exposure); not renewal of flow-through exposure; not North American species
Keduo et al.	Effects os six heavy metals on hatching eggs and survival of larval of marine fish	1987	Not North American species

Authors	Title	Year	Reason Unused
Keenan and Alikhan	Comparative study of cadmium and lead accumulations in *Cambarus bartoni* (Fab.) (Decapoda, Crustacea) from an acidic and a neutral lake	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Keil et al.	Significance and Interspecific Variability of Accumulated Trace Metal Concentrations in Antarctic Benthic Crustaceans	2008	Bioaccumulation: steady state not documented
Kelly and Whitton	Interspecific differences in Zn, Cd and Pb accumulation by freshwater algae and bryophytes	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kemble et al.	Toxicity of Metal-Contaminated Sediments From the Upper Clark Fork River, Montana, to Aquatic Invertebrates and Fish in Laboratory Exposures	1994	Mixture
Kennedy and Benson	Report Of Heavy Metal Analysis Conducted On Mussel *Mytilus edulis* Samples Collected At 55 Sites In Newfoundland	1994	Bioaccumulation: steady state not documented
Kennedy and Farrell	Immunological Alterations in Juvenile Pacific Herring, *Clupea pallasi*, Exposed to Aqueous Hydrocarbons Derived From Crude Oil	2008	Mixture
Kerfoot and Jacobs	Cadmium accrual in combined waste-treatment aquaculture system	1976	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Keskin et al.	Cadmium, Lead, Mercury and Copper in Fish From the Marmara Sea, Turkey	2007	Bioaccumulation: steady state not documented
Kessler	An extremely cadmium-sensitive strain of *Chlorella*	1985	The materials, methods or results were insufficiently described
Kessler	Limits of growth of five *Chlorella* species in the presence of toxic heavy metals	1986	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Keteles and Fleeger	The Contribution of Ecdysis to the Fate of Copper, Zinc and Cadmium in Grass Shrimp, *Palaemonetes pugio* Holthius	2001	Non-applicable
Kettle and deNoyelles	Effects of cadmium stress on the plankton communities of experimental ponds	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Khaled	Trace Metals in Fish of Economic Interest From the West of Alexandria, Egypt	2009	Bioaccumulation: steady state not documented
Khaleghzadeh-Ahangar et al.	The parasitic nematodes *Hysterothylacium sp*. type MB larvae as bioindicators of lead and cadmium: a comparative study of parasite and host tissues	2011	Bioaccumulation: steady state not documented
Khalil et al.	Effect of tapeworm parasitisation on cadmium toxicity in the bioindicator copepod, *Cyclops strenuous*	2014	Only one exposure concentration
Khan and Nugegoda	Sensitivity of juvenile freshwater crayfish *Cherax destructor* (Decapoda: Parastacidae) to trace metals	2007	Not North American species
Khan and Weis	Bioaccumulation of heavy metals in two populations of mummichog (*Fundulus heteroclitus*)	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Khan et al.	Bioaccumulation of four heavy metals in tow populations of grass shrimp, *Palaemonetes pugio*	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Khan et al.	Cadmium bound to metal rich granules and exoskeleton from *Gammarus pulex* causes increased gut lipid peroxidation in zebrafish following single dietary exposure	2010	Bioaccumulation: not renewal or flow-through; fed toxicant
Khangarot and Ray	Correlation between heavy metal acute toxicity values in *Daphnia magna* and fish	1987a	Review of previously published data
Khangarot and Ray	Sensitivity of toad tadpoles, *Bufo melanostictus* (Schneider), to heavy metals	1987b	Not North American species
Khangarot et al.	*Daphnia magna* as a model to assess heavy metal toxicity: Comparative assessment with mouse system	1987	The materials, methods or results were insufficiently described
Khoshmanesh et al.	Cadmium uptake by unicellular green microalgae	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Khoshmanesh et al.	Cell surface area as a major parameter in the uptake of cadmium by unicellular green microalgae	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Khosravi et al.	Toxic Effect of Pb, Cd, Ni and Zn on *Azolla filiculoides* in the International Anzali Wetland	2005	Mixture
Khoury et al.	Relating disparity in competitive foraging behavior between two populations of fiddler crabs to the subcellular partitioning of metals	2009	Mixture
Khristoforova et al.	Effect of cadmium on gametogenesis and offspring of the sea urchin *Strongylocentrotus intermedius*	1984	Not North American species
Khristoforova et al.	Heavy Metals in Mass Species of Bivalves in Ha Long Bay (South China Sea, Vietnam)	2007	Bioaccumulation: steady state not documented
Kiffney and Clements	Effects of Heavy Metals on a Macroinvertebrate Assemblage From a Rocky Mountain Stream in Experimental Microcosms.	1994	Mixture
Kiffney and Clements	Effects of heavy metals on a macroinvertebrate assemblage from a rocky mountain stream in experimental microcosms	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kilemade et al.	Genotoxicity of Field-Collected Inter-tidal Sediment exposures from Cork Harbor, Ireland, to Juvenile Turbot (*Scophthalmus maximus* L.) as Measured by the Comet Assay	2004	Sediment exposure
Kim et al.	The Geographic Distribution of Population Health and Contaminant Body Burden in Gulf of Mexico Oysters	2001	Bioaccumulation: steady state not documented
Kim et al.	Effect of Dietary exposure Cadmium on Growth and Haematological Parameters of Juvenile Rockfish, *Sebastes schlegeli* (Hilgendorf)	2004a	Dietary exposure

Authors	**Title**	**Year**	**Reason Unused**
Kim et al.	Cadmium accumulation and elimination in tissues of juvenile olive flounder, *Paralichthys olivaceus* after sub-chronic cadmium exposure	2004b	Dilution water not characterized; Bioaccumulation: unmeasured exposure; not North American species
Kim et al.	Kinetics of Cd Accumulation and Elimination in Tissues of Juvenile Rockfish (*Sebastes schlegeli*) Exposed to Dietary exposure Cd	2006	Dietary exposure
Kim et al.	Molecular Cloning of *Daphnia magna* Catalase and Its Biomarker Potential Against Oxidative Stresses	2010a	In vitro
Kim et al.	Expression Profiles of Seven Glutathione S-Transferase (GST) Genes in Cadmium-Exposed River Pufferfish (*Takifugu obscurus*)	2010b	In vitro
Kim et al.	Effects of Montmorillonite on Alleviating Dietary Cd-Induced Oxidative Damage in Carp (*Carassius auratus*)	2011a	Fed toxicant
Kim et al.	Perfluorooctane sulfonic acid exposure increases cadmium toxicity in early life stage of zebrafish, *Danio rerio*	2011b	Mixture
Kim et al.	8-Oxoguanine DNA Glycosylase 1 (Ogg1) From the Copepod *Tigriopus japonicus*: Molecular Characterization and Its Expression in Response to UV-B and Heavy Metals	2012b	Mixture
Kim et al.	Effect of cadmium exposure on expression of antioxidant gene transcripts in the river pufferfish, *Takifugu obscurus* (Tetraodontiformes)	2010c	Dilution water not characterized
King and Riddle	Effects of metal contaminants on the development of the common antarctic sea urchin *Sterechinus neumayeri* and comparisons of sensitivity with tropical and temperate echinoids	2001	Not North American species, duration too long
King et al.	Short-term accumulation of Cd and Cu from water, sediment and algae by the amphipod Melita plumulosa and the bivalve *Tellina deltoidalis*	2005	Sediment exposure; not North American species
King et al.	Acute toxicity and bioaccumulation of aqueous and sediment-bound metals in the estuarine amphipod *Melita plumulosa*	2006	Not North American species, control mortality (≥75%)
King et al.	Toxicity of metals to the bivalve *Tellina deltoidalis* and relationships between metal bioaccumulation and metal partitioning between seawater and marine sediments	2010	Not North American species; sediment
Kir et al.	Heavy Metal Concentrations in Organs of Rudd, *Scardinus erythrophthalmus* L.,1758 Populating Lake Karatas-Turkey	2006	Bioaccumulation: steady state not documented
Kiran et al.	Trace Metal Levels in the Organs of Finfish *Oreochromis mossambicus* (Peter) and Relevant Water of Jannapura Lake, India	2006	Bioaccumulation: steady state not documented
Kirby et al.	Changes in Selenium, Copper, Cadmium, and Zinc Concentrations in Mullet (*Mugil cephalus*) from the Southern Basin of Lake Macquarie, Australia, in Response to Alteration of Coal-Fired Power Station Fly Ash Handling Procedures	2001a	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Kirby et al.	Selenium, Cadmium, Copper, and Zinc Concentrations in Sediment exposures and Mullet (*Mugil cephalus*) from the Southern Basin of Lake Macquarie, NSW, Australia	2001b	Bioaccumulation: steady state not documented
Kiser et al.	Impacts and pathways of mine contaminants to bull trout (*Salvelinus confluentus*) in an Idaho watershed.	2010	Bioaccumulation: steady state not documented
Klaverkamp and Duncan	Acclimation to cadmium toxicity by white suckers: Cadmium binding capacity and metal distribution in gill and liver cytosol	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kleinert et al.	Concentration of Metals in Fish	1974	Bioaccumulation: steady state not documented
Klerks et al.	Effects of Ghost Shrimp on Zinc and Cadmium in Sediment exposures From Tampa Bay, Fl	2007	Sediment exposure
Klerks and Bartholomew	Cadmium accumulation and detoxification in a Cd-resistant population of the oligochaete *Limnodrilus hoffmeisteri*	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Klinck et al.	Branchial cadmium and copper binding and intestinal cadmium uptake in wild yellow perch (*Perca flavescens*) from clean and metal-contaminated lakes	2007	Prior exposure
Klinck et al.	Cadmium Accumulation and In Vitro Analysis of Calcium and Cadmium Transport Functions in the Gastro-intestinal Tract of Trout Following Chronic Dietary exposure Cadmium and Calcium Feeding	2009	Dietary exposure
Klinck et al.	In Vitro Characterization of Cadmium Transport Along the Gastro-Intestinal Tract of Freshwater Rainbow Trout (*Oncorhynchus mykiss*)	2011	In vitro
Kline et al.	Effects of Pollution on Freshwater Organisms	1987	Review
Kljakovic-Gaspic et al.	A. Distribution of cadmium and lead in *Posidonia oceanica* (L.) delile from the middle Adriatic sea	2004	Bioaccumulation: steady state not documented
Kljakovic-Gaspic et al.	Biomonitoring of Trace Metals (Cu, Cd, Cr, Hg, Pb, Zn) in the Eastern Adriatic Using the Mediterranean Blue Mussel (2001-2005)	2006	Bioaccumulation: steady state not documented
Klochenko et al.	Some Peculiarities of Accumulation of Heavy Metals by Macrophytes and Epiphyton Algae in Water Bodies of Urban Territories	2007	Bioaccumulation: steady state not documented
Kluttgen and Ratte	Effects of different food doses on cadmium toxicity to *Daphnia magna*	1994	Organisms were exposed to cadmium in food or by injection or gavage
Kluytmand et al.	Effects of cadmium on the reproduction of *Mytilus edulis* L.	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Knauer and Martin	Seasonal Variations of Cadmium, Copper, Manganese, Lead and Zinc and in Water and Phytoplankton in Monterey Bay, California	1973	Bioaccumulation: steady state not documented
Kneip	Effects of Cadmium in an Aquatic Environment	1978	Review

Authors	**Title**	**Year**	**Reason Unused**
Kneip and Hazen	Deposit and mobility of cadmium in marsh-cove ecosystem and the relation to cadmium concentration in biota	1979	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Kobayashi	Fertilized sea urchin eggs as an indicator material for marine pollution bioassay, preliminary experiments	1971	Not North American species
Kobayashi and Okamura	Effects of heavy metals on sea urchin embryo development. Part 2. Interactive toxic effects of heavy metals in synthetic mine effluents	2005	Effluent
Koca et al.	Genotoxic and Histopathological Effects of Water Pollution on Two Fish Species, *Barbus capito pectoralis* and *Chondrostoma nasus* in the Menderes River, Turkey	2008	Mixture
Kock et al.	Accumulation of trace metals (Cd, Pb, Cu, Zn) in Arctic char (*Salvelinus alpinus*) from oligotrophic alpine lakes: Relation to alkalinity	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kock et al.	Seasonal Patterns of Metal Accumulation in Arctic Char (*Salvelinus alpinus*) From an Oligotrophic Alpine Lake Related to Temperature	1996	Bioaccumulation: steady state not documented
Koelmans et al.	Influence of salinity and mineralization on trace metal sorption to cyanobacteria in natural waters	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kogan et al.	Effect of cadmium ions on *Chlorella* II: modification of the UV irridation effect	1975	Text in foreign language
Kohler and Riisgard	Formation of metallothioneins in relation to accumulation of cadmium in the common mussel *Mytilus edulis*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Koivisto et al.	Does cadmium pollution change trophic interactions in rockpool food webs?	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kojadinovic et al.	Bioaccumulation of Trace Elements in Pelagic Fish From the Western Indian Ocean	2007	Bioaccumulation: steady state not documented
Kola and Wilkinson	Cadmium Uptake by a Green Alga can be Predicted by Equilibrium Modelling	2005	Modeling
Kolok et al.	Individual variation in the swimming performance of fishes: An overlooked source of variation in toxicity studies	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kolyuchkina and Ismailov	Morpho-functional characteristics of bivalve mollusks under the experimental environmental pollution by heavy metals	2011	Only two exposure concentrations
Komjarova and Blust	Multi-Metal Interactions Between Cd, Cu, Ni, Pb and Zn in Water Flea *Daphnia magna*, a Stable Isotope Experiment	2008	Mixture
Komjarova and Blust	Effect of Na, Ca and Ph on Simultaneous Uptake of Cd, Cu, Ni, Pb, and Zn in the Water Flea *Daphnia magna* Measured Using Stable Isotopes	2009	Mixture

Authors	Title	Year	Reason Unused
Kondera and Witeska	Cadmium-induced alterations in heady kidney hematopoietic tissue of common carp	2012	Only one exposure concentration
Kooijman and Bedaux	Analysis of toxicity tests on *Daphnia* survival and reproduction	1996	Review of previously published data
Koop	Untersuchungen Ueber Die Schwermetallanreicherung In Fischen Aus Schwermetallbelasteten Gewaessern Im Hinblick Auf Deren Fischereiliche Nutzung. (Studies On Heavy Metal Enrichment In Fish From Waters Polluted By Heavy Metals With Reference To Their Use By The Fishing Industry)	1991	Mixture
Kopecka-Pilarczyk	The effect of pesticides and metals on acetylcholinesterase (AChE) in various tissues of blue mussel (*Mytilus trossulus* L.) in short-term in vivo exposures at different temperatures	2010	Mixture
Kopfler and Mayer	Concentrations of Five Trace Metals in the Waters and Oysters (*Crassostrea virginica*) of Mobile Bay, Alabama	1973	Bioaccumulation: steady state not documented
Korda et al.	Trace Elements in Samples of Fish, Sediment and Taconite From Lake Superior	1977	Bioaccumulation: steady state not documented
Kosakowska et al.	Effect of amino acids on the toxicity of heavy metals to phytoplankton	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Kosanovic et al.	Influence of Urbanization of the Western Coast of the United Arab Emirates on Trace Metal Content in Muscle and Liver of Wild Red-Spot Emperor (*Lethrinus lentjan*)	2007	Bioaccumulation: steady state not documented
Koskinen et al.	Response of rainbow trout transcriptome to model chemical contaminants	2004	Dilution water not characterized, only two exposure concentrations, duration too short
Kostaropoulos et al.	Effects of Exposure to a Mixture of Cadmium and Chromium on Detoxification Enzyme (GST, P450-MO) Activities in the Frog *Rana ridibunda*	2005	Mixture
Kovacik et al.	Comparison of methyl jasmonate and cadmium effect on selected physiological parameters in *Scenedesmus quadricauda* (Chlorophyta, Chlorophyceae)	2011	Dilution water not characterized
Kovarova et al.	Effect of metals, with special attention of Cd, content of the Svitava and Svratka rivers on levels of thiol compounds in fish liver and their use as biochemical markers	2009	Bioaccumulation: steady state not documented
Koyama et al.	The seawater fish for evaluation of the toxicity of pollutants	1992	The materials, methods or results were insufficiently described
Kraak et al.	Chronic ecotoxicity of mixtures of Cu, Zn, and Cd to the zebra mussel *Dreissena polymorpha*	1993a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Kraak et al.	Toxicity of heavy metals to the zebra mussel (*Dreissena polymorpha*)	1993b	No interpretable concentration, time, response data or examined only a single exposure concentration
Kraak et al.	Ecotoxicity of mixtures of metals to the zebra mussel *Dreissena polymorpha*	1994b	Review of previously published data
Kraal et al.	Uptake and tissue distribution of dietary and aqueous cadmium by carp (*Cyprinus carpio*)	1995	No useable data on cadmium toxicity or bioconcentration
Kraemer et al.	Dynamics of Cd, Cu and Zn accumulation in organs and sub-cellular fractions in field transplanted juvenile yellow perch (*Perca flavescens*)	2005	Mixture
Kraemer et al.	Modeling Cadmium Accumulation in Indigenous Yellow Perch (*Perca flavescens*)	2008	Modeling
Krantzberg	Accumulation of essential and nonessential metals by chironomid larvae in relation to physical and chemical properties of the elements	1989a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krantzberg	Metal accumulation by chironomid larvae: the effects of age and body weight on metal body burdens	1989b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krantzberg and Stokes	The importance of surface adsorption and pH in metal accumulation by chironomids	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krantzberg and Stokes	Metal regulation, tolerance, and body burdens in the larvae of the genus *Chironomus*	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Krasnov et al.	Hepatic responses of gene expression in juvenile brown trout (*Salmo trutta lacustris*) exposed to three model contaminants applied singly and in combination	2007	Not North American species
Krassoi and Julli	Chemical batch as a factor affecting the acute toxicity of the reference toxicant potassium dichromate to the cladoceran *Moina australiensis* (Sars)	1994	Not North American species
Kraus	Accumulation and Excretion of Five Heavy Metals by the Saltmarsh Cordgrass *Spartina alteriflora*	1988	Bioaccumulation: steady state not documented
Kremling et al.	Studies on the pathways and effects of cadmium in controlled ecosystem enclosures	1978	Mixture; field study
Krishna Kumari et al.	Bio-accumulation of some trace metals in the short-neck clam *Paphia malabarica* from Mandovi estuary, Goa	2006	Bioaccumulation: steady state not documented
Krishnaja et al.	effects of certain heavy metals (Hg, Cd, Pb, As and Se) on the intertidal crab *Scylla serrata*	1987	Not North American species
Kruatrachue et al.	Histopathological Changes in the Gastrointestinal Tract of Fish, *Puntius gonionotus*, fed on Dietary exposure Cadmium	2003	Dietary exposure
Krumschnabel et al.	Apoptosis and Necroptosis Are Induced in Rainbow Trout Cell Lines Exposed to Cadmium	2010	In vitro

Authors	Title	Year	Reason Unused
Krywult et al.	Metal Concentrations in Chub *Leuciscus cephalus* From a Submontane River (Poland)	2008	Bioaccumulation: steady state not documented
Kucuksezgin et al.	Trace metal and organochlorine residue levels in red mullet (*Mullus barbatus*) from the eastern Aegean, Turkey	2001	Bioaccumulation: steady state not documented
Kuehl and Haebler	Organochlorine, Organobromine, Metal, and Selenium Residues in Bottlenose Dolphins (*Tursiops truncatus*) Collected During an Unusual Mortality Event in the Gulf of Mexico, 1990	1995	Bioaccumulation: steady state not documented
Kuehl et al.	Coplanar PCB and Metal Residues in Dolphins From the U.S. Atlantic Coast Including Atlantic Bottlenose Obtained During the 1987/88 Mass Mortality	1994	Bioaccumulation: steady state not documented
Kuhn and Pattard	Results of the harmful effects of water pollutants to green algae (*Scenedesmus subspicatus*) in the cell multiplication inhibition test	1990	Not North American species
Kumar	Accumulation of Pb, Cd, and Zn in aquatic snails from four freshwater sites in Steuben County, Indiana	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Kumar and Achyuthan	Heavy Metal Accumulation in Certain Marine Animals Along the East Coast of Chennai, Tamil Nadu, India	2007	Bioaccumulation: steady state not documented
Kumar et al.	Selected Heavy Metals in the Sediment exposure and Macrobenthos of the Coastal Waters Off Mangalore	2003	Bioaccumulation: steady state not documented
Kumar et al.	Levels of Cadmium and Lead in Tissues of Freshwater Fish (*Clarias batrachus* L.) And Chicken in Western up (India)	2007	Bioaccumulation: steady state not documented
Kumar et al.	Selenium and spermine alleviate cadmium induced toxicity in the red seaweed *Gracilaria dura* by regulating antioxidants and DNA methylation	2012	Lack of exposure details
Kumarasamy et al.	Effect of some heavy metals on the filtration rate of an estuarine clam, *Meretrix casta* (Chemnitz)	2006	Effect level cannot be determined, dilution water not characterized, not North American species
Kumari et al.	Bio-Accumulation of Some Trace Metals in the Short-Neck Clam *Paphia malabarica* From Mandovi Estuary, Goa	2006	Bioaccumulation: steady state not documented
Kurochkin et al.	Cadmium affects metabolic responses to prolonged anoxia and reoxygenation in eastern oysters (*Crassostrea virginica*)	2009	Mixture
Kurochkin et al.	Top-Down Control Analysis of the Cadmium Effects on Molluscan Mitochondria and the Mechanisms of Cadmium-Induced Mitochondrial Dysfunction	2011	In vitro
Kuroshima	Cadmium accumulation and it effect on calcium metabolism in the girella *Girella punctata* during a long term exposure	1987	Not North American species
Kuroshima	Cadmium accumulation in the mummichog, *Fundulus heteroclitus*, adapted to various salinities	1992	Organisms were exposed to cadmium in food or by injection or gavage
Kuroshima and Kimura	Changes in toxicity of Cd and its accumulation in girella and goby with their growth	1990	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Kuroshima et al.	Kinetic analysis of cadmium toxicity to red sea bream, *Pagrus major*	1993	Not North American species
Kurun et al.	Accumulations of Total Metal in Dominant Shrimp Species (*Palaemon adspersus*, *Palaemon serratus*, *Parapenaeus longirostris*) and Bottom Surface Sediment exposures Obtained From the Northern Inner Shelf of the Sea of Marmara	2007	Bioaccumulation: steady state not documented
Kurun et al.	Total metal levels in crayfish *Astacus leptodactylus* (Eschscholtz, 1823), and surface sediments in Lake Terkos, Turkey	2010	Bioaccumulation: steady state not documented
Kusch et al.	Chronic exposure to low concentrations of water-borne cadmium during embryonic and larval development results in the long-term hindrance of anti-predator behavior in zebrafish	2007	Duration too short, high control mortality (85%)
Kwan and Smith	Some aspects of the kinetics of cadmium and thallium uptake by fronds of *Lemna minor* L.	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Kwong and Niyogi	The interactions of iron with other divalent metals in the intestinal tract of a freshwater teleost, rainbow trout (*Oncorhynchus mykiss*)	2009	Mixture
Kwong et al.	Molecular Evidence and Physiological Characterization of Iron Absorption in Isolated Enterocytes of Rainbow Trout (*Oncorhynchus mykiss*): Implications for Dietary Cadmium and Lead Absorption	2010	In vitro
Kwong et al.	Effects of Dietary Cadmium Exposure on Tissue-Specific Cadmium Accumulation, Iron Status and Expression of Iron-Handling and Stress-Inducible Genes in Rainbow Trout: Influence of Elevated Dietary Iron	2011	Fed toxicant
Kwong and Niyogi	Cadmium Transport in Isolated Enterocytes of Freshwater Rainbow Trout: Interactions With Zinc and Iron, Effects of Complexation With Cysteine, and an ATPase-Coupled Efflux.	2012	In vitro
La Touche and Mix	Seasonal Variations of Arsenic and Other Trace Elements in Bay Mussels (*Mytilus edulis*)	1982	Bioaccumulation: steady state not documented
Labonne et al.	Use of non-radioactive, mono-isotopic metal tracer for studying metal (Zn, Cd, Pb) accumulation in the mussel *Mytilus galloprovincialis*	2002	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Lacoue-Labarthe et al.	Acid phosphatase and cathepsin activity in cuttlefish (*Sepia officinalis*) eggs: The effects of Ag, Cd, and Cu exposure	2010	Not North American species
Lacroix and Hontela	A Comparative Assessment of the Adrenotoxic Effects of Cadmium in Two Teleost Species, Rainbow Trout, *Oncorhynchus mykiss*, and Yellow Perch, *Perca flavescens*	2004	Non-applicable
Laegreild et al.	Seasonal variation of cadmium toxicity toward the alga *Selenastrum capricornutum* Printz in two lakes with different humus content	1983	Results were only presented graphically

Authors	**Title**	**Year**	**Reason Unused**
Lahsteiner et al.	The sensitivity and reproducibility of the zebrafish (*Danio Rerio*) embryo test for the screening of waste water quality and for testing the toxicity of chemicals	2004	Duration too short, only one exposure concentration, some species are Not North American
Lake and Thorp	The Gill Lamellae of the Shrimp *Paratya tasmaniensis* (Atyidae: Crustacea). Normal Ultrastructure and Changes With Low Levels of Cadmium	1974	Abstract only
Lakshmi and Rao	Evaluation of cadmium toxicity on survival, accumulation and depuration in an intertidal gastropod, *Turbo intercostalis*	2002	Not North American species
Lam	Effects of cadmium on the consumption and absorption rates of a tropical freshwater snail, *Radix plicatulus*	1996a	Not North American species
Lam	Interpopulation differences in acute response of *Brotia hainanensis* (Gastropoda, Prosobranchia) to cadmium: genetic or environmental variance?	1996b	Not North American species
Lam et al.	Cadmium uptake and depuration in the soft tissues of *Brotia hainanensis* (Gastropoda: Prosobranchia: Thiaridae): A dynamic model	1997	Not North American species
Lamelas and Slaveykova	Comparison of Cd(II), Cu(II), and Pb(II) Biouptake by Green Algae in the Presence of Humic Acid	2007	Mixture
Lamelas et al.	Effect of Humic Acid on Cd(II), Cu(II), and Pb(II) Uptake by Freshwater Algae: Kinetic and Cell Wall Speciation Considerations	2009	Mixture
Lanceleur et al.	Long-Term Records of Cadmium and Silver Contamination in Sediments and Oysters From the Gironde Fluvial-Estuarine Continuum - Evidence of Changing Silver Sources	2011	Bioaccumulation: steady state not documented
Landner and Jernelov	Cadmium in aquatic systems	1969	The materials, methods or results were insufficiently described
Lane et al.	The interaction between inorganic iron and cadmium uptake in the marine diatom *Thalassiosira oceanica*	2008	Mixture
Lang and Lang-Dobler	The Chemical Environment of Tubificid and Lumbriculid Worms According to the Pollution Level of the Sediment	1979	Bioaccumulation: steady state not documented
Lange et al.	Alterations of tissue glutathione levels and metallothionein mRNA in rainbow trout during single and combined exposure to cadmium and zinc	2002	Bioaccumulation: not whole body or muscle content
Langston and Zhou	Cadmium accumulation, distribution and metabolism in the gastropod *Littorina littorea*: The role of metal-binding proteins	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Lannig et al.	Cadmium-dependent oxygen limitation affects temperature tolerance in eastern oysters (*Crassostrea virginica* Gmelin)	2008	Only one exposure concentration, unmeasured chronic exposure
Lannig et al.	Temperature-dependent effects of cadmium on mitochondrial and whole-organism bioenergetics of oysters (*Crassostrea virginica*)	2006a	Only one exposure concentration, lack of details

Authors	**Title**	**Year**	**Reason Unused**
Lannig et al.	Temperature-dependent stress response in oysters, Crassostrea virginica: pollution reduces temperature tolerance in oysters	2006b	Bioaccumulation: not whole body or muscle content
LaPoint et al.	Relationships among observed metal concentrations, criteria, and benthic community structural responses in 15 streams	1984	Not applicable per ECOTOX Duluth; survey
Lapota et al.	The use of bioluminescent dinoflagellates as an environmental risk assessment tool	2007	No cadmium toxicity information
Lares et al.	Mercury and cadmium concentrations in farmed bluefin tuna (*Thunnus orientalis*) and the suitability of using the caudal peduncle muscle tissue as a monitoring tool.	2012	Bioaccumulation: steady state not documented
Larsson	Some experimentally induced biochemical effects of cadmium on fish from the Baltic Sea	1977	Dilution water not characterized
Lasenby and Van Duyn	and cadmium accumulation by the opossum shrimp *Mysis relicta*	1992	Organisms were exposed to cadmium in food or by injection or gavage
Latif et al.	Effect of cadmium chloride and ascorbic acid exposure on the vital organs of freshwater Cyprinid, *Labeo rohita*	2012	Not North American species, dilution water not characterized
Latire et al.	Responses of Primary Cultured Haemocytes From the Marine Gastropod *Haliotis tuberculata* Under 10-Day Exposure to Cadmium Chloride	2012	In vitro
Laube	Strategies of response to copper, cadmium, and lead by a blue-green and a green alga	1980	Results were only presented graphically
Laurent et al.	Cadmium Biosorption by Ozonized Activated Sludge: the Role of Bacterial Flocs Surface Properties and Mixed Liquor Composition	2010	Bacteria
Lavoie et al.	Influence of essential elements on cadmium uptake and toxicity in a unicellular green alga: The protective effect of trace zinc and cobalt concentrations	2012	Excessive EDTA/NTA in growth media
Lawrence and Holoka	Response of crustacean zooplankton impounded *in situ* to cadmium at low environmental concentrations	1991	Organisms were exposed to cadmium in food or by injection or gavage
LeBlanc	Interspecies relationships in acute toxicity of chemicals to aquatic organisms	1984	Review of previously published data
Leblebici et al.	Influence of nutrient addition on growth and accumulation of cadmium and copper in *Lemna gibba*	2010	Dilution water not characterized
Lee	Occurrence of Heavy Metals and Antibiotic Resistance in Bacteria From Internal Organs of American Bullfrog (*Rana catesbeiana*) Raised in Malaysia	2009	Bioaccumulation: steady state not documented
Lee and Lee	Influence of acid volatile sulfides and simultaneously extracted metals on the bioavailability and toxicity of a mixture of Sediment exposure-associated Cd, Ni, and Zn to polychaetes *Neanthes arenaceodentata*	2005	Sediment exposure
Lee and Luoma	Influence of microalgal biomass on absorption efficiency of Cd, Cr, and Zn by two bivalves from San Francisco Bay	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Lee and Noone	Effect of reproductive toxicants on lipovitellin in female blue crabs, *Callinectes sapidus*	1995	Fed toxicant
Lee and Oshima	Effects of selected pesticides, metals and organometallics on development of blue crab (*Callinectes sapidus*) embryos	1998	The materials, methods or results were insufficiently described
Lee and Wang	Metal Accumulation in the Green Macroalga *Ulva fasciata*: Effects of Nitrate, Ammonium and Phosphate	2001	Non-applicable
Lee and Xu	Differential response of marine organisms to certain metal and agrichemical pollutants	1984	Not North American species
Lee et al.	Influence of Reactive Sulfide (AVS) and Supplementary Food on Ag, Cd and Zn Bioaccumulation in the Marine Polychaete *Neanthes arenaceodentata*	2001	Mixture
Lee et al.	Acute toxicities of trace metals and common xenobiotics to the marine copepod *Tigriopus japonicus*: Evaluation of its use as a benchmark species for routine ecotoxicity tests in western Pacific coastal regions	2007	Not North American species
Lee et al.	Acute toxicity of two CdSe/ZnSe quantum dots with different surface coating in *Daphnia magna* under various light conditions	2010	Mixture
Lee et al.	Binding Strength-Associated Toxicity Reduction by Birnessite and Hydroxyapatite in Pb and Cd Contaminated Sediments	2011	Sediment
Lefcort et al.	Aquatic Snails from Mining Sites have Evolved to Detect and Avoid Heavy Metals	2004	Mixture
Lefevre et al.	Chloride salinity reduces cadmium accumulation by the Mediterranean halophyte species *Atriplex halimus* L.	2009	Non-aquatic plant
Legeay et al.	Impact of cadmium contamination and oxygenation levels on biochemical responses in the Asiatic clam *Cobicula fluminea*	2005	Bioaccumulation: steady state not documented (only 13-14 day exposure), static exposure
Lehtonen et al.	Biomarkers of Pollution Effects in the Bivalves *Mytilus edulis* and *Macoma balthica* Collected From the Southern Coast of Finland (Baltic Sea)	2006	Bioaccumulation: steady state not documented
Lei et al.	Effect of cadmium on cytochrome C oxidase isozyme in the hepatopancreas, gill and heart of freshwater crab *Sinopotamon yangtsekiense*	2011a	Dilution water not characterized; Not North American species
Lei et al.	Histopathological and biochemical alternations of the heart induced by acute cadmium exposure in the freshwater crab *Sinopotamon yangtsekiense*	2011b	Dilution water not characterized; Not North American species
Lei et al.	Arsenic, cadmium, and lead pollution and uptake by rice (*Oryza sativa* L.)	2011c	Sediment exposure
Lekhi et al.	Role of dissolved and particulate cadmium in the accumulation of cadmium in cultured oysters (*Crassostrea gigas*)	2008	Mixture
Lera et al.	Variations in sensitivity of two populations of *Corophium orientale* (Crustacea: Amphipoda) towards cadmium and sodium laurylsulphate	2008	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Les	Cadmium uptake and depuration by the pleurocerid gastropod, *Leptoxis carinata* (Bruguiere), and its potential use as an indicator species	2008	Bioaccumulation: steady state not documented (only 21 day exposure)
Les and Walter	Toxicity and binding of copper, zinc and cadmium by the blue-green alga, *Chroococcus paris*	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Lesage et al.	Accumulation of Metals in the Sediment exposure and Reed Biomass of a Combined Constructed Wetland Treating Domestic Wastewater	2007a	Bioaccumulation: steady state not documented
Lesage et al.	Accumulation of Metals in a Horizontal Subsurface Flow Constructed Wetland Treating Domestic Wastewater in Flanders, Belgium	2007b	Bioaccumulation: steady state not documented
Leung et al.	Influence of static and fluctuating salinity on cadmium uptake and metallothionein expression by the dogwhelk *Nucella lapillus* (L.)	2002	Only one exposure concentration, unmeasured chronic exposure
Leung and Furness	Metallothionein induction and condition index of dogwhelks *Nucella lapillus* (L.) exposed to cadmium and hydrogen peroxide	2001a	Only one exposure concentration, unmeasured chronic exposure
Leung and Furness	Survival, growth, metallothionein and glycogen levels of *Nucella lapillus* (L.) exposed to sub-chronic cadmium stress: the influence of nutritional state and prey type	2001b	Only one exposure concentration, unmeasured chronic exposure
Leung et al.	Concentrations of metallothionein-like proteins and heavy metals in the freshwater snail *Lymnaea stagnalis* exposed to different levels of waterborne cadmium	2003	Duration too short, unmeasured chronic exposure, only two exposure concentrations
Leung et al.	Differential proteomic responses in hepatopancreas and adductor muscles of the green-lipped mussel *Perna viridis* to stresses induced by cadmium and hydrogen peroxide	2011	Only one exposure concentration
Lewis	Selected Heavy Metals in Sediments and Biota From Desert Streams of the Gila River Drainage (Arizona).	1980	Bioaccumulation: steady state not documented
Li	Cellular accumulation and distribution of cadmium in *Isochrysis galbana* during growth inhibition and recovery	1980	Bioaccumulation: not renewal or flow-through; Toxicity: only two exposure concentrations
Li	Cadmium toxicity and random motility studies using marine dinoflagellates	2001	Only two exposure concentrations
Li and Lin	Acute Toxicity of Cadmium to *Argopecten irradiams*	2006	Non-applicable
Li et al.	Metal uptake in zebrafish embryo-larvae exposed to metal-contaminated Sediment exposures	2004	Sediment exposure
Li et al.	Trace Metal Concentrations in Suspended Particles, Sediment exposures and Clams (*Ruditapes philippinarum*) From Jiaozhou Bay of China	2006	Bioaccumulation: steady state not documented
Li et al.	Bioaccumulation of Heavy Metals Along Food Chain in the Water of Zhalong Wetland	2007	Bioaccumulation: steady state not documented
Li et al.	Absorption and Accumulation of Heavy Metals by Plants in Poyang Lake Wetland	2008	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Li et al.	Effects of dietary squid viscera meal on growth and cadmium accumulation in tissues of large yellow croaker, *Pseudosciaena crocea* R.	2009	Dietary exposure
Li et al.	Kinetic study of the bioaccumulation of heavy metals (Cu, Pb, and Cd) in Chinese domestic oyster *Ostrea plicatula*	2010a	Dilution water not characterized; Not North American species
Li et al.	Influence of environmental related concentrations of heavy metals on motility parameters and antioxidant responses in sturgeon sperm	2010c	Dilution water not characterized; only two exposure concentrations
Li et al.	Evaluating the function of calcium antagonist on the Cd-induced stress in sperm of Russian sturgeon, *Acipenser gueldenstaedtii*. Aquat. Toxicol	2010d	Not North American species, only two exposure concentrations, duration too short
Li et al.	Low-molecular-weight-chitosan ameliorates cadmium-induced toxicity in the freshwater crab, *Sinopotamon yangtsekiense*	2011b	Not North American species, only two exposure concentrations
Li et al.	Protective roles of calcium channel blocker against cadmium-induced physiological stress in freshwater teleost *Oncorhynchus mykiss*	2011c	Dilution water not characterized; only two exposure concentrations
Li et al.	Uptake pathways and subcellular fractionation of Cd in the polychaete *Nereis diversicolor*	2012a	Bioaccumulation: steady state not documented, unmeasured exposure
Li et al.	Photosynthetic activity and antioidative response of seagrass *Thalassia hemprichii* to trace metal stress	2012c	Only three exposure concentrations
Liao and Hsieh	Toxicity of three heavy metals to *Macrobrachium rosenbergii*	1990	The materials, methods or results were insufficiently described
Liao et al.	Subcellular Partitioning Links BLM-Based Toxicokinetics for Assessing Cadmium Toxicity to Rainbow Trout	2011a	Modeling
Liao et al.	Assessing the impact of waterborne and dietborne cadmium toxicity on susceptibility risk for rainbow trout	2011b	Review
Lieb and Carline	Effects of Urban Runoff From a Detention Pond on Water Quality, Temperature and Caged *Gammarus minus* (Say) (Amphipoda) in a Headwater Stream	2000	Mixture
Lin et al.	Changes of glycogen metabolism in the gills and hepatic tissue of tilapia (*Oreochromis mossambicus*) during short-term Cd exposure	2011	Only one exposure concentration, duration too short
Lin et al.	Selenium reduces cadmium uptake and mitigates cadmium toxicity in rice	2012	Not applicable
Lira et al.	Effects of barium and cadmium on the population development of the marine nematode *Rhabditis* (*Pellioditis*) *marina*	2011	Non-aquatic exposure; not North American species
Lithner et al.	Bioconcentration factors for metals in humic waters at different pH in the Ronnskar area (N. Sweden)	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Liu and Deng	Accumulation of cadmium, copper, lead and zinc in the Pacific oyster, *Crassostrea gigas*, collected from the Pearl River Estuary, southern China	2007	Bioaccumulation: steady state not documented
Liu and Wang	Metallothionein-Like Proteins Turnover, Cd and Zn Biokinetics in the Dietary Cd-Exposed Scallop *Chlamys nobilis*	2011a	Fed toxicant
Liu and Wang	Differential Roles of Metallothionein-Like Proteins in Cadmium Uptake and Elimination by the Scallop *Chlamys nobilis*	2011b	In vitro

Authors	Title	Year	Reason Unused
Liu et al.	Complex toxicity of triadimefon and Cd towards aquatic organisms	2005	Text in foreign language
Liu et al.	Residual Concentrations of Micropollutants in Benthic Mussels in the Coastal Areas of Bohai Sea, North China	2007	Bioaccumulation: steady state not documented
Liu et al.	Distribution of Persistent Toxic Substances in Benthic Bivalves from the Inshore Areas of the Yellow Sea	2008	Bioaccumulation: steady state not documented
Liu et al.	Mitochondrial pathway of apoptosis in the hepatopancreas of the freshwater crab *Sinopotamon yangtsekiense* exposed to cadmium	2011a	Dilution water not characterized
Liu et al.	Toxicity of copper, lead, and cadmium on the motility of two marine microalgae *Isochrysis galbana* and *Tetraselmis chui*	2011b	Dilution water not characterized
Liu et al.	Antioxidant responses, hepatic intermediary metabolism, histology and ultrastructure in *Synechogobius hasta* exposed to waterborne cadmium	2011c	Not North American species
Liu et al.	Metabolic Profiling of Cadmium-Induced Effects in One Pioneer Intertidal Halophyte *Suaeda salsa* by NMR-Based Metabolomics	2011d	In vitro
Liu et al.	Metal accumulation in the tissues of grass carps (*Ctenopharyngodon idellus*) from fresh water around a copper mine in Southeast China	2012a	Bioaccumulation: steady state not documented
Liu et al.	Cadmium-induced changes in trace element bioaccumulation and proteomics perspective in four marine bivalves	2012b	Only two exposure concentrations
Liu et al.	Cloning and Characterization of the HSP90 Beta Gene from *Tanichthys albonubes* Lin (Cyprinidae): Effect of Copper and Cadmium Exposure	2012c	Mixture
Liu et al.	Effect of ambient cadmium with calcium on mRNA expressions of calcium uptake related transporters in zebrafish (*Danio rerio*) larvae	2012d	Only one exposure concentration
Liu et al.	Cadmium induces ultrastructural changes in the hepatopancreas of the freshwater crab *Sinopotamon henanense*	2013	Dilution water not characterized
Loayza-Muro and Elias-Letts	Responses of the mussel *Anodontites trapesialis* (Unionidae) to environmental stressors: Effect of pH, temperature and metals on filtration rate	2007	Not North American species, duration too short
Lobato et al.	The role of lipoic acid in the protection against of metallic pollutant effects in the shrimp *Litopenaeus vannamei* (Crustacea, Decapoda)	2013	Only one exposure concentration
Loehle and Paller	Heavy Metals In Fish From Streams Near F-Area And H-Area Seepage Basins	1991	Bioaccumulation: steady state not documented
Lokeshwari and Chandrappa	Heavy Metals Content in Water, Water Hyacinth and Sediment exposures of Lalbagh Tank, Bangalore (India)	2006	Bioaccumulation: steady state not documented
Lomagin and Ul'yanova	A new bioassay on water pollution using duckweed *Lemna minor* L	1993	Organisms were exposed to cadmium in food or by injection or gavage
Lombardi et al.	Trace metal levels in *Prochilodus lineatus* collected from the La Plata River, Argentina	2010	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Long and Wang	Metallothionein induction and bioaccumulation kinetics of Cd and Ag in the marine fish *Terapon jarbua* challenged with dietary or waterborne Ag and Cu	2005	Mixture
Long et al.	Short-term metal accumulation and MTLP induction in the digestive glands of *Perna virdis* exposed to Zn and Cd	2010	Bioaccumulation: steady state not documented
Lopez and Thompson	An Assessment of Heavy Metal Pollution in Egg Yolks of Olive Ridley Turtles of the Tropical Eastern Pacific	2009	Bioaccumulation: steady state not documented
Lopez Greco et al.	Toxicity of cadmium and copper on larval and juvenile stages of the estuarine crab *Chasmagnathus granulata* (Brachyura, Grapsidae)	2001	Not North American species, Duration too short
Lorenzon et al.	Heavy metals affect the circulating haemocyte number in the shrimp *Palaemon elegans*	2001	Not North American species, atypical endpoint
Loumbourdis	Hepatotoxic and nephrotoxic effects of cadmium in the frog *Rana ridibunda*	2005	Only one exposure concentration, not North American species, duration too short
Loumbourdis et al.	Effects of cadmium exposure on bioaccumulation and larval growth in the frog *Rana ridibunda*	1999	Not North American species
Loumbourdis et al.	Heavy metal accumulation and metallothionein concentration in the frog *Rana ridibunda* after exposure to chromium or a mixture of chromium and cadmium	2007	Mixture
Loureiro et al.	Assessing joint toxicity of chemicals in *Enchytraeus albidus* (Enchytraeidae) and *Porcellionides pruinosus* (Isopoda) using avoidance behaviour as an endpoint	2009	Sediment exposure
Lovett et al.	A Survey of the Total Cadmium Content of 406 Fish From 49 New York State Fresh Waters	1972	Bioaccumulation: steady state not documented
Lozano et al.	Lead and cadmium levels in coastal benthic algae (seaweeds) of Tenerife, Canary Islands	2003	Bioaccumulation: steady state not documented
Lozano et al.	Content of lead and cadmium in barred hogfish, *Bodianus scrofa*, island grouper, *Mycteroperca fusca*, and Portuguese dogfish, *Centroscymnus coelolepis*, from Canary Islands, Spain.	2009	Bioaccumulation: steady state not documented
Lu and Wu	Recolonization and succession of subtidal macrobenthic infauna in sediment exposures contaminated with cadmium	2003	Sediment exposure
Lu and Xu	Effects of cadmium on antioxidant enzyme activity and DNA damage in *Sinonovacula constricta*	2011	Text in foreign language
Lu et al.	Importance of waterborne cadmium and zinc accumulation in the suspension-feeding amphioxus *Branchiostoma belcheri*	2012a	Bioaccumulation: steady state not documented
Lu et al.	Effects of cadmium, 17β-estradiol and their interaction in the male Chinese loach (*Misgurnus anguillicaudatus*)	2012b	Only two exposure concentrations
Lucas et al.	Concentrations of Trace Elements in Great Lakes Fishes	1970	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Lucia et al.	Effect of Dietary Cadmium on Lipid Metabolism and Storage of Aquatic Bird *Cairina moschata*	2010	Fed toxicant
Lucker et al.	Experiments to determine the impact of salinity on the heavy metal accumulation of *Dreissena polymorpha* (Pallas 1771)	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Lue-Kim et al.	Cadmium toxicity on synchronous populations of *Chlorella ellipsoidea*	1980	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Lugowska	The effect of cadmium and cadmium/copper mixture during the embryonic development on deformed common carp larvae	2007	Species name not given
Luis et al.	Impact of Acid Mine Drainage (AMD) on Water Quality, Stream Sediment exposures and Periphytic Diatom Communities in the Surrounding Streams of Aljustrel Mining Area (Portugal)	2009	Mixture
Lukashev	Peculiarities of Seasonal Dynamics of Manganese, Cobalt and Chromium Accumulation by the Mollusks Dreissena Bugensis (Andr.) Nearby City of Kyiv	2008	Bioaccumulation: steady state not documented
Lussier et al.	Comparison of dissolved and total metals concentrations from acute tests with saltwater organisms	1999	No interpretable concentration, time, response data or examined only a single exposure concentration
Lytle and Lytle	Heavy Metals in Oysters and Clams of St. Louis Bay, Mississippi	1982	Bioaccumulation: steady state not documented
Lyubenova et al.	Direct effect of Cd on glutathione s-transferase and glutathione reductase from *Calystegia sepium*	2007	Non-aquatic plant
Ma et al.	Acute toxicity bioassay using the freshwater luminescent bacterium *Vibrio-qinghaiensis sp.* Nov.-Q67	1999	Not North American species
Ma et al.	Tissue-specific cadmium and metallothionein levels in freshwater crab *Sinopotamon henanense* during acute exposure to waterborne cadmium	2008	Deionized water without proper salts, duration too long, not North American species
Ma et al.	Oxidative damages and ultrastructural changes in the sperm of freshwater crab *Sinopotamon henanense* exposed to cadmium	2013	Dilution water not characterized, not North American species
Maanan	Biomonitoring of Heavy Metals Using *Mytilus galloprovincialis* in Safi Coastal Waters, Morocco	2007	Bioaccumulation: steady state not documented
Maanan	Heavy Metal Concentrations in Marine Molluscs From the Moroccan Coastal Region	2008	Bioaccumulation: steady state not documented
Maas	A field study of the relationship between heavy metal concentrations in stream water and selected benthic macroinvertebrate species	1978	The materials, methods or results were insufficiently described
MacDonald	Assessing the Toxicity of Aquatic Sediments Using Japanese Medaka (*Oryzias latipes*) Embryolarval Bioassays	2010	Sediment
Macdonald and Sprague	Cadmium in marine invertebrates and Arctic cod in the Canadian Arctic. Distibution and ecological implications	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Maceda-Veiga et al.	Metal bioaccumulation in the Mediterranean barbel (*Barbus meridionalis*) in a Mediterranean river receiving effluents from urban and industrial wastewater treatment plants	2012	Bioaccumulation: steady state not documented
Macek and Sleight III	Utility of Toxicity Tests With Embryos and Fry of Fish in Evaluating Hazards Associated With the Chronic Toxicity of Chemicals to Fishes	1977	Review
MacFarlane et al.	Effects of Five Metals on Susceptibility of Striped Bass to *Flexibacter columnaris*	1986	Mixture
Macfie et al.	Effects of cadmium, cobalt, copper, and nickel on growth of the green alga *Chlamydomonas reinhardtii*: The influences of the cell wall and pH	1994	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Machreki-Ajmi and Hamza-Chaffai	Accumulation of Cadmium and Lead in *Cerastoderma glaucum* Originating From the Gulf of Gabes, Tunisia	2006	Bioaccumulation: steady state not documented
Machreki-Ajmi and Hamza-Chaffai	Assessment of Sediment exposure/Water Contamination by in Vivo Transplantation of the Cockles *Cerastoderma glaucum* From a Non Contaminated to a Contaminated Area by Cadmium	2008	Mixture
Macka et al.	Uptake of $^{203}Hg^{++}$ and $^{115}Cd^{++}$ by *Chlamydomonas reinhardi* under various conditions	1979	Bioaccumulation: not renewal or flow-through
Mackey et al.	Bioaccumulation of Vanadium and Other Trace Metals in Livers of Alaskan Cetceans and Pinnipeds.	1996	Bioaccumulation: steady state not documented
Madhusudan et al.	Bioaccumulation of zinc and cadmium in freshwater fishes	2003	Dilution water not characterized, not North American species
Madkour and Ali	Heavy Metals in the Benthic Foraminifera From the Coastal Lagoons, Red Sea, Egypt: Indicators of Anthropogenic Impact on Environment (Case Study)	2009	Bioaccumulation: steady state not documented
Madoni et al.	Acute toxicity of lead, chromium, and other heavy metals to ciliates from activated sludge plants	1994	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Maeda et al.	A bioaccumulation of zinc and cadmium in freshwater alga, *Chlorella vulgaris*. Part II. Association mode of the metals and cell tissue	1990	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Maes et al.	Spatial Variations and Temporal Trends Between 1994 and 2005 in Polychlorinated Biphenyls, Organochlorine Pesticides and Heavy Metals in European Eel (*Anguilla anguilla* L.) In Flanders, Belgium	2008	Bioaccumulation: steady state not documented
Maffucci et al.	Trace element (Cd, Cu, Hg, Se, Zn) accumulation and tissue distribution in loggerhead turtles (*Caretta caretta*) from the Western Mediterranean Sea (southern Italy)	2005	Bioaccumulation: steady state not documented
Mahmoud et al.	Acute toxicities of cadmium and permethrin on the pre-spawning and post-spawning phases of *Hexaplex trunculus* from Bizerta Lagoon, Tunisia	2012	Only three exposure concentrations

Authors	**Title**	**Year**	**Reason Unused**
Mahon and Carman	The Influence of Salinity on the Uptake, Distribution, and Excretion of Metals by the Smooth Cordgrass, *Spartina alterniflora* (Loisel.), Grown in Sediment exposure Contaminated by Multiple Metals	2008	Sediment exposure
Mai et al.	Embryotoxic and genotoxic effects of heavy metals and pesticides on early life stages of Pacific oyster (*Crassostrea gigas*)	2012	Only three exposure concentrations
Maine et al.	Cadmium uptake by floating macrophytes	2001	No cadmium toxicity information; treatment study
Malea	Uptake of cadmium and the effect on viability of leaf cells in the seagrass *Halophila stipulacea* (Forsk.) Aschers	1994	Not North American species
Malea et al.	Metal content of some green and brown seaweeds from Antikyra Gulf (Greece)	1995	Bioaccumulation: steady state not documented
Malea et al.	Iron, Zinc, Copper, Lead and Cadmium Contents in *Ruppia maritima* From a Mediterranean Coastal Lagoon: Monthly Variation and Distribution in Different Plant Fractions	2008	Bioaccumulation: steady state not documented
Malea et al.	Kinetics of cadmium accumulation and its effects on microtubule integrity and cell viability in the seagrass *Cymodocea nodosa*	2013	Not North American species, Bioaccumualtion: steady state not documented
Malekpouri and Moshtaghie	Novel Observation in Cadmium-Zinc Interaction on Parameters Related to Bone Metabolism in Common Carp (*Cyprinus carpio* L.)	2011	Abstract only
Malekpouri et al.	Protective effect of zinc on related parameters to bone metabolism in common carp fish (*Cyprinus carpio* L.) intoxified with cadmium	2011	Dilution water not characterized
Maleva et al.	The response of hydrophytes to environmental pollution with heavy metals	2004	Bioaccumulation: steady state not documented; unmeasured exposure
Maleva et al.	Effect of heavy metals on photosynthetic apparatus and antioxidant status of *Elodea*	2012	Only one exposure concentration, mixture
Malley and Chang	Early observations on the zooplankton community of a precambrian shield lake receiving experimental additions of cadmium	1991	Organisms were exposed to cadmium in food or by injection or gavage
Malley et al.	Whole lake addition of cadmium-109: radiotracer accumulation in the mussel population in the first season	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mallick and Mohn	Use of chlorophyll fluorescence in metal-stress research: A case study with the green microalga *Scenedesmus*	2003	Excessive EDTA in growth media (10 g/L), duration too short
Malone-Oliver et al.	Metallothionein and cadmium toxicity in developing zebrafish	2011	Lack of exposure details, abstract only
Maloney	Influence of organic enrichment on the partitioning and bioavailability of cadmium in a microcosm study	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Mandal et al.	Experiences with some toxic and relatively accessible heavy metals on the survival and biomass production of *Amphora costata* W. Smith	2006	Lack of details, no statistical analysis

Authors	Title	Year	Reason Unused
Manga	Trace Metals In The Common Mussel *Mytilus edulis* From Belfast Lough Northern Ireland UK	1980	Bioaccumulation: steady state not documented
Mann and Fyfe	Algal Uptake of U and Some Other Metals: Implications for Global Geochemical Cycling	1985	Bioaccumulation: steady state not documented
Mann et al.	The Chemical Content of Algae and Waters: Bioconcentration	1988	Bioaccumulation: steady state not documented
Mansour	Effects on fish of cadmium concentrations in water	1993	The materials, methods or results were insufficiently described
Manyin and Rowe	Bioenergetic effects of aqueous copper and cadmium on the grass shrimp, *Palaemonetes pugio*	2009	Mixture
Manz et al.	*In situ* characterization of the microbial consortia active in two wastewater treatment plants	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Manzl et al.	Acute toxicity of cadmium and copper in hepatopancreas cells from the Roman snail (*Helix pomatia*)	2004	Excised tissue/cells
Manzo et al.	Cadmium, lead and their mixtures with copper: *Paracentrotus lividus* embryotoxicity assessment, prediction, and offspring quality evaluation	2010	Not North American species
Mao et al.	Expression and function analysis of metallothionein in the testis of stone crab *Charybdis japonica* exposed to cadmium	2012	Dilution water not characterized; Not North American species
Maranhao et al.	Zinc and cadmium concentrations in soft tissues of the red swamp crayfish *Procambarus clarkii* (Girard, 1852) after exposure to zinc and cadmium	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Marcussen et al.	Food Safety Aspects of Toxic Element Accumulation in Fish From Wastewater-Fed Ponds in Hanoi, Vietnam	2007	Mixture
Marie et al.	Metallothionein response to cadmium and zinc exposures compared in two freshwater bivalves, *Dreissena polymorpha* and *Corbicula fluminea*	2006b	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Marie et al.	Cadmium and Zinc Bioaccumulation and Metallothionein Response in Two Freshwater Bivalves (*Corbicula fluminea* and *Dreissena polymorpha*) Transplanted Along a Polymetallic Gradient	2006a	Mixture
Marigomez et al.	Lysosomal enlargement in digestive cells of mussels exposed to cadmium, benzo(a)pyrene and their combination	2005	Not North American species, only one exposure concentration
Marion and Denizeau	Rainbow Trout and Human Cells in Culture for the Evaluation of the Toxicity of Aquatic Pollutants: a Study With Cadmium	1983	In vitro
Mark and Solbe	Analysis of the ecetoc aquatic toxicity (EAT) database V: The relevance of *Daphnia magna* as a representative test species	1998	Review of previously published data
Markich and Jeffree	Absorption of divalent trace metals as analogues of calcium by Australian freshwater bivalves: An explanation of how water hardness reduces metal toxicity	1994	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Markich et al.	The effects of pH and dissolved organic carbon on the toxicity of cadmium and copper to a freshwater bivalve: Further support for the extended free ion activity model	2003	Not North American species, duration too short
Marr et al.	Differences in relative sensitivity of naive and metals-acclimated brown and rainbow trout exposed to metals representative of the Clark Fork River, Montana	1995a	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Marr et al.	Relative sensitivity of brown and rainbow trout to pulsed exposures of an acutely lethal mixture of metals typical of the Clark Fork River, Montana	1995b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Martignago et al.	Cadmium, lead and metallothionein contents in tissues of the sea bream *Sparus aurata* from three different fish farming systems	2009	Bioaccumulation: steady state not documented
Martin-Diaz et al.	Bioaccumulation and Toxicity of Dissolved Heavy Metals from the Guadalquivir Estuary After the Aznalcollar Mining Spill Using *Ruditapes philippinarum*	2005a	Mixture
Martin-Diaz et al.	Effects of cadmium and zinc on *Procambarus clarkii*: Simulation of the Aznalcollar mining Spill	2005b	Surgically altered (chelipeds removed), only two exposure concentrations
Martinez et al.	Cadmium toxicity, accumulation and metallothionein induction in *Echinogammarus echinosetosus*	1996	Not North American species
Martinez et al.	Morphological Abnormalities in Chironomus tentans Exposed to Cadmium- and Copper-Spiked Sediment exposures	2003	Sediment exposure
Martinez-Guitarte et al.	Overexpression of Long Non-Coding RNAs Following Exposure to Xenobiotics in the Aquatic Midge *Chironomus riparius*	2012	Mixture
Masoudzadeh et al.	Biosorption of Cadmium by *Brevundimonas sp*. Zf12 Strain, a Novel Biosorbent Isolated From Hot-Spring Waters in High Background Radiation Areas	2011	Bacteria
Masson et al.	Responses of Two Sentinel Species (*Hexagenia limbata*--Mayfly *Pyganodon grandis*--Bivalve) Along Spatial Cadmium Gradients in Lakes and Rivers in Northwestern Quebec.	2010	Bioaccumulation: steady state not documented
Mastrangelo et al.	Cadmium toxicity in tadpoles of *Rhinella arenarum* in relation to calcium and humic acids	2011	Not North American species
Mateo et al.	O_2-induced inactivation of nitrogenase as a mechanism for the toxic action of Cd^{2+} on *Nostoc* UAM 208	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Mathad et al.	Short and long term effects of exposure of microalgae to heavy metal stress	2004	Lack of details, no statistical analysis
Mathew and Menon	Toxic responses of bivalves to metal mixtures	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Mathew and Menon	Filtration Rates and Heavy Metal Toxicity in *Donax incarnatus*	2004	Non-applicable

Authors	**Title**	**Year**	**Reason Unused**
Mathew and Menon	Histological aberrations accompanying chronic metal toxicity in the mussel *Perna indica*	2005	Only one exposure concentration, unmeasured chronic exposure
Mathews et al.	Metal Concentrations in Mediterranean Fish Tissues: Exploring Biomagnification Patterns. Monaco	2007	Bioaccumulation: steady state not documented
Mathews et al.	Assimilation and Retention of Metals in Teleost and Elasmobranch Fishes Following Dietary Exposure	2008	Dietary exposure
Mathis and Cummings	Selected Metals in Sediments, Water, and Biota in the Illinois River	1973	Bioaccumulation: steady state not documented
Matozzo et al.	Effects of copper and cadmium exposure on functional responses of hemocytes in the clam, *Tapes philippinarum*	2001	Dilution water not characterized, duration too short, not North American species
Matsuo and Val	Dietary exposure Tissue Cadmium Accumulation in an Amazonian Teleost (Tambaqui, *Colossoma macropomum* Cuvier, 1818)	2007	Dietary exposure
Matz and Krone	Cell death, stress-responsive transgene activation, and deficits in the olfactory system of larval zebrafish following cadmium exposure	2007	No scientific name given, atypical endpoint
Matz et al.	Accumulation and elimination of cadmium in larval stage zebrafish following acute exposure	2007	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Maunder et al.	Uptake, tissue distribution and excretion of Dietary exposure cadmium and copper in discus fish *Symphysodon spp*.	2009	Dietary exposure
Maunder et al.	Accumulation of dietary and aqueous cadmium into the epidermal mucus of the discus fish *Symphysodon sp*	2011	Not North American species, only one exposure concentration
Mayrand and Dutil	Physiological responses of rock crab *Cancer irroratus* exposed to waterborne pollutants	2008	Mixture
Mazen and El Maghraby	Accumulation of Cadmium, Lead and Strontium, and a Role of Calcium Oxalate in Water Hyacinth Tolerance	1997	Mixture
Mazet et al.	Concentrations of PCBs, organochlorine pesticides and heavy metals (lead, cadmium, and copper) in fish from the Drome river: Potential effects on otters (*Lutra lutra*)	2005	Bioaccumulation: steady state not documented
McCahon and Pascoe	Cadmium toxicity to the freshwater amphipod *Gammarus pulex* (L.) during the molt cycle	1988a	Not North American species
McCahon and Pascoe	Increased sensitivity to cadmium of the freshwater amphipod *Gammarus pulex* (L.) during the reproductive period	1988b	Not North American species
McCahon and Pascoe	Use of *Gammarus pulex* (L.) in safety evaluation tests: Culture and selection of a sensitive life stage	1988c	Not North American species
McCahon et al.	The effect of the acanthocephalan *Pomphorhynchus laevis* (Muller 1776) on the acute toxicity of cadmium to its intermediate host, the amphipod *Gammarus pulex* (L.)	1988	Not North American species
McCahon et al.	The toxicity of cadmium to different larval instars of the trichopteran larvae *Agapetus fuscipes* Curtis and the importance of life cycle information to the design of toxicity tests	1989	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
McClain et al.	Laboratory and field validation of multiple molecular biomarkers of contaminant exposure in rainbow trout (*Oncorhynchus mykiss*)	2003	Surgically altered test species
McClosky and Newman	Sediment Preference in the Asiatic Clam (*Corbicula fluminea*) and Viviparid Snail (*Campeloma decisum*) as a Response to Low-Level Metal and Metalloid Contamination	1995	Sediment
McClurg	Effects of fluoride, cadmium and mercury on the estuarine prawn *Penaeus indicus*	1984	Not North American species
McDonald et al.	Incorporation of 28-d *Leptocheirus plumulosus* toxicity data in a sediment weight-of-evidence framework	2010	Sediment exposure
McFarlane and Franzin	Effects of Elevated Heavy Metals on a Natural Population of White Suckers, *Catostomus commersoni*, in Hamell Lake, Saskatchewan: Near a Base Metal Smelter at Flin Flon, Manitoba.	1977	Bioaccumulation: steady state not documented
McFarlane and Franzin	Elevated Heavy Metals: a Stress on a Population of White Suckers, *Catostomus Commersoni*, in Hamell Lake, Saskatchewan.	1978	Bioaccumulation: steady state not documented
McGeer et al.	Influence of acclimation and cross-acclimation of metals on acute Cd toxicity and Cd uptake and distribution in rainbow trout (*Oncorhynchus mykiss*)	2007	Mixture
McGeer et al.	Cadmium	2011	Review
McHardy and George	The Uptake of Selected Heavy Metals by the Green Alga *Cladophora glomerata*	1985	Bioaccumulation: steady state not documented
Mckee et al.	Contaminant Levels in Rainbow Trout, *Oncorhynchus mykiss*, and Their Diets From Missouri Coldwater Hatcheries	2008	Bioaccumulation: steady state not documented
McLean and Williamson	Cadmium accumulation by marine red alga *Porphyra umbilicalis*	1977	Bioaccumulation: steady state not documented
McLeese	Cadmium and marine invertebrates	1981	Lack of exposure details
McLeese and Ray	Toxicity of $CdCl_2$, CdEDTA, $CuCl_2$, and CuEDTA to marine invertebrates	1984	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
McLeese et al.	Lack of excretion of cadmium from lobsters	1981	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
McNicol and Scherer	Influence of cadmium pre-exposure on the preference-avoidance responses of lake whitefish (*Coregonus clupeaformis*) to cadmium	1993	Organisms were selected, adapted or acclimated for increased resistance to cadmium
McPherson and Brown	The Bioaccumulation of Cadmium by the Blue Swimmer Crab *Portunus pelagicus* L	2001	Non-applicable
Meador et al.	A comparison of the non-essential elements cadmium, mercury, and lead found in fish and sediment exposure from Alaska and California	2005	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Mebane	Development of site-specific water quality criteria for the segment of the South Fork Coeur d'Alene River from Daisy Gulch to Wallace, Idaho: Comparison of cadmium criteria to the results toxicity testing with species resident to the South Fork Coeur d'Alene River	2003	Review
Mebane	Cadmium risks to freshwater life: derivation and validation of low-effect criteria values using laboratory and field studies	2006b	Review
Mebane	Relevance of Risk Predictions Derived From a Chronic Species Sensitivity Distribution With Cadmium to Aquatic Populations and Ecosystems	2010	Review
Mebane et al.	Incubating rainbow trout in soft water increased their later sensitivity to cadmium and zinc	2010	Mixture
Medina et al.	Histopathological and biological studies of the effect of cadmium on *Rhinella arenarum* gonads	2012	Not North American species; injected toxicant
Meinelt et al.	Interaction of cadmium toxicity in embryos and larvae of zebrafish (*Danio rerio*) with calcium and humic substances	2001	Lack of detail
Mekkawy et al.	Effects of cadmium on some haematological and biochemical characteristics of *Oreochromis niloticus* (Linnaeus, 1758) dietary supplemented with tomato paste and vitamin E	2011	Dilution water not characterized
Melgar et al.	Accumulation profiles in rainbow trout (*Oncorhynchus mykiss*) after short-term exposure to cadmium	1997	Organisms were exposed to cadmium in food or by injection or gavage
Mellinger	The comparative metabolism of cadmium, mercury and zinc as environmental contaminants in the freshwater mussel, *Margaritifera margaritifera*	1972	Only one exposure concentration; median survival time
Menchaca et al.	Sensitivity comparison of laboratory-cultured and field-collected amphipod *Corophium multisetosum* in toxicity tests	2010	Duration too short, Not North American species
Mendez and Baird	Effects of Cadmium on Sediment exposure Processing on Members of the *Capitella* Species-Complex	2002	Sediment exposure
Mendez and Green-Ruiz	Preliminary observations of cadmium and copper effects on juveniles of the polychaete *Capitella sp*. Y (Annelida: Polychaeta) from Estero del Yugo, Mazatlan, Mexico	2005	Lack of detail, dilution water not characterized
Mendez and Green-Ruiz	Cadmium and copper effects on larval development and mortality of the polychaete *Capitella sp.* Y from Estero del Yugo, Mazatlan, Mexico	2006	Duration too long, dilution water not characterized
Mendoza-Cozatl et al.	Cadmium accumulation in the chloroplast of *Euglena gracilis*	2002	Bioaccumulation: steady state not documented (only 8 day exposure)
Merivirta et al.	Cadmium, mercury and lead content of river lamprey caught in Finnish rivers	2001	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Mersch et al.	Laboratory accumulation and depuration of copper and cadmium in the freshwater mussel *Dreissena polymorpha* and the aquatic moss *Rhynchostegium riparioides*	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mersch et al.	Copper in indigenous and transplanted zebra mussels in relation to changing water concentrations and body weight	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Messaoudi et al.	Study on the sensitivity to cadmium of marine fish *Salaria basilisca* (Pisces: Blennidae)	2009	Not North American species; only one exposure concentration; dilution water not characterized
Messiaen et al.	The micro-evolutionary potential of *Daphnia magna* population exposed to temperature and cadmium stress	2010	Only one exposure concentration
Messiaen et al.	The potential for adaptation in a natural *Daphnia magna* population: broad and narrow-sense heritability of net reproductive rate under Cd stress at two temperatures	2012	Only one exposure concentration
Metayer et al.	Accumulation of some trace metals (cadmium, lead, copper and zinc) in sole (*Solea solea*) and flounder (*Platichthus flesus*): Changes as a function of age and organotropism	1982	Not North American species
Metayer et al.	Evolution Of The Bioaccumulation Of Some Trace Elements In Elvers And Eels *Anguilla anguilla* Of 3 Estuaries Of The Atlantic Ocean	1984	Bioaccumulation: steady state not documented
Metcalfe-Smith	Influence of Species and Sex on Metal Residues in Freshwater Mussels (Family Unionidae) From the St. Lawrence River, With Implications for Biomonitoring Programs	1994	Bioaccumulation: steady state not documented
Metcalfe-Smith et al.	Influence of Biological Factors on Concentrations of Metals in the Tissues of Freshwater Mussels (*Elliptio complanata* and *Lampsilis radiata radiata*) From the St. Lawrence River	1996	Bioaccumulation: steady state not documented
Meteyer et al.	Effect of cadmium on early developmental stages of the sheepshead minnow (*Cyprinodon variegatus*)	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Metian et al.	Interspecific comparison of Cd bioaccumulation in European pectinidae (*Chlamys varia* and *Pecten maximus*)	2007	Bioaccumulation: steady state not documented (only 7 day exposure); dilution water not characterized; not North American species
Metian et al.	Accumulation of nine metals and one metalloid in the tropical scallop *Comptopallium radula* from coral reefs in New Caledonia	2008	Mixture, not North American species
Meyer	A mechanistic explanation for the ln(LC50) vs 1n(hardness) adjustment equation for metals	1999	Review of previously published data
Meyer et al.	Sensitivity analysis of population growth rates estimated from cladoceran chronic toxicity tests	1987	Review
Meyer et al.	Effects of water chemistry on bioavailability and toxicity of waterborne cadmium, copper, nickel, lead, and zinc on freshwater organisms	2007	Not applicable per ECOTOX Duluth; review

Authors	Title	Year	Reason Unused
Mhadhbi et al.	A standard ecotoxicological bioassay using early life stages of the marine fish *Psetta maxima*	2010	Not North American species
Miao et al.	Comparison of Cd, Cu, and Zn toxic effects on four marine phytoplankton by pulse-amplitude-modulated fluorometry	2005	Mixture
Michibata et al.	Effects of calcium and magnesium ions on the toxicity of cadmium to the egg of the teleost, *Oryzias latipes*	1986	Not North American species
Michibata et al.	Stage sensitivity of eggs of the teleost *Oryzias latipes* to cadmium exposure	1987	Not North American species
Migliarini et al.	Effects of cadmium exposure on testis apoptosis in the marine teleost *Gobius niger*	2005	Duration too short, dilution water not characterized, not North American species, only two exposure concentrations
Migliore and De Nicola Giudici	Effect of heavy metals (Hg, Cd, Cu and Fe) on two species of crustacean isopods, *Asellus aquaticus* (L.) and *Proasellus coxalis*	1988	Not North American species
Milani et al.	The Relative Sensitivity of Four Benthic Invertebrates to Metals in Spiked-Sediment exposure Exposures and Application to Contaminated Field Sediment exposure	2003	Sediment exposure
Mills et al.	Contaminant and Nutrient Element Levels in Soft Tissues of Zebra and Quagga Mussels From Waters of Southern Lake Ontario	1993	Bioaccumulation: steady state not documented
Millward et al.	Mixtures of Metals and Hydrocarbons Elicit Complex Responses by a Benthic Invertebrate Community	2004	Mixtures
Milne	The dynamics of chronically bioaccumulated Cd in rainbow trout (*Oncorhynchus mykiss*) during both moderately hard and soft waterborne exposures	2010	Bioaccumulation: not whole body or muscle
Ministry of Technology	-	1967	The materials, methods or results were insufficiently described
Mishra et al.	Accumulation of cadmium and copper from aqueous solutions using Indian lotus (*Nelumbo nucifera*)	2009	No cadmium toxicity information; treatment study
Misitano and Schiewe	Effect of Chemically Contaminated Marine Sediment on Naupliar Production of the Marine Harpacticoid Copepod, *Tigriopus californicus*	1990	Sediment
Mitchell et al.	Acute Toxicity of Mine Tailings to Four Marine Species	1985	Mixture
Mitchelmore et al.	Differential accumulation of heavy metals in the sea anemone *Anthopleura elegantissima* as a function of symbiotic state	2003	Bioaccumulation: unmeasured exposure; dilution water not characterized
Mitchelmore et al.	Uptake and partitioning of copper and cadmium in the coral *Pocillopora damicornis*	2007	Bioaccumulation: steady state not documented; dilution water not characterized; unmeasured exposure

Authors	**Title**	**Year**	**Reason Unused**
Mizutani et al.	Uptake of lead, cadmium and zinc by the fairy shrimp, *Branchinecta longiantenna* (Crustacea: Anostraca)	1991	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mohammed and Agard	Comparative sensitivity of three tropical cladoceran species (*Diaphanosoma brachyurum*, *Ceriodaphnia rigaudii* and *Moinodaphnia macleayi*) to six chemicals	2006	Not North American species
Moller et al.	Influence of acclimation and exposure temperature on the acute toxicity of cadmium to the freshwater snail *Potamopyrgus antipodarum* (Hydrobiidae)	1994	Not North American species
Mondal	Pesticides and Heavy Metals Influence Steroidogenic Activity in Fish Gonad and Interrenal.	1997	In vitro
Mondon et al.	Histological, Growth and 7-Ethoxyresorufin O-Deethylase (EROD) Activity Responses of Greenback Flounder *Rhombosolea tapirina* to Contaminated Marine Sediment exposure and Diet	2001	Sediment exposure
Monteiro-Neto et al.	Concentrations of heavy metals in *Sotalia fluviatilis* (Cetacea: Delphinidae) off the coast of Ceara, northeast Brazil	2003	Bioaccumulation: steady state not documented
Moolman et al.	Comparative studies on the uptake and effects of cadmium and zinc on the cellular energy allocation of two freshwater gastropods	2007	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure
Moraitou-Apostolopoulou et al.	Effects of sublethal concentrations of cadmium pollution for two populations of *Acartis clausi* (Copepoda) living at two differently polluted areas	1979	Questionable treatment of test organisms or inappropriate test conditions or methodology
Morales-Hernandez et al.	Heavy Metals in Sediment exposures and Lobster (*Panulirus gracilis*) from the Discharge Area of the Submarine Sewage Outfall in Mazatlan Bay (SE Gulf of California)	2004	Effluent
Moreno et al.	Inhibition of molting by cadmium in the crab *Chasmagnathus granulata* (Decapoda Brachyura)	2003	Surgically altered species, not North American species
Mori and Wakabayashi	Cells in culture for the evaluation of the toxicity of chemicals. 1. Cytotoxicity of cadmium and copper to CHSE-214 cells derived from Chinook salmon	1996	In vitro
Mori and Wakabayashi	Cells in culture for the evaluation of the toxicity of chemicals. 2. Cytotoxicity of metals toward cultured fish cells and effect of exposure temperature on cytotoxicity	1997	In vitro
Morillo-Velarde et al.	Effects of cadmium on locomotor activity rhythms of the amphipod *Gammarus aequicauda*	2011	Not North American species, short duration
Morin et al.	Detection of DNA damage in yolk-sac larvae of the Japanese medaka, *Oryzias latipes*, by the comet assay	2011	Not North American species, duration too short

Authors	**Title**	**Year**	**Reason Unused**
Morley et al.	Toxicity of Cadmium and Zinc Mixtures *to Diplostomum spathaceum* (Trematoda: Diplostomidae) Cercarial Survival	2002	Mixtures
Morley et al.	Toxicity of Cadmium and Zinc Mixtures to Cercarial Tail Loss in *Diplostomum spathaceum* (Trematoda: Diplostomidae)	2005	Mixtures
Mormede and Davies	Heavy metal concentrations in commercial deep-sea fish from the Rockall Trough	2001	Bioaccumulation: steady state not documented
Morris	Toxicity of Cyanide, Chromium, Cadmium, Copper, Lead, Nickel, and Zinc. Summary Report	1973	Review
Morrison et al.	Proximate Composition and Organochlorine and Heavy Metal Contamination of Eggs From Lake Ontario, Lake Erie and Lake Michigan Coho Salmon (*Oncorhynchus kisutch* Walbaum) in Relation to Egg Survival	1985	Bioaccumulation: steady state not documented
Mostafa and Khalil	Uptake, release and incorporation of radio active cadmium and mercury by the fresh water alga *Phormidium fragile*	1986	Not North American species
Motohashi and Tsuchida	Uptake of cadmium by pure cultured diatom, *Skeletonema costatum*	1974	Bioaccumulation: not renewal or flow-through
Mouneyrac et al.	Comparison of metallothionein concentrations and tissue distribution of trace metals in crabs (*Pachygrapsus marmoratus*) from a metal-rich estuary, in and out of the reproductive season	2001	Bioaccumulation: steady state not documented
Mount et al.	Dietary and waterborne exposure of rainbow trout (*Oncorhynchus mykiss*) to copper, cadmium, lead and zinc using a live diet	1994	Organisms were exposed to cadmium in food or by injection or gavage
Moureaux et al.	Effects of field contamination by metals (Cd, Cu, Pb, Zn) on biometry and mechanics of echinoderm ossicles	2011	Bioaccumulation: steady state not documented
Moza et al.	Effect of sub-lethal concentrations of cadmium on food intake, growth and digestibility in the gold fish, *Carassius auratus* L	1995	The materials, methods or results were insufficiently described
Mueller and Prosi	Distribution Of Zinc, Copper, And Cadmium In Various Organs Of Roaches (*Rutilus rutilus* L.) From The Neckar And Elsenz Rivers	1978	Bioaccumulation: steady state not documented
Muino et al.	Protective action of ions against cadmium toxicity to young *Bufo arenarum* tadpoles	1990	Not North American species
Mullaugh and Luther III	Formation and Persistence of Cadmium Sulfide Nanoparticle in Aqueous Solution	2009	Inappropriate form of toxicant
Muller and Payer	The influence of pH on the cadmium-repressed growth of the alga *Coelostrum proboscideum*	1979	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Munawar and Legner	Detection of Metal Toxicity Using Natural Phytoplankton as Test Organisms in the Great Lakes.	1993	Mixture
Muncke	Molecular Scale Ecotoxicological Testing in Developing Zebrafish (*Danio rerio*)	2006	In vitro

Authors	**Title**	**Year**	**Reason Unused**
Munger and Hare	Relative importance of water and food as cadmium sources to an aquatic insect (*Chaoborus punctipennis*): Implications for predicting Cd bioaccumulation in nature	1997	Organisms were exposed to cadmium in food or by injection or gavage
Munger et al.	Influence of exposure time on the distribution of cadmium within the cladoceran *Ceriodaphnia dubia*	1999	The materials, methods or results were insufficiently described
Muramoto	Decrease in cadmium concentration in a Cd-contaminated fish by short-term exposure to EDTA	1980	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Musko et al.	The impact of Cd and different pH on the amphipod *Gammarus fossarum* Koch (Crustacea: amphipoda)	1990	Not North American species
Musthafa et al.	Bioaccumulation of cadmium in selected tissues of *Oreochromis mossambicus* exposed to sublethal concentrations of cadmium chloride	2009	Lack of exposure details
Muyssen and Janssen	Multi-generation cadmium accumulation and tolerance in *Daphnia magna* Straus	2004	Excessive EDTA (testing used Elendt M4 medium which complexes the metal)
Mwangi and Alikhan	Cadmium and nickel uptake by tissues of *Cambarus bartoni* (Astacidae, Decapoda, Crustacea): Effects on copper and zinc stores	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Mwashote	Levels of Cadmium and Lead in Water, Sediment exposures and Selected Fish Species in Mombasa, Kenya	2003	Bioaccumulation: steady state not documented
Nagel and Voigt	Impaired photosynthesis in a cadmium-tolerant *Chlamydomonas* mutant strain	1995	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Nair and Choi	Identification, Characterization and Expression Profiles of *Chironomus riparius* Glutathione S-Transferase (GST) Genes in Response to Cadmium and Silver Nanoparticles Exposure	2011	Inappropriate form of toxicant
Nair et al.	Expression of catalase and glutathione S-transferase genes in *Chironomus riparius* on exposure to cadmium and nonylphenol	2011	Dilution water not characterized; only three exposure concentrations
Najeeb et al.	Insights into cadmium induced physiological and ultra-structural disorders in *Juncus effusus* L. and its remediation through exogenous citric acid	2011	Excessive EDTA
Nakagawa and Ishio	Aspects of accumulation of cadmium ion in the egg of medaka *Oryzias latipes*	1988	Not North American species
Nakagawa and Ishio	Effects of water hardness on the toxicity and accumulation of cadmium in eggs and larvae of medaka *Oryzias latipes*	1989	Not North American species
Nakamoto and Hassler	Selenium and Other Trace Elements in Bluegills From Agricultural Return Flows in the San Joaquin Valley, California.	1992	Bioaccumulation: steady state not documented
Nakamura	Experimental studies on the accumulation of cadmium in the fish body	1974	Text in foreign language

Authors	**Title**	**Year**	**Reason Unused**
Nakhle et al.	Cadmium and Mercury in Seine Estuary Flounders and Mussels: the Results of Two Decades of Monitoring	2007	Bioaccumulation: steady state not documented
Nalewajko	Effects of cadmium and metal-contaminated sediments on photosynthesis heterotrophy, and phosphate uptake in Mackenzie River delta phytoplankton	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Narayanan et al.	Pattern of depuration of accumulated heavy metals in the mud crab, *Scylla serrata* (Forskal)	1999	Not North American species
Narvaez et al.	Uptake, depuration and effect of cadmium on the green mussel *Perna viridis* (L. 1758) (Mollusca: Bivalvia)	2005	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure; dilution water not characterized
Nassiri et al.	Cadmium bioaccumulation in *Tetraselmis suecica* and electron energy loss spectroscopy (EELS) study	1997	Not North American species
Nasu et al.	Comparative studies on the absorption of cadmium and copper in *Lemna paucicostata*	1983	The dilution water or medium used was open to questions because of its origin or content
Nasu et al.	The toxicity of some water pollutants for Lemnaceae (duckweed) plant	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Naumann et al.	Growth rate based dose-response relationships and EC-values of ten heavy metals using the duckweed growth inhibition test (ISO 20079) with *Lemna minor* L. Clone St.	2007	Excessive EDTA in the medium (>200 ug/L)
Nawaz et al.	In vitro toxicity of copper, cadmium, and chromium to isolated hepatocytes from carp, *Cyprinus carpio* L.	2005	In vitro
Nawaz et al.	Determination of heavy metals in fresh water fish species of the River Ravi, Pakistan compared to farmed fish varieties.	2010	Bioaccumulation: steady state not documented
Naylor et al.	Effect of differing maternal food ration on susceptibility of *Daphnia magna* Straus neonates to toxic substances	1992	The materials, methods or results were insufficiently described
Negilski	Acute toxicity of zinc, cadmium and chromium to the marine fishes, yellow-eye mullet (*Aldrichetta forsteri* C. and V.) and smallmouth hardy head (*Atherinasoma microstoma* Whitley)	1976	Not North American species
Negri et al.	Contamination in Sediment exposures, Bivalves and Sponges of McMurdo Sound, Antarctica	2006	Bioaccumulation: steady state not documented
Nelson	Observed field tolerance of caddisfly larvae (*Hesperophylax sp.*) to fish metal concentrations and low pH	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Nendza et al.	Potential for secondary poisoning and biomagnification in marine organisms	1997	Review of previously published data
Nessim et al.	Biosorption of lead and cadmium using marine algae	2011	Homogenized algal material
Nesto et al.	Bioaccumulation and Biomarker Responses of Trace Metals and Micro-Organic Pollutants in Mussels and Fish from the Lagoon of Venice, Italy	2007	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Neuberger-Cywiak et al.	Effects of zinc and cadmium on the burrowing behavior, LC50, and LT50 on *Donax trunculus* Linnaeus (Bivalvia-Donacidae)	2003	Dilution water not characterized, not North American species
Neuberger-Cywiak et al.	Sublethal effects of Zn++ and Cd++ on respiration rate, ammonia excretion, and O:N ratio of *Donax trunculus* (Bivalvia; Donacidae)	2007	Mixture
Neumann and Leimkuhler	Heavy Metal Ions Inhibit Molybdoenzyme Activity by Binding to the Dithiolene Moiety of Molybdopterin in *Escherichia coli*	2008	Mixture
Ney and Martin	Influence of Prefreezing on Heavy Metal Concentrations in Bluegill Sunfish	1985	Bioaccumulation: steady state not documented
Ng and Wang	Detoxification and Effects of Ag, Cd, and Zn Pre-Exposure on Metal Uptake Kinetics in the Clam *Ruditapes philippinarum*	2004	Prior exposure
Ng and Wang	Modeling of cadmium bioaccumulation in two populations of the green mussel *Perna viridis*	2005	Modeling
Ng and Wang	Interactions of silver, cadmium, and copper accumulation in green mussels (*Perna viridis*)	2007	Bioaccumulation: steady state not documented; unmeasured exposure
Ng and Wood	Trophic Transfer and Dietary exposure Toxicity of Cd from the Oligochaete to the Rainbow Trout	2008	Dietary exposure
Ng et al.	Does Dietary exposure Ca Protect Against Toxicity of a Low Dietborne Cd Exposure to the Rainbow Trout?	2009	Dietary exposure
Ng et al.	Cadmium Accumulation and Loss in the Pacific Oyster *Crassostrea gigas* Along the West Coast of the USA.	2010	Bioaccumulation: steady state not documented
Nguyen and Janssen	Embryo-larval toxicity tests with the African catfish (*Clarias gariepinus*): Comparative sensitivity of endpoints	2002	Duration too long, not North American species
Ni et al.	Influences of salinity on the biokinetics of Cd, Se, and Zn in the intertidal mudskipper *Periophthalmus cantonensis*	2005	Mixture
Nimick et al.	Influence of in-stream diel concentration cycles of dissolved trace metals on acute toxicity to one-year-old cutthroat trout (*Oncorhynchus clarki lewisi*)	2007	Mixture
Nimmo et al.	Three Studies Using *Ceriodaphnia* to Detect Nonpoint Sources of Metals From Mine Drainage.	1990	Mixture
Nimmo et al.	Cadmium and Zinc Accumulation in Aquatic Bryophytes Immersed in the Arkansas River, Colorado: Comparison of Fall Versus Spring	2006	Bioaccumulation: steady state not documented
Nir et al.	Cadmium uptake and toxicity to water hyacinth: Effect of repeated exposures under controlled conditions	1990	Not North American species
Niyogi and Wood	Effects of chronic waterborne and dietary metal exposures on gill metal-binding: implications for the biotic ligand model	2003	Review

Authors	Title	Year	Reason Unused
Niyogi et al.	Kinetic Analyses of Waterborne Ca and Cd Transport and Their Interactions in the Gills of Rainbow Trout (*Oncorhynchus mykiss*) and Yellow Perch (*Perca flavescens*), Two Species Differing Greatly in Acute Waterborne Cd Sensitivity	2004a	Mixture
Noel-Lambot et al.	Distribution of Cd, Zn and Cu in liver and gills of the eel *Anguilla anguilla* with special reference to metallothioneins	1978	Bioaccumulation: unmeasured exposure; not North American species
Noel-Lambot et al.	Cadmium, zinc, and copper accumulation in limpets (*Patella vulgata*) from the British channel and special reference to metallothioneins	1980	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Nolan and Duke	Cadmium accumulation and toxicity in *Mytilus edulis*: Involvement of metallothioneins and heavy molecular weight protein	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Noraho and Gaur	Effect of cations, including heavy metals, on cadmium uptake by *Lemna polyrhiza* L.	1995	Not North American species
Norberg-King et al.	Interlaboratory evaluation of *Hyalella azteca* and *Chironomus tentans* short-term and long-term sediment toxicity tests	2006	Non-applicable
Nordberg	Historical perspectives on cadmium toxicology	2009	Review
Nordberg et al.	Cadmium: Handbook on the Toxicology of Metals (Third Edition)	2007	Review
Norey et al.	Induction of metallothionein gene expression by cadmium and the retention of the toxic metal in the tissues of rainbow Trout (*Salmo gairdneri*)	1990c	Injected toxicant
Norey et al.	A comparison of the accumulation, tissue distribution and secretion of cadmium in different species of freshwater fish	1990a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Norris and Lake	Trace Metal Concentrations in Fish From the South Esk River, Northeastern Tasmania, Australia.	1984	Bioaccumulation: steady state not documented
Norum et al.	Trace element distribution during the reproductive cycle of female and male spiny and Pacific scallops, with implications for biomonitoring	2005	Bioaccumulation: steady state not documented
Norwood et al.	Interactive effects of metals in mixtures on bioaccumulation in the amphipod *Hyalella azteca*	2007	Mixture
Notenboom et al.	Effect of ambient oxygen concentration upon the acute toxicity of chlorophenols and heavy metals to the groundwater copepod *Parastenocaris germanica* (crustacea)	1992	Not North American species
Nott and Nicolaidou	Variable transfer of detoxified metals from snails to hermit crabs in marine food chains	1994	Not North American species

Authors	Title	Year	Reason Unused
Novais et al.	Reproduction and biochemical responses in *Enchytraeus albidus* (Oligochaeta) to zinc or cadmium exposures	2011	Sediment exposure
Novais et al.	Exposure of *Enchytraeus albidus* to Cd and Zn - Changes in cellular energy allocation (CEA) and linkage to transcriptional, enzymatic and reproductive effects	2013	Soil exposure
Novakova et al.	Zinc and cadmium toxicity using a biotest with *Artemia franciscana*	2007	Brine shrimp
Novelli et al.	Toxicity of heavy metals using sperm cell and embryo toxicity bioassays with *Paracentrotus lividus* (Echinodermata: Echinoidea): Comparisons with exposure concentrations in the Lagoon of Venice, Italy	2003	Not North American species
Nowak et al.	Consequences of inbreeding and reduced genetic variation on tolerance to cadmium stress in the midge *Chironomus riparius*	2007	Sediment exposure
Nowak et al.	Variation in sensitivity to cadmium among genetically characterized laboratory strains of the midge *Chironomus riparius*	2008	Sediment exposure
Nowierski et al.	Effects of water chemistry on the bioavailability of metals in sediment to *Hyalella azteca*: Implications for sediment quality guidelines	2005	Sediment exposure
Nowierski et al.	Lac Dufault Sediment exposure core trace metal distribution, bioavailability and toxicity to *Hyalella azteca*	2006	Sediment exposure
Nugegoda and Rainbow	The uptake of dissolved zinc and cadmium by the decapod crustacean *Palaemon elegans*	1995	Not North American species
Nunez-Nogueira and Rainbow	Cadmium uptake and accumulation by the decapod crustacean *Penaeus indicus*	2005	Bioaccumulation: steady state not documented; not North American species
Nusetti et al.	Pyruvate kinase, phosphoenolpyruvate carboxykinase, cytochrome c oxidase and catalase activities in cadmium exposed *Perna viridis* subjected to anoxic and aerobic conditions	2010	Too few exposure concentrations, atypical endpoint
Nyholm and Kallqvist	Methods for Growth Inhibition Toxicity Tests With Freshwater Algae	1989	Review
Nyman et al.	Current levels of DDT, PCB and trace elements in the Baltic ringed seals (*Phoca hispida baltica*) and grey seals (*Halichoerus grypus*)	2002	Bioaccumulation: steady state not documented
Nyquist and Greger	Response of two wetland plant species to Cd exposure at low and neutral pH	2009	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure; dilution water not characterized
O'Hara	Cadmium uptake by fiddler crabs exposed to temperature and salinity stress	1973b	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
O'Neill	Effects of intraperitoneal lead and cadmium on the humoral immune response of *Salmo trutta*	1981	Organisms were not exposed to cadmium in water

Authors	Title	Year	Reason Unused
Oakley et al.	Accumulation of cadmium by *Abarenicola pacifica*	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Obande et al.	Trace metal analysis of the prawn (*Atya gabonesis*), water and bottom sediments of Lower River Benue	2006	Bioaccumulation: steady state not documented
Occhiogrosso et al.	Effects of heavy metals on benthic macroinvertebrate densities in foundry cove on the Hudson River	1979	Bioaccumulation: steady state not documented
O'Connor and Lauenstein	Trends in chemical concentrations in mussels and oysters collected along the US Coast: Update to 2003	2006	Bioaccumulation: steady state not documented
Odin et al.	Temperature and pH effects on cadmium and methylmercury bioaccumulation by nymphs of the burrowing mayfly *Hexagenia rigida*, from water column or sediment source	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Odin et al.	Depuration processes after exposure of burrowing mayfly nymphs (*Hexagenia rigida*) to methylmercury and cadmium from water column or sediment: Effects of temperature and pH	1997	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Offermann et al.	Assessing the importance of dietborne cadmium and particle characteristics on bioavailability and bioaccumulation in the nematode *Caenorhabditis elegans*	2009	Dietary exposure
Oguma and Klerks	The role of native salinity regime on grass shrimp (*Palaemonetes pugio*) sensitivity to cadmium	2013	Only one exposure concentration
Ogwok et al.	Pesticide residues and heavy metals in Lake Victoria Nile perch, *Lates niloticus*, belly flap oil	2009	Bioaccumulation: steady state not documented
Oikari et al.	Acute toxicity of chemicals to *Daphnia magna* in humic water	1992	Review of previously published data
Ojaveer et al.	On the effect of copper, cadmium and zinc on the embryonic development of Baltic spring spawning herring	1980	Not North American species
Olesen and Weeks	Accumulation of Cd by the marine sponge *Halichondria panicea* Pallas: Effects upon filtration rate and its relevance for biomonitoring	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Olgunoglu and Polat	Trace metals in marine macroalgae samples from the Iskenderun Bay, Turkey	2008	Bioaccumulation: steady state not documented
Oliveira et al.	Hepatic metallothionein concentrations in the golden grey mullet (*Liza aurata*) relationship with environmental metal concentrations in a metal-contaminated coastal system in Portugal	2010	Bioaccumulation: steady state not documented
Ololade et al.	Influence of diffuse and chronic metal pollution in water and sediments on edible seafoods within Ondo oil-polluted coastal region, Nigeria.	2011	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Olson and Christensen	Effects of water pollutants and other chemicals on fish acetylcholinesterase (in vitro)	1980	In vitro
Olsvik et al.	Metal accumulation and metallothionein in brown trout, Salmo trutta, from two Norwegian rivers differently contaminated with Cd, Cu and Zn	2001	Bioaccumulation: steady state not documented
Olsvik et al.	Effects of combined gamma-irradiation and metal (Al+Cd) exposures in Atlantic salmon (*Salmo salar* L.).	2010	Mixture (Al and Cd)
Olusegun et al.	Heavy metal distribution in crab (*Callinectes amnicola*) living on the shores of Ojo Rivers, Lagos, Nigeria	2009	Bioaccumulation: steady state not documented
Omoregie et al.	Metal concentrations in water column, benthic macroinvertebrates and tilapia from Delimi River, Nigeria	2002	Bioaccumulation: steady state not documented
Oner et al.	Changes in serum biochemical parameters of freshwater fish *Oreochromis niloticus* following prolonged metal (Ag, Cd, Cr, Cu, Zn) exposures	2008	Unmeasured chronic exposure, only one exposure concentration
Ong and Din	Cadmium, copper, and zinc toxicity to the clam, *Donax faba* C., and the blood cockle, *Anadara granosa* L	2001	Not North American species
Ongeri et al.	Seasonal variability in cadmium, lead, copper, zinc and iron concentrations in the three major fish species, *Oreochromis niloticus*, *Lates niloticus* and *Rastrineobola argentea* in Winam Gulf, Lake Victoria: Impact of wash-off into the lake	2012	Bioaccumulation: steady state not documented
Onuoha et al.	Comparative toxicity of cadmium to crustacean zooplankton (copepods and ostracods)	1996	The materials, methods or results were insufficiently described
Opuene and Agbozu	Relationships between heavy metals in shrimp (*Macrobrachium felicinum*) and metal levels in the water column and sediments of Taylor Creek	2008	Bioaccumulation: steady state not documented
Orchard et al.	A rapid response toxicity test based on the feeding rate of the tropical cladoceran *Moinodaphnia macleayi*	2002	Duration too short, not North American species
Oronsaye et al.	The toxicity of zinc and cadmium to *Clarias subnaginatus*	2003	Mixture, not North American species
Orun and Tolas	Antioxidative role of sodium selenite against the toxic effect of heavy metals (Cd+2, Cr+3) on some biochemical and hematological parameters in the blood of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792)	2008	Mixture
Osuna-Martinez et al.	Cadmium, copper, lead and zinc in cultured oysters under two contrasting climatic conditions in coastal lagoons from SE Gulf of California, Mexico	2011	Bioaccumulation: steady state not documented
Othman et al.	Cadmium accumulation in two populations of rice frogs (*Fejervarya limnocharis*) naturally exposed to different environmental cadmium levels	2009	Bioaccumulation: steady state not documented
Otitoloju and Don-Pedro	Integrated laboratory and field assessments of heavy metals accumulation in edible periwinkle, *Tympanotonus fuscatus var radula* (L.)	2004	No cadmium toxicity information
Otitoloju and Don-Pedro	Determination of types of interactions exhibited by binary mixtures of heavy metals tested against the hermit crab, *Clibanarius africanus*	2006	Sediment substrate in exposure water, not North American species

Authors	Title	Year	Reason Unused
Outridge et al.	Changes in mercury and cadmium concentrations and the feeding behaviour of beluga (*Delphinapterus leucas*) near Somerset Island, Canada, during the 20th century	2005	Bioaccumulation: steady state not documented
Packer et al.	Cadmium copper lead zinc and manganese in the polychaete *Arenicola marina* from Sediment exposures around the coast of Wales UK	1980	Bioaccumulation: steady state not documented
Pajevic et al.	The content of some macronutrients and heavy metals in aquatic macrophytes of three ecosystems connected to the Danube in Yugoslavia	2002	Bioaccumulation: steady state not documented
Pajevic et al.	Heavy metal accumulation of Danube River aquatic plants -- indication of chemical contamination	2008	Bioaccumulation: steady state not documented
Palackova et al.	Sublethal effects of cadmium on carp (*Cyprinus carpio*) fingerlings	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Palm and Wikberger	Tungmetallanalyser av mossor och baeckvattenvaexter i norra Estland. (Heavy metals in mosses and aquatic plants in northern Estonia)	1995	Bioaccumulation: steady state not documented
Pan	Application of biokinetic model in studying the bioaccumulation of cadmium, zinc, and copper in the scallop *Chlamys nobilis*	2009	Bioaccumulation: not renewal or flow-through exposure; not North American species
Pan and Wang	Influences of dissolved and colloidal organic carbon on the uptake of Ag, Cd, and Cr by the marine mussel *Perna viridis*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Pan and Wang	The subcellular fate of cadmium and zinc in the scallop *Chlamys nobilis* during waterborne and dietary exposure	2008	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Pan and Zhang	Metallothionein, antioxidant enzymes and DNA strand breaks as biomarkers of Cd exposure in a marine crab, *Charybdis japonica*	2006	Dilution water not characterized, duration too short, not North American species
Pan et al.	Effects of heavy metal ions (Cu2+, Pb2+ and Cd2+) on DNA damage of the gills, hemocytes and hepatopancreas of marine crab, *Charybdis japonica*	2011	Only three exposure concentrations
Pandeswara and Yallapragada	Tolerance, accumulation and depuration in an intertidal gastropod, *Turbo intercostalis*, exposed to cadmium	2000	Not North American species, abstract only
Pandey et al.	Effects of exposure to multiple trace metals on biochemical, histological and ultrastructural features of gills of a freshwater fish, *Channa punctata* Bloch	2008	Mixture
Pantani et al.	Comparative acute toxicity of some pesticides, metals, and surfactants to *Gammarus italicus* Goedm. and *Echinogammarus tibaldii* Pink. and stock (Crustacea: Amphipoda)	1997	Not North American species
Papa et al.	Determination of heavy metal in seawater and macroalgae of shorelines of Naples and Ischia Island, Italy	2008	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Papathanassiou	Cadmium accumulation and ultrastructural alterations in oogenesis of the prawn *Palaemon serratus* (Pennant)	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Papathanassiou	Effects of cadmium and mercury ions on respiration and survival of the common prawn *Palaemon serratus* (Pennant)	1983	Not North American species
Papoutsoglou and Abel	Studies on the lethal and sublethal effects of cadmium on some commercially cultured species of the Mediterranean	1993	Review of previously published data
Park and Kim	Bioassays on marine organisms: Acute toxicity test of mercury, cadmium and copper to arkshell, *Anadara broughtonii*, from Jin-Dong Bay, and to oyster, *Crassostrea gigas*, from Kwang-Do Bay, south coast of Korea	1978	Not North American species
Park and Kim	Bioassays on marine organisms. II. Acute toxicity test of mercury, copper and cadmium to clam, *Meretrix lusoria*	1979	Not North American species
Park and Presley	Trace metal contamination of sediments and organisms from the Swan Lake Area of Galveston Bay	1997	Bioaccumulation: steady state not documented
Parker	The effects of selected chemicals and water quality on the marine polychaete *Ophryotrocha diadema*	1984	Questionable treatment of test organisms or inappropriate test conditions or methodology
Part and Svanberg	Uptake of cadmium in perfused rainbow trout (*Salmo gairdneri*) gills	1981	In vitro
Parveen and Shadab	Cytogenetic evaluation of cadmium chloride on *Channa punctatus*	2012	Dilution water not characterized, not North American species
Parvin et al.	Preliminary acute toxicity bioassays of lead and cadmium on fresh water climbing perch, *Anabas testudineus* (Bloch)	2011	Dilution water not characterized
Pascal et al.	The toxicological interaction between ocean acidity and metals in coastal meiobenthic copepods	2010	Bioaccumulation: steady state not documented
Pascoe and Shazili	Episodic pollution - a comparison of brief and continuous exposure of rainbow trout to cadmium	1986	The materials, methods or results were insufficiently described
Pastorinho et al.	Amphipod susceptibility to metals: cautionary tales	2009	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Patel et al.	Sponge 'sentinel' of heavy metals	1985	Bioaccumulation: steady state not documented
Patthebahadur and Bais	Studies on some physiological aspects in fresh water fish *Ophiocephalus striatus* (Channa) in relation to heavy metal cadmium (Cd) toxicity	2008	Duration too short, test species fed, not North American species
Pauli and Berger	Toxicological comparisons of *Tetrahymena* species, end points and growth media: Supplementary investigations to the pilot ring test	1997	The materials, methods or results were insufficiently described
Paul-Pont et al.	Short-term metallothionein inductions in the edible cockle *Cerastoderma edule* after cadmium or mercury exposure: Discrepancy between MRNA and protein responses	2010a	In vitro

Authors	**Title**	**Year**	**Reason Unused**
Paul-Pont et al.	How life history contributes to stress response in the manila clam *Ruditapes philippinarum*	2010b	Only one exposure concentration
Paul-Pont et al.	Cloning, characterization and gene expression of a metallothionein isoform in the edible cockle *Cerastoderma edule* after cadmium or mercury exposure	2012	Not North American species, only one exposure concentration
Pavicic	Combined cadmium-zinc toxicity on embryonic development of *Mytilus galloprovincialis* LMK. (Mollusca, Mytilidae)	1977	Abstract only
Pavicic and Jarvenpaa	Cadmium toxicity in adults and early larval stages of the mussel *Mytilus galloprovincialis* Lam.	1974	Not North American species
Pavicic et al.	Embryo-larval tolerance of *Mytilus galloprovincialis*, exposed to the elevated sea water metal concentrations - I. Toxic effects of Cd, Zn and Hg in relation to the metallothionein level	1994	Not North American species
Pawlik and Skowronski	Transport and toxicity of cadmium: Its regulation in the cyanobacterium *Synechocystis aquatilis*	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pawlik et al.	pH-dependent cadmium transport inhibits photosynthesis in the cyanobacterium *Synechocystis aquatilis*	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pecon and Powell	Effect of the amino acid histidine on the uptake of cadmium from the digestive system of the blue crab, *Callinectes sapidus*	1981	Questionable treatment of test organisms or inappropriate test conditions or methodology
Pedersen and Petersen	Variability of species sensitivity to complex mixtures	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Pedro et al.	The influence of cadmium contamination and salinity on the survival, growth and phytoremediation capacity of the saltmarsh plant *Salicornia ramosissima*	2013	Soil exposure
Pelgrom et al.	Interactions between copper and cadmium during single and combined exposure in juvenile tilapia *Oreochromis mossambicus*: Influence of feeding condition on whole body metal accumulation and the effect of the metals on tissue water and ion content	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pelgrom et al.	Calcium fluxes in juvenile tilapia, *Oreochromis mossambicus*, exposed to sublethal waterborne Cd, Cu or mixtures of these metals	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pellegrini et al.	Interactions between the toxicity of the heavy metals cadmium, copper, zinc in combinations and the detoxifying role of calcium in the brown alga *Cystoseira barbata*	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	**Title**	**Year**	**Reason Unused**
Pellet et al.	Model predicting waterborne cadmium bioaccumulation in *Gammarus pulex*: the effects of dissolved organic ligands, calcium, and temperature	2009	Not North American species
Peltier et al.	Accumulation of trace elements and growth responses in *Corbicula fluminea* downstream of a coal-fired power plant	2009	Bioaccumulation: steady state not documented
Pempkowiak et al.	Toxicants accumulation rates and effects in *Mytilus trossulus* and *Nereis diversicolor* exposed separately or together to cadmium and PAHs	2006a	Non-applicable
Pempkowiak et al.	Heavy metals in zooplankton from the southern Baltic	2006b	Bioaccumulation: steady state not documented
Peng et al.	Trace metals in *Iaustinogebia edulis* (Ngoc-Ho & Chan, 1992) (Decapoda, Thalassinidea, Upogebiidae) and its habitat sediment from the central western Taiwan coast	2006	Bioaccumulation: steady state not documented
Peng et al.	Bioaccumulation of heavy metals by the aquatic plants *Potamogeton pectinatus* L. and *Potamogeton malaianus* Miq. and their potential use for contamination indicators in wastewater treatment	2008	No cadmium toxicity information
Pennington et al.	Contaminant levels in fishes from Brown’s Lake, Mississippi	1982	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Penttinen et al.	The kinetics of cadmium in *Daphnia magna* as affected by humic substances and water hardness	1995	No useable data on cadmium toxicity or bioconcentration
Penttinen et al.	Combined effects of dissolved organic material and water hardness on toxicity of cadmium to *Daphnia magna*	1998	The materials, methods or results were insufficiently described
Perceval et al.	Long-term trends in accumulated metals (Cd, Cu and Zn) and metallothionein in bivalves from lakes within a smelter-impacted region	2006	Bioaccumulation: steady state not documented
Percy	Heavy metal and sulphur concentrations in *Sphagnum magellanicum* Brid. in the maritime provinces, Canada	1983	Bioaccumulation: steady state not documented
Pereira et al.	Effect of cadmium accumulation on serum vitellogenin levels and hepatosomatic and gonadosomatic indices of winter flounder (*Pleuronectes americanus*)	1993	No interpretable concentration, time, response data or examined only a single exposure concentration
Perez-Coll and Herkovits	Stage-dependent uptake of cadmium by *Bufo arenarum* embryos	1996	Not North American species
Perez-Coll et al.	Teratogenic effects of cadmium on *Bufo arenarum* during gastrulation	1986	Not North American species; too few exposure concentrations; no statistical analysis
Perez-Legaspi and Rico-Martinez	Acute toxicity tests on three species of the genus *Lecane* (Rotifera: Monogononta)	2001	Duration too short, not North American species
Perez-Legaspi and Rico-Martinez	Phospholipase A2 activity in three species of littoral freshwater rotifers exposed to several toxicants	2003	Duration too short, not North American species
Perez-Legaspi et al.	Toxicity testing using esterase inhibition as a biomarker in three species of the genus *Lecane* (Rotifera)	2002	Duration too short, not North American species
Perkins et al.	The potential of screening for agents of toxicity using gene expression fingerprinting in *Chironomus tentans*	2004	Exposure in distilled water without the addition of proper salts

Authors	**Title**	**Year**	**Reason Unused**
Pernice et al.	Comparative Bioaccumulation of Trace Elements Between *Nautilus pompilius* and *Nautilus macromphalus* (Cephalopoda: Nautiloidea) from Vanuatu and New Caledonia	2009	Bioaccumulation: steady state not documented
Pery et al.	Assessing the risk of metal mixtures in contaminated sediments on *Chironomus riparius* based on cytosolic accumulation	2008	Sediment exposure
Pesonen and Andersson	Fish primary hepatocyte culture; and important model for xenobiotic metabolism and toxicity studies	1997	Review of previously published data
Pestana et al.	Effects of cadmium and zinc on the feeding behaviour of two freshwater crustaceans: *Atyaephyra desmarestii* (Decapoda) and *Echinogammarus meridionalis* (Amphipoda)	2007	Not North American species
Peterson	Toxicity testing using a chemostat-grown green alga, *Selenastrum capricornutum*	1991	The materials, methods or results were insufficiently described
Peterson et al.	Metal toxicity to algae: A highly pH dependent phenomenon	1984	The materials, methods or results were insufficiently described
Phelps	Cadmium sorption in estuarine mud-type sediment and the accumulation of cadmium in the soft-shell clam, *Mya arenaria*	1979	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
Phillips	The common mussel *Mytilus edulis* as an indicator of trace metals in Scandinavian waters. I. Zinc and cadmium	1977	Bioaccumulation: steady state not documented
Phillips	Trace metals in the common mussel, *Mytilus edulis* (L.), and in the alga *Fucus vesiculosus* (L.) from the region of the Sound (Oresund)	1979	Bioaccumulation: steady state not documented
Phillips	Toxicity and accumulation of cadmium in marine and estuarine biota. Part 1. Ecological cycling	1980	Review
Phillips and Russo	Metal bioaccumulation in fishes and aquatic invertebrates: A literature review	1978	Review of previously published data
Philp	Effects of experimental manipulation of pH and salinity on Cd2+ uptake by the sponge *Microciona prolifera* and on sponge cell aggregation induced by Ca2+ and Cd2+	2001	Excised tissue/cells
Phipps et al.	Effects of pollution on freshwater organisms.	1984	Review
Pierron et al.	Impairment of lipid storage by cadmium in the European eel (*Anguilla anguilla*)	2007a	Only one exposure concentration, not North American species
Pierron et al.	Effects of salinity and hypoxia on cadmium bioaccumulation in the shrimp *Palaemon longirostris*	2007b	Bioaccumulation: steady state not documented; not North American species
Pierron et al.	Transcriptional responses to environmental metal exposure in wild yellow perch (*Perca flavescens*) collected in lakes with differing environmental metal concentrations (Cd, Cu, Ni)	2009a	Bioaccumulation: steady state not documented
Pierron et al.	Ovarian gene transcription and effect of cadmium pre-exposure during artificial sexual maturation of the European eel (*Anguilla anguilla*)	2009b	Only one exposure concentration, not North American species

Authors	Title	Year	Reason Unused
Pierron et al.	Effects of chronic metal exposure on wild fish populations revealed by high-throughput cDNA sequencing	2011	Bioaccumulation: steady state not documented
Pinkina	Effect of the ionic form of cadmium on reproduction and development of *Lymnaea stagnalis* L.	2006	Dilution water not characterized, unmeasured chronic exposure
Pinto et al.	Influence of organic matter on the uptake of cadmium, zinc, copper and iron by sorghum plants	2004	Non-aquatic plants
Pip and Mesa	Cadmium, copper, and lead in two species of *Artemisia* (compositae) in southern Manitoba, Canada	2002	Bioaccumulation: steady state not documented
Piyatiratitivorakul and Boonchamoi	Comparative toxicity of mercury and cadmium to the juvenile freshwater snail, *Filopaludina martensi martensi*	2008	Not North American species, dilution water not characterized
Piyatiratitivorakul et al.	Comparative toxicity of heavy metal compounds to the juvenile golden apple snail, *Pomacea sp*.	2006	Dilution water not characterized
Planello et al.	Effect of acute exposure to cadmium on the expression of heat-shock and hormone-nuclear receptor genes in the aquatic midge *Chironomus riparius*	2010	Only one exposure concentration; duration too short; mixture
Playle	Physiological and toxicological effects of metals at gills of freshwater fish	1997	Review
Playle et al.	Copper and cadmium binding to fish gills: Estimates of metal-gill stability constants and modelling of metal accumulation	1993a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Playle et al.	Copper and cadmium binding to fish gills: Modification by dissolved organic carbon and synthetic ligands	1993b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Ploetz et al.	Differential accumulation of heavy metals in muscle and liver of a marine fish, (king mackerel, *Scomberomorus cavalla cuvier*) from the northern Gulf of Mexico, USA	2007	Bioaccumulation: steady state not documented
Podgurskaya and Kavun	Cadmium concentration and subcellular distribution in organs of the mussel *Crenomytilus grayanus* from upwelling regions of Okhotsk Sea and Sea of Japan	2006	Bioaccumulation: steady state not documented
Pohl	Wechselbeziehungen zwischen spurenmetallkonzentrationen (Cd, Cu, Pb, Zn) im meerwasser und in zooplanktonorganismen (Copepoda) der arktis und des atlantiks. (Correlations between trace metal concentrations (Cd, Cu, Pb, Zn) in seawater and zooplankton organisms (Copepoda) of the Arctic and Atlantic	1993	Bioaccumulation: steady state not documented
Pokora and Tukaj	The combined effect of anthracene and cadmium on photosynthetic activity of three desmodesmus (Chlorophyta) species	2010	Only one exposure concentration
Polak-Juszczak	Temporal trends in the bioaccumulation of trace metals in herring, sprat, and cod from the southern Baltic Sea in the 1994-2003 period	2009	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Polar and Kucukcezzar	Influence of some metal chelators and light regimes on bioaccumulation and toxicity of Cd2+ in duckweed (*Lemna gibba*)	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Portmann and Wilson	The toxicity of 140 substances to the brown shrimp and other marine animals	1971	Not North American species
Postma and Davids	Tolerance induction and life cycle changes in cadmium-exposed *Chironomus riparius* (Diptera) during consecutive generation	1995	Organisms were exposed to cadmium in food or by injection or gavage
Postma et al.	Chronic toxicity of cadmium to *Chironomus reparius* (Diptera: Chironomidae) at different food levels	1994	Organisms were exposed to cadmium in food or by injection or gavage
Postma et al.	Increased cadmium excretion in metal-adapted populations of the midge *Chironomus riparius* (Diptera)	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Poteat et al.	Divalent metal (Ca, Cd, Mn, Zn) uptake and interactions in the aquatic insect *Hydropsyche sparna*	2012	Bioaccumulation: steady state not reached (only 9 hour exposure)
Poulsen et al.	Accumulation of cadmium and bioenergetics in the mussel *Mytilus edulis*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Poulton et al.	Relations between benthic community structure and metals concentrations in aquatic macroinvertebrates: Clark Fork River, Montana	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Pourang and Dennis	Distribution of trace elements in tissues of two shrimp species from the Persian Gulf and roles of metallothionein in their redistribution	2005	Bioaccumulation: steady state not documented
Powell and Powell	Trace Elements in Fish Overlying Subaqueous Tailings in the Tropical West Pacific	2001	Bioaccumulation: steady state not documented
Powell et al.	Use of *Azolla* to assess toxicity and accumulation of metals from artificial and natural Sediment exposures containing cadmium, copper, and zinc	1998	Sediment exposure
Prafulla et al.	Concentrations of trace metals in the squids, *Loligo duvauceli* and *Doryteuthis sibogae* caught from the southwest coast of India	2001	Bioaccumulation: steady state not documented
Prasad et al.	Toxicity of cadmium and copper in *Chlamydomonas reinhardtii* wild-type (WT2137) and cell wall deficient mutant strain (CW15)	1998	No interpretable concentration, time, response data or examined only a single exposure concentration
Pratap and Wendelaar	Mineral composition and cadmium accumulation in Oreochromis mossambicus exposed to waterborne cadmium	2004	Bioaccumulation: not whole body or muscle content
Prato and Biandolino	Combined toxicity of mercury, copper and cadmium on embryogenesis and early larval stages of the *Mytlius galloprovincialis*	2007	Not North American species, duration too short
Prato et al.	Effects of temperature on the sensitivity of *Gammarus aequicauda* (Martynov, 1931) to cadmium	2009	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Presing et al.	Cadmium uptake and depuration in different organs of *Lymnaea stagnalis* L. and the effect of cadmium on the natural zinc level	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Pretto et al.	Acetylcholinesterase activity, lipid peroxidation, and bioaccumulation in silver catfish (*Rhamdia quelen*) exposed to cadmium	2010	Dilution water not characterized, not North American species
Pretto et al.	Effects of water cadmium concentrations on bioaccumulation and various oxidative stress parameters in *Rhamdia quelen*	2011	In vitro
Prevot and Soyer-Gobillard	Combined action of cadmium and selenium on two marine dinoflagellates in culture, *Prorocentrum micans* Ehrbg. and *Crypthecodinium cohnii* Biecheler	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Price and Knight	Mercury cadmium lead and arsenic in sediment exposures plankton and clams from Lake Washington and Sardis reservoir Mississippi October 1975-may 1976	1978	Bioaccumulation: steady state not documented
Prowe et al.	Heavy metals in crustaceans from the Iberian Deep Sea Plain	2006	Bioaccumulation: steady state not documented
Pundir and Malhotra	Haematological alterations induced by heavy metal cadmium toxicity in *Clarias batrachus*	2011	Only one exposure concentration
Pundir et al.	Toxicopathological changes in liver of *Clarias batrachus* due to cadmium sulphate toxicity	2012	Dilution water not characterized
Puvaneswari and Karuppasamy	Accumulation of cadmium and its effects on the survival and growth of larvae of *Heteropneustes fossilis* (Bloch, 1794)	2007	Unmeasured chronic exposure, duration too short, not North American species
Pynnonen	Effect of pH, hardness and maternal pre-exposure on the toxicity of Cd, Cu and Zn to the glochidial larvae of a freshwater clam *Anodonta cygnea*	1995	Not North American species
Pytharopoulou et al.	Translational responses and oxidative stress of mussels experimentally exposed to Hg, Cu and Cd: One pattern does not fit at all	2011	Mixture
Qian et al.	Combined effect of copper and cadmium on *Chlorella vulgaris* growth and photosynthesis-related gene transcription	2009	Mixture
Qian et al.	Photoperiod and temperature influence cadmium's effects on photosynthesis-related gene transcription in *Chlorella vulgaris*	2010	Mixture
Qian et al.	Combined effect of copper and cadmium on heavy metal ion bioaccumulation and antioxidant enzymes induction in *Chlorella vulgaris*	2011	Mixture
Qichen et al.	A comprehensive investigation of the toxic effects of heavy metals on fish	1988	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Qin et al.	Effect of nanometer selenium on nonspecific immunity and antioxidase of gift stressed by cadmium	2011	Mixture
Qin et al.	Immune responses and ultrastructural changes of hemocytes in freshwater crab *Sinopotamon henanense* exposed to elevated cadmium	2012	In vitro

Authors	**Title**	**Year**	**Reason Unused**
Qiu et al.	Effects of calcium on the uptake and elimination of cadmium and zinc in Asiatic clams	2005	Mixture
Rachlin and Grosso	The effects of pH on the growth of *Chlorella vulgaris* and its interactions with cadmium toxicity	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Rachlin and Grosso	The growth response of the green alga *Chlorella vulgaris* to combined divalent cation exposure	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Radenac et al.	Bioaccumulation and toxicity of four dissolved metals in *Paracentrotus lividus* sea-urchin embryo	2001	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; unmeasured exposure
Radhakrishnan and Hemalatha	Sublethal toxic effects of cadmium chloride to liver of freshwater fish *Channa striatus* (Bloch.)	2010	Only one exposure concentration
Radhakrishnan and Hemalatha	Bioaccumulation of cadmium in the organs of freshwater fish *Heteropneustes fossilis* (Bloch, 1794)	2011	Not North American species
Rai et al.	Chromium and cadmium bioaccumulation and toxicity in *Hydrilla verticillata* (l.f.) Royle and *Chara corallina* Wildenow.	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Raimundo et al.	Geographical variation and partition of metals in tissues of *Octopus vulgaris* along the Portuguese coast	2004	Bioaccumulation: steady state not documented
Raimundo et al.	Sub-cellular partitioning of Zn, Cu, Cd and Pb in the digestive gland of native *Octopus vulgaris* exposed to different metal concentrations (Portugal)	2008	Bioaccumulation: steady state not documented
Raimundo et al.	Association of Zn, Cu, Cd and Pb with protein fractions and sub-cellular partitioning in the digestive gland of *Octopus vulgaris* living in habitats with different metal levels.	2010	Bioaccumulation: steady state not documented
Raimundo et al.	Decrease of Zn, Cd and Pb concentrations in marine fish species over a decade as response to reduction of anthropogenic inputs: the example of Tagus estuary.	2011	Bioaccumulation: steady state not documented
Rainbow	Accumulation of Zn, Cu and Cd by crabs and barnacles	1985	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Rainbow and Black	Cadmium, zinc and the uptake of calcium by two crabs, *Carcinus maenas* and *Eriocheir sinensis*	2005	Excised tissue/cells
Rainbow and Kwan	Physiological responses and the uptake of cadmium and zinc by the amphipod crustacean *Orchestia gammarellus*	1995	Not North American species

Authors	Title	Year	Reason Unused
Rainbow and Wang	Comparative assimilation of Cd, Cr, Se, and Zn by the barnacle *Elminius modestus* from phytoplankton and zooplankton diets	2001	Dietary exposure
Rainbow and Wang	Trace metals in barnacles: the significance of trophic transfer	2005	Review
Rainbow and White	Comparative strategies of heavy metal accumulation by crustaceans: Zinc, copper and cadmium in a decapod, and amphipod and a barnacle	1989	Not North American species
Rainbow et al.	Effects of chelating agents on the accumulation of cadmium by the barnacle *Semibalanus balanoides*, and the complexation of soluble Cd, Zn and Cu	1980	Not North American species
Rainbow et al.	Geographical and seasonal variation of trace metal bioavailabilities in the Gulf of Gdansk, Baltic Sea using mussels (*Mytilus trossulus*) and barnacles (*Balanus improvisus*) as biomonitors	2004a	Bioaccumulation: steady state not documented
Rainbow et al.	Acute dietary pre-exposure and trace metal bioavailability to the barnacle *Balanus amphitrite*	2004b	Dietary exposure
Rainwater et al.	Metals and organochlorine pesticides in caudal scutes of crocodiles from Belize and Costa Rica	2007	Bioaccumulation: steady state not documented
Raissy et al.	Mercury, arsenic, cadmium and lead in lobster (*Panulirus homarus*) from the Persian Gulf	2011	Bioaccumulation: steady state not documented
Ralph and Burchett	Photosynthetic response of *Halophila ovalis* to heavy metal stress	1998	Not North American species
Ramachandran et al.	Effect of copper and cadmium on three Malaysian tropical estuarine invertebrate larvae	1997	Not North American species
Ramesha et al.	Toxicity of cadmium to common carp *Cyprinus carpio* (Linn.)	1996	Review of previously published data
Ramos et al.	Metal contents in Porites corals: Anthropogenic input of river run-off into a coral reef from an urbanized area, Okinawa	2004	Bioaccumulation: steady state not documented
Ramsak et al.	Evaluation of metallothioneins in blue mussels (*Mytilus galloprovincialis*) as a biomarker of mercury and cadmium exposure in the Slovenian Waters (Gulf of Trieste): A long-term field study	2012	Bioaccumulation: steady state not documented
Rangsayatorn et al.	Ultrastructural changes in various organs of the fish *Puntius gonionotus* fed cadmium-enriched cyanobacteria	2004	Dietary exposure
Rank et al.	DNA damage, acetylcholinesterase activity and lysosomal stability in native and transplanted mussels (*Mytilus edulis*) in areas close to coastal chemical dumping sites in Denmark	2007	Mixture
Rao and Madhyastha	Toxicities of some heavy metals to the tadpoles of frog, *Microhyla ornata* (Dumeril and Bibron)	1987	Not North American species
Rao et al.	Toxic effect of two heavy metals on phytoplankton photosynthesis	1979	No species name given; dilution water not characterized
Rao et al.	Distribution of contaminants in aquatic organisms from East Fork Poplar Creek	1996	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Raposo et al.	Trace metals in oysters, *Crassotrea sps*., from UNESCO protected natural reserve of Urdaibai: Space-time observations and source identification	2009	Bioaccumulation: steady state not documented
Rasmussen et al.	Effect of age and tissue weight on the cadmium concentration in Pacific oysters (*Crassostrea gigas*)	2007	Lack of details; exposure concentration not known
Raungsomboon and Wongrat	Bioaccumulation of cadmium in an experimental aquatic ecosystem involving phytoplankton, zooplankton, catfish and sediment	2007	Bioaccumulation: steady state not documented (only 72 hour exposure), sediment exposure
Ray and White	Selected aquatic plants as indicator species for heavy metal pollution	1976	Bioaccumulation: steady state not documented
Ray et al.	Accumulation of copper, zinc, cadmium and lead from two contaminated sediments by three marine invertebrates - a laboratory study	1981	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Rayms-Keller et al.	Effect of heavy metals on *Aedes aegypti* (Diptera: Culicidae) larvae	1998	The materials, methods or results were insufficiently described
Raynal et al.	Cadmium uptake in isolated adrenocortical cells of rainbow trout and yellow perch	2005	In vitro
Razinger et al.	Real-time visualization of oxidative stress in a floating macrophyte *Lemna minor* L. exposed to cadmium, copper, menadione, and AAPH	2010	Mixture
Re et al.	Estuarine sediment acute toxicity testing with the european amphipod *Corophium multisetosum* Stock, 1952	2009	Sediment
Reader et al.	The effects of eight trace metals in acid soft water on survival, mineral uptake and skeletal calcium deposition in yolk-sac fry of brown trout, *Salmo trutta* L.	1989	No interpretable concentration, time, response data or examined only a single exposure concentration
Rebhun and Ben-Amotz	The distribution of cadmium between the marine alga *Chlorella stigmatophora* and sea water medium	1984	Not North American species
Rebhun and Ben-Amotz	Effect of NaCl concentration on cadmium uptake by the halophilic alga *Dunaliella salina*	1986	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Rebhun and Ben-Amotz	Antagonistic effect of maganese to cadmium toxicity in the alga *Dunaliella salina*	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Reboucas do Amaral et al.	Bioaccumulation and Depuration of Zn and Cd in Mangrove Oysters (*Crassostrea rhizophorae*, Guilding, 1828) Transplanted to and from a Contaminated Tropical Coastal Lagoon	2005	Bioaccumulation: steady state not documented
Reddy and Fingerman	Effect of cadmium chloride on amylase activity in the red swamp crayfish, *Procambarus clarkii*	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Reddy et al.	Effects of cadmium and mercury on ovarian maturation in the red swamp crayfish, *Procambarus clarkii*	1997	Organisms were exposed to cadmium in food or by injection or gavage
Reddy et al.	Biochemical effects of cadmium on the liver of catfish, *Mystus tengara* (Ham.)	2010	In vitro

Authors	Title	Year	Reason Unused
Reddy et al.	Cadmium and mercury-induced hyperglycemia in the fresh water crab, *Oziotelphusa senex senex*: Involvement of neuroendocrine system	2011	Mixture
Reddy et al.	Effect of cadmium, lead and zinc on growth of some cyanobacteria	2002	Lack of details; exposure concentration not known
Rehwoldt et al.	The effect of increased temperature upon the acute toxicity of some heavy metal ions	1972	Questionable treatment of organisms; River water is dilution water (uncharacterized)
Reichelt-Brushett and Harrison	The effect of selected trace metals on the fertilization success of several scleractinian coral species	2005	Not North American species, duration too short
Reichert et al.	Uptake and metabolism of lead and cadmium in coho salmon (*Oncorhynchus kisutch*)	1979	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Reid and McDonald	Metal binding activity of the gills of rainbow trout (*Oncorhynchus mykiss*)	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Reinfelder and Fisher	The assimilation of elements ingested by marine planktonic bivalve larvae	1994a	Organisms were exposed to cadmium in food or by injection or gavage
Reinfelder and Fisher	Retention of elements absorbed by juvenile fish (*Menidia menidia*, *Menidia beryllina*) from zooplankton prey	1994b	Organisms were exposed to cadmium in food or by injection or gavage
Reinfelder et al.	Assimilation efficiencies and turnover rates of trace elements in marine bivalves: a comparison of oysters, clams and mussels	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Reish et al.	The effect of cadmium and DDT on the survival and regeneration in the amphinomid polychaete *Eurythoe complanata*	1988	Not North American species
Rejomon et al.	Trace metal concentrations in zooplankton from the eastern Arabian Sea and western Bay of Bengal	2008	Bioaccumulation: steady state not documented
Rejomon et al.	Trace metal dynamics in fishes from the southwest coast of India	2010	Bioaccumulation: steady state not documented
Remacle et al.	Cadmium fate in bacterial microcosms	1982	Results were only presented graphically
Ren et al.	Using factorial experiments to study the toxicity of metal mixtures	2004	Modeling
Ren et al.	Bioavailability and oxidative stress of cadmium to *Corbicula fluminea*	2013	Sediment exposure
Revathi et al.	Effect of cadmium on the ovarian development in the freshwater prawn *Macrobrachium rosenbergii* (De Man)	2011	Only one exposure concentration, dilution water not characterized
Reynders et al.	Dynamics of cadmium accumulation and effects in common carp (*Cyprinus carpio*) during simultaneous exposure to water and food (*Tubifex tubifex*)	2006a	Dietary exposure
Reynders et al.	Patterns of gene expression in carp liver after exposure to a mixture of waterborne and dietary cadmium using a custom-made microarray	2006b	Dietary exposure

Authors	Title	Year	Reason Unused
Reynders et al.	Accumulation and effects of metals in caged carp and resident roach along a metal pollution gradient	2008	Bioaccumulation: steady state not documented
Rhea et al.	Biomonitoring in the Boulder River watershed, Montana, USA: Metal concentrations in biofilm and macroinvertebrates, and relations with macroinvertebrate assemblage	2006	Bioaccumulation: steady state not documented
Rhodes et al.	Interactive effects of cadmium, polychlorinated biphenyls, and fuel oil on experimentally exposed English sole (*Parophrys vetulus*)	1985	Organisms were exposed to cadmium in food or by injection or gavage
Riba et al.	The influence of pH and salinity on the toxicity of heavy metals in sediment to the estuarine clam *Ruditapes philippinarum*	2004	Non-applicable
Ribo	Interlaboratory comparison studies of the luminescent bacteria toxicity bioassay	1997	No interpretable concentration, time, response data or examined only a single exposure concentration
Rice	A simple mass transport model for metal uptake by marine macroalgae growing at different rates	1984	Review of previously published data
Rice and Chien	Uptake, binding and clearance of divalent cadmium in *Glycera dibranchiata* (Annelida: Polychaeta)	1979	Bioaccumulation: not renewal or flow-through; injected toxicant; dilution water not characterized
Richards et al.	Effects of natural organic matter source on reducing metal toxicity to rainbow trout (*Oncorhynchus mykiss*) and on metal binding to their gills	2001	Mixture
Richelle et al.	Experimental and field studies on the effect of selected heavy metals on three freshwater sponge species: *Ephydatia fluviatilis*, *Ephydatia muelleri* and *Spongilla lacustris*	1995	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Riches et al.	Effect of heavy metals on lipids from the freshwater alga *Selenastrum capricornutum*	1996	In vitro
Riddell et al.	Behavioral responses to sublethal cadmium exposure within an experimental aquatic food web	2005b	Only two exposure concentrations, duration too long
Riddell et al.	Sublethal effects of cadmium on prey choice and capture efficiency in juvenile brook trout (*Salvelinus fontinalis*)	2005a	Only two exposure concentration, atypical endpoint
Ridlington et al.	Metallothionein and Cu-chelation: Characterization of metal-binding proteins from the tissues of four marine animals	1981	Questionable treatment of test organisms or inappropriate test conditions or methodology
Ridout et al.	Concentrations of manganese iron copper zinc and cadmium in the mesopelagic decapod Systellaspis debilis from the east Atlantic ocean	1985	Bioaccumulation: steady state not documented
Riedel and Christensen	Effect of selected water toxicants and other chemicals upon adenosine triphosphatase activity in vitro	1979	In vitro
Riget et al.	Influence of length on element concentrations in blue mussels (*Mytilus edulis*)	1996	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Riisgard et al.	Accumulation of cadmium in the mussel *Mytilus edulis*: Kinetics and importance of uptake via food and sea water	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ringwood	Accumulation of cadmium by larvae and adults of an Hawaiian bivalve, *Isognomon californicum*, during chronic exposure	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ringwood	Effects of chronic cadmium exposures on growth of larvae of an Hawaiian bivalve, *Isognomon californicum*	1992b	Dilution water not characterized
Ringwood	Comparative sensitivity of gametes and early developmental stages of a sea urchin species (*Echinometra mathaei*) and a bivalve species (*Isognomon californicum*) during metal exposures	1992a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ringwood	Age-specific differences in cadmium sensitivity and bioaccumulation in bivalve molluscs	1993	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Risso-de Faverney et al.	Cadmium induces apoptosis and genotoxicity in rainbow trout hepatocytes through generation of reactive oxygen species	2001	In vitro
Ritterhoff et al.	Calibration of the estuarine amphipods, *Gammarus zaddachi* Sexton (1912), as biomonitors: Toxicokinetics of cadmium and possible role of inducible metal-binding proteins in Cd detoxification	1996	Not North American species
Roach et al.	Assessment of metals in fish from Lake Macquarie, New South Wales, Australia	2008	Bioaccumulation: steady state not documented
Roast et al.	Impairment of mysid (*Neomysis integer*) swimming ability: An environmentally realistic assessment of the impact of cadmium exposure	2001a	Only two exposure concentrations, duration too long, Not North American species
Roast et al.	Behavioural responses of estuarine mysids to hypoxia and disruption by cadmium	2002a	Not North American species
Roast et al.	Trace metal uptake by the Chinese mitten crab *Eriocheir sinensis*: the role of osmoregulation	2002c	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Roast et al.	Distribution and swimming behaviour of *Neomysis integer* (Peracarida: Mysidacea) in response to gradients of dissolved oxygen following exposure to cadmium at environmental concentrations	2002b	Review; Not North American species
Roberto et al.	Carbonic anhydrase activity in Mytilus galloprovincialis digestive gland: Sensitivity to heavy metal exposure	2010	Mixture
Robertson and Liber	Bioassays with caged *Hyalella azteca* to determine in situ toxicity downstream of two Saskatchewan, Canada, uranium operations	2007	Mixture

Authors	Title	Year	Reason Unused
Roccheri et al.	Cadmium induces the expression of specific stress proteins in sea urchin embryos	2004	Not North American species
Roch and Mccarter	Metallothionein induction, growth, and survival of chinook salmon exposed to zinc, copper, and cadmium	1984	Mixture
Roch and McCarter	Metallothionein induction growth and survival of rainbow trout exposed to mixed heavy metal contamination	1986	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Roch et al.	Determination of no effect levels of heavy metals for rainbow trout using hepatic metallothionein	1986	Mixture
Rodgher and Espindola	Effects of interactions between algal densities and cadmium concentrations on *Ceriodaphnia dubia* fecundity and survival	2008	Dietary exposure
Rodrigues and Pawlowsky	Acute toxicity tests by bioassays applied to the solubilized extracts of solid wastes Class II A - non inerts and Class II B	2007	Text in foreign language
Rodriguez et al.	Accumulation of lead, chromium, and cadmium in muscle of capitan (*Eremophilus mutisii*), a catfish from the Bogota River Basin	2009	Bioaccumulation: steady state not documented
Roesijadi and Fellingham	Influence of Cu, Cd, and Zn preexposure on Hg toxicity in the mussel *Mytilus edulis*	1987	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Roesijadi et al.	Dietary cadmium and benzo(a)pyrene increased intestinal metallothionein expression in the fish *Fundulus heteroclitus*	2009	Dietary exposure
Roh et al.	A cadmium toxicity assay using stress responsive *Caenorhabditis elegans* mutant strains	2009	Data previously reported
Roline and Boehmke	Heavy metals pollution of the Upper Arkansas River, Colorado, and its effects on the distribution of the aquatic macrofauna	1981	Bioaccumulation: steady state not documented
Roman et al.	Seasonal studies on cadmium toxicity in *Choromytilus chorus* (Molina 1782)	1994	Not North American species
Rombough	The influence of the zona radiata on the toxicities of zinc, lead, mercury, copper and silver ions to embryos of steelhead trout *Salmo gairdneri*	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Romeo	Toxicology of trace metals in the marine	1991	Text in foreign language
Romeo and Gnassia-Barelli	Metal distribution in different tissues and in subcellular fractions of the Mediterranean clam *Ruditapes decussatus* treated with cadmium, copper, or zinc	1995	Not North American species
Romera et al.	Comparative study of biosorption of heavy metals using different types of algae	2007	No cadmium toxicity information; treatment study
Romera et al.	Biosorption of heavy metals by *Fucus spiralis*	2008b	Mixture
Romera et al.	Biosorption of Cd, Ni, and Zn with mixtures of different types of algae	2008a	Bioaccumulation: steady state not documented
Romero et al.	Toxic effects of cadmium on microalgae isolated from the northeastern region of Venezuela	2002	Non-applicable
Ros and Slooff	Integrated criteria document cadmium; Appendix 1. Effects	1988	Review

Authors	**Title**	**Year**	**Reason Unused**
Rosas and Ramirez	Effect of chromium and cadmium on the thermal tolerance of the prawn *Macrobrachium rosenbergii* expose to hard and soft water	1993	No interpretable concentration, time, response data or examined only a single exposure concentration
Rosas et al.	Trace metal concentrations in southern right whale (*Eubalaena australis*) at Peninsula Valdes, Argentina.	2012	Bioaccumulation: steady state not documented
Roseman et al.	bsorption of cadmium from water by North American zebra and quagga mussels (Bivalvia: Dreissenidae)	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Rossi and Jamet	In situ heavy metals (copper, lead and cadmium) in different plankton compartments and suspended particulate matter in two coupled Mediterranean coastal ecosystems (Toulon Bay, France)	2008	Bioaccumulation: steady state not documented
Rouleau et al.	Kinetics and body distribution of waterborne ^{65}Zn(II), ^{109}Cd(II), ^{203}Hg(II), and $CH_3{}^{203}$Hg(II) in phantom midge larvae (*Chaoborus americanus*) and effects of complexing agents	1998	No useable data on cadmium toxicity or bioconcentration
Rowe	Elevated standard metabolic rate in a freshwater shrimp (*Palaemonetes paludosus*) exposed to trace element-rich coal combustion waste	1998	Mixture
Roy et al.	Adsorption of heavy metals by green algae and ground rice hulls	1993	In vitro
Ruan	Contents of and assessment on heavy metals in aquatic organisms in the Yuandang Lake of Xiamen	2006	Bioaccumulation: steady state not documented
Ruangsomboon and Wongrat	Bioaccumulation of cadmium in an experimental aquatic food chain involving phytoplankton (*Chlorella vulgaris*), zooplankton (*Moina macrocopa*), and the predatory catfish *Clarias macrocephalus* x *C. gariepinus*	2006	Dietary exposure
Rubinstein et al.	Accumulation of PCBs, mercury and cadmium by *Nereis virens*, *Mercenaria mercenaria* and *Palaemontes pugio* from contaminated harbor sediments	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Ruelaqs-Inzunza and Paez-Osuna	Trophic Distribution of Cd, Pb, and Zn in a Food Web from Altata-Ensenada del Pabellon Subtropical Lagoon, SE Gulf of California	2008	SS not do
Ruelas-Inzunza et al.	Trophic distribution of Cd, Pb, and Zn in a food web from Altata-Ensenada del Pabellon subtropical lagoon, SE Gulf of California	2010	Bioaccumulation: steady state not documented
Ruelle and Keenlyne	Contaminants in Missouri River pallid sturgeon	1993	Bioaccumulation: steady state not documented
Rumolo et al.	Heavy metals in benthic foraminifera from the highly polluted sediments of the Naples Harbour (southern Tyrrhenian Sea, Italy)	2009	Bioaccumulation: steady state not documented
Saavedra et al.	Interspecific variation of metal concentrations in three bivalve mollusks from Galicia	2004	Bioaccumulation: steady state not documented
Safadi	The use of freshwater planarians in acute toxicity test with heavy metals	1998	Not North American species

Authors	Title	Year	Reason Unused
Saglam et al.	Investigations on the osmoregulation of freshwater fish (*Oreochromis niloticus*) following exposures to metals (Cd, Cu) in differing hardness	2013	Only one exposure concentration
Saglamtimur et al.	Effects of different concentrations of copper alone and a copper+cadmium mixture on the accumulation of copper in the gill, liver, kidney and muscle tissues of *Oreochromis niloticus* (L.)	2003	Mixture
Sahu et al.	Accumulation of metals in naturally grown weeds (aquatic macrophytes) grown on an industrial effluent channel	2007	Effluent
Saiki et al.	Copper, cadmium, and zinc concentrations in juvenile chinook salmon and selected fish-forage organisms (aquatic insects) in the upper Sacramento River, California	2001	Bioaccumulation: steady state not documented
Sajwan et al.	Elemental status in sediment and American oyster collected from Savannah marsh/estuarine ecosystem: A preliminary assessment	2008	Bioaccumulation: steady state not documented
Salahshur et al.	Use of *Solen brevis* as a biomonitor for Cd, Pb and Zn on the intertidal zones of Bushehr-Persian Gulf, Iran.	2012	Bioaccumulation: steady state not documented
Salanki et al.	Heavy metals in animals of Lake Balaton	1982	Bioaccumulation: steady state not documented
Salazar-Lugo et al.	Effect of chronic cadmium exposure on structure of head kidney of neotropical fish *Colossoma macropomum*	2011	Abstract only
Salazar-Medina et al.	Inhibition by Cu2+ and Cd2+ of a mu-class glutathione S-transferase from shrimp *Litopenaeus vannamei*	2010	In vitro
Saleem et al.	Heavy metal concentration in the fish and shellfish of Karachi harbour area	1999	Bioaccumulation: steady state not documented
Salice et al.	Demographic responses to multigeneration cadmium exposure in two strains of the freshwater gastropod, *Biomphalaria glabrata*	2009	Prior exposure, unmeasured chronic exposure
Salice et al.	Adaptive responses and latent costs of multigeneration cadmium exposure in parasite resistant and susceptible strains of a freshwater snail	2010	Too few exposure concentrations, atypical endpoint
Salvado et al.	Monitoring of nutrients, pesticides, and metals in waters, sediments, and fish of a wetland	2006	Bioaccumulation: steady state not documented
Samecka-Cymerman and Kempers	Heavy metals in aquatic macrophytes from two small rivers polluted by urban, agricultural and textile industry sewages SW Poland	2007	Bioaccumulation: steady state not documented
Samecka-Cymerman et al.	Heavy metals in aquatic bryophytes from the Ore mountains (Germany)	2002	Bioaccumulation: steady state not documented
Sanchez	Development of novel biomarkers of fish exposure to environmental contaminants	2009	Injected toxicant
Sanchez-Chardi et al.	Bioaccumulation of lead, mercury, and cadmium in the greater white-toothed shrew, *Crocidura russula*, from the Ebro Delta (NE Spain): Sex- and age-dependent variation	2007	Bioaccumulation: steady state not documented
Sanchiz et al.	Bioaccumulation of Hg, Cd, Pb and Zn in four marine phanerogams and the alga *Caulerpa prolifera* (Forsskal) Lamouroux from the east coast of Spain	1999	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Sanchiz et al.	Relationships between sediment physico-chemical characteristics and heavy metal bioaccumulation in Mediterranean soft-bottom macrophytes	2001	Bioaccumulation: steady state not documented
Sanchiz et al.	Mercury, cadmium, lead and zinc bioaccumulation in soft-bottom marine macrophytes from the east coast of Spain	2002	Bioaccumulation: steady state not documented
Sandau et al.	Heavy metal sorption by microalagae	1996	The materials, methods or results were insufficiently described
Sandhu et al.	Cadmium-mediated disruption of cortisol biosynthesis involves suppression of corticosteroidogenic genes in rainbow trout	2011	In vitro
Sandhu et al.	Exposure to environmental levels of waterborne cadmium impacts corticosteroidogenic and metabolic capacities, and compromises secondary stressor performance in rainbow trout	2014	Only two exposure concentrations
Sandrini et al.	Short-term responses to cadmium exposure in the estuarine polychaete *Laeonereis acuta* (Polychaeta, Nereididae): Subcellular distribution and oxidative stress generation	2006	Only one exposure concentration, duration too short, not North American species
Sanger et al.	The effects of cadmium on *Mytilus edulis*: Metallothionein, micronuclei and heart rate	2002	Non-applicable
Santojanni et al.	Prediction of fecundity in chronic toxicity tests on *Daphnia magna*	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Santoro et al.	Bioaccumulation of heavy metals by aquatic macroinvertebrates along the Basento River in the south of Italy	2009	Bioaccumulation: steady state not documented
Santos et al.	Biomonitoring of metal contamination in a marine prosobranch snail (*Nassarius reticulatus*) by imaging laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS)	2009	Bioaccumulation: steady state not documented
Sapozhnikova et al.	Evaluation of pesticides and metals in fish of the Dniester River, Moldova	2005	Bioaccumulation: steady state not documented
Sarosiek et al.	The effect of copper, zinc, mercury and cadmium on some sperm enzyme activities in the common carp (*Cyprinus carpio* L.)	2009	Mixture
Sasikumar et al.	Monitoring trace metal contaminants in green mussel, *Perna viridis* from the coastal waters of Karnataka, southwest coast of India	2006	Bioaccumulation: steady state not documented
Sasmaz et al.	The accumulation of heavy metals in *Typha latifolia* L. grown in a stream carrying secondary effluent	2008	Effluent
Sassi et al.	Influence of high temperature on cadmium-induced skeletal deformities in juvenile mosquitofish (*Gambusia affinis*)	2010	Only one exposure concentration, dilution water not characterized
Sastry and Shukla	Influence of protective agents in the toxicity of cadmium to a freshwater fish (*Channa punctatus*)	1994	Not North American species
Sastry and Sunita	Effect of cadmium and chromium on the intestinal absorption of glucose in the snakehead fish, *Channa punctatus*	1982	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Satake et al.	Inorganic elements in some aquatic bryophytes from streams in New Caledonia	1984	Bioaccumulation: steady state not documented
Sauvant et al.	Toxicity assessment of 16 inorganic environmental pollutants by six bioassays	1997	No interpretable concentration, time, response data or examined only a single exposure concentration
Sauve et al.	Phagocytic response of terrestrial and aquatic invertebrates following in vitro exposure to trace elements	2002a	In vitro
Sauve et al.	Phagocytic activity of marine and freshwater bivalves: In vitro exposure of hemocytes to metals (Ag, Cd, Hg and Zn)	2002b	In vitro
Saxena et al.	Experimental studies on toxicity of zinc and cadmium to *Heteropneustes fossilis* (Bl.)	1993	Not North American species
Saygideger and Dogan	Lead and cadmium accumulation and toxicity in the presence of EDTA in *Lemna minor* L. and *Ceratophyllum demersum* L.	2004	Mixture
Saygideger and Dogan	Variation of lead, cadmium, copper, and zinc in aquatic macrophytes from the Seyhan River, Adana, Turkey	2005	Bioaccumulation: steady state not documented
Saygideger et al.	Adsorption of Cd(II), Cu(II) and Ni(II) ions by *Lemna minor* L.: Effect of physicochemical environment	2005	Mixture
Sayk and Schmidt	Algae fluorescence auto meter, a computer-controlled measuring apparatus biotest	1986	Text in foreign language
Schaeffer et al.	Evaluation of the reference toxicant addition procedure for testing the toxicity of environmental samples	1991	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Schiff et al.	Characterization of stormwater toxicants from an urban watershed to freshwater and marine organisms	2002	Effluent
Schintu et al.	Trace metals in algae from the south-western coast of Sardinia (Italy)	2007	Bioaccumulation: steady state not documented
Schmidt	Possible use and results of an algal fluorescence bioassay	1987	Text in foreign language
Schmitt	Concentrations of arsenic, cadmium, copper, lead, selenium, and zinc in fish from the Mississippi River basin, 1995	2004	Bioaccumulation: steady state not documented
Schmitt et al.	Organochlorine residues and elemental contaminants in U.S. freshwater fish, 1976-1986: National contaminant biomonitoring program	1999	Bioaccumulation: steady state not documented
Schmitt et al.	Biochemical effects of lead, zinc, and cadmium from mining on fish in the tri-states district of northeastern Oklahoma, USA	2005	Bioaccumulation: steady state not documented
Schmitt et al.	A screening-level assessment of lead, cadmium, and zinc in fish and crayfish from northeastern Oklahoma, USA	2006	Bioaccumulation: steady state not documented
Schmitt et al.	Accumulation of metals in fish from lead-zinc mining areas of southeastern Missouri, USA	2007	Bioaccumulation: steady state not documented
Schmitt et al.	Concentrations of cadmium, cobalt, lead, nickel, and zinc in blood and fillets of northern hog sucker (*Hypentelium nigricans*) from streams contaminated by lead-zinc mining: Implications for monitoring	2009a	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Schmitt et al.	Concentrations of metals in aquatic invertebrates from the Ozark National Scenic Riverways, Missouri	2009b	Bioaccumulation: steady state not documented
Schoenert et al.	The sensitivity of six strains of unicellular algae *Selenastrum capricornutum* to six reference toxicants	1983	Abstract only
Schor-Fumbarov et al.	Characterization of cadmium uptake by the water lily *Nymphaea aurora*	2003	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Schorr and Backer	Localized effects of coal mine drainage on fish assemblages in a Cumberland plateau stream in Tennessee	2006	Mixture
Schroeder	Development of models for the prediction of short-term and long-term toxicity to *Hyalella azteca* from separate exposures to nickel and cadmium	2008	Bioaccumulation: steady state not documented
Schuwerack et al.	The dynamics of protein and metal metabolism in acclimated and Cd-exposed freshwater crabs (*Potamonautes warreni*)	2009	Only one exposure concentration, duration too short, not North American species
Schwartz et al.	Influence of natural organic matter source on acute copper, lead, and cadmium toxicity to rainbow trout (*Oncorhynchus mykiss*)	2004	Mixture
Secor et al.	Bioaccumulation of toxicants, element and nutrient composition, and soft tissue histology of zebra mussels (*Dreissena polymorpha*) from New York State waters	1993	Bioaccumulation: steady state not documented
Sedlacek et al.	Influence of different aquatic humus fractions on uptake of cadmium to alga *Selenastrum capriconutum* Printz	1989	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Seebaugh and Wallace	Assimilation and subcellular partitioning of elements by grass shrimp collected along an impact gradient	2009	Bioaccumulation: steady state not documented
Seebaugh et al.	Digestive toxicity in grass shrimp collected along an impact gradient	2011	Fed toxicant
Seebaugh et al.	Carbon assimilation and digestive toxicity in naive grass shrimp (*Palaemonetes pugio*) exposed to dietary cadmium	2012	Fed toxicant
Segner and Lenz	Cytotoxicity assays with the rainbow trout R1 cell line	1993	In vitro
Segovia-Zavala et al.	Cadmium and silver in Mytilus californianus transplanted to an anthropogenic influenced and coastal upwelling areas in the Mexican northeastern Pacific	2004	Bioaccumulation: steady state not documented
Sehgal and Saxena	Determination of acute toxicity levels of cadmium and lead to the fish *Lebistes reticulatus* (Peters)	1987	Not North American species
Sekine and Noriko	Studies on the accumulation and transfer of pollutants through food chain. 6. Study on the optimum condition on simulation test and effect of culturing density on the toxicity of cadmium for killifish throughout the year	1985	Text in foreign language

Authors	Title	Year	Reason Unused
Sekkat et al.	Study of the interactions between copper, cadmium, and ferbam using the protozoan *Colpidium campylum* bioassay	1992	The materials, methods or results were insufficiently described
Selck and Forbes	The relative importance of water and diet for uptake and subcellular distribution of cadmium in the deposit-feeding polychaete, *Capitella sp.*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Sellin et al.	Cadmium exposures in fathead minnows: Are there sex-specific differences in mortality, reproductive success, and Cd accumulation?	2007	Only one exposure concentration, duration too short
Semsari and Megateli	Effect of cadmium toxicity on survival and phototactic behaviour of *Daphnia magna*	2007	Duration too short, only one exposure concentration
Sen and Sunlu	Effects of cadmium (CdCl(2)) on development and hatching of eggs in European squid (*Loligo vulgaris* Lamarck, 1798) (Cephalopoda: Loliginidae)	2007	No acclimation to test media, not North American species
Senadheera and Pathiratne	Bioaccumulation potential of three toxic heavy metals in shrimp, *Penaeus monodon* from different fractions of the culture environment	2003	Bioaccumulation: field study, exposure concentration not known
Senger et al.	In vitro effect of zinc and cadmium on acetylcholinesterase and ectonucleotidase activities in zebrafish (*Danio rerio*) brain	2006	In vitro
Serafim and Bebianno	Kinetic model of cadmium accumulation and elimination and metallothionein response in *Ruditapes decussatus*	2007	Bioaccumulation: not whole body or muscle content; not North American species
Serafim and Bebianno	Effect of a polymetallic mixture on metal accumulation and metallothionein response in the clam *Ruditapes decussatus*	2010	Mixture
Serafim et al.	Effect of temperature and size on metallothionein synthesis in the gill of *Mytilus galloprovincialis* exposed to cadmium	2002	Dilution water not characterized, only one exposure concentration
Serfozo	Necrotic effects of the xenobiotics' accumulation in the central nervous system of a crayfish (*Astacus leptodactylus* Eschz.)	1993	Lack of exposure details
Servizi and Martens	Effects of selected heavy metals on early life of sockeye and pink salmon	1978	Questionable treatment of test organisms or inappropriate test conditions or methodology
Seth et al.	Toxic effect of arsenate and cadmium alone and in combination on giant duckweed (*Spirodela polyrrhiza* L.) in response to its accumulation	2007	Excessive EDTA in medium (2,628 ug/L)
Shanmukhappa and Neelakantan	Influence of humic acid on the toxicity of copper, cadmium and lead to the unicellular alga, *Synechosystis aquatilis*	1990	Not North American species
Sharma and Patino	Effects of cadmium, estradiol-17beta and their interaction on gonadal condition and metamorphosis of male and female african clawed frog, *Xenopus laevis*	2010	Only one exposure concentration
Sharma and Selvaraj	Zinc, lead and cadmium toxicity to selected freshwater zooplankters	1994	Organisms only acclimated 5 days, lake water (dilution water) not completely characterized
Sharma et al.	Diurnal variation of Texas "brown tide" (*Aureoumbra lagunensis*) in relation to metals	2000	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Shaw et al.	Gene response profiles for *Daphnia pulex* exposed to the environmental stressor cadmium reveals novel crustacean metallothioneins	2007	Lack of detail
Shazili	Effects of salinity and pre-exposure on acute cadmium toxicity to seabass, *Lates calcarifer*	1995	Not North American species
Shcherban	Toxicity of some heavy metals for *Daphnia magna* Strauss, as a function of temperature	1977	The materials, methods or results were insufficiently described
Sheela et al.	Impact of cadmium on food utilization, growth and body composition in the fish *Oreochromis mossambicus*	1995	The materials, methods or results were insufficiently described
Sheir and Handy	Tissue injury and cellular immune responses to cadmium chloride exposure in the common mussel *Mytilus edulis*: Modulation by lipopolysaccharide	2010	In vitro
Shi and Wang	Understanding the differences in Cd and Zn bioaccumulation and subcellular storage among different populations of marine clams	2004	Bioaccumulation: steady state not documented
Shiber and Shatila	Lead cadmium copper nickel and iron in limpets mussels and snails from the coast of Ras Beirut Lebanon	1978	Bioaccumulation: steady state not documented
Shilla et al.	Distribution of heavy metals in dissolved, particulate and biota in the Scheldt Estuary, Belgium	2008	Bioaccumulation: steady state not documented
Shirakashi and El-Matbouli	Effect of cadmium on the susceptibility of *Tubifex tubifex* to *Myxobolus cerebralis* (Myxozoa), the causative agent of whirling disease	2010	Mixture
Shirvani and Jamili	Assessing Cd, Pb accumulation in the tissues of *Chalcalbumus chalcoides* in Anzali Port	2009	Bioaccumulation: steady state not documented
Shivaraj and Patil	Toxicity of cadmium and copper to a freshwater fish *Puntius arulius*	1988	Not North American species
Shuhaimi-Othman and Pascoe	Bioconcentration and depuration of copper, cadmium, and zinc mixtures by the freshwater amphipod *Hyallela azteca*	2007	Bioaccumulation: steady state not documented (only 5 day exposure)
Shuhaimi-Othman et al.	Toxicity of eight metals to Malaysian freshwater midge larva *Chironomus javanus* (Diptera, Chironomidae)	2011	Not North American species
Shuhaimi-Othman et al.	Toxicity of metals to tadpoles of the common Sunda toad, *Duttaphrynus melanostictus*	2012a	Not North American species
Shukla et al.	Effect of cadmium individually and in combination with other metals on the nutritive value of fresh water fish, *Channa punctatus*	2002	Dilution water not characterized, not North American species
Shukla et al.	Bioaccumulation of Zn, Cu and Cd in *Channa punctatus*	2007b	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
Shukla et al.	Preferential accumulation of cadmium and chromium: Toxicity in *Bacopa monnieri* L. under mixed metal treatments	2007a	Mixture
Shulkin and Presley	Metal concentrations in mussel *Crenomytilus grayanus* and oyster *Crassostrea gigas* in relation to contamination of ambient sediment exposures	2003	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Shulkin et al.	The influence of metal concentration in bottom sediments on metal accumulation by *Mytilids crenomytilus grayanus* and *Modiolus kurilensis*	2002	Sediment exposure
Siboni et al.	Coastal coal pollution increases Cd concentrations in the predatory gastropod *Hexaplex trunculus* and is detrimental to its health	2004	Bioaccumulation: steady state not documented
Sick and Baptist	Cadmium incorporation by the marine copepod *Pseudodiaptomous coronatus*	1979	Bioconcentration tests used radioactive isotopes and were not used because of the possibility of isotope discrimination
Sidoumou et al.	Cadmium and calcium uptake in the mollusc *Donax rugosus* and effect of a calcium channel blocker	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Sidoumou et al.	Heavy metal concentrations in molluscs from the Senegal coast	2006	Bioaccumulation: steady state not documented
Sieratowicz et al.	Effects of test media on reproduction in *Potamopyrgus antipodarum* and of pre-exposure population densities on sensitivity to cadmium in a reproduction test	2013	Only one exposure concentration
Sikorska and Wolnicki	Cadmium toxicity to rudd (*Scardinius erythrophthalmus* L.) larvae after short-term exposure	2006	Dilution water not characterized, duration too short, not North American species
Silva et al.	Utilization of *Odontesthes regia* (Atherinidae) from the south eastern Pacific as a test organism for bioassays: Study of its sensitivity to six chemicals	2001	Duration too short, not North American species
Silva et al.	Effects of phenanthrene- and metal-contaminated sediment on the feeding activity of the harpacticoid copepod, *Schizopera knabeni*	2009	Sediment exposure
Silvestre et al.	Uptake of cadmium through isolated perfused gills of the chinese mitten crab, *Eriocheir sinensis*	2004	Non-applicable
Silvestre et al.	Hyper-osmoregulatory capacity of the Chinese mitten crab (*Eriocheir sinensis*) exposed to cadmium; Acclimation during chronic exposure	2005	High control mortality (26%), not North American species
Simas et al.	Shrimp - a dynamic model of heavy-metal uptake in aquatic macrofauna	2001	Modeling
Simoes Goncalves et al.	Effect of nutrients, temperature and light on uptake of cadmium by *Selenastrum capricornutum* Printz	1988	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Simoes Goncalves et al.	Effect of speciation on uptake and toxicity of cadmium to shrimp *Crangon crangon* (L.)	1989	Not North American species
Simon et al.	In situ evaluation of cadmium biomarkers in green algae	2011	Effluent
Simonetti et al.	Heavy-metal concentrations in soft tissues of the burrowing crab *Neohelice granulata* in Bahia Blanca estuary, Argentina	2012	Bioaccumulation: steady state not documented
Simonova et al.	Comparison of tolerance of *Brassica juncea* and *Vigna radiata* to cadmium	2007	Non-aquatic plants

Authors	Title	Year	Reason Unused
Sindhe et al.	Ovarian changes in response to heavy metal exposure to the fish, *Notopterus notopterus* (Pallas)	2002	Dilution water not characterized, lack of exposure details, not North American species
Singh	Toxic effects of cadmium chloride n growth and oogonium formation in *Oedogonium hatei*	2005	Lack of details, no statistical analysis
Singh and Ferns	Accumulation of heavy metals in rainbow trout *Salmo gairdneri* (Richardson) maintained on a diet containing activated sewage sludge	1978	Effluent
Singh et al.	Changes in haematocrit values of *Labeo rohita* (Ham.) under the toxicity of cadmium chloride	2003	Lack of details, not North American species
Singh et al.	Heavy metal concentrations in water, sediments and body tissues of red worm (*Tubifex spp*.) collected from natural habitats in Mumbai, India	2007b	Bioaccumulation: steady state not documented
Singh et al.	Cadmium induced changes on the secretion of branchial mucous cells of peppered loach, *Lepdocephalichthys guntea*	2007a	Dilution water not characterized, only one exposure concentration, not North American species, duration too long
Singh et al.	Bioaccumulation of cadmium in tissues of *Cirrihna mrigala* and *Catla catla*	2008	Lack of details; not North American species
Sinha et al.	Bioaccumulation and toxicity of Cu and Cd in *Vallisneria spiralis* (L.).	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Sinha et al.	Calorific changes in liver, ovary and muscle of hill stream fish *Garra mullya* (sykes) due to cadmium toxicity	2001	Unmeasured chronic exposure, only one exposure concentration, not North American species
Siva Kiran et al.	Bioaccumulation of cadmium in blue green alga *Spirulina* (*Arthrospira*) *indica*	2012	Excessive EDTA in medium (80,000 ug/L)
Skinner et al.	Heavy metal concentrations in wild and cultured blacklip abalone (*Haliotis rubra* Leach) from southern Australian waters	2004	Bioaccumulation: steady state not documented
Skorkowski et al.	Effect of cadmium and glutathione on malic enzyme activity in brown shrimps (*Crangon crangon*) from the Gulf of Gdansk (Baltic Sea, Poland)	2011	Bioaccumulation: steady state not documented
Skowronski and Przytocka-Jusiak	Effect of cadmium on the growth of *Chlorella vulgaris* and *Stichococcus baccillaris*	1981	Cannot determine effect concentration, no statistical analysis
Skowronski and Przytocka-Jusiak	Cadmium removal by green alga *Stichococcus bacillaris*	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Skowronski et al.	Reduction of cadmium toxicity to green microalga *Stichococcus bacillaris* by manganese	1988	Review of previously published data

Authors	**Title**	**Year**	**Reason Unused**
Skowronski et al.	The influence of pH on cadmium toxicity to the green alga *Stichococcus bacillaris* and on the cadmium forms present in the culture medium	1991	No interpretable concentration, time, response data or examined only a single exposure concentration
Slobodskova et al.	Evaluation of the genotoxicity of cadmium in gill cells of the clam *Corbicula japonica* using the Comet Assay	2010	In vitro
Sloman et al.	The effects of trace metal exposure on agonistic encounters in juvenile rainbow trout, *Oncorhynchus mykiss*	2003a	Only one exposure concentration, duration too short
Sloman et al.	Cadmium affects the social behaviour of rainbow trout, *Oncorhynchus mykiss*	2003b	Only one exposure concentration, duration too short
Sloof et al.	Kinetics of cadmium uptake by green algae	1995	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Smith et al.	Distribution and significance of copper, lead, zinc and cadmium in the Corio Bay ecosystem	1981	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Smith et al.	Chemical contaminants, lymphocystis, and dermal sarcoma in walleyes spawning in the Thames River, Ontario	1992	Bioaccumulation: steady state not documented
Smith et al.	Inhibited cytotoxic leukocyte activity in tilapia (*Oreochromis niloticus*) following exposure to immunotoxic chemicals	1999a	Injected toxicant
Smith et al.	Tilapia (*Oreochromis niloticus*) and rodents exhibit similar patterns of inhibited antibody production following exposure to immunotoxic chemicals	1999b	Injected toxicant
Smokorowski et al.	Quantifying the uptake and release of cadmium and copper by the opossum shrimp *Mysis relicta* preying upon the cladoceran *Daphnia magna* using stable isotope tracers	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Snodgrass et al.	Microcosm investigations of stormwater pond sediment toxicity to embryonic and larval amphibians: Variation in sensitivity among species	2008	Sediment exposure
Soares et al.	Vanadium and cadmium in vivo effects in teleost cardiac muscle: Metal accumulation and oxidative stress markers	2008	Mixture
Sobhan and Sternberg	Cadmium removal using cladophora	1999	No useable data on cadmium toxicity or bioconcentration
Sobral et al.	In vitro development of parthenogenetic eggs: a fast ecotoxicity test with *Daphnia magna*?	2001	In vitro
Sobrino-Figueroa and Caceres-Martinez	Alterations of valve closing behavior in juvenile catarina scallops (*Argopecten ventricosus* Sowerby, 1842) exposed to toxic metals	2009	Mixture
Softeland et al.	Toxicological application of primary hepatocyte cell cultures of Atlantic cod (*Gadus morhua*)--effects of BNF, PCDD and Cd	2010	In vitro

Authors	Title	Year	Reason Unused
Sokolova et al.	Effects of temperature and cadmium exposure on the mitochondria of oysters (*Crassostrea virginica*) exposed to hypoxia and subsequent reoxygenation	2012	Abstract only
Sokolova et al.	Cadmium exposure affects mitochondrial bioenergetics and gene expression of key mitochondrial proteins in the eastern oyster *Crassostrea virginica* Gmelin (Bivalvia: Ostreidae)	2005b	Only one exposure concentration, unmeasured chronic exposure
Sokolova et al.	Tissue-specific accumulation of cadmium in subcellular compartments of eastern oyster *Crassostrea virginica* Gmelin (Bivalvia: Ostreidae)	2005a	Bioaccumulation: steady state not documented; unmeasured exposure
Sokolowski et al.	The relationship between metal concentrations and phenotypes in the Baltic clam *Macoma balthica* (L.) from the Gulf of Gdansk, southern Baltic	2002	Bioaccumulation: steady state not documented
Sola et al.	Heavy metal bioaccumulation and macroinvertebrate community changes in a Mediterranean stream affected by acid mine drainage and an accidental spill (Guadiamar River, SW Spain)	2004	Bioaccumulation: steady state not documented
Solanke	Toxicity of cadmium in fresh water fish *Cyprinus carpio*	2012	Dilution water not characterized; only one exposure concentration
Sole Rovira et al.	Effects on metallothionein levels and other stress defenses in Senegal sole larvae exposed to cadmium	2005	Bioaccumulation: steady state not documented; unmeasured exposure; not North American species
Soltan and Rashed	Laboratory study on the survival of water hyacinth under several conditions of heavy metal concentrations	2003	Distilled water without the proper salts, only one exposure concentration
Sommer and Winkler	The effect of heavy metals on the rates of photosynthesis and respiration of *Fontinalis antipyretica* Hedw.	1982	Text in foreign language
Song et al.	Single and joint toxic effects of benzo(a)pyrene and cadmium on development of three-setiger juvenile of ploychaete *Pernereis aibuhitensis* Grube	2011	Text in foreign language
Sooksawat et al.	Phytoremediation potential of charophytes: Bioaccumulation and toxicity studies of cadmium, lead and zinc	2013	Only two exposure concentration; Bioaccumalation: steady state not documented
Sorgeloos et al.	The use of *Artemia nauplii* for toxicity tests - a critical analysis	1978	Artemia
Sornom et al.	Effects of sublethal cadmium exposure on antipredator behavioural and antitoxic responses in the invasive amphipod, *Dikerogammarus villosus*	2012	Only one exposure concentration, not North American species
Soto-Jimenez et al.	Nonessential metals in striped marlin and Indo-Pacific sailfish in the southeast Gulf of California, Mexico: concentration and assessment of human health risk	2010	Bioaccumulation: steady state not documented
Souid et al.	Effect of acute cadmium exposure on metal accumulation and oxidative stress biomarkers of *Sparus aurata*	2013	Only one exposure concentration
Soukupova et al.	Effect of cadmium(II) ions on level of biologically active compounds in carps and invertebrates	2011	Abstract only

Authors	Title	Year	Reason Unused
Sovenyi and Szakolczai	Studies on the toxic and immunosuppressive effects of cadmium on the common carp	1993	The materials, methods or results were insufficiently described
Spann et al.	Size-dependent effects of low level cadmium and zinc exposure on the metabolome of the asian clam, *Corbicula fluminea*	2011	Mixture
Specht et al.	Structural, functional, and recovery responses of stream invertebrates to fly ash effluent	1984	Effluent
Sprague	Measurement of pollutant toxicity to fish i. bioassay methods for acute toxicity	1969	Review
Sprenger et al.	Concentrations of trace elements in yellow perch (Perca flavescens) from six acidic lakes	1988	Bioaccumulation: steady state not documented
Spry and Wiener	Metal bioavailability and toxicity to fish in low-alkalinity lakes: A critical review	1991	Review of previously published data
Srivastav et al.	Ultimobranchial gland of a freshwater teleost, *Heteropneustes fossilis*, in response to cadmium treatment	2009	In vitro
Srivastava and Appenroth	Interaction of EDTA and iron on the accumulation of Cd2+ in duckweeds (Lemnaceae)	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Srivastava et al.	Physiological changes in a freshwater catfish, *Heteropneustes fossilis* following exposure to cadmium	2001	Dilution water not characterized, not North American species
St. Louis	Element concentrations in chironomids and their abundance in the littoral zone of acidified lakes in Northwestern Ontario	1993	Bioaccumulation: steady state not documented
Stary and Kratzer	The cumulation of toxic metals on alga	1982	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Stary et al.	The cumulation of zinc and cadmium in fish (*Poecilia reticulata*)	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Stary et al.	Cumulation of zinc, cadmium and mercury on the alga *Scenedesmus obliquus*	1983	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Staub et al.	Respiratory and reproductive characteristics of eastern mosquitofish (*Gambusia holbrooki*) inhabiting a coal ash settling basin	2004	Effluent
Stawarz et al.	Heavy-metal concentration in the toad *Bufo bufo* from a region of Mochovce, Slovakia	2003	Bioaccumulation: steady state not documented
Stefano et al.	Cholinesterase activities in the scallop *Pecten jacobaeus*: Characterization and effects of exposure to aquatic contaminants	2008	Non-applicable

Authors	**Title**	**Year**	**Reason Unused**
Stepanyan et al.	Effect of molybdenum, chrome and cadmium ions on metamorphosis and erythrocytes morphology of the marsh frog *Pelophylax ridibundus* (Amphibia: Anura)	2011	Not North American species, only one exposure concentration
Stephenson and Macki	Net cadmium flux in *Hyalella azteca* (Crustacea: Amphipoda) populations from five central Ontario lakes	1989	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Stern and Stern	Effects of fly ash heavy metals on *Daphnia magna*	1980	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Stoiber	Analysis of toxicity biomarkers for understanding copper and cadmium stress in freshwater algae	2011	EDTA in exposure media not defined
Stoiber et al.	Relationships between surface-bound and internalized copper and cadmium and toxicity in *Chlamydomonas reinhardtii*	2012	Bioaccumulation: steady state not documented
Stokes and Dreier	Copper requirement of a copper-tolerant isolate of *Scenedesmus* and the effect of copper depletion on tolerance	1981	Not applicable
Stolyar et al.	Comparison of metal bioavailability in frogs from urban and rural sites of western Ukraine	2008	Bioaccumulation: steady state not documented
Stom and Zubareva	Comparative resistance of *Daphnia* and *Epischura* to toxic substances in acute exposure	1994	The materials, methods or results were insufficiently described
Storelli and Marcotrigiano	Heavy metal monitoring in fish, bivalve molluscs, water, and sediments from Varano Lagoon, Italy	2001	Bioaccumulation: steady state not documented
Storelli and Marcotrigiano	Content of mercury and cadmium in fish (*Thunnus alalunga*) and cephalopods (*Eledone moschata*) from the southeastern Mediterranean Sea	2004	Bioaccumulation: steady state not documented
Storelli et al.	Accumulation of mercury, cadmium, lead and arsenic in swordfish and bluefin tuna from the Mediterranean Sea: A comparative study	2005b	Bioaccumulation: steady state not documented
Storelli et al.	Trace elements in loggerhead turtles (*Caretta caretta*) from the eastern Mediterranean Sea: overview and evaluation	2005a	Bioaccumulation: steady state not documented
Storelli et al.	Metals and organochlorine compounds in eel (*Anguilla anguilla*) from the Lesina lagoon, Adriatic Sea (Italy)	2007	Bioaccumulation: steady state not documented
Storelli et al.	Total and subcellular distribution of trace elements (Cd, Cu and Zn) in the liver and kidney of green turtles (*Chelonia mydas*) from the Mediterranean Sea	2008	Bioaccumulation: steady state not documented
Stout et al.	Phytoprotective influence of bacteria on growth and cadmium accumulation in the aquatic plant *Lemna minor*	2010	Only one exposure concentration
Strady et al.	Roles of regional hydrodynamic and trophic contamination in cadmium bioaccumulation by Pacific oysters in the Marennes-Oleron Bay (France)	2011a	Bioaccumulation: steady state not documented
Stripp et al.	Trace element accumulation in the tissues of fish from lakes with different pH values	1990	Bioaccumulation: steady state not documented

Authors	**Title**	**Year**	**Reason Unused**
Stromgren et al.	Acute toxic effects of produced water in relation to chemical composition and dispersion	1995	Effluent
Stubblefield et al.	Acclimation-induced changes in the toxicity of zinc and cadmium to rainbow trout	1999	The materials, methods or results were insufficiently described
Stuhlbacher and Maltby	Cadmium resistance in *Gammarus pulex* (L.)	1992	Not North American species
Sullivan	Effects of salinity and temperature on the acute toxicity of cadmium to the estuarine crab *Paragrapsus gaimardii* (Milne Edwards)	1977	Not North American species
Sun and Zhou	Oxidative stress biomarkers of the Polychaete *Nereis diversicolor* exposed to cadmium and petroleum hydrocarbons	2008	Dilution water not characterized, duration too short, unmeasured chronic exposure
Sun et al.	Influences of petroleum on accumulation of copper and cadmium in the polychaete *Nereis diversicolor*	2006	Mixture
Sun et al.	Joint effects of arsenic and cadmium on plant growth and metal bioaccumulation: A potential Cd-hyperaccumulator and As-excluder *Bidens pilosa* L	2009	Mixture
Sunda and Huntsman	Antagonisms between cadmium and zinc toxicity and manganese limitation in a coastal diatom	1996	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Sunda et al.	Effect of chemical speciation on toxicity of cadmium to grass shrimp, *Palaemonetes pugio*: Importance of free cadmium ion	1978	Questionable treatment of test organisms or inappropriate test conditions or methodology
Sunil et al.	A method for partitioning cadmium bioaccumulated in small aquatic organisms	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Sunila and Lindstrom	Survival, growth and shell deformities of copper- and cadmium-exposed mussels (*Mytilus edulis* L.) in brackish water	1985	No interpretable concentration, time, response data or examined only a single exposure concentration
Sunlu	Trace metal levels in mussels (*Mytilus galloprovincialis* L. 1758) from Turkish Aegean Sea coast	2006	Bioaccumulation: steady state not documented
Sura et al.	Cadmium toxicity related to cysteine metabolism and glutathione levels in frog *Rana ridibunda* tissues	2006	Only two exposure concentrations, not North American species
Suresh	Effect of cadmium chloride on liver, spleen and kidney melano macrophage centres in *Tilapia mossambica*	2009	Duration too long, lack of exposure details
Suryawanshi	Accumulation and depuration of cadmium in oyster *Crassostrea cattuckensis* from Bhatye Estuary in Ratnagiri coast	2006a	Bioaccumulation: steady state not documented
Suryawanshi	Zinc and cadmium content in the estuarine oyster from Ratnagiri coast of Maharashtra	2006b	Bioaccumulation: steady state not documented
Suryawanshi and Langekar	Zinc and cadmium toxicity to estuarine rock oyster *Crassostrea cattuckensis* on Ratnagiri coast	2006	Mixture

Authors	Title	Year	Reason Unused
Suzuki et al.	Environmental and injected cadmium are sequestered by two major isoforms of basal copper, zinc-metallothionein in gibel (*Carassius auratus langsdorfi*) liver	1987	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Svecevicius	The use of fish avoidance response in identifying sublethal toxicity of heavy metals and their mixtures	2007	Mixture
Swansburg et al.	Mouthpart deformities and community composition of chironomidae (Diptera) larvae downstream of metal mines in New Brunswick, Canada	2002	Mixture
Swartz et al.	Sediment toxicity, contamination, and macrobenthic communities near a large sewage outfall	1985	Sediment
Swinehart	Final Technical Report for U.S.G.S. Grant: The effects of humic substances on the interactions of metal ions with organisms and liposo	1990	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Szarek-Gwiazda and Amirowicz	Bioaccumulation of trace elements in roach, silver bream, rudd, and perch living in an inundated opencast sulphur mine	2006	Bioaccumulation: steady state not documented
Szarek-Gwiazda et al.	Trace element concentrations in fish and bottom sediments of an eutrophic dam reservoir	2006	Bioaccumulation: steady state not documented
Szczerbik et al.	Influence of long-term exposure to dietary cadmium on growth, maturation and reproduction of goldfish (subspecies: Prussian carp *Carassius auratus gibelio* B.)	2006	Dietary exposure
Szebedinszky et al.	Effects of chronic Cd exposure via the diet or water on internal organ-specific distribution and subsequent gill Cd uptake kinetics in juvenile rainbow trout (*Oncorhynchus mykiss*)	2001	Only one exposure concentration
Szefer et al.	A comparative assessment of heavy metal accumulation in soft parts and byssus of mussels from subarctic, temperate, subtropical and tropical marine environments	2006	Bioaccumulation: steady state not documented
Szivak et al.	Metal-induced reactive oxygen species production in *Chlamydomonas reinhardtii* (Chlorophyceae)	2009	Lack of details
Tabari et al.	Heavy metals (Zn, Pb, Cd and Cr) in fish, water and sediments sampled form Southern Caspian Sea, Iran	2010	Bioaccumulation: steady state not documented
Takamura et al.	Effects of Cu, Cd and Zn on photosynthesis of freshwater benthic algae	1989	Not North American species
Talas et al.	Antioxidative role of selenium against the toxic effect of heavy metals (Cd+2, Cr+3) on liver of rainbow trout (*Oncorhynchus mykiss* Walbaum 1792)	2008	Mixture
Talbot	Relationship between cadmium concentrations in seawater and those in the mussel *Mytilus edulis*	1985	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge

Authors	Title	Year	Reason Unused
Talbot	Relationship between lead concentrations in seawater and in the mussel *Mytilus edulis*: A water-quality criterion	1987	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Tan et al.	Comparative evaluation of the cytotoxicity sensitivity of six fish cell lines to four heavy metals in vitro	2008	In vitro
Tan et al.	Effect of dietary cadmium level on the growth, body composition and several hepatic enzymatic activities of juvenile yellow catfish, *Pelteobagrus fulvidraco*	2010b	Fed toxicant
Tan et al.	Validation of an in vitro cytotoxicity test for four heavy metals using cell lines derived from a green sea turtle (*Chelonia mydas*)	2010a	In vitro
Tan et al.	Phytoaccumulation of cadmium through *Azolla* from aqueous solution	2011	Bioaccumulation: not renewal or flow-through; excessive EDTA in media
Tan et al.	Role of titanium dioxide nanoparticles in the elevated uptake and retention of cadmium and zinc in *Daphnia magna*	2012	Mixture
Tanhan et al.	Histopathological alterations in the edible snail, *Babylonia areolata* (spotted Babylon), in acute and subchronic cadmium poisoning	2005	Not North American species
Tao et al.	Toxicity of Cd2+ on the photosynthetic and respiratory rate and atpase activity of *Nymphoides peltatum* (Gmel.) O'Ktze	2002	Text in foreign language
Tapia et al.	Study of the content of cadmium, chromium and lead in bivalve molluscs of the Pacific Ocean (Maule Region, Chile)	2010	Bioaccumulation: steady state not documented
Tarasov et al.	Efficiency of batteries of tests for estimating potential mutagenicity of chemicals	2003	Review
Taravati et al.	Determination of lead, mercury and cadmium in wild and farmed *Barbus sharpeyi* from Shadegan Wetland and Azadegan aquaculture site, South of Iran	2012	Bioaccumulation: steady state not documented
Tarzwell and Henderson	Toxicity of less common metals to fishes	1960	The materials, methods or results were insufficiently described
Tawari-Fufeyin et al.	Toxicity of cadmium to *Parachanna obscura*: As evidenced by alterations in hematology, histology, and behavior	2007	Not North American species
Taylor	Impacts of cadmium contamination and fish presence on wetland invertebrate communities: An application of population measures and multi-metric tests	2010	Bioaccumulation: steady state not documented
Taylor and Maher	Exposure-dose-response of *Anadara trapezia* to metal contaminated estuarine sediments. 1. Cadmium spiked sediments	2012	Sediment
Taylor et al.	Surface binding of contaminants by algae: Consequences for lethal toxicity and feeding to *Daphnia magna* Straus	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	**Title**	**Year**	**Reason Unused**
Tehseen et al.	A scientific basis for proposed quality assurance of a new screening method for tumor-like growths in the planarian, *Dugesia dorotocephala*	1992	Mixture (Cd and PCBs; Cd and Aroclor)
Tekin-Ozan and Kir	Seasonal variations of heavy metals in some organs of carp (*Cyprinus carpio* L., 1758) from Beysehir Lake (Turkey)	2008	Bioaccumulation: steady state not documented
Temara et al.	Experimental cadmium contamination of *Asterias rubens* (Echinodermata)	1996a	Not North American species
Temara et al.	Allometric variations in heavy metal bioconcentration in the asteroid *Asterias rubens* (Echinodermata)	1996b	Not North American species
Temara et al.	Factors influencing the concentrations of heavy metals in the asteroid *Asterias rubens* L. (Echinodermata)	1997	Bioaccumulation: steady state not documented
Templeman and Kingsford	Trace element accumulation in *Cassiopea sp*. (Scyphozoa) from urban marine environments in Australia	2010	Bioaccumulation: steady state not documented
Ten Hoopen et al.	Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. I. Development of cadmium tolerance in batch cultures	1985	Not North American species
Tepe	Metal concentrations in eight fish species from Aegean and Mediterranean Seas	2009	Bioaccumulation: steady state not documented
Tepe et al.	Assessment of heavy metals in two commercial fish species of four Turkish seas	2008	Bioaccumulation: steady state not documented
Terra et al.	Chronic assays with *Daphnia magna*, 1820, Straus in sediment samples from Cai River, Rio Grande Do Sul, Brazil	2007	Sediment exposure
Tessier et al.	Modeling Cd partitioning in oxic lake sediments and Cd concentrations in the freshwater bivalve *Anodonta grandis*	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Tessier et al.	Laboratory study of Cd and Hg uptake by two freshwater molluscs in relation to concentration, age and exposure time	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Tevlin	An improved experimental medium for freshwater toxicity studies using *Daphnia magna*	1978	Complexing chelators used in test media
Thaker and Haritos	Cadmium bioaccumulation and effects on soluble peptides, proteins and enzymes in the hepatopancreas of the shrimp *Callianassa tyrrhena*	1989	Not North American species
Thebault et al.	Short term cadmium intoxication of the shrimp *Palaemon serrat*us: Effect on adenylate metabolism	1996	Not North American species
Theede et al.	Temperature and salinity effects on the acute toxicity of cadmium to *Laomedea loveni* (Hydrozoa)	1979	Not North American species
Thilaga and Sivakumar	Accumulation of heavy metals in the gastropod *Bullia vittata* at Gulf of Mannar	2006	Bioaccumulation: steady state not documented
Thirumathal et al.	Effect of heavy metal (cadmium borate) on the biochemical composition of chironomus larvae (Diptera: chironomidae)	2002	Lack of details, inappropriate form of chemical, cadmium borate

Authors	Title	Year	Reason Unused
Thomann et al.	A pharmacokinetic model of cadmium in rainbow trout	1997	Review of previously published data
Thomas et al.	A comparison of the accumulation and protein binding of environmental cadmium in the gills, kidney and liver of rainbow trout (*Salmo gairdneri* Richardson)	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Thomas et al.	A comparison of the sequestration of cadmium and zinc in the tissues of rainbow trout (*Salmo gairdneri*) following exposure to the metals singly or in combination	1985	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Thompson et al.	Concentration factors of the chemical elements in edible aquatic organisms	1972	Review of previously published data
Thongra-Ar	Toxicity of cadmium, zinc and copper on sperm cell fertilization of sea urchin, *Diadema setosum*	1997	In vitro
Thongra-Ar and Matsuda	Effects of cadmium and zinc on growth of *Thalassiosira weissflogii* and *Heterosigma akiashiwo*	1995	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Thophon et al.	Histopathological alterations of white seabass, *Lates calcarifer*, in acute and subchronic cadmium exposure	2003	Not North American species
Thophon et al.	Ultrastructural alterations in the liver and kidney of white sea bass, *Lates calcarifer*, in acute and subchronic cadmium exposure	2004	Not North American species, only two exposure concentrations
Thorpe	A toxicological assessment of cadmium toxicity to the larvae of two estuarine crustaceans, *Rhithropanopeus harrisii* and *Palaemonetes pugio*	1988	Inappropriate test medium
Thorpe and Costlow	The relation of the acute (96-h) uptake and subcellular distribution of cadmium and zinc to cadmium toxicity in larvae of *Rhithropanopeus harrisii* and a *Palaemonetes pugio*	1989	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Thorsson et al.	Effects of settling organic matter on the bioaccumulation of cadmium and BDE-99 by Baltic Sea benthic invertebrates	2008	Bioaccumulation: steady state not documented
Thwala et al.	Influence of salinity and cadmium on the survival and osmoregulation of *Callianassa kraussi* and *Chiromantes eulimene* (Crustacea: Decapoda)	2011	Not North American species
Tiam et al.	Development of Q-PCR approaches to assess water quality: Effects of cadmium on gene expression of the diatom *Eolimna minima*	2012	In vitro
Tichy et al.	The *Tubifex tubifex* assay for the determination of acute toxicity	2007	Dilution water not characterized, duration too short
Tilton et al.	Effects of cadmium on the reproductive axis of Japanese medaka (*Oryzias latipes*)	2003	Not North American species
Timmermans	Ecotoxicity of trace metals for chironomids	1992	Review
Titus and Pfister	Bacteria and cadmium interactions in natural and laboratory model aquatic systems	1984	Bacteria
Tiwari et al.	Time kinetic study of metallothionein mRNA expression due to cadmium exposure in freshwater murrel, *Channa punctata* (Bloch)	2010	In vitro

Authors	**Title**	**Year**	**Reason Unused**
Tkalec et al.	Cadmium-induced responses in duckweed *Lemna minor* L.	2008	Only one exposure concentration
Todd et al.	Effects of acid rock drainage on stocked rainbow trout (*Oncorhynchus mykiss*): An in-situ, caged fish experiment	2007	Mixture
Tokunaga and Kishikawa	Acute visible and invisible injuries to submerged plants by water pollutants	1982	Text in foreign language
Tomasik et al.	Metal-metal interaction in biological systems. Part IV. Freshwater snail *Bulinus globosus*	1995b	Not North American species
Topcuoglu et al.	Heavy metal concentrations in marine algae from the Turkish Coast of the Black Sea, during 1979-2001	2004	Bioaccumulation: steady state not documented
Topperwien et al.	Cadmium accumulation in *Scenedesmus vacuolatus* under freshwater conditions	2007a	Mixture
Topperwien et al.	Competition among zinc, manganese, and cadmium uptake in the freshwater alga *Scenedesmus vacuolatus*	2007b	Mixture
Tortell and Price	Cadmium toxicity and zinc limitation in centric diatoms of the genus *Thalassiosira*	1996	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Toussaint et al.	A comparison of standard acute toxicity test with rapid-screening toxicity test	1995	Review of previously published data
Tran et al.	How water oxygenation levels influences cadmium accumulation pattern in the Asiatic clam *Corbicula fluminea*: A laboratory and field study	2001	Bioaccumulation: steady state not documented (only 14 day exposure)
Tran et al.	Relationship between feeding-induced ventilatory activity and bioaccumulation of dissolved and algal-bound cadmium in the Asiatic clam *Corbicula fluminea*	2002	Bioaccumulation: steady state not documented; dilution water not characterized
Trannum et al.	Effects of copper, cadmium and contaminated harbour sediment exposures on recolonisation of soft-bottom communities	2004	Sediment exposure
Trehan and Maneesha	Cadmium mediated control of nitrogenase activity and other enzymes in a nitrogen fixing cyanobacterium	1994	No interpretable concentration, time, response data or examined only a single exposure concentration
Trevors et al.	Cadmium transport, resistance, and toxicity in bacteria, algae, and fungi	1986	Review of previously published data
Trieff et al.	Effluent from bauxite factory induces developmental and reproductive damage in sea urchins	1995	Effluent
Trinchella et al.	Differential gene expression profiles in embryos of the lizard *Podarcis sicula* under in ovo exposure to cadmium	2010	In vitro
Tryfonas et al.	Metal accumulation in eggs of the red-eared slider (*Trachemys scripta elegans*) in the lower Illinois River	2006	Bioaccumulation: steady state not documented
Tsui and Wang	Biokinetics and tolerance development of toxic metals in *Daphnia magna*	2007	Review
Tucker and Matte	In vitro effects of cadmium and lead on ATPases in the gill of the rock crab, *Cancer irroratus*	1980	No pertinent adverse effects reported

Authors	Title	Year	Reason Unused
Tuerkmen et al.	Determination of metals in fish species from Aegean and Mediterranean Seas	2009	Bioaccumulation: steady state not documented
Tueros et al.	Integrating long-term water and sediment pollution data, in assessing chemical status within the European water framework directive	2009	Review
Tuezen et al.	Investigation of trace metal levels in fish species from the Black Sea and the River Yesilirmak, Turkey by atomic absorption spectrometry	2004	Bioaccumulation: steady state not documented
Turan et al.	Levels of heavy metals in some commercial fish species captured from the Black Sea and Mediterranean coast of Turkey	2009	Bioaccumulation: steady state not documented
Turk Culha et al.	Heavy metals levels in some fishes and molluscs from Inop Peninsula of the Southern Black Sea, Turkey	2007	Bioaccumulation: steady state not documented
Turkmen et al.	Heavy metals in three commercially valuable fish species from Iskenderun Bay, Northern East Mediterranean Sea, Turkey	2005	Bioaccumulation: steady state not documented
Turkmen et al.	Metal levels in tissues of the European anchovy, *Engraulis encra*sicolus L., 1758, and picarel, *Spicara smaris* L., 1758, from Black, Marmara and Aegean Seas	2008	Bioaccumulation: steady state not documented
Turkmen et al.	Heavy metal contaminants in tissues of the garfish, *Belone belone* L., 1761, and the bluefish, *Pomatomus saltatrix* L., 1766, from Turkey waters	2009	Bioaccumulation: steady state not documented
Turner et al.	Influence of salinity and humic substances on the uptake of trace metals by the marine macroalga, *Ulva lactuca*: Experimental observations and modeling using WHAM	2008	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Turoczy et al.	Cadmium, copper, mercury, and zinc concentrations in tissues of the king crab (*Pseudocarcinus gigas*) from southeast Australian waters	2001	Bioaccumulation: steady state not documented
Tuzen	Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey	2009	Bioaccumulation: steady state not documented
Tuzen et al.	Trace element content in marine algae species from the Black Sea, Turkey	2009	Bioaccumulation: steady state not documented
Tyurin and Khristoforova	Effect of toxicants on the development of the chiton *Ischnochiton hakodadensis*	1993	Not North American species
Udoidiong and Akpan	Toxicity of cadmium, lead and lindane to *Egeria radiata* Lamarck (Lamellibranchia, Donacidae)	1991	Not North American species
Ugolini et al.	Behavioural responses of the supralittoral amphipod *Talitrus saltator* (Montagu) to trace metals contamination	2012	Mixture
Uluozlu et al.	Trace metal content in nine species of fish from the Black and Aegean Seas, Turkey	2007	Bioaccumulation: steady state not documented
Uluturhan and Kucuksezgin	Heavy metal contaminants in red pandora (*Pagellus erythrinus*) tissues from the eastern Aegean Sea, Turkey	2007	Bioaccumulation: steady state not documented
Urech	Melimex, an experimental heavy metal pollution study: effects of increased heavy metal load on crustacea plankton	1979	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Urek and Tarhan	Response of the antioxidant systems of the cyanobacterium *Spirulina maxima* to cadmium	2011	Abstract only
Usero et al.	Heavy metals in fish (*Solea vulgaris*, *Anguilla anguilla* and *Liza aurata*) from salt marshes on the southern Atlantic coast of Spain	2004	Bioaccumulation: steady state not documented
Uthe et al.	Cadmium in American lobster (*Homarus americanus*) from the area of a lead smelter	1982	Bioaccumulation field study not used because an insufficient number of measurements of the concentration of cadmium in the water
Uysal and Taner	Determination of growth rate change and accumulation efficiency of *Lemna minor* exposed to cadmium and lead ions	2012	Bioaccumulation: steady state not documented
Valencia et al.	The effect of estrogen on cadmium distribution in rainbow trout (*Oncorhynchus mykiss*)	1998	Not North American species
Valova et al.	Spatiotemporal trends of heavy metal concentrations in fish of the River Morava (Danube basin)	2010	Bioaccumulation: steady state not documented
van Aardt and Booysen	Water hardness and the effects of Cd on oxygen consumption, plasma chlorides and bioaccumulation in *Tilapia sparrmanii*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure; not North American species
van Aardt and Erdmann	Heavy metals (Cd, Pb, Cu, Zn) in mudfish and sediment exposures from three hard-water dams of the Mooi River catchment, South Africa	2004	Bioaccumulation: steady state not documented
Van Campenhout et al.	Cytosolic distribution of Cd, Cu and Zn, and metallothionein levels in relation to physiological changes in Gibel carp (*Carassius auratus gibelio*) from metal-impacted habitats	2010	Bioaccumulation: steady state not documented
Van den Hurk et al.	Interaction of cadmium and benzo[a]pyrene in mummichog (*Fundulus heteroclitus*): Effects on acute mortality	1998	Organisms were exposed to cadmium in food or by injection or gavage
Van Gemert et al.	Effects of temperature on cadmium toxicity to the green alga *Scenedesmus acutus*. II. Light-limited growth in continuous culture	1985	Not North American species
Van Ginneken et al.	Bioavailability of cadmium and zinc to the common carp, *Cyprinus carpio*, in complexing environments: A test for the validity of the free ion activity model	1999	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Van Ginneken et al.	Bioavailability of Cd to the common carp, *Cyprinus carpio* in the presence of humic acid	2001	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Van Hattum et al.	Trace metals in populations of freshwater isopods: Influence of biotic and abiotic variables	1996	Bioaccumulation: steady state not documented
Van Leeuwen et al.	The use of cohorts and populations in chronic toxicity studies with *Daphnia magna*: A cadmium example	1985b	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	Title	Year	Reason Unused
Van Leeuwen et al.	Effects of chemical stress on the population dynamics of *Daphnia magna*: A comparison of two test procedures	1987	Review of previously published data
Van Steveninck et al.	Heavy-metal (Zn, Cd) tolerance in selected clones of duck weed (*Lemna minor*)	1992	Organisms were selected, adapted or acclimated for increased resistance to cadmium
Vardanyan and Ingole	Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems	2006	Bioaccumulation: steady state not documented
Vashchenko and Zhadan	Ecological assessment of marine environment using two sea urchin tests: Disturbance of reproduction and sediment embryotoxicity	1993	Not North American species
Vasseur and Pandard	Influence of some experimental factors on metals toxicity to *Selenastrum capricornutum*	1988	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Vassiliev et al.	Heavy metal concentrations in lobster (*Homarus americanus*)	2005	Bioaccumulation: steady state not documented
Vazquez-Sauceda et al.	Cadmium, lead and zinc concentrations in water, sediment and oyster (*Crassostrea virginica*) of San Andres Lagoon, Mexico	2011	Bioaccumulation: steady state not documented
Vecchia et al.	Morphogenetic, ultrastructural and physiological damages suffered by submerged leaves of *Elodea canadensis* exposed to cadmium	2005	Dilution water not characterized, only one exposure concentration
Vellinger et al.	Antagonistic toxicity of arsenate and cadmium in a freshwater amphipod (*Gammarus pulex*)	2012a	Not North American species
Vellinger et al.	Comparison of arsenate and cadmium toxicity in a freshwater amphipod (*Gammarus pulex*)	2012b	Not North American species; duration too long
Vellinger et al.	Behavioural and physiological responses of *Gammarus pulex* exposed to cadmium and arsenate at three temperatures: Individual and combined effects	2012c	Not North American species, only two exposure concentrations
Vellinger et al.	Single and combined effects of cadmium and arsenate in *Gammarus pulex* (Crustacea, Amphipoda): Understanding the links between physiological and behavioural responses	2013	Not North American species, only two exposure concentrations
Venanzi et al.	Effects of heavy metals on some photosynthetic characteristics in *Lemna trisulca* L.	1989	Text in foreign language
Venkateswara Rao et al.	The use of marine sponge, *Haliclona tenuiramosa* as bioindicator to monitor heavy metal pollution in the coasts of Gulf of Mannar, India	2009	Bioaccumulation: steady state not documented
Venkatrayulu et al.	Hepatogonadal changes in the female fresh water field crab, *Oziotelphusa senex senex* (Fabricius) in response to cadmium toxicity	2005	Duration too short, unmeasured chronic exposure, not North American species
Verbost et al.	Cadmium inhibition of Ca2+ uptake in rainbow trout gills	1987	No interpretable concentration, time, response data or examined only a single exposure concentration
Vergauwen et al.	Effect of temperature on cadmium toxicity in zebrafish: From transcriptome to physiology	2012	Abstract only
Verma	Effect of cadmium on fin regeneration in the freshwater fish, *Oreochromis mossambicus*	2005	Inappropriate form of toxicant, Cd acetate

Authors	**Title**	**Year**	**Reason Unused**
Verma et al.	Short term toxicity tests with heavy metals for predicting safe concentrations	1980	The materials, methods or results were insufficiently described
Verriopoulos and Moraitou-Apostolopoulou	Effects of some environmental factors on the toxicity of cadmium to the copepod *Tisbe holothuriae*	1981	Not North American species
Verriopoulos and Moraitou-Apostolopoulou	Differentiation of the sensitivity to copper and cadmium in different life stages of a copepod	1982	Not North American species
Verslycke et al.	The toxicity of metal mixtures to the estuarine mysid *Neomysis integer* (Crustacea: Mysidacea) under changing salinity	2003	Not North American species
Viarengo et al.	Effects of heavy metals on the Ca2+-ATPase activity present in gill cell plasma-membrane of mussels (*Mytilus galloprovincialis* Lam.)	1993	In vitro
Vieira et al.	Mercury, cadmium, lead and arsenic levels in three pelagic fish species from the Aatlantic Ocean: Intra- and inter-specific variability and human health risks for consumption	2011	Bioaccumulation: steady state not documented
Vigneault and Campbell	Uptake of cadmium by freshwater green algae: effects of pH and aquatic humic substances	2005	Mixture
Villar et al.	Metals contents in two fishes of different feeding behaviour in the lower Parana River and Rio de la Plata Estuary	2001	Bioaccumulation: steady state not documented
Vinagre et al.	Accumulation of heavy metals by flounder, *Platichthys flesus* (Linnaeus 1758), in a heterogeneously contaminated nursery area	2004	Bioaccumulation: steady state not documented
Vincent et al.	Susceptibility of *Catla catla* (Ham.) to the toxic effects of the heavy metals, cadmium and chromium	1994	Not North American species
Vincent et al.	Accumulation of Al, Mn, Fe, Cu, Zn, Cd, and Pb by the bryophyte *Scapania undulata* in three upland waters of different pH	2001	Field bioaccumulation: steady state not documented, exposure concentration unknown
Vincent et al.	Impact of cadmium on food utilization of the Indian major carp, *Catla catla* (Ham)	2002	Not North American species, unmeasured chronic exposure
Vincent-Hubert et al.	Early genotoxic effects in gill cells and haemocytes of *Dreissena polymorpha* exposed to cadmium, B[a]P and a combination of B[a]P and Cd	2011	In vitro
Vincent-Hubert et al.	DNA strand breaks detected in embryos of the adult snails, *Potamopyrgus antipodarum*, and in neonates exposed to genotoxic chemicals	2012	In vitro
Viparelli et al.	Inhibition of the R1 fragment of the cadmium-containing zeta-class carbonic anhydrase from the diatom *Thalassiosira weissflogii* with anions	2010	In vitro
Visviki and Rachlin	The toxic action and interactions of copper and cadmium to the marine alga *Dunaliella minuta*, in both acute and chronic exposure	1991	Not North American species
Visviki and Rachlin	Acute and chronic exposure of *Dunaliella salina* and *Chlamydomonas bullosa* to copper and cadmium: Effects on growth	1994	No interpretable concentration, time, response data or examined only a single exposure concentration

Authors	Title	Year	Reason Unused
Voets et al.	Differences in metal sequestration between zebra mussels from clean and polluted field locations	2009	Bioaccumulation: steady state not documented
Vogiatzis and Loumbourdis	Cadmium accumulation in liver and kidneys and hepatic metallothionein and glutathione levels in *Rana ridibunda*, after exposure to CdCl2	1998	Not North American species
Vogt et al.	Effects of cadmium and tributyltin on development and reproduction of the non-biting midge *Chironomus riparius* (Diptera)-baseline experiments for future multi-generation studies	2007	Sediment exposure
Vogt et al.	Effects of cadmium on life-cycle parameters in a multi-generation study with *Chironomus riparius* following a pre-exposure of populations to two different tributyltin concentrations for several generations	2010	Sediment exposure
Voigt	Concentrations of mercury and cadmium in some coastal fishes from the Finnish and Estonian parts of the Gulf of Finland	2003	Bioaccumulation: steady state not documented
Voigt	Heavy metal concentrations in four-horn sculpin *Triglopsis quadricornis* (L.) (Pisces), its main food organism *Saduria entomon* L. (Crustacea), and in bottom sediments in the Archipelago Sea and the Gulf of Finland (Baltic Sea)	2007	Bioaccumulation: steady state not documented
Vuori	Influence of water quality and feeding habits on the whole-body metal concentrations in lotic trichopteran larvae	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Vuori	Rapid behavioral and morphological responses of hydropsychid larvae (Trichoptera, Hydropsychidae) to sublethal cadmium exposure	1994	Not North American species
Vykusova and Svobodova	Comparison of the sensitivity of male and female guppies (*Poecilia reticulata* Peters) to toxic substances	1987	The materials, methods or results were insufficiently described
Vymazal	Short-term uptake of heavy metals by periphyton algae	1984	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Vymazal	Uptake of lead, chromium, cadmium and cobalt by *Cladophora glomerata*	1990b	Not North American species
Vymazal	Toxicity and accumulation of lead with respect to algae and cyanobacteria: A review	1990a	Review of previously published data
Vymazal	Influence of pH on heavy metals uptake by *Cladophora glomerata*	1995	Not North American species
Wachs	Concentration of heavy metals in fishes from the River Danube	1982	Text in foreign language
Walker et al.	Influence of culture conditions on metal-induced responses in a cultured rainbow trout gill epithelium	2007	In vitro
Wall	Sublethal effects of cadmium and diazinon on reproduction and larval behavior in zebrafish (*Brachydanio rerio*)	1999	Only one exposure concentration
Wall et al.	Fish bioturbation of cadmium-contaminated sediments: Factors affecting Cd availability to *Daphnia magna*	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Wallace and Lopez	Bioavailability of biologically sequestered cadmium and the implications of metal detoxification	1997	Organisms were exposed to cadmium in food or by injection or gavage

Authors	**Title**	**Year**	**Reason Unused**
Walsh and Hunter	Influence of phosphorus storage on the uptake of cadmium by the marine alga *Macrocystis pyrifera*	1992	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Walsh et al.	Differential bioaccumulation of heavy metals and organopollutants in the soft tissue and shell of the marine gastropod, *Austrocochlea constricta*	1995	Not North American species
Wang	Investigation of heavy metal content in fish at Chongqing section of the Yangtze River before water storage in the three Gorges Reservoir	2008	Bioaccumulation: steady state not documented
Wang	A study of the New York/New Jersey coastal water: Bio-optical characteristics of the harbor estuary and the effects of heavy metals on brown tide alga of the Bight	2011	Bioaccumulation: steady state not documented
Wang and Dei	Metal uptake in a coastal diatom influenced by major nutrients (N, P, and Si)	2001	Bioaccumulation: steady state not documented
Wang and Fisher	Assimilation of trace elements and carbon by the mussel *Mytilus edulis*: Effects of food composition	1996	Organisms were exposed to cadmium in food or by injection or gavage
Wang and Fisher	Accumulation of trace elements in a marine copepod	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Wang and Ke	Dominance of dietary intake of cadmium and zinc by two marine predatory gastropods	2002	Dietary exposure
Wang and Wang	Cadmium in three marine phytoplankton: accumulation, subcellular fate and thiol induction	2009a	Mixture
Wang and Wang	Biochemical response of the copepod *Tigriopus japonicus* Mori experimentally exposed to cadmium	2009b	Not North American species
Wang and Wong	Combined effects of food quantity and quality on Cd, Cr, and Zn assimilation to the green mussel, *Perna viridis*	2003	Mixture
Wang and Yin	Accumulation of Heavy Metals in Arca Granosa.	1987	Text in foreign language
Wang and Zauke	Size-dependent bioaccumulation of metals in the amphipod *Gammarus zaddachi* (Sexton 1912) from the River Hunte (Germany) and its relationship to the permeable body surface area	2004	Bioaccumulation: steady state not documented
Wang et al.	Reciprocal effect of Cu, Cd, Zn on a kind of marine alga	1995	No interpretable concentration, time, response data or examined only a single exposure concentration
Wang et al.	Kinetic determinations of trace element bioaccumulation in the mussel *Mytilus edulis*	1996	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Wang et al.	Metal and oxygen uptake in the green mussel *Perna viridis* under different metabolic conditions	2005a	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Wang et al.	Seasonal study on the Cd, Se, and Zn uptake by natural coastal phytoplankton assemblages	2005b	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Wang et al.	Safety assessment and acute toxicity of copper, cadmium and zinc to white clound mountain minnow *Tanichthys albonubes*	2006	Non-applicable
Wang et al.	Ecotoxicological effect of Cu, Pb, Zn and Cd on *Prorocentrum donghaiense* Lu.	2008a	Non-applicable
Wang et al.	Single and joint effects of petroleum hydrocarbons and cadmium on the polychaete *Perinereis aibuhitensis* Grube.	2008b	Not North American species
Wang et al.	Assessment of mixture toxicity of copper, cadmium, and phenanthrenequinone to the marine bacterium *Vibrio fischeri*	2009a	Mixture
Wang et al.	Alteration of metallothionein mRNA in bay scallop *Argopecten irradians* under cadmium exposure and bacteria challenge	2009b	Mixture
Wang et al.	Acute and chronic cadmium toxicity to a saltwater cladoceran *Moina monogolica* Daday and its relative importance	2009d	Not North American species, test species fed
Wang et al.	Toxicity of lead, cadmium and mercury on embryogenesis, survival, growth and metamorphosis of *Meretrix meretrix* larvae	2009c	Not North American species
Wang et al.	Formation of a combined Ca/Cd toxicity on lifespan of nematode *Caenorhabditis elegans*	2010a	Only one exposure concentration; dilution water is deionized water
Wang et al.	Single and joint toxicity of mercury, cadmium and benzo(a) pyrene, polychlorinated biphenyls1254 for juvenile *Chlamys farreri*	2010c	Text in foreign language
Wang et al.	Analysis of metallotionein expression and antioxidant enzyme activities in *Meretrix meretrix* larvae under sublethal cadmium exposure	2010e	In vitro
Wang et al.	Molecular characterization and expression analysis of elongation factors 1A and 2 from the Pacific white shrimp, *Litopenaeus vannamei*	2011a	In vitro
Wang et al.	Biomarkers and bioaccumulation of clam *Ruditapes philippinarum* in response to combined cadmium and benzo(a)pyrene exposure	2011b	Mixture
Wang et al.	The content variation characteristics and risk analysis for cadmium, copper, lead and zinc in some species of shellfish	2011c	Bioaccumulation: steady state not documented
Wang et al.	Cadmium-induced oxidative stress and apoptotic changes in the testis of freshwater crab, *Sinopotamon henanense*	2011d	Not North American species
Wang et al.	Characterization of phospholipid hydroperoxide glutathione metabolizing peroxidase (gpx4) isoforms in Coho salmon olfactory and liver tissues and their modulation by cadmium	2012a	In vitro
Wang et al.	Effects of Cd, Cu, Ni, and Zn on brown tide alga *Aureococcus anophagefferens* growth and metal accumulation	2012b	Only two exposure concentrations, excessive EDTA in growth media
Wang et al.	Cadmium induces hydrogen peroxide production and initiates hydrogen peroxide-dependent apoptosis in the gill of freshwater crab, *Sinopotamon henanense*	2012c	Not North American species
Wang et al.	Cadmium bioaccumulation and bioelimination in *Patinopecten yessoensis*	2012d	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Wang et al.	Effects of cadmium stress on antioxidant defense system of *Patinopecten yessoensis*	2012e	Not North American species
Wang et al.	The effects of chronic exposure to environmentally relevant levels of waterborne cadmium on reproductive capacity and behavior in fathead minnows	2014b	Only three exposure concentrations
Wani	Toxicity of heavy metals to embryonic stages of *Cyprinus carpio* Communis	1986	The materials, methods or results were insufficiently described
Ward and Mendonca	Chronic exposure to coal fly ash causes minimal changes in corticosterone and testosterone concentrations in male southern toads *Bufo terrestris*	2006	Fly Ash
Waring et al.	Trace metal bioaccumulation in eight common coastal Australian polychaeta	2006	Field bioaccumulation: steady state not documented, exposure concentration unknown
Warnau et al.	Allometry of heavy metal bioconcentration in the echinoid *Paracentrotus lividus*	1995a	Not North American species
Warnau et al.	Experimental cadmium contamination of the echinoid *Paracentrotus lividus*: Influence of exposure mode and distribution of the metal in the organism	1995b	Not North American species
Warnau et al.	Effect of feeding on cadmium bioaccumulation in the echinoid *Paracentrotus lividus* (Echinodermata)	1995c	Not North American species
Warnau et al.	Biokinetics of selected heavy metals and radionuclides in two marine macrophytes: The seagrass *Posidonia oceanica* and the alga *Caulerpa taxifolia*	1996a	Not North American species
Warnau et al.	Spermiotoxicity and embryotoxicity of heavy metals in the echinoid *Paracentrotus lividus*	1996b	Not North American species
Warnau et al.	Cadmium bioconcentration in the echinoid *Paracentrotus lividus*: Influence of the cadmium concentration in seawater	1997	Not North American species
Warren et al.	Modelling cadmium accumulation by benthic invertebrates in situ: The relative contributions of sediment and overlying water reservoirs to organism cadmium concentrations	1998	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Watling	Effects of metals on the development of oyster embryos	1981	No pertinent adverse effects reported
Watling	Accumulation of seven metals by *Crassostrea gigas*, *Crassostrea margaritacea*, *Perna perna*, and *Choromytilus meridionalis*	1983a	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Wayland and Crosley	Selenium and other trace elements in aquatic insects in coal mine-affected streams in the Rocky Mountains of Alberta, Canada	2006	Bioaccumulation: steady state not documented
Weber	Concentration of metals in fish from the River Rednitz	1985	Bioaccumulation: steady state not documented
Weber et al.	Effects of multiple effluents on resident fish from Junction Creek, Sudbury, Ontario	2008	Effluent

Authors	**Title**	**Year**	**Reason Unused**
Webster et al.	Cadmium exposure and phosphorus limitation increases metal content in the freshwater alga *Chlamydomonas reinhardtii*	2011	Bioaccumulation: steady state not documented
Wehr and Whitton	Aquatic cryptogams of natural acid springs enriched with heavy metals: The Kootenay Paint Pots, British Columbia	1983	Bioaccumulation: steady state not documented
Wei et al.	Interactions between Cd, Cu, and Zn influence particulate phytochelatin concentrations in marine phytoplankton: Laboratory results and preliminary field data	2003	Mixture
Weimin et al.	Metal bioavailability to the soldier crab *Mictyris longicarpus*	1994	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Weir and Salice	High tolerance to abiotic stressors and invasion success of the slow growing freshwater snail, *Melanoides tuberculatus*	2012	Only two exposure concentrations
Weis et al.	Effects of cadmium, zinc, salinity, and temperature on the teratogenicity of methylmercury to the killifish (*Fundulus heteroclitus*)	1981	No pertinent adverse effects reported
Wentsel et al.	Avoidance response of midge larvae (*Chironomus tentans*) to sediments containing heavy metals	1977	Sediment
Werner	Development of methods to assess metallothionein expression in lake trout (*Salvelinus namaycush*) during a reproductive cycle and the effects of cadmium and ethynyestradiol	2007	Field bioaccumulation: steady state not documented, exposure concentration unknown
Werner et al.	Biomarker responses in *Macoma nasuta* (Bivalvia) exposed to sediment exposures from northern San Francisco Bay	2004	Sediment exposure
Westernhagen and Dethlefsen	Combined effects of cadmium and salinity on development and survival of flounder eggs	1975	Not North American species
Westernhagen et al.	Combined effects of cadmium and salinity on development and survival of garpike eggs	1975	Not North American species
Westernhagen et al.	Fate and effects of cadmium in an experimental marine ecosystem	1978	Not North American species
White and Rainbow	Regulation and accumulation of copper, zinc and cadmium by the shrimp *Palaemon elegans*	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
White and Rainbow	Accumulation of cadmium by *Palaemon elegans* (Crustacea: Decapoda)	1986	Not North American species
White et al.	Metal concentrations in loggerhead sea turtle eggs from the Florida Gulf and Atlantic Coasts	2008	Bioaccumulation: steady state not documented
Whyte et al.	Ethoxyresorufin-o-deethylase (EROD) activity in fish as a biomarker of chemical exposure	2000	Review
Wicklund and Runn	Calcium effects on cadmium uptake, redistribution, and elimination in minnows, *Phoxinus phoxinus*, acclimated to different calcium concentrations	1988	Not North American species

Authors	**Title**	**Year**	**Reason Unused**
Wicklund et al.	Cadmium and zinc interactions in fish: effects of zinc on the uptake, organ distribution, and elimination of 109Cd in the zebrafish, *Brachydanio rerio*	1988	Not North American species
Widmeyer and Bendell-Young	Influence of food quality and salinity on dietary cadmium availability in *Mytilus trossulus*	2007	Dietary exposure
Wiesner et al.	Temporal and spatial variability in the heavy-metal content of *Dreissena polymorpha* (Pallas) (Mollusca: Bivalvia) from the Kleines Haff (northeastern Germany)	2001	Bioaccumulation: steady state not documented
Wikfors and Ukeles	Growth and adaptation of estuarine unicellular algae in media with excess copper, cadmium or zinc, and effects of metal-contaminated algal food on *Crassostrea virginica* larvae	1982	Questionable treatment of test organisms or inappropriate test conditions or methodology
Wildgust and Jones	Salinity change and the toxicity of the free cadmium ion [Cd2+(aq)] to *Neomysis integer* (Crustacea: Mysidacea)	1998	Not North American species
Williams and Gallagher	Effects of cadmium on olfactory mediated behaviors and moleculat biomarkers in coho salmon (*Oncorhynchus kisutch*)	2013	Only two exposure concentrations
Williams et al.	Accumulation of Hsp70 in Juvenile and Adult Rainbow Trout Gill Exposed to Metal-Contaminated Water and/or Diet.	1996	Mixture
Williams et al.	Comparison between biosorbents for the removal of metal ions from aqueous solutions	1998	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Williams et al.	Trends in trace metal burdens in sediment, fish species and filtered water of Igbede River, Lagos, Nigeria	2007	Bioaccumulation: steady state not documented
Williams et al.	Transcriptomic responses of European flounder (*Platichthys flesus*) to model toxicants	2008	Injected toxicant; not North American species
Williams et al.	Metal (as, Cd, Hg, and Ch_3Hg) bioaccumulation from water and food by the benthic amphipod *Leptocheirus plumulosus*	2010	Bioaccumulation: not renewal or flow-through
Williamson and Nelson	Bacterial bioassay for level I toxicity assessment	1983	Bacteria
Windom et al.	Metal accumulation by the polychaete *Capitella capitata*: Influences of metal content and nutritional quality of detritus	1982	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
WindWard Environmental	Results of 2000 toxicity testing	2001	Dilution water not characterized
Winger and Andreasen	Contaminant residues in fish and sediments from lakes in the Atchafalaya River Basin (Louisiana)	1985	Bioaccumulation: steady state not documented
Winger et al.	Residues of organochlorine insecticides, polychlorinated biphenyls, and heavy metals in biota from Apalachicola River, Florida, 1978	1984	Bioaccumulation: steady state not documented

Authors	Title	Year	Reason Unused
Winner and Gauss	Relationship between chronic toxicity and bioaccumulation of copper, cadmium and zinc as affected by water hardness and humic acid	1986	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Winter	Cadmium uptake kinetics by freshwater mollusc soft body under hard and soft water conditions	1996	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Witeska	Changes in the common carp blood cell picture after acute exposure to cadmium	2001	No scientific name given, only one exposure concentration, atypical endpoint
Witeska and Baka	The effect of long-term cadmium exposure on common carp blood	2002	No scientific name given, only one exposure, duration too short
Witeska and Wakulska	The effects of heavy metals on common carp white blood cells in vitro	2007	In vitro
Witeska et al.	The influence of cadmium on common carp embryos and larvae	1995	The materials, methods or results were insufficiently described
Witeska et al.	Changes in oxygen consumption rate and red blood parameters in common carp *Cyprinus carpio* L. after acute copper and cadmium exposures	2010	Mixture
Wo et al.	A comparison of growth biomarkers for assessing sublethal effects of cadmium on a marine gastropod, *Nassarius festivus*	1999	Not North American species
Wolfe et al.	Sediment toxicity in the Hudson-Raritan Estuary: Distribution and correlations with chemical contamination	1996	Mixture
Wolff et al.	The use of *Salvinia auriculata* as a bioindicator in aquatic ecosystems: biomass and structure dependent on the cadmium concentration	2012	Only four plants per exposure concentration
Won et al.	Response of glutathione S-gransferase (GST) genes to cadmium exposure in the marine pollution indicator worm, *Perinereis nuntia*	2011	In vitro
Wong	Toxicity of cadmium to freshwater microorganisms, phytoplankton, and invertebrates	1987	Review of previously published data
Wong	Effects of cadmium on the feeding behavior of the freshwater cladoceran *Moina macrocopa*	1989	Organisms were exposed to cadmium in food or by injection or gavage
Wong and Au	Contents of cadmium iron manganese and zinc in the tissue of *Katelysia-hiantina* collected from Tolo Harbor Hong-Kong an almost land-locked sea	1984	Bioaccumulation: steady state not documented
Wong and Beaver	Algal bioassays to determine toxicity of metal mixtures	1980	Mixture
Wong and Chan	A study of cadmium, copper and lead uptake by the unicellular green alga *Chlorella salina* Cu-1	1979	Excessive EDTA
Wong and Chau	Toxicity of metal mixtures to phytoplankton	1988	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Wong and Li	An ecological survey of the heavy metal contamination of the edible clam *Paphia sp*. on the iron-ore tailings of Tolo Harbour, Hong Ko	1977	Bioaccumulation: steady state not documented
Wong et al.	Toxicity of a mixture of metals on freshwater algae	1978	Mixture
Wong et al.	Physiological and biochemical responses of several freshwater algae to a mixture of metals	1982	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Wood	Trace metal uptake by *Cladophora* Chlorophyta	1974	Non-applicable
Wood et al.	Environmental toxicology of metals	1997	Modeling
Wood et al.	The protective role of dietary calcium against cadmium uptake and toxicity in freshwater fish: an important role for the stomach	2006	Review
Woodall et al.	Responses of trout fry (*Salmo gairdneri*) and *Xenopus laevis* tadpoles to cadmium and zinc	1988	No interpretable concentration, time, response data or examined only a single exposure concentration
Woodling	Survival and mortality of brown trout (*Salmo trutta*) exposed to in situ acute toxic concentrations of cadmium and zinc	1993	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Woodling et al.	Nonuniform accumulation of cadmium and copper in kidneys of wild brown trout (*Salmo trutta*) populations	2001	Bioaccumulation: steady state not documented
Woodward et al.	Brown trout avoidance of metals in water characteristic of the Clark Fork River, Montana	1995a	Mixture
Woodward et al.	Metals-contaminated benthic invertebrates in the Clark Fork River, Montana: Effects on age-0 brown trout and rainbow trout	1995b	Cadmium was a component of a drilling mud, effluent, mixture, sediment or sludge
Woodworth and Pascoe	Cadmium uptake and distribution in sticklebacks related to the concentration and method of exposure	1983	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Wright	Dose-related toxicity of copper and cadmium in striped bass larvae from the Chespeake Bay: Field considerations	1988	High control mortality reported
Wright and Welbourn	Cadmium in the aquatic environment: A review of ecological, physiological, and toxicological effects on biota	1994	Review of previously published data
Wright et al.	Effect of calcium on cadmium uptake and toxicity in larvae and juveniles of striped bass (*Morone saxatilis*)	1985	Inappropriate medium of medium contained too much of a complexing agent for algal studies
Wu and Chen	Metallothionein induction and heavy metal accumulation in white shrimp *Litopenaeus vannamei* exposed to cadmium and zinc	2005b	Bioaccumulation: unmeasured exposure
Wu and Deng	Effect of cadmium on hematological functions in tilapia (*Oreochromis mossambicus*)	2006	Injected toxicant
Wu and Wang	NMR-based metabolomic studies on the toxicological effects of cadmium and copper on green mussels *Perna viridis*	2010	Only one exposure concentration
Wu and Yang	A new view explaining how cadmium-treated parents have higher Cd-resistant offspring: the case of tilapia larvae (*Oreochromis mossambicus*)	2008	Injected toxicant; lack of details

Authors	Title	Year	Reason Unused
Wu et al.	A settlement inhibition assay with cyprid larvae of the barnacle *Balanus amphitrite*	1997	Not North American species
Wu et al.	Toxic effects of several heavy metal on amphioxus and living activity of *Branchiostoma belcheri* Tsingtaoensis Tchang Et Koo	1999	Text in foreign language
Wu et al.	The joint-biotoxicity effect of different forms of nitrogen on heavy metals in water by the phototacti behavior of Daphnia	2006a	Text in foreign language
Wu et al.	Changes of cortisol and metallothionein upon cadmium exposure and handling stressed in tilapia (*Oreochromis mosssambicus*)	2006b	Injected toxicant
Wu et al.	Relationships among metallothionein, cadmium accumulation, and cadmium tolerance in three species of fish	2006c	Bioaccumulation: unmeasured exposure
Wu et al.	Toxicological stress response and cadmium distribution in hybrid tilapia (*Oreochromis sp*.) upon cadmium exposure	2007	Only one exposure concentration, duration too short, unmeasured exposure
Wu et al.	The effects of maternal Cd on the metallothionein expression in tilapia (*Oreochromis mossambicus*) embryos and larvae	2008a	Injected toxicant
Wu et al.	Phototaxis index of *Daphnia carinata* as an indicator of joint toxicity of copper, cadmium, zinc, nitrogen and phosphorus in aqueous solutions	2008b	Non-applicable
Wu et al.	Histopathological and biochemical evidence of hepatopancreatic toxicity caused by cadmium and zinc in the white shrimp, *Litopenaeus vannamei*	2008c	Lack of exposure details, dilution water not characterized, only two exposure concentrations
Wu et al.	Histopathological alterations in gills of white shrimp, *Litopenaeus vannamei* (Boone) after acute exposure to cadmium and zinc	2009	Dilution water not characterized, duration too short, only one exposure concentration
Wu et al.	Bioaccumulation of cadmium bound to humic acid by the bivalve *Meretrix meretirx* Linnaeus from solute and particulate pathways	2010	Sediment
Wu et al.	NMR-based metabolomic investigations on the differential responses in adductor muscles from two pedigrees of Manila clam *Ruditapes philippinarum* to cadmium and zinc	2011a	Bioaccumulation: steady state not documented
Wu et al.	The preferential accumulation of cadmium in the head portion of the freshwater planarian, *Dugesia japonica* (Platyhelminthes: Turbellaria)	2011b	Not North American species, duration too short
Wu et al.	Bioaccumulation of cadmium bound to ferric hydroxide and particulate organic matter by the bivalve *M. meretrix*	2012a	Sediment
Wu et al.	Maternal cadmium exposure induces mt2 and smtB mRna expression in zebrafish (*Danio rerio*) females and their offspring	2012b	Duration too short
Wundram et al.	The *Chlamydomonas* test: A new phytotoxicity test based on the inhibition of algal photosynthesis enables the assessment of hazardous leachates from waste disposals in salt mines	1996	Not North American species; no interpretable concentration, time, response data or examined only a single exposure concentration
Xiaorong et al.	Effects of chelation on the bioconcentration of cadmium and copper by carp (*Cyprinus carp*io L.)	1997	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured

Authors	**Title**	**Year**	**Reason Unused**
Xie and Klerks	Changes in cadmium accumulation as a mechanism for cadmium resistance in the least killifish *Heterandria formosa*	2004	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Xie et al.	Trophic transfer of Cd from natural periphyton to the grazing mayfly *Centroptilum triangulifer* in a life cycle test	2010	Dietary exposure
Xie et al.	Cadmium accumulation in the rootless macrophyte *Wolffia globosa* and its potential for phytoremediation	2013	Excessive EDTA (848 ug/L)
Xin et al.	Responses of different water spinach cultivars and their hybrid to Cd, Pb and Cd-Pb exposures	2010	Soil exposure
Xu et al.	Heavy metal distribution in tissues and eggs of Chinese alligator (*Alligator sinensis*)	2006a	Bioaccumulation: steady state not documented
Xu et al.	Generation of active oxygen and change of antioxidant enzyme activity in *Hydrilla verticillata* under Cd, Cu and Zn stress	2006b	Text in foreign language
Xu et al.	Acute toxicity and synergism of binary mixtures of antifouling biocides with heavy metals to embryos of sea urchin *Glyptocidaris crenularis*	2010	Not North American species
Xu et al.	Study on single and joint toxic effects of cadmium and lead on *Ruditapes phillippinarum*	2013	Text in foreign language
Xuan et al.	Oxygen consumption and metabolic responses of freshwater crab *Sinopotamon henanense* to acute and sub-chronic cadmium exposure	2013	Not North American species, only three exposure concentrations
Xue and Sigg	Cadmium speciation and complexation by natural organic ligands in freshwater	1998	No interpretable concentration, time, response data or examined only a single exposure concentration
Yager and Harry	The uptake of radioactive zinc, cadmium and copper by the freshwater snail, *Taphius glabratu*	1964	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Yamamoto and Inoue	Lethal tolerance of acute cadmium toxicity in rainbow trout previously exposed to cadmium	1985	The materials, methods or results were insufficiently described
Yamamura and Suzuki	Metallothionein induced in the frog *Xenopus laevis*	1983	Injected toxicant
Yamamura et al.	Cadmium uptake and induction of cadmium-binding protein in the waterflea (*Moina macrocopa*)	1983b	Bioaccumulation: steady state not documented (only 72 hour exposure)
Yan and Wang	Metal exposure and bioavailability to a marine deposit-feeding sipuncula, *Sipunculus nudus*	2002	Bioaccumulation: steady state not documented (only 24 hour exposure)
Yan et al.	Demographic and genetic evidence of the long-term recovery of *Daphnia galeata* Mendotae (Crustacea: Daphniidae) in Sudbury Lakes following additions of base: The role of metal toxicity	1996	Mixture
Yang and Kong	Bioavailability of copper and cadmium speciation in sediment exposure for aquatic organism under varying temperature	1997	Sediment exposure

Authors	**Title**	**Year**	**Reason Unused**
Yang et al.	Involvement of polyamines in adaptation of *Potamogeton crispus* L. to cadmium stress	2010	Mixture
Yang et al.	Acute temperature and cadmium stress response characterization of small heat shock protein 27 in large yellow croaker, *Larimichthys crocea*	2012a	In vitro
Yang et al.	Cd2+ toxicity to a green alga *Chlamydomonas reinhardtii* as influenced by its adsorption on TiO2 engineered nanoparticles	2012b	Mixture
Yap et al.	Correlations between speciation of Cd, Cu, Pb and Zn in sediment exposure and their concentrations in total soft tissue of green-lipped mussel *Perna viridis* from the west coast of Peninsular Malaysia	2002	Bioaccumulation: steady state not documented
Yap et al.	Accumulation, depuration and distribution of cadmium and zinc in the green-lipped mussel *Perna viridis* (Linnaeus) under laboratory conditions	2003a	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Yap et al.	Background concentrations of Cd, Cu, Pb and Zn in the green-lipped mussel *Perna viridis* (Linnaeus) from Peninsular Malaysia	2003b	Bioaccumulation: steady state not documented
Yap et al.	Heavy metal (Cd, Cu, Pb and Zn) concentrations in the green-lipped mussel *Perna viridis* (Linnaeus) collected from some wild and aquaculture sites in the west coast of Peninsular Malaysia	2004a	Bioaccumulation: steady state not documented
Yap et al.	Allozyme polymorphisms and heavy metal levels in the green-lipped mussel *Perna viridis* (Linnaeus) collected from contaminated and uncontaminated sites in Malaysia	2004b	Bioaccumulation: steady state not documented
Yap et al.	Distribution of heavy metal concentrations in the different soft tissues of the freshwater snail *Pomacea insularum* (D'orbigny, 1839; Gastropoda), and sediments collected from polluted and unpolluted sites from Malaysia	2009	Bioaccumulation: steady state not documented
Yarsan et al.	Copper, lead, cadmium and mercury concentrations in the mussel *Elliptio*	2007	Bioaccumulation: steady state not documented
Yasuno et al.	Characteristic distribution of chironomids in the rivers polluted with heavy metals	1985	Bioaccumulation: steady state not documented
Yeh et al.	Heavy metal concentrations of the soldier crab (*Mictyris brevidactylus*) along the inshore area of Changhua, Taiwan	2009	Bioaccumulation: steady state not documented
Yigit and Altindag	Accumulation of heavy metals in the food web components of Burdur Lake, Turkey	2002	Bioaccumulation: steady state not documented
Yilmaz	Bioaccumulation of heavy metals in water, sediment, aquatic plants and tissues of *Cyprinus carpio* from Kizilirmak, Turkey	2006	Bioaccumulation: steady state not documented
Yin et al.	Induction of phytochelatins in *Lemna aequinoctialis* in response to cadmium exposure	2002	Lack of exposure details, no statistical analysis
Yipmantin et al.	Pb(II) and Cd(II) Biosorption on *Chondracanthus chamissoi* (a red alga)	2011	Mixture
You et al.	Chemical availability and sediment toxicity of pyrethroid insecticides to *Hyalella azteca*: Application to field sediment with unexpectedly low toxicity	2008	Sediment exposure

Authors	**Title**	**Year**	**Reason Unused**
Young and Harvey	Metals in chironomidae larvae and adults in relation to lake pH and lake oxygen deficiency	1988	Bioaccumulation: steady state not documented
Youssef and Tayel	Metal accumulation by three *Tilapia spp*. from some Egyptian waters	2004	Bioaccumulation: steady state not documented
Yu and Wang	Kinetic uptake of bioavailable cadmium, selenium, and zinc by *Daphnia magna*	2002	Mixture
Yu et al.	New method for evaluating toxicity of heavy metals on marine macroalgae	1999	Text in foreign language
Zabotkina et al.	Influence of cadmium ions on some morphofunctional and immune-physiological parameters of perch (*Perca fluviatilis*, Perciformes, Percidae) underyearlings	2009	Unmeasured chronic exposure, duration too short, not North American species, only one exposure
Zadory	Monitoring heavy metal pollution and genetic consequences in aquatic invertebrates	1983	Bioaccumulation: steady state not documented
Zadory	Freshwater molluscs as accumulation indicators for monitoring heavy metal pollution	1984	Bioaccumulation: steady state not documented
Zaki and Osman	Clinicopathological and pathological studies on *Tilapia nilotica* exposed to cadmium chloride (0.25 ppm)	2003	Bioaccumulation: steady state not documented; not renewal or flow-through exposure
Zanders and Rojas	Cadmium accumulation, LC50 and oxygen consumption in the tropical marine amphipod *Elasmopus rapax*	1992	Not North American species
Zanders and Rojas	Salinity effects on cadmium accumulation in various tissues of the tropical fiddler crab *Uca rapax*	1996	Not North American species
Zanella	Shifts in caddisfly species composition in Sacramento River invertebrate communities in the presence of heavy metal contamination	1982	Bioaccumulation: steady state not documented
Zaosheng et al.	Effects of dietary cadmium exposure on reproduction of saltwater cladoceran *Moina monogolica* Daday: Implications in water quality criteria	2010	Fed toxicant
Zauke and Schmalenbach	Heavy metals in zooplankton and decapod crustaceans from the Barents Sea	2006	Bioaccumulation: steady state not documented
Zauke et al.	Validation of estuarine gammarid collectives (Amphipoda: Crustacea) as biomonitors for cadmium in semi-controlled toxicokinetic flow-through experiments	1995	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Zauke et al.	Heavy metals of inshore benthic invertebrates from the Barents Sea	2003	Bioaccumulation: steady state not documented
Zbigniew and Wojciech	Individual and combined effect of anthracene, cadmium, and chloridazone on growth and activity of SOD izoformes in three *Scenedesmus* species	2006	Mixture
Zbikowski et al.	Distribution and relationships between selected chemical elements in green alga *Enteromorpha sp*. from the southern Baltic	2006	Bioaccumulation: steady state not documented
Zeng and Wang	Temperature and irradiance influences on cadmium and zinc uptake and toxicity in a freshwater cyanobacterium, *Microcystis aeruginosa*	2011	Mixture

Authors	Title	Year	Reason Unused
Zeng et al.	Toxicity effects of Cd and Cu on the respiration and excretion metabolism of asian clam	2007	Non-applicable
Zhang and Wang	Waterborne cadmium and zinc uptake in a euryhaline teleost *Acanthopagrus schlegeli* acclimated to different salinities	2007a	Mixture; not North American species
Zhang and Wang	Gastrointestinal uptake of cadmium and zinc by a marine teleost *Acanthopagrus schlegeli*	2007b	Mixture; not North American species
Zhang and Wang	Size-dependence of the potential for metal biomagnification in early life stages of marine fish	2007c	Mixture; not North American species
Zhang et al.	Study on the relationship between speciation of heavy metals and their ecotoxicity	1992	The materials, methods or results were insufficiently described
Zhang et al.	Influence of toxicity of heavy metal ions to growth of *Phaeodactylum tricornutum*	1995	Text in foreign language
Zhang et al.	Heavy metal accumulation and tissue damage in goldfish *Carassius auratus*	2005	Bioaccumulation: unmeasured exposure,; not whole-body or muscle content
Zhang et al.	Enhanced bioaccumulation of cadmium in carp in the presence of titanium dioxide nanoparticles	2007a	Inappropriate form of toxicant, nanoparticles
Zhang et al.	Effects of cadmium stress on photosynthetic function of leaves of *Lemna minor* L.	2007b	Text in foreign language
Zhang et al.	Long-term toxicity effects of cadmium and lead on *Ibufo raddei* tadpoles	2007c	Unmeasured chronic exposure, not North American species
Zhang et al.	A review; research on cadmium in aquatic animals	2007d	Review
Zhang et al.	Toxicity and behavioral effects of cadmium in planarian (*Dugesia japonica* Ichikawa Et Kawakatsu)	2010a	Not North American species
Zhang et al.	Cadmium accumulation and translocation in four emergent wetland species	2010b	Excessive EDTA
Zhang et al.	Concentrations of cadmium and zinc in seawater of Bohai Bay and their effects on biomarker responses in the bivalve *Chlamys farreri*	2010c	Mixture
Zhang et al.	Cadmium-induced oxidative stress and apoptosis in the testes of frog *Rana limnocharis*	2012a	Not North American species, duration too long
Zhang et al.	The toxicity of cadmium (Cd2+) towards embryos and pro-larva of Soldatov's catfish (*Silurus soldatovi*)	2012b	Not North American species
Zhang et al.	Identification and expression profile of a new cytochrome P50 isoform (CYP414A1) in the hepatopancreas of *Venerupis* (*Ruditapes*) *philippinarum* exposed to benzo(a)pyrene, cadmium and copper	2012c	Mixture
Zhang et al.	Expression profiles of seven glutathione S-transferase (GST) genes from *Venerupis philippinarum* exposed to heavy metals and benzo(a)pyrene	2012d	Mixture
Zhang et al.	Biological effect of cadmium in *Daphnia magna*: Influence of nitrogen and phosphorus	2012e	Mixture

Authors	**Title**	**Year**	**Reason Unused**
Zheng et al.	Reproductive toxic effects of sublethal cadmium on the marine polychaete *Perinereis nuntia*	2010	Not North American species
Zhou et al.	Growth response of *Isochrysis galbana* 3011 to seven kinds of heavy metals	1990	Lack of details; abstract only
Zhu et al.	Gonad differential proteins revealed with proteomics in oyster (*Saccostrea cucullata*) using alga as food contaminated with cadmium	2012	Fed toxicant
Zhuang and Lin	The effects of nutrients and heavy metals on the plankton in marine enclosed ecosystem	1991	Mixture
Zia and McDonald	Role of the gills and gill chloride cells in metal uptake in the freshwater-adapted rainbow trout, *Oncorhynchus mykiss*	1994	Bioconcentration studies conducted in distilled water, not conducted long enough, not flow-through or water concentrations not adequately measured
Zolotukhina et al.	Effect of some heavy metal ions on cholorophyll photostability in marine green macroalgae	1993	Text in foreign language
Zou and Bu	Acute toxicity of copper, cadmium, and zinc to the water flea, *Moina irrasa* (Cladocera)	1994	Not North American species

Appendix K Issue Summary Regarding Test Conditions and Methods for Water Only Toxicity Testing with *Hyalella azteca*

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OFFICE OF
RESEARCH AND DEVELOPMENT

August 6, 2015

MEMORANDUM

SUBJECT: Issue summary regarding test conditions and methods for water only toxicity testing with *Hyalella azteca*

FROM: David R. Mount and J. Russell Hockett

TO: Kathryn Gallagher
Health and Ecological Criteria Division/OST/OW

We are writing at the request of your staff to summarize current understanding regarding appropriate procedures and conditions for water only toxicity testing with the amphipod, *Hyalella azteca*, with an emphasis on how this understanding intersects with the selection of toxicity data for deriving ambient water quality criteria. Recommendations are provided based on our experience and interpretation of published and unpublished data. A draft of this document was provided to two outside experts, Drs. Chris Ingersoll (USGS Columbia, MO) and David Soucek (Illinois Natural History Survey, Champaign, IL), for their comment and input.

A complicating factor is that recent research has found that organisms taxonomically described as *Hyalella azteca* comprise a complex of numerous genetically distinct, but thus far undescribed species; for the purposes of this memo, we refer to them as "strains." Major et al. (2013) determined that most North American laboratories that cultured and tested *Hyalella azteca* had the same strain (called the "US Lab" strain). A single laboratory, in Burlington, ON, had a different strain or species in culture; they called this the "Burlington" strain. These two strains show some differences that may require different evaluation criteria to be applied. As much of the available toxicological data published are known or presumed to have been generated using the US Lab strain, the bulk of the discussion that follows pertains to the US Lab strain, though notes are included where differences with the Burlington strain may be important.

1) **Bromide**

Bromide was originally proposed as an essential micronutrient by Borgmann (1996) in work conducted using the Burlington strain. Subsequent studies using the US Lab strain indicate bromide is also an essential micronutrient for that strain, though the apparent levels of sufficiency appear to differ from the original suggestion by Borgmann (0.8 mg/L). Research conducted by USGS in Columbia, MO indicates that a much lower bromide concentration of around 0.02 mg/L is sufficient to support long-term survival, growth, and reproduction of the US Lab strain (Ivey et al. SETAC 2011 poster; see Figure 1). Here in our laboratory, we have found that the ambient Br concentration in Lake Superior water (about 0.01 to 0.015 mg/L) will support cultures of the US Lab strain). While these concentrations are much lower than the 0.8 mg/L, they are not necessarily in conflict with Borgmann's findings, as Borgmann's original experimental design was not structured to determine minimum concentrations with a high level of resolution (he was also using a different strain). In addition, experiments conducted by USGS in Columbia, MO (CD Ivey and CG Ingersoll, personal communication) have shown that bromide concentrations as high as 80 mg/L are not detrimental to the US Lab strain. It is uncertain whether the overall composition (e.g., hardness, specific ion content) of the water influences the Br requirement. Limited survey work done by USGS-Columbia suggests that natural waters (ground or surface waters) typically have sufficient Br to support the US Lab strain (C.G. Ingersoll, personal communication). The 0.8 mg Br/L contained in Borgmann "SAM-5" water is much higher than is found in typical fresh waters, but as noted above, we have no evidence that this would be problematic unless the toxicant of concern interacts with Br.

Recommendation: Reconstituted waters used for testing with *Hyalella azteca* should have at least 0.02 mg Br/L. For tests conducted with natural waters (ground or surface) with accompanying Br measurements, it is reasonable to presume that sufficient Br was present, as long as control performance appears adequate.

2) **Chloride**

Chloride also appears to be important to supporting long term survival, growth, and reproduction of the US Lab strain. A survey of waters used successfully by various laboratories for culture of *Hyalella azteca* (known or presumed to be the US Lab strain) indicates that most have Cl concentrations at or above those typical of natural surface waters (Figure 2). And, notably, the concentrations in reconstituted waters often recommended by ASTM and EPA for aquatic toxicity studies have very low concentrations of Cl, relative to natural waters. Studies in our laboratory found that the roughly 2 mg Cl/L found in Lake Superior water limited performance of the US Lab Strain. Performance was improved by the addition of sodium chloride up to a concentration of about 15 mg/L, above which there was no additional improvement (Figure 3; Soucek et al. 2015). Longer-term studies conducted at the Illinois Natural History Survey demonstrated a similar response to chloride for long-term growth and reproduction (Figure 4; Soucek et al., 2015). It is unclear whether the minimum Cl concentrations apply equally across all water types or if the Cl requirement is dependent on other aspects of water chemistry. Natural waters with hardness less than 80 mg/L commonly have <10 mg Cl/L (about 0.3 mM; see Figure 2).

An additional finding by Soucek et al. (2015) is that the acute sensitivity of the US Lab strain to sodium sulfate and sodium nitrate varied with chloride in a manner similar to that observed for control performance (Figure 5). However, when the Burlington strain was tested, both control growth and toxicant sensitivity were independent of chloride concentrations. This suggests, though does not prove, that the Cl-dependence of toxicity shown for the US Lab strain may be related more to its innate Cl requirement rather than a broader toxicological interaction of Cl and those toxicants. It's also worth noting that the change in toxicant sensitivity was observed even though control survival was good across all Cl concentrations; this means that meeting control survival requirements is not by itself a good indication that chloride concentrations were sufficient.

Recommendation: For toxicity data generated using the US Lab strain, it is preferred that control/dilution waters have Cl concentrations at or above about 15 mg/L. Where control/dilution waters have lower Cl concentrations, toxicity data should be used with great caution unless there are ancillary data demonstrating that organism health was not impaired despite lower Cl.

3) Reconstituted Waters

As noted above, reconstituted waters based on the formula proposed by Marking and Dawson (1973; this includes reconstituted waters recommended by EPA for effluent testing, and by some ASTM standards) have low Cl concentrations and have been directly shown to be insufficient to support long-term health of the US Lab strain. In addition to low Cl, they do not include added Br. A modification of these waters proposed by Smith et al. (1997) has sufficient chloride, but does not have added Br. Results obtained with this water have been inconsistent and it is not recommended unless it is supplemented with Br. The Borgmann (1996) "SAM-5" water has an unnaturally high Br concentration, but there is no reason to believe this concentration is harmful, unless it would interact with the toxicant being tested.

Recommendation: Data generated using Marking and Dawson-based waters should not be used. Data generated using "Smith" water should not be used unless Br was supplemented. Data generated using "Borgmann SAM-5" water should be acceptable unless there is reason to think the excess Br would compromise the test. Other reconstituted water formulations should be evaluated in light of the Br and Cl recommendations above.

4) Substrate

There is general consensus that a substrate should be provided when conducting water-only testing with *Hyalella azteca*. Common substrates include stainless steel screen, nylon (e.g., Nitex®) screen, quartz sand, cotton gauze, and maple leaves. In general, more inert substrates, such as screen or sand, are preferred over plant material, which may break down during testing and/or encourage microbial growth. Consideration should be given to whether one would expect interactions between the toxicant and the substrate; hydrophobic organic compounds in particular can bind strongly to Nitex® screen, which might reduce exposure concentrations, especially for studies using static or intermittent renewal exposure methods.

Recommendation: A fine layer of clean quartz sand is a preferred substrate. Nylon screen may be used if known to be compatible with the test chemical. Analytical confirmation of exposure concentrations in "old" solutions (prior to renewal) is very important, particularly where there could be interactions between the substrate and the test chemical.

5) Control Survival in Long-Term Tests

Experience with 42-d exposures (beginning with 7-8 d old organisms) is that 42-d survival is frequently well above 80% (e.g., 85%-95%) and 80% seems a reasonable minimum for control survival. For tests longer than 42 days, some decline in control survival might be expected, though experience is limited for these longer exposures. In general, survival should not decline by more than 2-3% per week beyond 6 weeks, unless exposures continue so long that organisms are becoming senescent.

Recommendation: Control survival should not be below 80% in 42-d tests; slightly lower control survival may be acceptable in tests substantially longer than 42 d.

6) Control Growth/Weight and Reproduction

The bulk of the available data on control growth comes from the context of 42-d exposures, which generally begin with 7-8-d old organisms (starting size typically 0.02-0.03 mg dwt). In experiments with the US Lab strain (including a 24-laboratory round robin evaluation), improved diets have been shown to produce average weights of ≥0.35 mg dwt (about 1.75 mg wwt assuming 80% water) at d 28 of a 42-d tests (35-36 d of overall age) and ≥0.50 mg dwt (about 2.5 mg wwt assuming 80% water) at d 42. Information on growth rates for tests longer than 42 d is limited, though growth rates are thought to decrease markedly as organisms reach reproductive stages. Data generated at EPA-Duluth show that the standard diet recommended in EPA and ASTM test methods for 42-d testing with *Hyalella azteca* (1 ml/beaker-d of YCT) limits growth relative to higher rations (either more YCT or other foods such as Tetramin® + YCT; see Figure 6). However, this limited growth does not seem to be so stressful as to reduce long-term survival, and reproduction still occurs though at lower rates than higher rations. Where 28-d and 42-d growth is comparable to that described above, reproduction is typically ≥6 young per female.

David Soucek of the Illinois Natural History Survey has conducted some laboratory culture and control growth experiments using the Burlington strain. From those experiments, it appears that the Burlington strain grows at about the same rate (provided similar rations) as the US Lab strain, but appears to reproduce at a lower rate (one-third to one-half the rate of the US Lab strain; D.J. Soucek, personal communication).

Recommendation: For 42-d exposures with the US Lab strain (beginning with 7-8-d old organisms), control organism average dry weight should be ≥0.35 mg after 28 days and ≥0.50 mg after 42 days. At the end of a 42-day test, control reproduction should average ≥6 young per female. Lower performance may indicate diet/ration may have been limiting. For tests with the Burlington strain, similar growth would be expected, but reproductive rate may be somewhat lower.

7) Applicability of Data from Different Strains of *Hyalella azteca*

The organisms of the US Lab strain are generally thought to trace to an original collection by Alan Nebeker of EPA-Corvallis in 1982. *Hyalella azteca* identified as the same US Lab strain have been found in the wild in several states, including FL, KS, OK, TX, CA, and their original collection location in OR (D.J. Soucek, personal communication). It is less clear whether the chloride requirement found for the US Lab strain is present in all wild populations, or whether the US Lab strain occurs naturally in waters with chloride below 15 mg/L. David Soucek (Illinois Natural History Survey) conducted a study examining response to chloride in a culture started from a wild population of the US Lab strain collected in Kansas, and found indication of reduced performance at low Cl concentrations, though the magnitude of the effect may be somewhat smaller.

It is noteworthy that in strain comparisons of sensitivity to sodium nitrate and sodium sulfate, the sensitivity of the US Lab strain at Cl ≥15 mg/L was generally similar to the sensitivity of the Burlington strain. Absent data to the contrary, we know of no compelling reason to think that the toxicant sensitivity of the US Lab strain in waters with adequate Cl and Br should not be appropriate for inclusion in species sensitivity distributions as is intended for deriving water quality criteria.

References:

Borgmann, U. 1996. Systematic analysis of aqueous ion requirements of *Hyalella azteca*: A standard artificial medium including the essential bromide ion. Arch. Environ. Contam. Toxicol. 30: 356-363.

Ivey, C.D., W.G. Brumbaugh, C.G. Ingersoll, N.E. Kemble, J.K. Kunz, D.R. Mount and J.R. Hockett. 2011. Evaluation of the influence of bromide on the performance of the amphipod *Hyalella azteca* in reconstituted waters. Presented at the SETAC North America 32nd Annual Meeting, Boston, MA, November 2011.

Major, K.M., D.J. Soucek, R. Giordano, M.J. Wetzel and F. Soto-Adames. 2013. The common ecotoxicology laboratory strain of *Hyalella azteca* is genetically distinct from most wild strains sampled in eastern North America. Environ. Toxicol. Chem. 32: 2637-2647.

Marking, L.L. and V.K. Dawson. 1973. Toxicity of quinaldine sulfate to fish. Investigative Fish Control, No. 48, U.S. Fish and Wildlife Service, Department of the Interior, Washington, DC.

Smith, M.E., J.M. Lazorchak, L.E. Herrin, S. Brewer-Swartz and W.T. Thoney. 1997. A reformulated, reconstituted water for testing the freshwater amphipod, *Hyalella azteca*. Environ. Toxicol. Chem. 16: 1229-1233.

Soucek, D.J., D.R. Mount, A. Dickinson, J.R. Hockett and A.R. McEwen. 2015. Contrasting effects of chloride on growth, reproduction, and toxicant sensitivity in two genetically distinct strains of *Hyalella azteca*. Environ. Toxicol. Chem. 34(10): 2354-2362.

Figure 1. Long-term performance of *Hyalella* as a function of Br concentration in water (from Ivey et al. 2011). Different symbols represent different trials and/or different water compositions (other than Br).

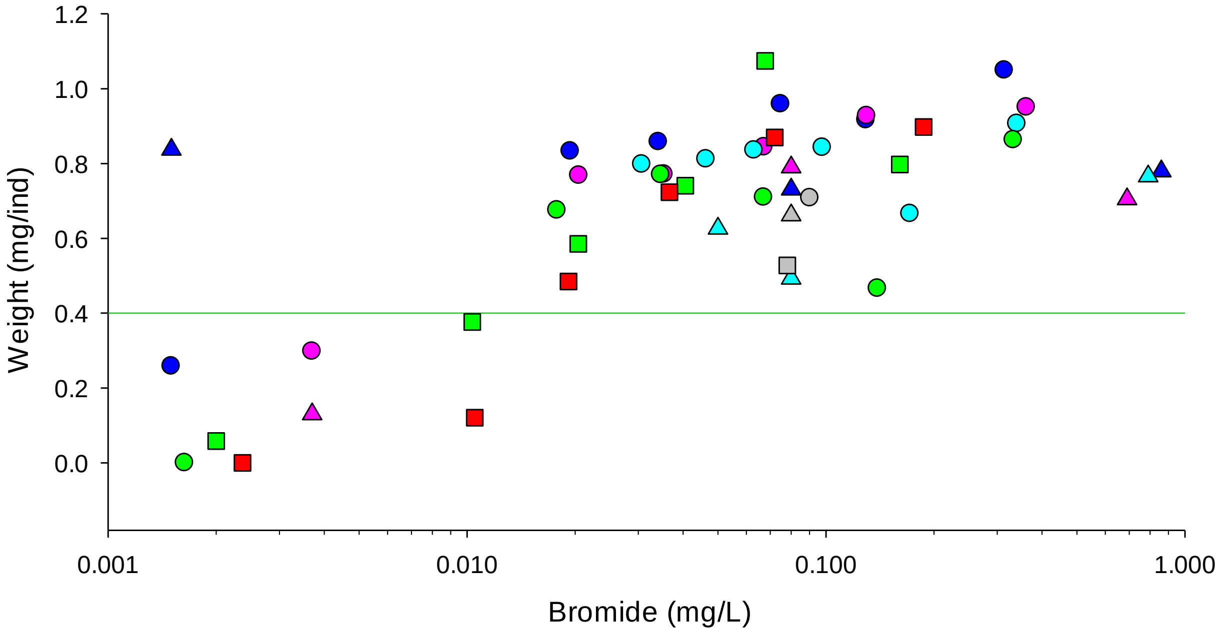


Figure 2. Concentrations of Cl in natural surface waters, waters used successfully to culture *Hyalella*, and in reconstituted waters based on Marking and Dawson (EPA/ASTM).

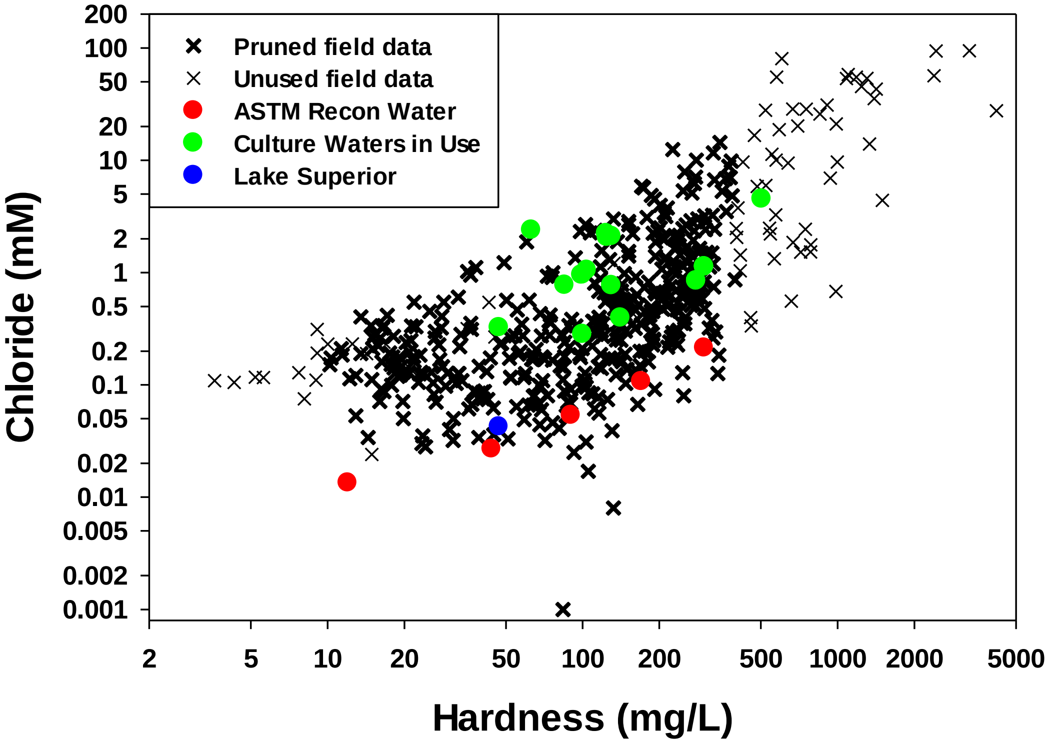


Figure 3. 10-d weights of *Hyalella* reared in Lake Superior water with varying Cl concentrations (from Soucek et al. 2015).

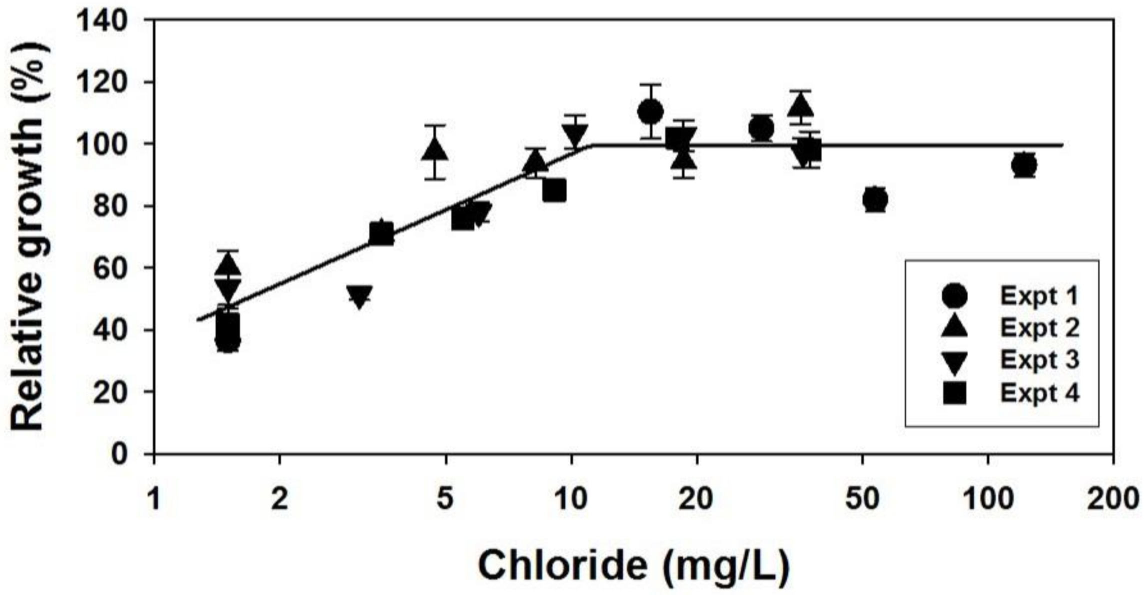


Figure 4. Influence of chloride on growth and reproduction of the US Lab strain in a 42-d test (from Soucek et al. 2015).

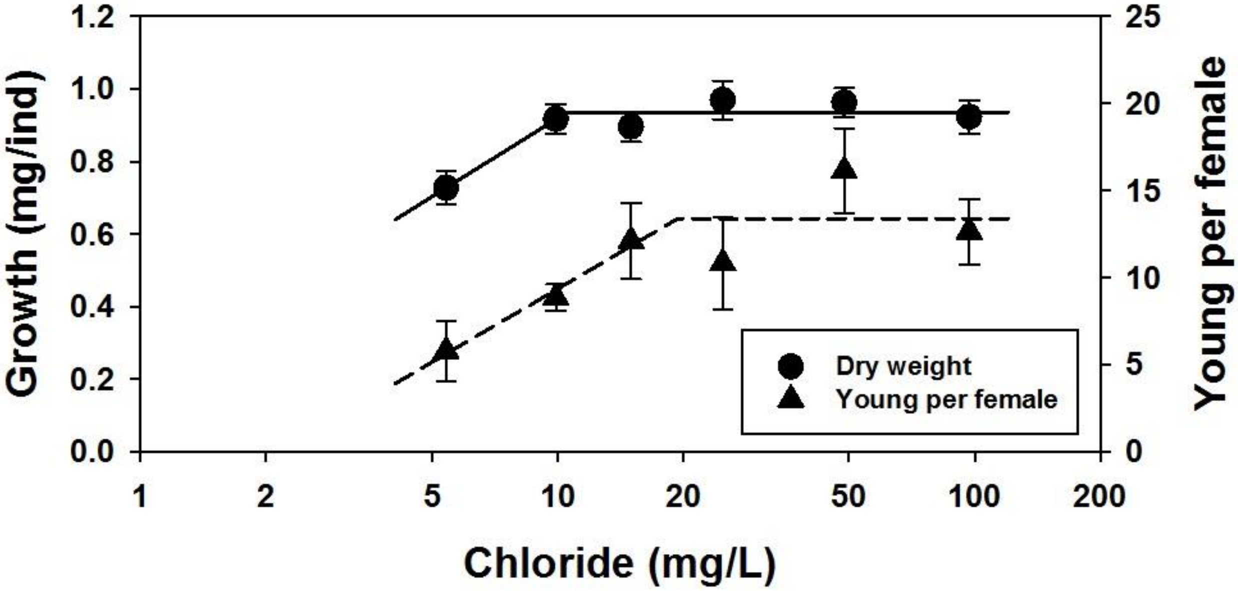


Figure 5. Comparison of control growth (a), and acute toxicity of sodium nitrate (b) and sodium sulfate (c) between the US Lab and Burlington strains of *Hyalella azteca* (from Soucek et al. 2015).

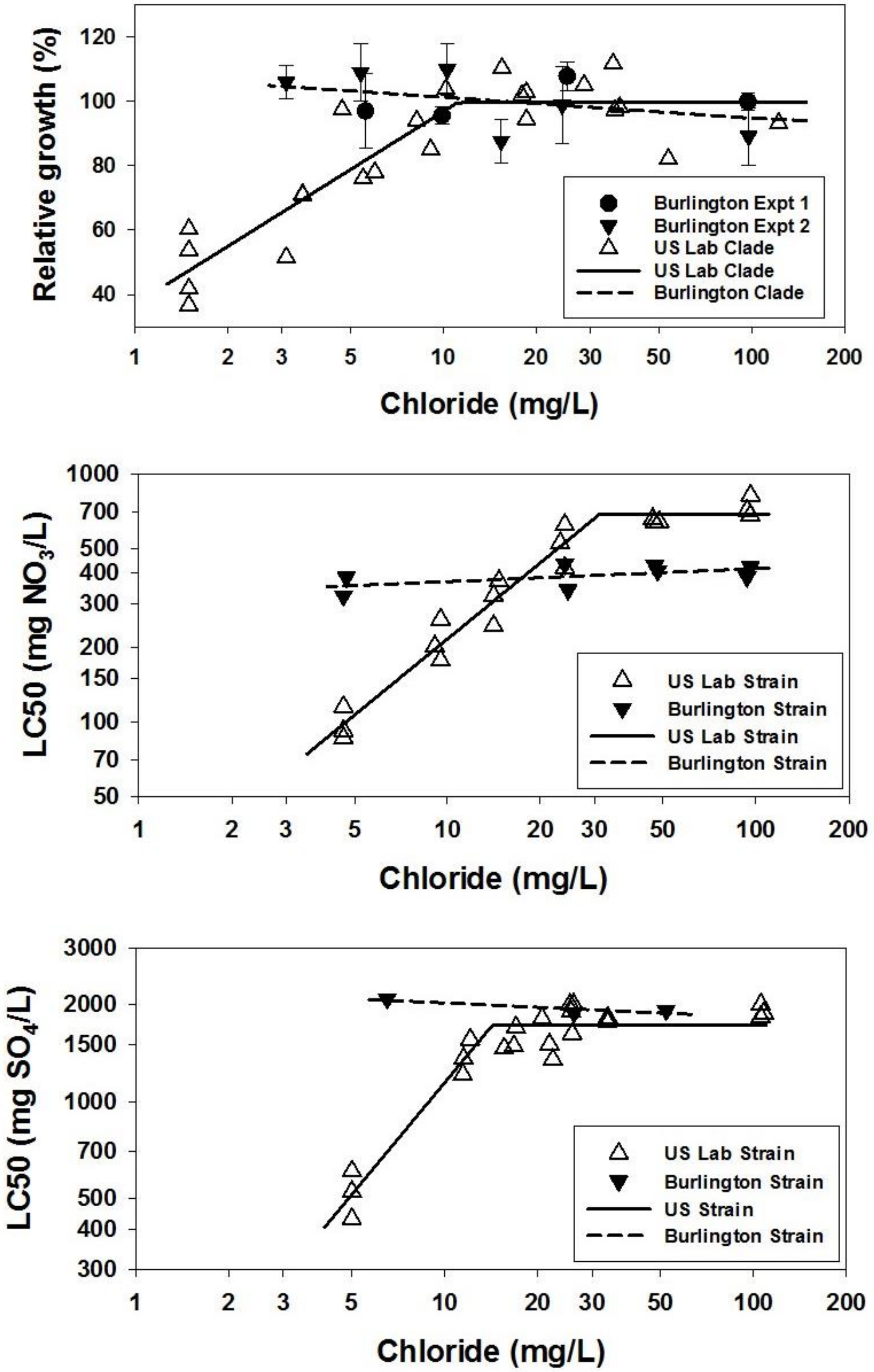
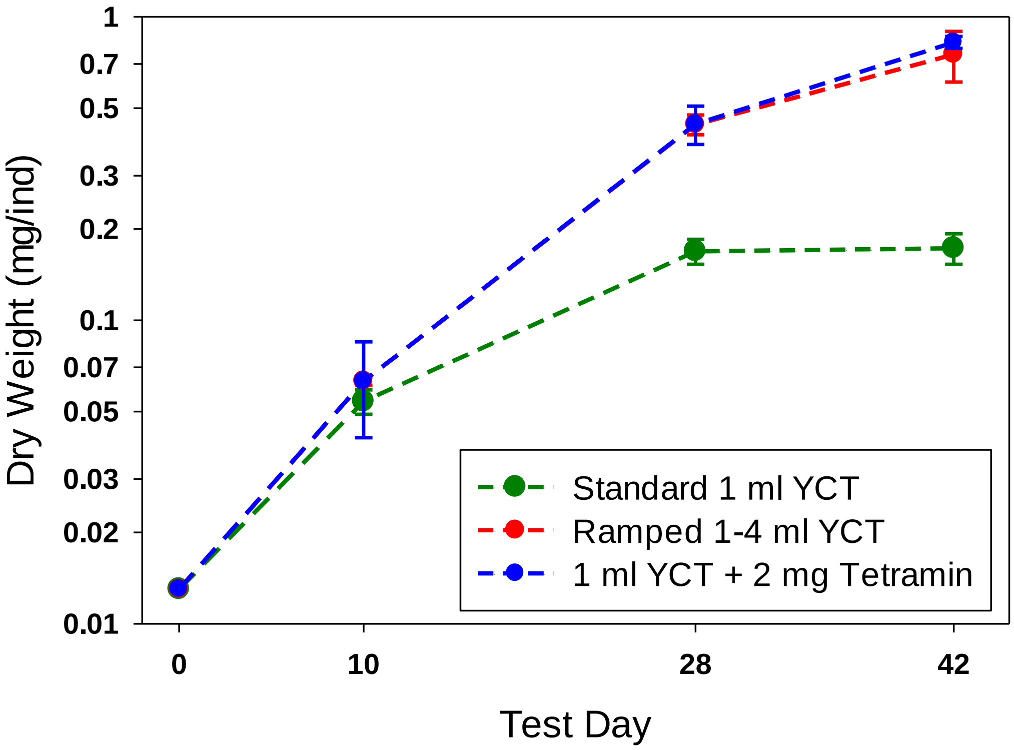


Figure 6. Growth rates of *Hyalella* reared on standard (EPA or ASTM 2000) ration of 1 ml YCT/d or on alternate rations (D.R. Mount unpublished data).



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Downstream Protection

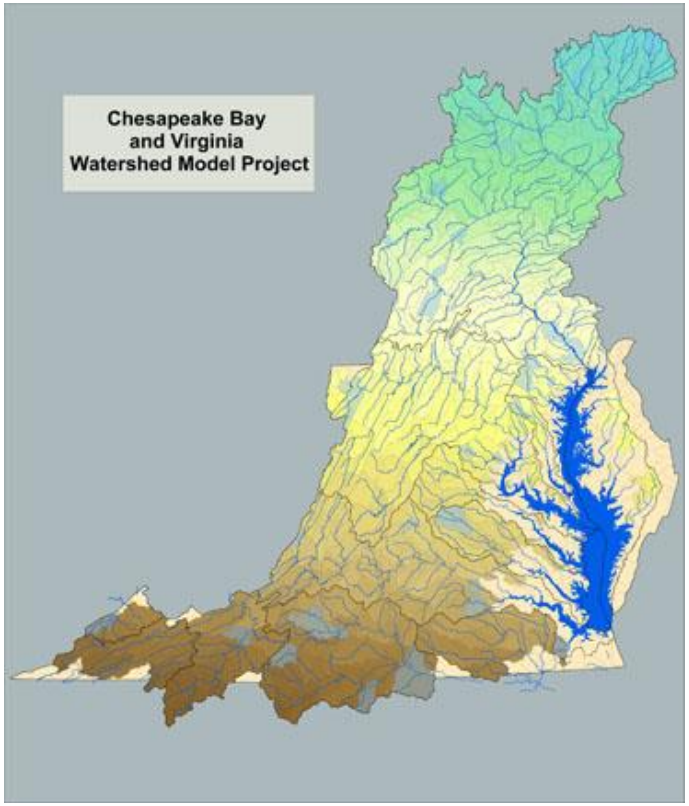
Goal: Illustrate considerations and procedures associated with incorporating downstream protection into development of numeric nutrient criteria

Outline

- Background
- Methods for setting criteria at the pour point:
  - Downstream criteria
  - Reference approach
  - Regression approach
  - Mechanistic modeling
- Methods for setting criteria farther upstream:
  - Fraction delivered
  - Mechanistic modeling
- Additional methods and considerations

Why is Downstream Protection Important?

Gravity...Because it all flows downstream...



- Adoption of criteria that address protection of downstream water quality standards is important in:
  - Helping avoid situations where downstream segments become impaired because of individual or multiple pollution sources in upstream segments
  - Providing clear water quality goals for trans-boundary waters
  - Determining if criteria protective of the downstream waters are more stringent than the levels needed to protect upstream waters

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Why is Downstream Protection Important?

- Demonstrating consistency with the existing regulatory requirement at 40 CFR §131.10(b)

  "In designating uses of a waterbody and the appropriate criteria for those uses, the State shall take into consideration the water quality standards of downstream waters and shall ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters."

- Other water quality programs that consider downstream protection include:
  - Permitting
  - Total maximum daily load
  - Assessment

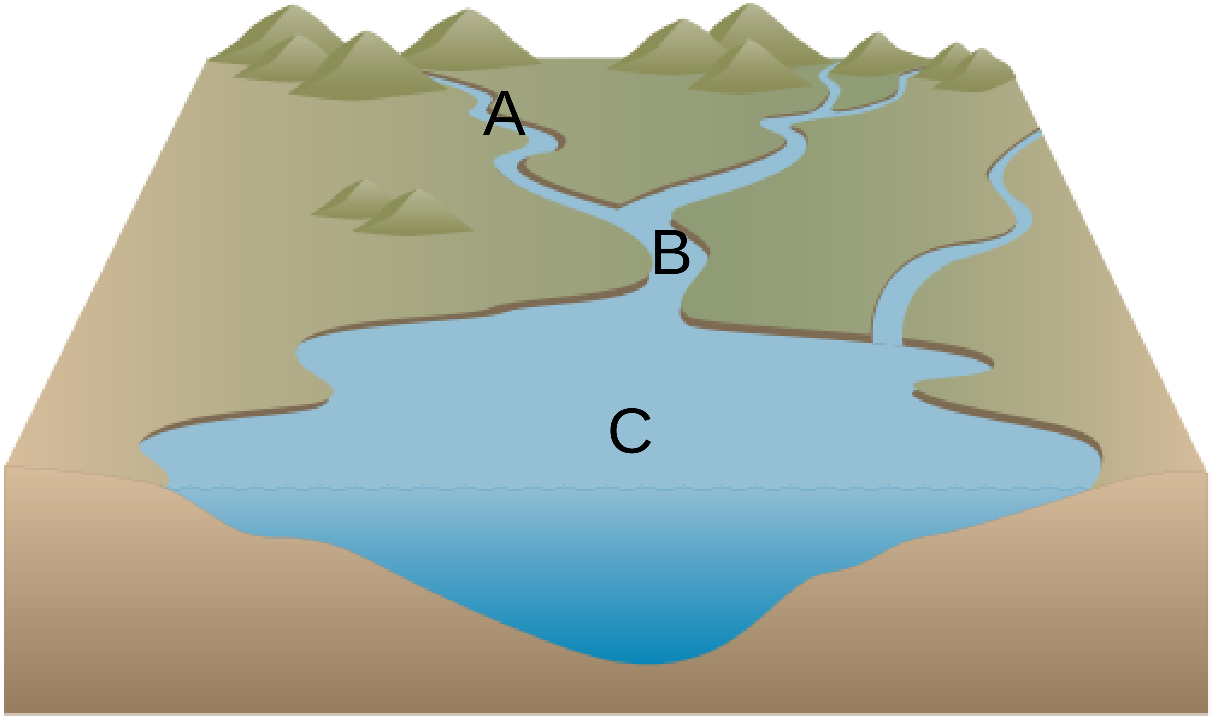
Additional Considerations for Nutrients

What we've learned and observed:

- Effects can be displaced in space and time
- The limiting nutrient varies spatially
- Numeric criteria clearly ensure downstream protection
- Impacts exist in lakes, reservoirs, and estuaries all across the United States

Where is Downstream?

The next segment down, as far as nutrient effects are observed

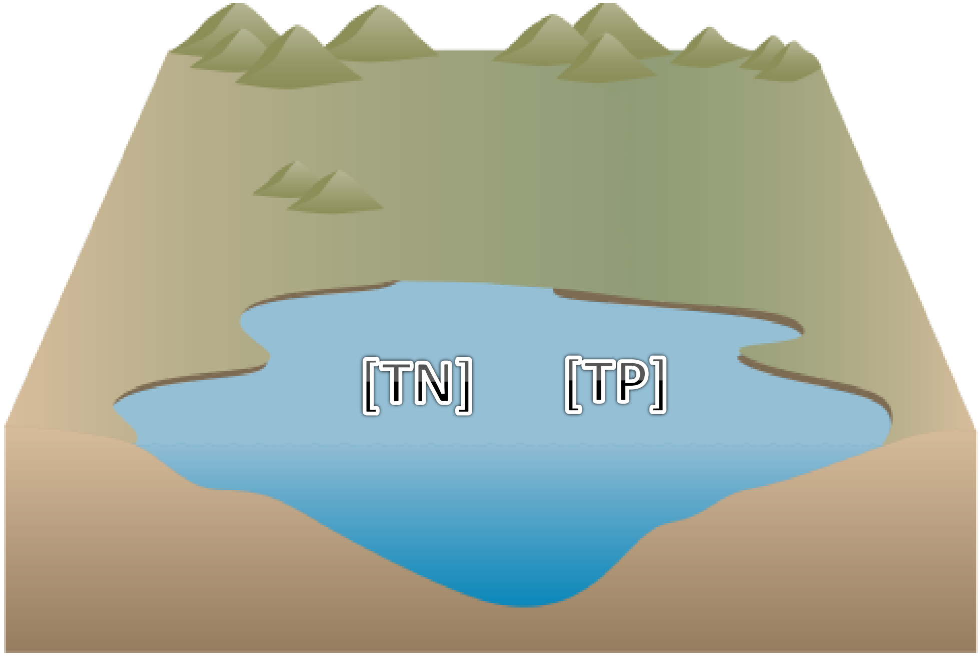


Development of Downstream Protection

- Establish numeric criteria in the receiving waterbody and build upstream
- Methods for setting criteria at the pour point (segment immediately upstream of the receiving waterbody):
  1) Downstream criteria
  2) Reference approach
  3) Regression approach
  4) Mechanistic modeling
- Methods for setting criteria farther upstream:
  1) Fraction delivered
  2) Mechanistic modeling

Downstream Criteria

Determine protective limits for the receiving waterbody on which to base downstream protection



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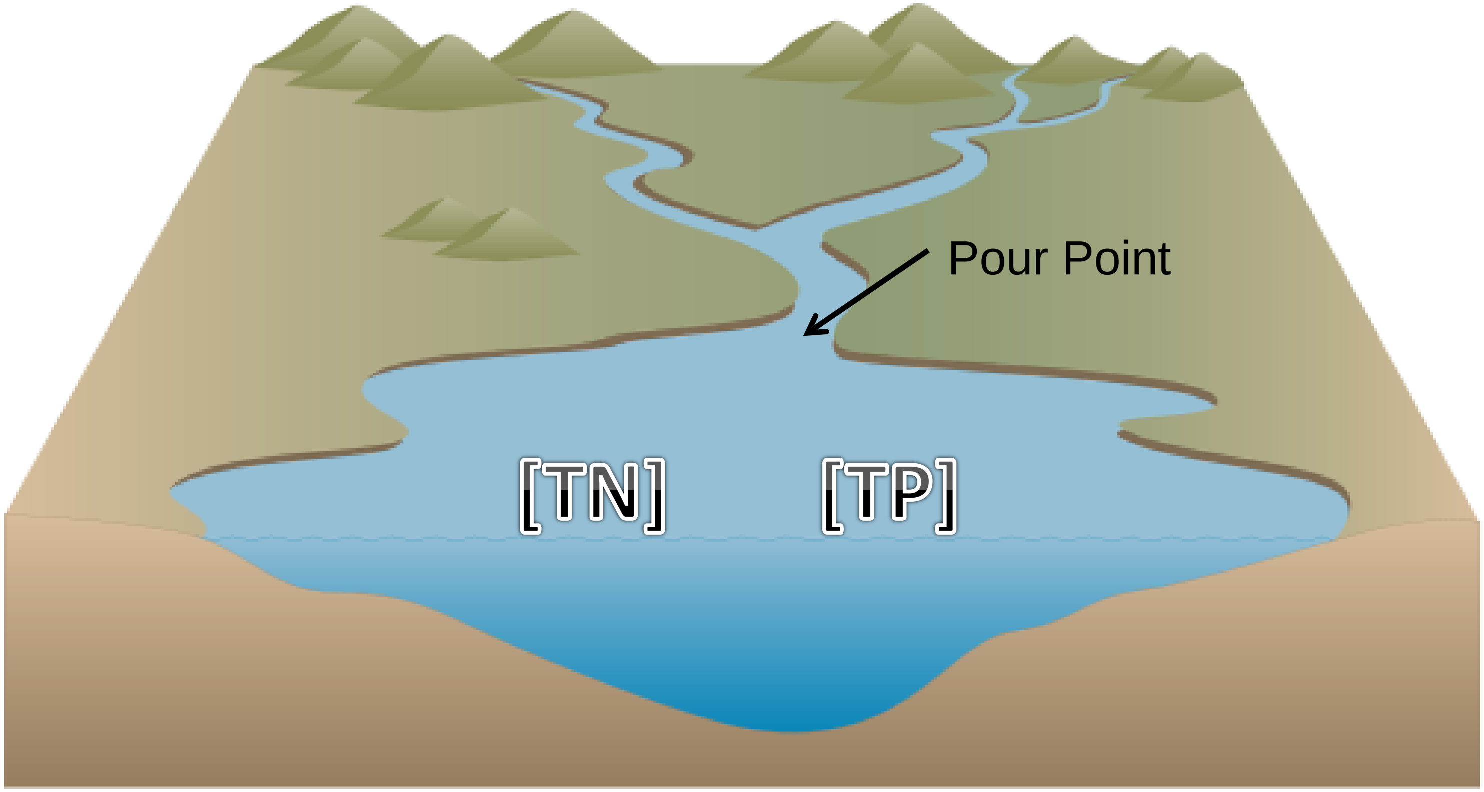
Set Criteria at Pour Point



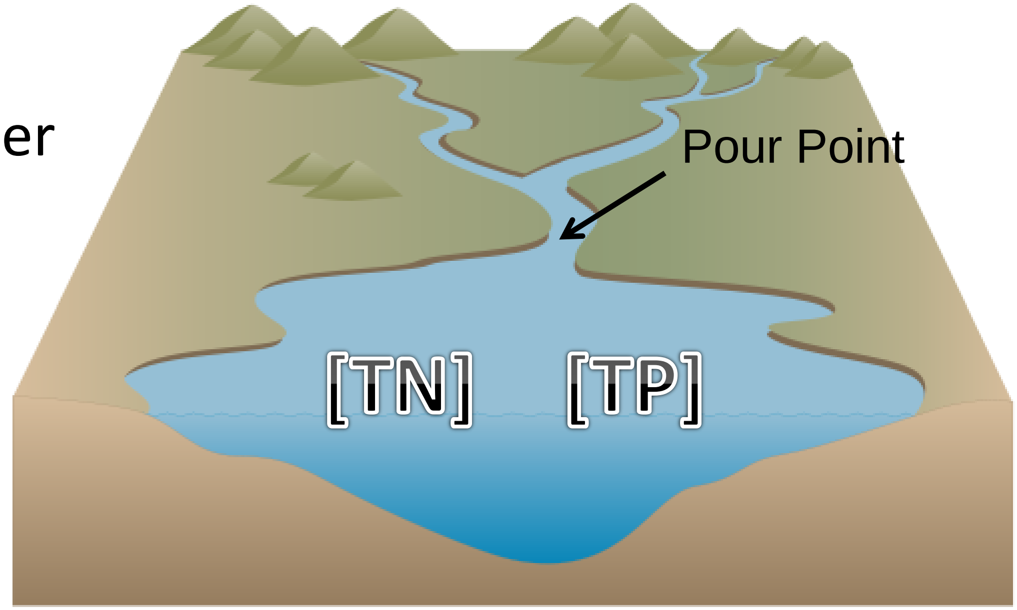
Set Criteria at Pour Point

1) Downstream Criteria

Apply downstream waterbody criteria at the pour point.

- Requires no additional data or analyses
- Conservative value

Criteria = downstream water
[TN] and [TP]



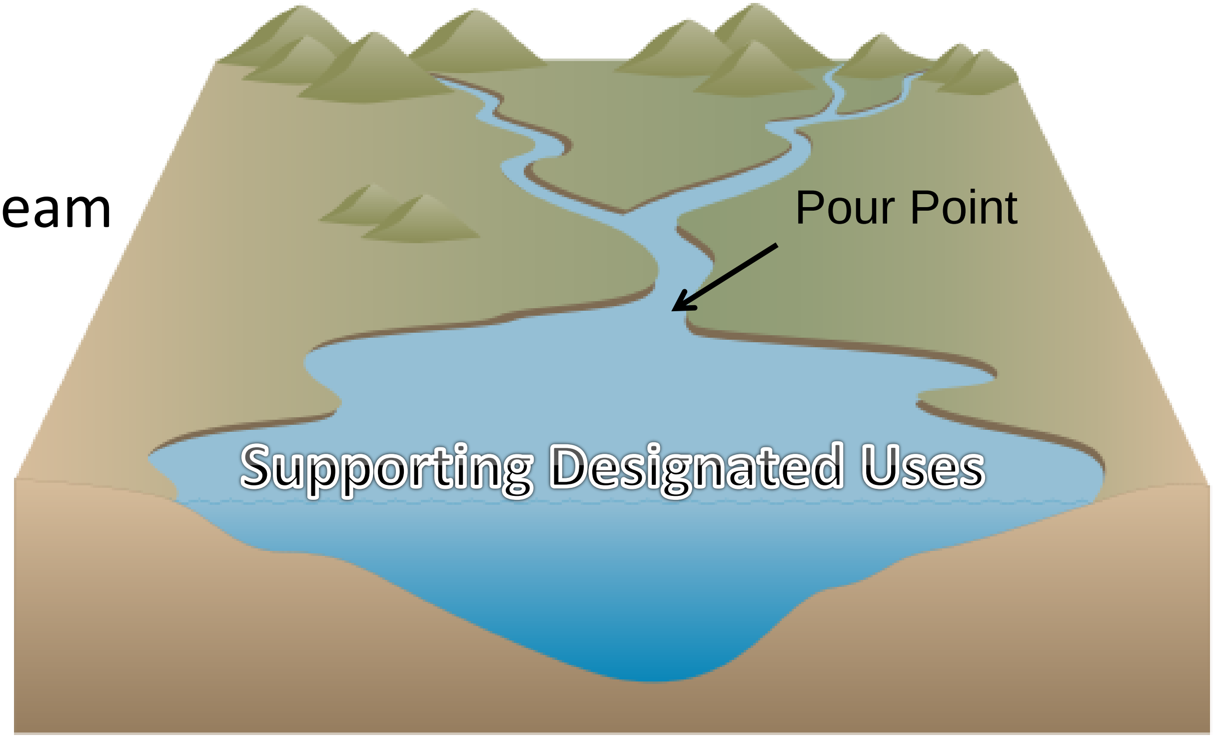
Set Criteria at Pour Point

2) Reference Approach

Reference Approach:

- When concentrations in the receiving water are supporting designated uses, maintaining the concentrations in the inflowing streams can be protective.

Criteria = existing instream [TN] and [TP]

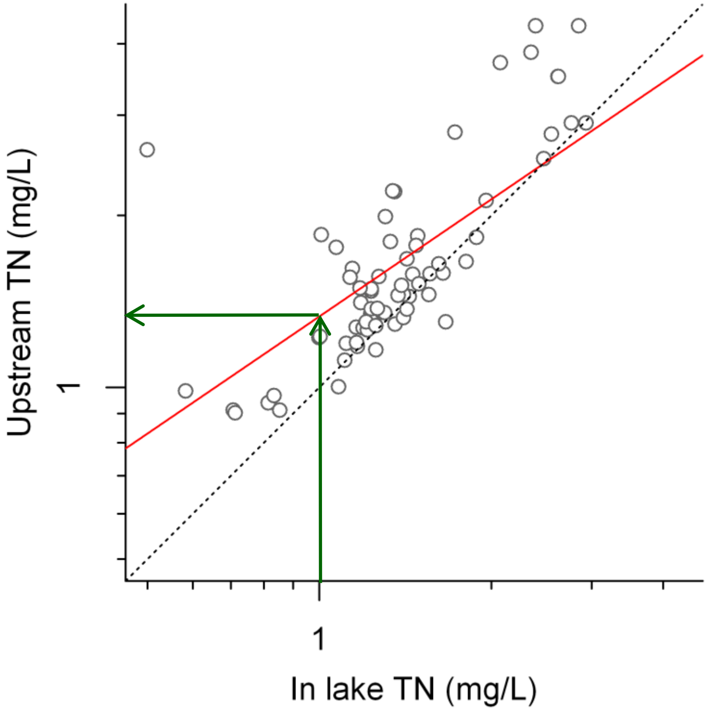


Set Criteria at Pour Point

3) Regression Approach

Regression approach:

- Derive pour point concentration from empirical relationship between lake and stream concentrations



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Set Criteria at Pour Point

4) Mechanistic Modeling

Use models in a lake or estuary to ensure inflowing streams support lake or estuary criteria. Models include:

- BATHTUB in lakes
- Water Quality Analysis Simulation Program (WASP) in estuaries/lakes
- Other models include:
  - Soil & Water Assessment Tool (SWAT)
  - One Dimensional Riverine Hydrodynamic and Water Quality Model (EPD-RIV1)
  - River and Stream Water Quality Model (QUAL2K)
  - Hydrological Simulation Program – FORTRAN (HSPF)

Set Criteria Upstream

1) Fraction Delivered

From any given upstream reach, calculate the criteria needed to support downstream waters using:

$$\bar{C}_i = \frac{\bar{C}_t}{\bar{F}_i}$$

Where:

C_i = Criterion for an upstream reach

C_t = Terminal reach protective concentration

F_i = Average fraction of total nitrogen or phosphorus transported out of the upstream reach that eventually enters the receiving waterbody

Set Criteria Upstream

1) Fraction Delivered

Before proceeding, scale needs to be considered; do criteria need to be set over long or short distances?

- Short:
  - Aquatic environments, and thus fraction delivered, are likely to be more similar
  - Potentially easier to directly measure nutrient retention/removal
- Long:
  - Multiple environments through a stream network can mean multiple processes may affect the fraction delivered

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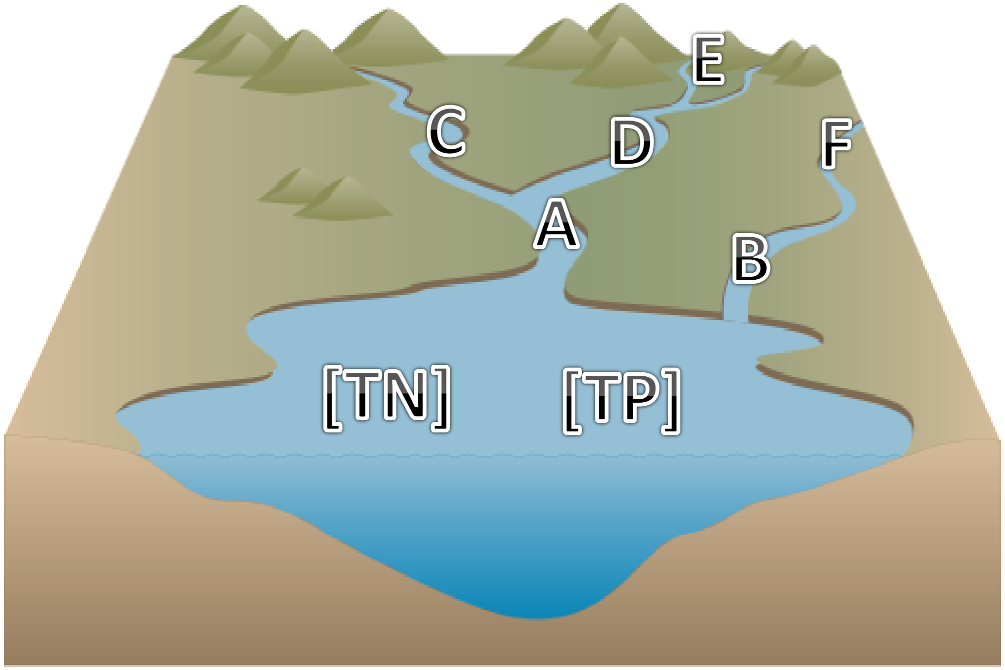
Set Criteria Upstream

2) Mechanistic Modeling

- Water quality models:
  - Calibrated scenario
  - Nutrient reduction scenario
    - Watershed anthropogenic nutrient loads are reduced from calibrated levels until the endpoints in the receiving waterbody are met.
- How to allocate the reduction to tributaries in watershed:
  - Spatial
    - Equal
    - Flow weighted
  - Temporal
    - Equal
    - Seasonal
    - Flows
  - Percent of anthropogenic reduction

Additional Considerations

- Use instream criterion or downstream criterion. The most stringent value applies to any one location.
  - Attainment
  - Exceedance at individual stations or throughout upstream network



Additional Considerations

- Groundwater input
- Burial/removal (loss rates)
- Estimating load
  - Ungauged rivers
- Criteria as load or concentration
  - Streamflow can come from observations or watershed model

Methods: Other Approaches

Narrative:

- Narrative downstream protection should be specific. For example:
  - Use of tiered models
  - Pollutants to address
  - Conditions that should be examined (seasonal/annual criteria, hydrological conditions, ecological conditions)
  - How criteria apply to permits
  - Endpoints to use

- Should facilitate:
  - Establishment of effluent limitations
  - Assessment and listing of impaired waters
  - Development of total maximum daily loads
  - Application of antidegradation requirements

Lessons Learned

- Downstream criteria ensure that designated uses are met near- and far- field
- Many approaches to derive downstream criteria give states flexibility
- State regulators indicate that downstream criteria would simplify other aspects of water quality protection, including permitting and TMDLs

EPA RESPONSE
TO EXTERNAL PEER REVIEW COMMENTS

on the

DRAFT AQUATIC LIFE AMBIENT WATER QUALITY CRITERIA FOR CADMIUM – 2015

November 19, 2015

Office of Water
U.S. Environmental Protection Agency
Washington, DC

TABLE OF CONTENTS

1 INTRODUCTION

EPA submitted its *Draft Aquatic Life Ambient Water Quality Criteria (AWQC) for Cadmium – 2015* for contractor-led independent, external peer review from August 25 to September 14, 2015. The external peer reviewers provided their independent responses to EPA's charge questions. This report documents the EPA's response to the comments provided to EPA.

This report presents the four peer review charge questions and individual reviewer comments (verbatim) in Sections 2.1 through 2.4. Section 2.5 presents additional minor comments provided by one reviewer. New information (e.g., references) provided by reviewers is presented in Section 3. EPA separated each reviewer's comments by charge question into distinct topics and responded to each topic individually, and also indicated how the draft cadmium criteria document was revised in response to peer reviewer comments.

1.1 BACKGROUND

EPA's Office of Water is charged with protecting ecological integrity and human health from adverse anthropogenic, water-mediated effects, under the purview of the Clean Water Act (CWA) Section 304(a)(l). The Agency has been working to update water quality criteria to protect aquatic life and aquatic-dependent wildlife from the presence of cadmium in freshwater and estuarine/marine environments in order to reflect the latest scientific knowledge.

EPA's AWQC for cadmium presents draft acute and chronic criteria expressed as concentrations of cadmium in fresh and estuarine/marine waters (dissolved). The 2015 draft cadmium criteria document is an update to the 2001 cadmium criteria. The 2015 draft incorporates additional toxicological data for cadmium, while using the same criteria derivation process that was used in 2001.

1.2 PEER REVIEWERS

An EPA contractor identified and selected five reviewers who met the technical selection criteria provided by EPA and who had no conflict of interest in performing this review.

The EPA contractor provided reviewers with instructions, the review document (including appendices), the charge to reviewers) prepared by EPA, and supporting reference materials as described in the charge. Reviewers worked individually to develop written comments in response to the charge questions.

1.3 REVIEW MATERIALS PROVIDED

- Internal Draft Cadmium AWQC_ 042115 (081315).pdf
- Internal Draft Cadmium AWQC_Appendicies_7 1 15 (081315).pdf
- Appendix K Issue Summary Regarding Test Conditions and Methods...H. Azteca.pdf
- Internal Draft Cadmium AWQC_References_11 4 14 (081315).pdf

Background/Supplemental Material (not for review, reference only)

- Cadmium Risks to Freshwater (Mebane 2010).pdf

1.4 CHARGE QUESTIONS

1. Please comment on the overall clarity of the document and construction as it relates to the derivation of each criterion.

2. Please comment on the technical approach used to derive the draft cadmium criteria; is it logical, does the science support the conclusion, and is it consistent with the protection of freshwater and

estuarine/marine aquatic life from acute, chronic, and bioaccumulative effects? Are the methods described in the document scientifically sound?

3. Please comment on the data used to derive the revised criteria, including data adequacy/comprehensiveness, and the appropriateness of the data selected and/or excluded from the derivation of the draft criteria. Is the data used correctly for the intended purpose? Are there other relevant data that you are aware of that should be included? If so, please provide the data along with supporting information.

4. Are the derived criteria appropriately protective of listed species and commercially and recreationally important species, particularly as the criteria relates to salmonids?

2 EXTERNAL PEER REVIEWER COMMENTS AND EPA RESPONSES, ORGANIZED BY CHARGE QUESTION

The following tables list the charge questions submitted to the external peer reviewers, the external peer reviewers' comments regarding those questions (broken into distinct topics), and EPA's responses to the peer reviewers' comments. EPA revised the 2015 draft considering the external peer review comments, and noted in the table where the document was edited.

2.1 CHARGE QUESTION 1

1. Please comment on the overall clarity of the document and construction as it relates to the derivation of each criterion.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 1	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 1	This report makes for very dull reading, but it is well-written and it is usually clear what the author is trying to say. There are no insightful comments or new ideas presented in this report, but the report is laid out in a clear, logical fashion.	Thank you for your comment.	No edit needed.
Reviewer 2	Overall the document is relatively clear with formatting in a risk assessment format which allows the reader to evaluate each criteria. Of minor concern was the lack of inclusion of emerging materials as sources of cadmium such as quantum dots which do make up photovoltaic substances (mentioned). However, the increased use of these materials as “inorganic” Cd sources and the uncertainties surrounding the potential absorption and effects of these materials to aquatic organisms needs some discussion.	Information regarding quantum dots has been added to the document.	Section 2.1
Reviewer 2	In addition, some inconsistencies were noted with regard to sub-lethal effects mentioned in the Estuarine/Marine Acute section. While present in this section, discussions of sublethal effects were largely omitted in the Freshwater sections and chronic sections of both water types.	The Estuarine/Marine Acute section was revised to remove inconsistencies. Additionally, information about sublethal effects in other media was added to the appropriate sections of the document.	Section 5.1 Section 5.2 Section 5.4 Section 5.5

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 1**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 2	There was also inconsistencies with regard to the use of flow-through vs. static exposures and whether more or less uncertainty is involved in utilization of the values. For example, flow-through methods were stated for *Salmo trutta*, but methods for *Morone* were static or static-renewal. One would clearly suggest the flow through values should be given greater weight with regard to uncertainty assessments. As it reads right now, it appears there are no differences between using static or flow-through exposures.	Data selected to calculate the SMAV for each species follows 1985 Guidelines recommendations. Specifically, flow-through measured exposures are preferred and selected for use over static and static-renewal exposure studies. If only static or static renewal exposure studies are available, EPA considers the study data and determines whether the study is acceptable for inclusion considering factors, such as known compound stability and other relevant information presented by the study author. EPA's goal is to consider and include as much high quality, scientifically defensible data in its assessments as possible in order to characterize potential response in a broad array of aquatic organisms. For example, if a species of concern had only static renewal data for acute studies, and EPA knew the compound was stable in water during the test duration, the data would be considered for inclusion if it met with the other data quality screens EPA.	No edits needed.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 1	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 2	The inability to determine salinity relationships to toxicity is also a concern but it is likely due to varied salinity regimes confounded with temperature and solute constituents in experimental designs (see comments below). It is noteworthy that a 1ppt value is considered “estuarine” for the *Morone* value, when there are “freshwater” systems that likely have higher conductance than this value. There should also be some statement or better clarity documenting the lack of a standard salinity value being utilized to compare toxicity values. It appears that the most sensitive toxicity value is being used regardless of the salinity.	The current statement in the Executive Summary about the salinity relationship addresses this comment: "Available data suggest the acute toxicity of cadmium may be influenced by salinity, with a trend of decreasing sensitivity to cadmium with increasing salinity. However, this trend could not be definitively characterized and a mathematical relationship could not be described to define the dependency (See Section 5.4.1)." Text has been added to elaborate on why a salinity normalization approach is not being used in criteria development. The estuarine/marine value is intended to be applicable to the broad range of salinities present in non-freshwater systems. EPA will accordingly continue to use 1 ppt as the lowest salinity level for a salt water test. This salinity is consistent with Mitsch and Gosselink (1986) who classify a waterbody with a salinity of 0.5-5.0 ppt is oligohaline. Mitsch, W.J. and J.G. Gosselink. 1986. *Wetlands.* Van Nostrand Reinhold, New York. 539 pp.	Section 2.3.1 Section 5.4.1
Reviewer 2	Overall, the uncertainty analysis section should be extended to include aspects of uncertainty with the data used for the derivation of the criteria. As it stands presently, the emphasis seems to be more on justification of data not utilized for the derivations.	Data selection is consistent with the procedures presented in the 1985 Guidelines. The Effects Characterization section was revised to include further discussion about uncertainty in the criteria calculations.	Section 5.1 Section 5.2 Section 5.4 Section 5.5
Reviewer 3	In general, the document language is reasonably clear. However, throughout the document, there are several instances where certain decisions are made that appear to be rather arbitrary without sufficient justification as to how or why these decisions were made (see details below).	Thank you for your comment. Please see responses to specific comments.	No edits needed.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 1	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 3	Minor comments: p. 8 and elsewhere: use mass units rather than ppm, ppb etc.	These values are mineral deposit concentrations in units reported by the author(s), but were changed to mg/kg based on the comment. There are no other uses of ppm or ppb in the document.	Section 2.1
Reviewer 3	p. 9: quantify concentrations found in impaired water ("several micrograms per liter" is vague)	The text has been revised to give a definitive value.	Section 2.1
Reviewer 3	p. 10: is the suggestion that precipitated/particulate forms of Cd that ultimately end up in sediments are not bioavailable?	Text was added to clarify that particulate forms of cadmium are potentially available to benthic feeders and sediment dwellers.	Section 2.2
Reviewer 3	p. 19: do data exist for any other salts of Cd that has been excluded?	The 1985 Guidelines note specific salts to test for metals; only these salts were used. According to the Manual of Instruction for Preparing Aquatic Life Water Quality Criteria Document, Stephan 1985, Section III. Defining the Pollutant, "for metals such as cadmium, chromium (III), and zinc, only data from tests on chloride, nitrate, and sulfate salts (either anhydrous or hydrated) should be used", therefore, other data for other cadmium salts were not included in the evaluation. Thus, studies conducted with cadmium acetate and cadmium borate salts were not used, nor were tests with nanoparticles and quantum dots. Stephan, C.E. 1985. Manual of instructions for preparing aquatic life water quality criteria documents. Draft report dated 12-12-85. U.S. EPA. Environmental Research laboratory, Duluth, MN. 49 pp.	No edits needed.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 1	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 3	P.63: Please be explicit about how the constants in the equations are derived for both the CMC and CCC.	The reviewed draft contained explicit information about how the constants in the equations for the CMC and CCC were derived: The CMC=$e^{(1.103 \text{ x } \ln(\text{hardness})-4.247)}$ Where, 1.103 is the acute pooled slope and; -4.247 is calculated as =ln(CMC at 100 hardness) - (Pooled Acute Slope x (ln(100))) =ln(2.3)-(1.103 x 4.605) Similarly, the CCC=$e^{(0.8161 \text{ x } \ln(\text{hardness})-3.663)}$ Where, 0.8161 is the chronic pooled slope and; -3.663 is calculated as =ln(CCC at 100 hardness) - (Pooled Chronic Slope x (ln(100))) =ln(1.1)-(0.8161 x 4.605)	No edits needed.
Reviewer 3	P. 67: Define the values listed under the two tables: (S2, L, A)	Footnotes were added to the document to define the terms S, L and A. These terms are refer to the following: S = slope; L = intercept; A = lnFAV. FAV = Final Acute Value.	Section 4.3.1 Section 4.3.2 Section 4.4.1.
Reviewer 3	Major comments: p. 12: "Mebane (2014) conclude that, although there were not adequate data to establish acceptable tissue effects concentrations for aquatic life, <u>cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish</u>. The evaluation of direct exposure effects is therefore considered to be more applicable to the development of criteria for aquatic life." This line of reasoning is questionable on many levels. Establishing critical tissue effects thresholds that work across species is problematic, especially in invertebrates, because species vary in their abilities to store/sequester Cd in	EPA concurs with the reviewer about the difficulty in characterizing dietary exposure and establishing critical tissue effects thresholds for bioaccumulated metals. Text has been added to discuss these points and incorporate the work of other researchers, such as Mebane (2006), who discuss cadmium bioaccumulation and dietary exposure in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium	Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 1	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
	physiologically inert forms. However, this does not mean that bioaccumulated metals are non-toxic as is implied by the language in this document. I think Mebane is being grossly misquoted here (aside from the fact that there is no 2014 reference). Here are some quotes from his 2010 document that directly refute the underlined text above: "Thus the consequences of elevated tissue residues or effects of dietary exposures may be important when estimating protective thresholds for cadmium and other pollutants (McCarty and Mackay, 1993; Meyer and others, 2005)." P. 32 "A diet of cadmium-contaminated green algae *Chlorella sp* caused reduced growth in the amphipod *Hyalella azteca* in a recent study (Ball and others, 2006)." P. 38 "Dietary cadmium exposures appear to be an important risk for at least some invertebrates. The data reviewed on dietary effects of cadmium to invertebrates indicated that adverse effects could occur at concentrations realistic in cadmium-polluted waters". P. 38 "Toxicity to mayflies from feeding on cadmium-contaminated algal mats at environmentally realistic concentrations was observed (Irving and others, 2003). P. 38 I understand that dealing with dietary exposures is incredibly inconvenient in the context of the 1985 Guidelines, but pretending that they are not important in 2015 is irresponsible because we know better. The Irving et al., 2003 study referenced above provides direct evidence that diet derived Cd can be problematic in this aquatic insect example.	concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	

Reviewer	External Peer Reviewer Comments Regarding Charge Question 1	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 4	I found the overall clarity of the document to be quite good. I especially appreciated the document being generally organized in a risk assessment format. I think this is very useful, particularly the Problem Formulation section that outlines various sources, potential exposure pathways and receptors. I hope EPA will use this overall structure for future criteria documents as well. I also like all of the comparisons to previous Cd criteria documents. This makes key changes to the criteria very transparent.	Thank you for your comment.	No edits
Reviewer 4	My only significant criticism of the overall format is that there are a number of redundancies where information is presented multiple times, often the exact same wording (for example, Section 5.4.1 is redundant of earlier text in the document). I encourage EPA to consider consolidating and reducing these redundancies.	The document was reviewed and revised to minimize redundant text.	Various locations
Reviewer 4	An additional minor point is that it is unclear how the data tables in the appendices are organized. They don't seem to be listed alphabetically by either common or scientific name. It would be useful if they were.	Data tables are organized as recommended by the 1985 Guidelines (phylogenetically) and text was added to each table in the Appendices to clarify this.	Appendices
Reviewer 5	Generally sufficient. Problem formulation section seemed a bit of a forced fit, as if added to satisfy a new stylist protocol.	Thank you for your comment.	No edits needed.

2.2 CHARGE QUESTION 2

2. Please comment on the technical approach used to derive the draft cadmium criteria; is it logical, does the science support the conclusion, and is it consistent with the protection of freshwater and estuarine/marine aquatic life from acute, chronic, and bioaccumulative effects? Are the methods described in the document scientifically sound?

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 1	This report is rather antiquated in its thinking. It basically assumes that Cd is accumulated only from the aqueous phase rather than from both the aqueous phase and ingested food. Over the past 10-15 years, it has been shown that many toxicants, including Cd and other metals, can be bioaccumulated from food as well as from the aqueous phase. Indeed, a number of laboratory, field, and modeling studies have shown that diet can be the dominant source of metals for marine invertebrates and fish. The relative importance of diet has been shown to vary with species, but it is rarely a minor source and sometimes (for some fish species, for example) the predominant source. Moreover, once accumulated from diet, Cd can reach sensitive organs within animals that are not reached by Cd taken up from the aqueous phase. Therefore, the toxic response of an animal to either ambient Cd or body burden Cd can vary considerably, depending on whether the source is ingested food or solute in ambient water. Thus, dissolved metal may be sorbed onto exoskeletons in crustacean zooplankton (often the most sensitive species, as the author points out) but this does not directly affect the animal because the metal (Cd in this case) bound to chitosan on the exoskeleton does not interact with metabolic processes, whereas metal assimilated from ingested food can enter into internal tissues where it may interfere with a variety of metabolic and reproductive processes. I saw no acknowledgement of the possible significance of dietary Cd on aquatic (freshwater or marine) animals in this report, and	EPA concurs with the reviewer about the multiple potential exposure routes and the complexity of characterizing these routes and establishing critical tissue effects thresholds for bioaccumulated metals. Text has been added to discuss these points and incorporate the work of other researchers, such as Mebane (2006), who discuss cadmium bioaccumulation and dietary exposure in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
	yet numerous papers describing such effects appeared in the reference section. In looking over appendices, many of these reports were not used, often for what appear to be spurious reasons or misinterpretations of studies. In some cases, dietary metals could be 1-2 orders of magnitude more toxic than dissolved metals to freshwater cladocerans and marine copepods, for example. In the case of Cd, an EC_{50} value of 5 nM (~0.5 µg/L) was observed in copepods in a study by Hook & Fisher (cited in this report) if the animal had been fed food exposed to that Cd concentration, whereas the measured LC_{50} value based on a dissolved Cd source was 200 times greater. Also, measuring growth or mortality, as is often the case in simple toxicity tests, would have missed the effect—rather the reproductive capability of the copepods was affected by the dietary Cd, but no mortality was observed at environmentally realistic concentrations. Because dissolved Cd concentrations are typically at very low concentrations in natural waters (at least 10-fold lower in surface seawater, for example), the lower EC_{50} value derived from dietary rather than dissolved sources still indicates that Cd is unlikely to cause toxic effects in most natural waters.		
Reviewer 2	With a few notable exceptions, the technical approach for the freshwater acute and chronic derivations appear valid. Incorporation of hardness normalization is warranted given the likelihood that Cd and Ca compete for similar biological and abiotic sites. In addition, the increased number of species extending the SSDs is also an excellent step forward in confirming proposed criteria.	Thank you for your comment.	No edits needed.
Reviewer 2	Of concern is the approach utilized for the chronic estuarine/marine values. Utilization of ACRs with freshwater fish or other organism to derive estuarine/ marine values is not appropriate, especially when the criteria concentrations are increased. It is also unclear why freshwater salmonid values	The use of a freshwater ACR to derive estuarine/ marine values is described as an acceptable approach in the 1985 Guidelines, and was used in the draft criterion document reviewed by the external peer reviewers.	Section 2.7.3 Section 4.4.2 Section 5.5.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
	were not utilized for the ACRs, as many reside in estuarine/marine environments (see salmonid comments below).	Based on the peer reviewer comment, the estuarine/marine ACR approach was re-examined and revised for the 2015 draft proposal for public comment. The revised FACR incorporates data for seven genus-level ACRs and was derived using data for marine species and a diversity of freshwater species, many of which have taxonomically-related marine species. ACRs used to derive the FACR incorporate data for five freshwater fish species, three freshwater invertebrate species, and two acutely sensitive estuarine/marine mysids.	
Reviewer 3	Bioaccumulative effects of Cd are largely ignored in this document.	Text has been added to discuss these points and incorporate the work of other researchers, such as Mebane (2006), who discuss cadmium bioaccumulation and dietary exposure in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 3	My comments for this section are divided into 2 parts: 1. The technical approach according to the 1985 Guidelines, and 2. The technical approach in light of our current understanding of cadmium bioaccumulation, effects, and deficiencies in the traditional testing approaches. The technical approach according to the 1985 Guidelines A. What is the rationale for use of EC20 values for the chronic toxicity assessment? I understand that a MATC approach (based on NOEC and LOECs) has its issues, and I'm generally in favor of more statistically robust approaches such as the use of an EC level based on entire datasets. But why is a 20% effect level chosen here? This value seems rather high. There should be some rationale for choosing this value, and this rationale should be clearly articulated in the text. How do we know that a 20% effect level has no impacts at the population level?	The endpoint for chronic exposure is the EC_{20}, which represents a 20 percent effect/inhibition concentration. This is in contrast to a concentration that causes a low level of reduction in response, such as an EC_5 or EC_{10}, which is rarely statistically significantly different from the control treatment. U.S. EPA selected an EC_{20} to estimate a low level of effect that would be statistically different from control effects, but not severe enough to cause chronic effects at the population level (see U.S. EPA 1999c). Reported NOECs (No Observed Effect Concentrations) and LOECs (Lowest Observed Effect Concentrations) were only used for the derivation of chronic criterion when an EC_{20} could not be calculated for the genus. A NOEC is the highest test concentration at which none of the observed effects are statistically different from the control. A LOEC is the lowest test concentration at which the observed effects are statistically different from the control. When LOECs and NOECs are used, a Maximum Acceptable Toxicant Concentration (MATC) is calculated, which is the geometric mean of the NOEC and LOEC. Regression analysis was used to characterize a concentration-effect relationship and to estimate concentrations at which chronic effects are expected to occur. For the calculation of chronic criterion, point estimates were selected for use as the measure of effect over a MATC, as MATCs are highly dependent on the concentrations tested. Point estimates also provide additional information that is difficult to determine with an MATC, such as a measure of effect level across a range of tested concentrations. U.S. EPA. 1999c. 1999 Update of ambient water quality criteria for ammonia. EPA-822-R-99-014. National Technical Information Service, Springfield, VA.	No edits needed.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 3	Only 3 species (all fish) were used to generate the hardness correction for the freshwater chronic toxicity data set. *D. magna* and *P. promelas* data were not used because only MATCs were available and not EC20s. Is it not possible to estimate EC20's from these datasets? The use of only 3 species to make this very important hardness adjustment would seem to add a significant level of uncertainty to the final analysis, especially since 2 of species used have divergent slopes. ANCOVA ($p=0.08$) based on data from 3 species was used to say that the slopes 0.32, 1.46 and 1.08 are not different and can be pooled. Is this defensible? Shouldn't a conservative slope estimate be chosen here…. especially in light of the fact that a 20% effect level is much higher than an MATC or EC05 would be?	EC_{20}s were not estimated for species other than the three fish species because the data necessary to calculate EC_{20} point estimates were not provided by the authors. EC_{20} point estimates were preferentially selected for use over a NOEC or LOEC as the measure of effect, as NOECs and LOECs, which are the basis of the MATCs, are highly dependent on the test concentrations selected. Furthermore, point estimates provide additional information that is difficult to determine using NOEC and LOEC effect measures, such as a measure of effect level across the range of tested concentrations, and the confidence intervals around those measures of effect. Correspondence has been sent to the authors who did not provide raw data for their studies, so EC_{20}s can be calculated if the data are available. Additional EC_{20}s were calculated based on their responses. An additional analysis was conducted to determine if the inclusion of 3 MATCs from the Chapman Manuscript for *D. magna* could be included in the hardness relationship along with the new EC_{20}s. This additional data supported the same conclusion that a pooled slope could be generated with a slightly different slope of 0.7977. Values were edited to reflect this new pooled slope.	Section 3.1.2 Appendix C
Reviewer 3	The most acutely sensitive marine genus, Tigriopus was not used in the analysis. The rationale was that it falls below the 5th percentile of the distribution. Isn't the whole point of the SSD to determine what is protective of 95% of the species? (Not 95% of the remaining taxa after sensitive taxa are arbitrarily removed from the dataset). Shouldn't all of the data be used here?	The 1985 Guideline recommendations were followed in that the four GMAVs closest to the 5th percentile are used to estimate the FAV.	Section 2.5 Section 2.7.2

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 2**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 3	The use of 2 ACRs from freshwater species in the development of a marine chronic criterion is dubious on many fronts. The justification for doing this needs to be articulated. If justifiable, the authors should then justify their choices as to why these 2 species were chosen. The reason given in the text is that the freshwater species were chosen on the basis of being acutely sensitive. However the purpose of ACRs is to evaluate the potential for the chemical to cause chronic toxicity. Use of an acutely sensitive species for ACR choice should theoretically result in species with low ACRs, and in this case, this is borne out. The freshwater invertebrate *L. silquoidea* has a reported ACR of 2.727, suggesting that is chronically not very toxic. However, the ACRs for most species are considerably higher: (see below) Mebane (2010) list ACRs for freshwater invertebrates: Ephemerella: 158.67 Physa: 47.6 Aplexa: 28.5 and 47.87 Ceriodaphnia: 12.41 and 31.5 Daphnia: 65, 155, 112, 13 Hyalella: 17.5 This document lists the following freshwater invertebrate ACRs: Aplexa: 49.7 Lymnea: 12.81 Ceriodaphnia: 19.82 Daphnia: 57.3 With all of these values to choose from, 2.727 is clearly not a representative ACR for freshwater invertebrates. Since the use of a "mean ACR" is being applied across taxa, shouldn't the	The use of a freshwater ACR to derive estuarine/ marine values is consistent with the1985 Guidelines. However, based on the peer reviewer comment, the estuarine/marine ACR approach was re-examined and revised in the 2015 draft proposal for public comment. The revised FACR incorporates data for seven genus-level ACRs and was derived using data for both marine species and a diversity of freshwater species, many of which have taxonomically-related marine species. The revised FACR of 8.291 was derived from a geometric mean of genus-level ACRs for the following: • Estuarine/marine mysids, *Americamysis bahia* and *A. bigelowi* • Cladocerans, *Ceriodaphnia dubia* and *Daphnia* (*D. magna* and *D. pulex*) • Mottled sculpin, *Cottus bairdii* • Salmonids, *Oncorhynchus* (*O. mykiss*, *O. tshawytscha*) and *Salmo* (*S. trutta*) • Fathead minnow, *Pimephales promelas* The seven ACRs differ by a factor of ≤ 11.95, which approximates the factor of 10 or less recommended by the 1985 Guidelines. The ACRs for salmonids were less than 2.0 and were therefore raised to 2.0 to be consistent with the 1985 Guidelines. The ACRs for the other freshwater species were not used for the revised FACR because they have no taxonomically-related marine species (e.g., pulmonate snails) and/or the ACRs appear to be outliers. The description of and rational for the new estuarine/marine ACR approach is provided in the post-peer review 2015 draft document.	Section 2.7.3 Section 4.4.2 Section 5.5.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
	values be representative? Would it make sense to have higher ACRs apply to invertebrates and lower ACRs apply to fish since fish generally have low ACRs and inverts generally have high ACRs?		
Reviewer 3	Technical approach based on what we understand about the world post 1985: Cadmium has been demonstrated to be toxic to practically every in vitro system it has been tested in. We strive to limit human dietary exposures in part because it is a known carcinogen and is nephrotoxic after dietary exposure. Effects of Cd on antioxidant physiology are well described in several species including aquatic insects. <u>What evidence can we point to suggest that bioaccumulated Cd is not toxic to aquatic organisms? This is a fundamental flaw in this document.</u>	Text has been added to discuss these points and incorporate the work of other researchers, such as Mebane (2006), who discuss cadmium bioaccumulation and dietary exposure in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	Section 5.6.1
Reviewer 3	We have a major and important disconnection between what traditional laboratory tests (using only direct aqueous exposures) and what field ecologists tell us about metal effects in aquatic insects. Because insects are such important players in freshwater ecosystems, and are the focus of CWA-driven biomonitoring programs, we have numerous examples of stream community structure being impaired by metal	Criteria were derived considering lab water-based exposures using procedures that are consistent with the 1985 Guidelines. Additional discussion has been added to address the uncertainty of using lab-based tests to determine protective field concentrations and the importance of dietary exposures to this faunal group.	Section 2.5 Section 5.1.3 Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
	exposures. Yet lab (aqueous) tests generally suggest that insects are insensitive to Cd. Work in our laboratory has used Cd uptake and depuration kinetics to clearly demonstrate that 96 hour exposures are insufficient to elicit toxicity in aquatic insects are ecologically relevant concentrations (Buchwalter et al. 2007, Buchwalter et al. 2008, Poteat and Buchwalter 2014, Poteat and Buchwalter 2014). We have also shown that periphyton is a major sink for Cd, and is readily bioaccumulated in insects (Xie et al. 2010). We have also showed that Cd exposure does not negatively affect Ca transport in insects (Poteat and Buchwalter 2014) (as it is known to do in acutely sensitive taxa), and Ca provides little protective effects on Cd uptake (Poteat et al. 2012). Finally, we show that diet derived (but not water derived) Cd affects antioxidant physiology suggesting that dietary exposures may be more challenging to aquatic insects that aqueous exposures (Xie and Buchwalter 2011). These findings mirror those of Irving et al., 2003. All of these findings point towards short-term, water-only exposures are insufficient for evaluating metal toxicity in this important faunal group (see (Poteat and Buchwalter 2014) for discussion of these findings).	In addition, generally good agreement has been reported for microcosm studies/whole effluent toxicity test results with corresponding field observed effects (Clements and Kiffney 1996; Clements et al. 2002; Norberg-King 1986). Mebane (2006) compared chronic criterion values and apparent effects values from ecosystem studies and field surveys and concluded that the data showed mostly good agreement between the laboratory-based predictions and effects observed in the field surveys or ecosystem experiments. EPA concurs with the reviewer about the importance of considering the dietary exposure route. Text has been added to discuss this and incorporate the work of other researchers, such as Mebane (2006), who discuss cadmium bioaccumulation and dietary exposure in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 4	Overall yes, I think the technical approach is scientifically sound and consistent with the protection of aquatic life. I do, however, have some specific significant comments for EPA to consider which I list below.	Thank you for your comment.	No edits needed
Reviewer 4	<u>Page 15:</u> EPA concludes that most changes in Cd toxicity can be explained by changes in hardness and therefore incorporation of the BLM into this revision is not necessary. I strongly disagree with this statement. Every study I'm aware of in which a range of DOC and pH have been measured has shown that these parameters strongly influence Cd toxicity. Just because the majority of laboratory studies are conducted in laboratory waters with low DOC and do not measure dissolved organic carbon (DOC), does not provide a valid rationale for not using the BLM (biotic ligand model). Obviously, in the natural environment, DOC varies widely. I would think the objective of the criteria is to ensure that they are protective/predictive of toxicity in the natural environment, not in artificial laboratory waters.	EPA revised the text to indicate that hardness is a critical factor in determining toxicity, and additional water quality parameters such as DOC, alkalinity, and pH may also influence cadmium toxicity. As the external peer reviewer noted, the objective of the criteria is to ensure that they are protective and predictive of toxicity in the natural environment. The addition of consideration of DOC would generally yield higher criteria values. Thus the focus on hardness only in this draft is expected to be protective. The EPA may consider the applicability of the BLM including parameters such as DOC in future revisions of the cadmium criteria. Criteria were derived considering lab water-based exposures using procedures that are consistent with the 1985 Guidelines. Additional discussion has been added to address the uncertainty of using lab-based tests to determine safe field concentrations and the importance of dietary exposures to this faunal group. In addition, generally good agreement has been reported for microcosm studies/whole effluent toxicity test results with corresponding field observed effects (Clements and Kiffney 1996; Clements et al. 2002; Norberg-King 1986). Mebane (2006) compared chronic criterion values and apparent effects values from ecosystem studies and field surveys and concluded that the data showed mostly good agreement between the laboratory-based predictions and effects observed in the field surveys or ecosystem experiments.	Section 2.3.1 Section 2.5 Section 5.1.3

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 2**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 4	Page 34: Following up on the previous comment regarding not using the BLM, why did EPA only consider a multiple linear regression with alkalinity? Why not pH and/or DOC? It is quite possible that pH autocorrelates with hardness as well given this is the case for most artificial laboratory waters (though not as consistent for natural waters), but there will not be an autocorrelation with DOC. This is a really important water quality parameter that EPA is ignoring.	Text relating directly to alkalinity was removed from the document and replaced with the text discussed in the previous response to comment. EPA notes that integrating DOC into the analysis would be expected in most cases to make the criteria less stringent. Thus, while recognizing the need to consider applicability of the BLM in future cadmium criteria updates, it is notable that the inclusion of DOC in the BLM approach will likely not make the criteria more stringent or conservative.	Section 2.3.1 Section 2.5 Section 5.1.3
Reviewer 4	Page 50-51: Is the study by Voyer et al. (1974), the only study where the effects of salinity on Cd toxicity was not consistent or are there multiple studies with this problem? If it's only this one study, it's not clear why the general trend would be ignored. I don't think EPA would ignore the hardness relationship in freshwater if only a single study was inconsistent with the general trend. It is a concern that there is an obvious and significant salinity effect for the *Neomysis integer* data (p. 51), which is one of the four taxa used for the criteria derivation, and yet this obvious effect is ignored and the geometric mean is used to develop the species mean acute values (SMAV). Does EPA consider a test performed at a salinity of 1 ppt to be a marine test?	Based on the peer reviewer's comments, additional analysis of the relationship between salinity and cadmium toxicity was conducted. As discussed in a previous comment, text has been added detailing why a salinity normalization approach was not used in the criteria development. A salinity-toxicity trend could not be definitively characterized and a mathematical relationship could not be described to define the dependency. EPA will continue to use the 1 ppt as the lowest salinity level for a saltwater test, consistent with the development of estuarine/marine criteria, which is applicable to the broad range of salinities characterized by these habitats. This salinity is also consistent with Mitsch and Gosselink (1986) who classify a waterbody with a salinity of 0.5-5.0 ppt as oligohaline. Note that for the salinity in the 1ppt *Morone* exposure, the conductance in this experiment was 1,600 uS/cm at 25C. This was approximately three times the conductance compared to fresh hard water. Mitsch, W.J. and J.G. Gosselink. 1986. *Wetlands.* Van Nostrand Reinhold, New York. 539 pp.	Section 2.3.1 Section 5.4.1

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 2**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 5	Unfortunately some aspects of the document lead to answering both parts of the charge question 2 with answers of “no.” I am only commenting on aspects which to me did not follow the available science, deviate from the principles of the 1985 “Guidelines” or otherwise have logical problems. While Stephan et al. (1985) Guidelines for derivation of aquatic life criteria are 30 years old and aspects of the science have progressed such that some details may not fit, they include solid principals that should continue to guide the approach. Key among Stephan et al. guiding concepts is from their p. 3: “*The guidelines were intended to provide the same level of protection as would an (infeasible) approach of conducting field tests on a wide variety of unpolluted bodies of water, adding various amounts of the material to each body of water in order to determine the highest concentration that would not cause any unacceptable long-term or short-term effects on the aquatic organisms or their uses*.” Further (p. 10), *These National Guidelines have been developed on the theory that effects which occur on a species in appropriate laboratory tests will generally occur on the same species in <u>comparable field situations</u>. All North American bodies of water and resident aquatic species and their uses are meant to be taken into account*.” Not bodies of water for which conditions are optimal – all bodies of water. Thus, a key concept behind the logic of criteria derivation is that criteria be suitable for diverse, natural water bodies, and laboratory data should attempt to encompass comparable field situations. The draft document instead moves towards a very different concept of only using data from an idealized aquaculture setting, without regard to whether the species occurs in the wild in waters with “suboptimal” conditions.	We concur that an objective of the 1985 Guidelines is to provide for the development of criteria that are applicable to a variety of field conditions. The testing procedures must, however, be conducted with organisms that are determined to be fundamentally healthy and with tests that meet with a consistent set of standards in order to evaluate test acceptability and develop criteria that are not impacted by testing artifacts and that are applicable on a national basis. This approach is consistent with internationally-recognized and broadly applied approaches for developing effects analyses for toxicants, relying on such reproducible laboratory data because they are designed to be as free from confounding influences as possible, in order to permit for robust, unconfounded consideration of risk for a given chemical, and relative risk across chemicals. States, tribes, and other end users can then consider site-specific conditions and variables in the development of standards that are applicable to their specific end use, such as the application to a particular water body or region. A further discussion of uncertainty regarding differences between laboratory and field conditions and implications for criteria has been added to the document.	Section 2.5 Section 5.1.3

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 2**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 5	Drilling down on Hyalella Most fundamentally, by throwing out all long-term test endpoints for the most sensitive genus (Hyalella) this document strays from a guiding principle of the Guidelines that criteria are to protect diverse natural waters. Criteria are indeed developed using laboratory data, but they are not intended to apply to laboratory waters; they are intended to apply to natural waters. This disconnect between laboratory-based derivation of numeric water quality criteria and application to natural waters has repeatedly debated in the literature, with me chiming in specifically with cadmium (Mebane 2010). In essence, optimal aquaculture conditions are defined for culturing *Hyalella azteca*, and chronic tests in which less than 15 mg/L chloride was present in dilution waters, or control growth, survival, and reproduction did not meet expectations. These were control growth (≥0.35 mg at 28 days and ≥0.5 mg at 42 days), survival (80% at 42d) and reproduction (≥6 per young). No explanation was found in the document why researchers were tasked to drill down on Hyalella, as any commonly used test organism could have been similarly scrutinized. Absent explanation, the inference is that Hyalella must have been chosen because it was the most sensitive organism, and there was a desire to exclude data if this heightened sensitivity could be shown to be an artifact of stressful laboratory culture conditions. In essence this logic requires the following implicit assumptions. Since only Hyalella data obtained from laboratory test waters >15 mg/L are to be used for criteria development, it follows that: In ambient waters, Hyalella (and presumably other freshwater amphipods) are only expected to occur in waters with >15 mg/L chloride; Alternatively if Hyalella do in fact occur in	In addition to the response to the previous comment, additional text has been added to further detail the decision process that was used, based on the recently-completed evaluation, to determine which *Hyalella* tests were included in the evaluation. The basic premise behind the selection of specific *Hyalella* tests, based on the consideration of test conditions, is that in order to develop robust comparative toxicity tests, animal husbandry conditions should be optimal and provide for low control mortality and optimal control growth to decrease control noise, increase the ability to capture low level effects, and thus understand the implications of introducing a toxicant into the system even at low levels. EPA developed this test condition/husbandry analysis for *Hyalella* after repeatedly observing extremely high variability in *Hyalella* test results for the same compound under different lab/husbandry conditions (e.g., chloride concentrations in test water) and considering less than optimal control survival, growth and reproduction. These analyses led to the determination of conditions under which repeatable results could be obtained by minimizing interfering confounders, such as water chemistry and diet. These analyses were <u>not</u> developed to exclude sensitive tests. EPA's analyses are developed with the goal of generating high quality and scientifically defensible predictions of concentrations, that if not exceeded beyond the specified frequency and duration, will be protective of aquatic life.	Section 2.5 Section 5.1.3 Section 5.2.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
	waters with lower chloride concentrations, the criteria are only intended to apply to waters with >15 mg/L. Chloride is an important factor affecting the toxicity of cadmium to Hyalella (and presumably other related but less well studied amphipods or freshwater crustaceans). If so, then it follows that: Chloride should be included in the criteria derivation and factored into the criteria. Per the Guidelines (p32), "when enough data are available to show that the chronic toxicity is similarly related to a water quality characteristic, the relationship should be taken into account …. If two or more factors affect toxicity, multiple regression analysis should be used." Alternatively, while not specifically mentioned in the guidance, if data were insufficient for the covariance or multiple regression analyses endorsed, it would seem reasonable to establish different criteria in brackets, such as waters ≤15 mg/L chloride or >15 mg/L chloride. Alternatively, if chloride is not an important factor affecting, then there is no reason to factor it into the criteria development. However, Appendix K does not address the question of whether chloride is a factor affecting cadmium toxicity, all that has been established is that Hyalella growth and reproductive output is greatest in waters with chloride >15 mg/L. This is not unexpected. Freshwater environments usually have an osmolarity far less than blood plasma, and energy requirements to maintain hydromineral balance increase in more dilute waters (e.g., Wendelaar Bonga and Lock 2008). Fish in dilute waters don't grow well either. For instance, about 80% of the restaurant/retail rainbow trout sold in the United States come from a 30 mile stretch known as the		

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 2**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
	Thousand Springs area of southern Idaho. There the constant chloride of about 20 mg/L, hardness of about 180 mg/L and temperature of 15°C provide optimal energy conversions and growth per unit feed. It would follow just as logically that only rainbow trout data that were generated from waters with chloride >15 mg/L or so should be used, because that optimizes growth? Why would it not follow that only acute data in which organisms were fed should be used, because starvation stresses organisms? This seems to be internally inconsistent logic.		
Reviewer 5	The reason why Appendix K was requested was never stated. It should be. I assume the reason must be a presumption that if organisms do not grow and reproduce at high rates, then they will "too sensitive" or not represent responses expected in natural conditions. It is not obvious that this is the case. McNulty et al. (1999) showed that starved amphipods exposed to low levels of cadmium survived better than controls. However, even if optimal diets do produce higher (less sensitive) growth and reproduction effects with Cd and Hyalella, the universal use of optimal diets could lead to underestimation of the toxicity risks experienced by wild populations, which may experience limited food availability. In the wild, organisms don't live in optimal conditions. Even in the center of their ranges, conditions are seldom optimal all of the time. Organisms also live in marginal conditions, for they tend to expand their ranges to the limits of their physiological tolerances. See for example France's (1996) description of Hyalella living on the margins of lakes with tolerable mineral content (France 1996). Similarly, Gibbons and Mackie (1991) showed that increasing reproductive output of H. azteca was associated with increasing sulfate, calcium hardness, sediment particle size, conductivity, alkalinity, seston, and the organic matter of the fine sediment. This	The basic premise behind the selection of specific *Hyalella* tests, based on the consideration of test conditions, is that in order to develop robust comparative sensitivity analyses, animal husbandry conditions should be optimal and provide for low control mortality and optimal control growth to decrease control noise, increase the ability to capture low level effects, and thus understand the implications of introducing a toxicant into the system even at low levels. EPA developed this test condition/husbandry analysis for *Hyalella* after repeatedly observing extremely high variability in *Hyalella* test results for the same compound under different lab/husbandry conditions (e.g., chloride concentrations in test water) and considering less than optimal control survival, growth and reproduction. These analyses led to the determination of conditions under which repeatable results could be obtained by minimizing interfering confounders, such as water chemistry and diet. These analyses were <u>not</u> developed to exclude sensitive tests. EPA's analyses are developed with the goal of generating high quality and scientifically defensible predictions of concentrations that if not exceeded beyond the specified	Section 2.5 Section 5.1.3 Section 5.2.1 Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
	consistent with Appendix K, but begs the question, what are effects of Cd in these suboptimal waters? Why assume that if Cd criteria are needed, they should only be developed from exposures in high hardness, but then blindly extrapolate results to low chloride, low hardness conditions using tests with other organisms? This is further logical problem with Appendix K's rationale – as noted in appendix K, waters with hardness less than 80 mg/L tend to have chloride less than 10 mg/L. Does the hardness-toxicity relation predict safe conditions for Hyalella at low hardness? No way to know.	frequency and duration will be protective of aquatic life. We concur that an objective of the 1985 Guidelines is to provide for the development of criteria that are applicable to a variety of field conditions. The testing procedures must, however, be conducted with organisms that are determined to be fundamentally healthy and with tests that meet with a consistent set of standards in order to evaluate test acceptability and develop criteria that are not impacted by testing artifacts and that are applicable on a national basis.	
Reviewer 5	I've poked around a bit the literature on Hyalella life histories under different environmental stresses in an effort to include extrapolate organism-level effects of Cd to potential population-level effects (Mebane 2010). While by no means exhaustive, and by now a bit dated, this leads to some other thoughts on the expected control survival, growth, and reproduction in long term tests in Appendix K. With control survival, in at least some wild populations, I estimated half-month survival rates for juveniles of about 0.9, or close to a 5% decline per week (Mebane 2010, Table II). This is higher than the 2-3% noted in Appendix K, and suggests that in the wild, survival to 42-days would likely be less than 80%. With regards to growth, while some wild populations grew as much as those in the laboratory settings discussed in Appendix (>0.5 mg at sexual maturity), this cannot be assumed in all natural waters. Cooper (1965) reported average dry weights of adults Hyalella were 0.2 mg in a population in a warm, shallow lake in Michigan. Gibbons and Mackie (1991) reported mean weights of Hyalella at maturity were only 0.1 mg, and weights of all Hyalella were only 0.3 mg. Thus the 0.35 at day 28 and 0.5 mg at day 42 may be higher than that expected in some natural settings. Gibbons and Mackie (1991) reported ranges	The basic premise behind the selection of specific *Hyalella* tests, based on the consideration of test conditions, is that in order to develop robust comparative sensitivity analyses, animal husbandry conditions should be optimal and provide for low control mortality and optimal control growth to decrease control noise, increase the ability to capture low level effects, and thus understand the implications of introducing a toxicant into the system even at low levels. EPA developed this test condition/husbandry analysis for *Hyalella* after repeatedly observing extremely high variability in *Hyalella* test results for the same compound under different lab/husbandry conditions (e.g., chloride concentrations in test water) and considering less than optimal control survival, growth and reproduction. These analyses led to the determination of conditions under which repeatable results could be obtained by minimizing interfering confounders, such as water chemistry and diet. These analyses were <u>not</u> developed to exclude sensitive tests. EPA's analyses are developed with the goal of generating high quality and scientifically defensible predictions of	Section 2.5 Section 5.1.3 Section 5.2.1 Section 5.6.1

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	of brood per female ranged from 6 – 15, which is consistent with appendix K. However, Strong (1972), his fig 4, showed sometimes natural brook sizes may be as low as 3 per female. In sum, the logical problems of how Appendix K's analyses are used in the document are analogous to the metaphor of not seeing the forest because of all the trees. Some trees were examined in great detail (lab performance of Hyalella) but it misses the point that the comparisons of acceptable conditions should be again performance in the wild.	concentrations that if not exceeded beyond the specified frequency and duration will be protective of aquatic life. We concur that an objective of the 1985 Guidelines is to provide for the development of criteria that are applicable to a variety of field conditions. The testing procedures must, however, be conducted with organisms that are determined to be fundamentally healthy and with tests that meet with a consistent set of standards in order to evaluate test acceptability and develop criteria that are not impacted by testing artifacts and that are applicable on a national basis.	
Reviewer 5	Other items: Problem formulation: It is germane to note that in natural waters, Cd is always in association with Zn, usually at about mass ratios of 1:200 (Wanty et al. 2009).	This information was added to Section 2.1 of the document.	Section 2.1
Reviewer 5	p. 12, I was not quoted quite accurately. "Mebane (2014 2006) concluded that, although there were not adequate data to establish acceptable tissue effect concentrations for aquatic life, cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish, <u>at calculated chronic criterion concentrations, which were lower than that chronic criterion concentration derived here.</u> " This report is variously cited as Mebane (2006), Mebane (2010), or Mebane (2014). The suggested citation is, "*Mebane, C.A. 2006. Cadmium risks to freshwater life: derivation and validation of low-effect criteria values using laboratory and field studies. U.S. Geological Survey Scientific Investigation Report 2006-5245 (2010 rev.). http://pubs.usgs.gov/sir/2006/5245/.*" The 2010 revision only corrected minor mistakes, and did not include any updated literature reviews.	Text was added as suggested and the citation was fixed.	References and various locations in document Section 2.3 Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 2	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 5	p. 28, the approach of requiring data used in the hardness-toxicity regressions to have a 3X spread and 100 mg/L absolute difference between the highest and lowest value was indeed used in the 2001 version, but was not really presented as policy. In contrast, my colleagues and I found that hardness-toxicity relations were more reliable from test series that concurrently tested the same cohort of organisms in waters with different hardness, than were ad hoc collections of found data tested under different conditions at different hardness levels (Mebane et al. 2012). Where available, giving concurrent test series data obtained at different hardnesses precedence over general hardness-toxicity compilations would be warranted.	The approach of requiring data used in the hardness-toxicity regressions to have a 3X spread and 100 mg/L absolute difference between the highest and lowest value was established when updating the cadmium document in 2001. This practice has been followed for all subsequent criteria document updates because it was found that the variability associated with different test conditions that are associated with multiple studies can sometimes be so great that it masks the hardness/toxicity relationship. Data for each species are first reviewed to determine if they are potentially suitable for use in the hardness-toxicity evaluation. The data are initially considered regardless of source/test condition (laboratory, dilution water, temperature, etc.). However, if the hardness/toxicity data are widely scattered, we then attempt to decrease uncertainty introduced by the differing test conditions by focusing on those studies specifically evaluating the toxicity relationship. In addition, studies are excluded when only a single acute toxicity value was available and where multiple tests were conducted at the same hardness. When different life stages were used at test initiation, only data for the same life stage is evaluated. The end result is that the most defensible data are used to develop the hardness-toxicity slope.	No edits

2.3 CHARGE QUESTION 3

3. Please comment on the data used to derive the revised criteria, including data adequacy/comprehensiveness, and the appropriateness of the data selected and/or excluded from the derivation of the draft criteria. Is the data used correctly for the intended purpose? Are there other relevant data that you are aware of that should be included? If so, please provide the data along with supporting information.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 3	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 1	As noted above, the author chose to ignore many relevant studies that did not conform with standard EPA toxicity protocols. But the problem is that these protocols basically ignore the fact that animals eat, hardly a realistic scenario and are too simplistic in looking only at growth and mortality. Typically, the test organisms are exposed to dissolved Cd at varying concentrations, but in the absence of food. Occasionally, some artificial food (fish flakes or the like) is presented once every several days (sometimes never!) to keep the animals alive. But these studies are hardly representative of what happens in natural waters.	Studies that were determined not to be acceptable were presented in Appendix J, along with a rationale for their exclusion. However, the exclusion of food in acute tests is standard practice in EPA, ASTM and internationally-harmonized toxicity test protocols. This is based on the potential for food to alter the exposure concentration and/or bioavailability of the chemical. This approach is consistent with procedures stated on page 14 of the 1985 Guidelines: “Except for test with saltwater annelids and mysids, results of acute tests during which the test organisms were fed should not be used, unless data indicate that the food did not affect the toxicity of the test material”.	No edits needed.
Reviewer 2	The use of additional species for SSD reduced uncertainty and greatly improved criteria assessments for freshwater. The QA evaluations of data usefulness was adequate and the data selected for the acute responses was correctly used for the intended purpose. The mechanistic assumption that adverse effects are primarily related to calcium uptake at the gill, is accurate for acute effects. Consequently, the data used for derivation of the criteria for acute effects is valid.	Thank you for your comment.	No edits needed.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 3	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 2	However, with regard to chronic effects, there are other targets once absorption of cadmium occurs, particularly the kidney, brain and gonad. In addition to specific interactions with signaling proteins, Cd clearly binds sulfhydral groups of proteins within targets disrupting cellular maintenance. The latter two tissue targets above are likely involved in the reproductive effects observed with chronic exposures. Cd clearly disrupts the Hypothalmic Pituitary Gonadal axis and gonadal function in fish (Vetillard, and Bailhache 2005). It reduces vitellogenin in females and accumulates in kidney upon chronic exposures either via diet or water (Szczerbik et al. 2006; Thomann et al. 1997). It is understood that tissue data from these organs are limited, but studies that have these data, or the fact that these data are limited should be discussion points of the uncertainty analysis. Clearly, discussions of uncertainty regarding accumulation are needed, particularly in light of limited data for chronic effects in estuarine/marine organism. The statement "Aquatic organisms are considered to be more susceptible to cadmium from direct aqueous exposure than through bioaccumulation and the development of criteria protective of direct exposure effects are considered more applicable to the development of criteria for aquatic life" is clearly biased toward acute toxicity and should be re-visited with particular emphasis on reproductive effects of cadmium which likely result from accumulation and not direct exposure.	EPA recognizes the difficulty in characterizing dietary exposure and establishing critical tissue effects thresholds associated with bioaccumulated metals. The information provided regarding tissue targets has been added to the Uncertainty section along with additional discussion about limitations in the organ data. Text has been added to discuss these points and incorporate the work of other researchers, such as Mebane (2006), who discuss cadmium bioaccumulation and dietary exposure in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 3	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 2	With regard to reproduction, it is unclear what endpoint data is being used to determine the effect values in the Appendices. Tests are provided in terms of exposure duration, but it is unclear whether growth, survival or reproduction is being utilized as the endpoint. Again, given the potential for reproductive effects upon chronic exposure, reproduction would be expected to be the most sensitive endpoint. If other endpoints were used then the uncertainties inherent to these endpoints should be discussed. Clearly growth and survival effects have likely difference mechanisms and targets than that of reproduction.	The most sensitive acceptable endpoint is used for each study. The endpoint for each exposure concentration was added for each study in the table.	Appendix C
Reviewer 2	It is also significantly disappointing that data from the same 2 species in 1980s are still the only two species being used to derive the 2015 values. In addition, it is puzzling how criteria values can be raised for estuarine/marine organisms when the same degree of uncertainty exists (only 2 species) in each year criteria were assessed. To add in data from freshwater organisms for ACR estimates *increases* uncertainty and does not reduce it. Therefore, the 2001 value should stay as is, or be reduced because of the uncertainty associated with its derivation.	Additional acceptable estuarine/marine chronic data were not found based on an extensive literature search that was conducted in 2014. The CCC was calculated using the saltwater FAV and FACR as recommended in the 1985 Guidelines. The use of a freshwater ACR to derive estuarine/ marine values is described as an acceptable approach in the 1985 Guidelines, and was used in the draft criterion document reviewed by the external peer reviewers. Based on the peer reviewer comment, the estuarine/marine ACR approach was re-examined and revised for the 2015 draft proposal for public comment. The revised FACR incorporates data for seven genus-level ACRs and was derived using data for marine species and a diversity of freshwater species, many of which have taxonomically-related marine species. ACRs used to derive the FACR incorporate data for five freshwater fish species, three freshwater invertebrate species, and two acutely sensitive estuarine/marine mysids.	Section 2.7.3 Section 4.4.2 Section 5.5.1

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 3**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 3	Practically all relevant work related to bioaccumulated Cd and the importance of dietary exposures is ignored. (see (Barata et al. 2002, Barata et al. 2002, Buchwalter et al. 2008, Cain et al. 2004, Croteau et al. 2003, Hare et al. 2001, Hare et al. 2003, Irving et al. 2003, Klaassen et al. 1999, Luoma and Rainbow 2005, Luoma et al. 2009, Luoma and Carter 1991, Martin et al. 2007, Timmermans et al. 1992, Wallace et al. 2003, Xie et al. 2010, Xie and Buchwalter 2011, Xie et al. 2008) for some examples)	The referenced materials were evaluated and added, as applicable, to the bioaccumulation uncertainty section.	Section 5.6.1
Reviewer 3	I suspect that there are other reviewers who can comment more directly on the issues with *Hyalella* data, so I will refrain from doing so here.	Thank you for your comment.	No edits needed.
Reviewer 4	Overall, I found the data used by EPA to derive the criteria to be comprehensive and generally sound. There are a few specific data where I have concerns that EPA should consider as described below.	Thank you for your comment.	No edits needed.
Reviewer 4	Page 51: I'm very concerned that EPA is still allowing studies in which test concentrations were unmeasured as being acceptable for WQC derivation. This is particularly concerning when they are for one of the four taxa used to calculate the criteria. In my opinion, these studies should not be included.	The use of unmeasured acute test study results is an acceptable approach in the 1985 Guidelines under specific conditions. The lack of measured exposure concentrations in an acute toxicity test does not invalidate the results if there is a demonstration that the material tested is stable during the testing period. Only if there were observed solubility problems (e.g., precipitant present) would the data be suspect and therefore potentially not acceptable.	No edits needed.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 3	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 4	Page 68: I agree with EPA's use of freshwater ACRs to supplement the limited marine ACRs for the purpose of deriving a final marine ACR. However, I question whether use of the ACR for *Lampsilis siliquoidea* is appropriate. There are obviously a number of factors that influence the ACR, but a major factor is the life history of the organism and the life stage selected for the acute toxicity test used to derive the ACR. It seems to me that freshwater mussels have a unique life history with no real analog in marine systems (marine bivalves have a different life history). Consequently, use of this of the ACR for this species to derive a marine ACR seems inappropriate. I think use of an ACR for daphnids would be more appropriate and representative of the life history of the most acutely sensitive taxa in marine systems, the copepod *Tirgriopus*.	Based on peer reviewer comments, calculation of the FACR was revised and does not include *Lampsilis*. The revised FACR incorporated data for seven genus-level ACRs and was derived from data for marine species and a diversity of freshwater species, many of which also have taxonomically-related marine species. ACRs used to derive the FACR incorporate data for five freshwater fish species, three freshwater invertebrate species (including applicable data for daphnids), and two acutely sensitive estuarine/marine mysids.	Section 2.7.3 Section 4.4.2 Section 5.5.1 Section 5.5.2
Reviewer 4	Table 17: Why is the pH 6.0 test for *H. azteca* excluded? This is within the range of test pH values (6.0-9.0) normally considered by EPA. Additionally, earlier in the document it was stated that hardness was the only water quality parameter that mattered for normalizing Cd toxicity data. I disagree with that statement, but if EPA is going to argue other water quality parameters are not important, then I don't see how it can then exclude data for this reason.	In addition to the pH being below the level accepted by EPA for tests (6.5-9.0), Br and Cl^- concentrations were not provided and the dilution water was comprised of well water that was significantly diluted from a hardness of 380 mg/L to 15.3 mg/L (Mackie 1989). The *Hyalella* memo found in Appendix K of the draft criteria document states that "Natural waters with hardness less than 80 mg/L typically have <10 mg Cl/L". The rationale for the exclusion of this study from the criteria derivation was clarified in the document table.	Table 17

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 3**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 4	Table 18: I agree with EPA's re-evaluation of the *Hyalella* data and their application of water quality and performance criteria for test acceptability. However, I'm concerned about the study EPA retained for purposes of criteria derivation for several reasons. First, I do not believe use of a 10-d survival endpoint constitutes a chronic study as defined in Stephan et al. (1985). EPA has excluded a number of other studies from use in criteria derivation for this reason (e.g., the 21-d survival study on the sea starlet anemone, p. 81) in this document that creates a major internal inconsistency. Having said that, it could be argued that inclusion of this sub-chronic data is warranted given that it is the lowest toxicity value in the data set and exclusion of the data would be non-conservative in terms of environmental protection (as opposed to including sub-chronic data for insensitive species). However, using this logic why would the 7-d survival/growth data with the fountain darter then be excluded?	In response to peer reviewers' comments, a further examination of this issue was conducted. Thus, after further evaluation, the full-life cycle study by Ingersoll and Kemble (2001) was found to satisfy the acceptability criteria for *H. azteca* and was used to replace the 10d study used in the previous draft of the document. This change is based on consultation with the study author, where it was determined that techniques used to measure length data are likely to more accurately reflect growth than the originally-reported direct weight measurements. Since the original study was conducted, this laboratory has developed a robust empirical relationship between amphipod length and weight. Applying the formula, the 28-d average control length translates into a weight that is above the minimum control performance values listed in Appendix K of the draft criteria document. The average control reproduction for this study also met minimum performance values. Although the feeding rate used in this test was below that recommended for *H. azteca*, the finding that control organisms met the performance criteria of tests using a higher feeding rate supports retaining these data for use in deriving the AWQC.	Section 3.1.2 Section 5.2.1

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 3**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 4	My second concern is whether the sensitivity of *H. azteca* is real? Given that these 10-d data come from a 42-d study that fails to meet control performance criteria, how does EPA know that these animals weren't already stressed at 10 d and inappropriately sensitive? Given both the duration and performance issues associated with these data, in my opinion they should not be used for WQC derivation. However, I strongly encourage EPA to conduct a 28- or 42-d *Hyalella* study that meets the necessary performance criteria. Finally, after Table 18, EPA has descriptions of each of the chronic *H. azteca* studies and rationale for their rejection but did not include a description of the Ingersoll and Kemble study that was accepted and the rationale for use of the 10-d survival endpoint. This should be added to the document.	Please see response to previous comment. As indicated in the response, the full-life cycle study by Ingersoll and Kemble (2001) was found to satisfy the acceptability criteria for *H. azteca* and was used to replace the 10d study used in the previous draft of the document. The Agency is interested in obtaining information regarding new toxicity tests on *H. azteca* as noted in the Federal Register Notice to be issued announcing the availability of the 2015 draft cadmium criteria document for public comment.	Section 3.1.2 Section 5.2.1

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 3**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 5	As noted in the response above, the exclusion of most Hyalella data is doubtfully justifiable, because the criteria for doing so are questionable. However, even with these Appendix K criteria as they are, the Ingersoll and Kemble data reproductive data should not have been excluded. The 42d reproductive endpoint from that test met the Appendix K criteria for control survival and brood size (6.35 per female). The 28 day endpoint was presumably excluded because of low growth as weight. However, the organisms were not weighed, but rather lengths were measured and weights were inferred from lengths. Regardless, by the stated logic, it would follow to exclude the 28-day endpoint with low (estimated) weight. But to then pick an acute survival endpoint (10-day) instead of the 42-day reproductive endpoint is inexplicable. The entry for this test in Table 2 is misleading. Saying the test was a life cycle test, but then using an acute endpoint, is misleading. I estimated the EC20 for reduced reproduction to be about 1.2 µg/L using logistic regression, or the MATC (geomean of LOEC and NOEC) would be 0.98 µg/L.	In response to peer reviewers' comments, a further examination of this issue was conducted. Thus, after further evaluation, the full-life cycle study by Ingersoll and Kemble (2001) was found to satisfy the acceptability criteria for *H. azteca* and was used to replace the 10d study used in the previous draft of the document. This change is based on consultation with the study author, where it was determined that techniques used to measure length data are likely to more accurately reflect growth than the originally-reported direct weight measurements. Since the original study was conducted, this laboratory has developed a robust empirical relationship between amphipod length and weight. Applying the formula, the 28-d average control length translates into a weight that is above the minimum control performance values listed in Appendix K of the draft criteria document. The average control reproduction for this study also met minimum performance values. Although the feeding rate used in this test was below that recommended for *H. azteca*, the finding that control organisms met the performance criteria of tests using a higher feeding rate supports retaining these data for use in deriving the AWQC.	Section 3.1.2 Section 5.2.1

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 3**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 5	Other specific points on data used or not used. <u>Durations of tests</u> If 30-day tests with salmonids that started with fry consistently yield more sensitive results than 60-day tests that started with eggs or embryos, why ignore all the shorter, more sensitive tests. The Guidance counsels to beware of tests in which acclimation probably occurred during resistant states. Chapman (1985) recently described this problem. It would make more sense to exclude the less sensitive data, rather exclude the more sensitive data.	Use of the life cycle (LC) tests over the early life stage (ELS) tests in the draft reviewed by the external peer reviewers was consistent with the 1985 Guidelines. It was noted that there was no consistent pattern of early life stage tests being more sensitive than life cycle tests for salmonids Subsequently, based upon peer reviewer comments, use of sensitive salmonid tests was reconsidered and changes in the approach were made for the 2015 draft criteria. Specifically, ELS tests were used to calculate the revised SMCV in instances where they were more sensitive than the LC tests (e.g., *Salmo trutta*).	Section 3.1.2 Section 5.2.2 Appendix C
Reviewer 5	Likewise with Mottled Sculpin, there's doubtfully anything special about 28-day exposures over 21-day exposures. Besser et al. (2007) ran two tests, one 28-day and one 21-day test. The 28-day was less sensitive, and it was used with the other ignored. There is no established ASTM protocol for Mottled Sculpin, and the ASTM (1998) mention of "28 to 120-day (depending on species) continuous exposure" tests for early-life stage tests refers back to their species-specific appendices.	The SMCV/GMCV for the most sensitive fish species, *Cottus bairdii*, is from the results of one 28-d ELS test (Besser et al. 2007). The other study reported in the same paper, a 21-d ELS study, was not used quantitatively for the criteria derivation because there is a lack of guidance on the most appropriate duration for ELS tests with this species. U.S. EPA and ASTM guidance implies that ELS tests should last at least 28 days, so these data were not added to Appendix C. However, it is noteworthy that incorporating these data would only change the CCC slightly; the SMCV would change from 1.721 to 1.470 µg/L, and the criteria would only change by one-hundredth of a microgram, from 0.80 to 0.79 µg/L total cadmium.	Section 5.2.2
Reviewer 5	Other data (Calfee et al. 2014) and (Wang et al. 2014) report acute and chronic data with White Sturgeon and Rainbow Trout. The same data are reported in Environmental Toxicology and Chemistry, but Wang is paywalled, so I would use the open access USGS report version.	The cited papers were reviewed and the additional acceptable data were added to the appropriate tables and appendices.	Appendix A Appendix C Table 7 Table 20 Sections 5.1 Section 5.8.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 3	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 5	An acute test with Mottled Sculpin, (*Cottus bairdi*) and Cd was attributed to Mebane et al. (2012). We tested Shorthead Sculpin, *Cottus confusus*.	This was an error. The species name will be corrected, as appropriate.	Various locations

2.4 CHARGE QUESTION 4

4. Are the derived criteria appropriately protective of listed species and commercially and recreationally important species, particularly as the criteria relates to salmonids?

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 4**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 1	I agree with the author that marine animals are less at risk than freshwater animals, and this is primarily due to the strong chloro-complexation of Cd in seawater, thereby reducing the bioavailability of Cd. Consequently, marine bioconcentration factors are often 1-2 orders of magnitude higher in freshwater.	Thank you for your comment.	No edits needed.
Reviewer 1	I also agree that plants (e.g., phytoplankton) are less sensitive to Cd than animals, and thus it is appropriate to focus on the animals.	Thank you for your comment.	No edits needed.

Reviewer	External Peer Reviewer Comments Regarding Charge Question 4	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 1	I think that the criteria that the author generated for dissolved Cd have taken into consideration many of the key issues influencing this (e.g., water hardness) are probably ok, but by missing the effects of dietary Cd, the report is missing a large part of the overall story. This is not to suggest that ambient Cd concentrations are unsafe for animals, but the derived criteria are probably over-estimates of the safe levels of Cd.	Text has been added to discuss dietary exposure and incorporate the work of other researchers, such as Mebane (2006), who discuss cadmium bioaccumulation and dietary exposure in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	Section 5.6.1
Reviewer 1	Another complicating issue is the influence of dissolved organic carbon and its effect on Cd bioavailability. Thus, expressing Cd toxicity as a function of body burden is appropriate; the caveats associated with this approach have been appropriately discussed in the report.	EPA revised the text to indicate that in addition to hardness, which is a critical factor in determining toxicity, other water quality parameters such as DOC, alkalinity, and pH may also influence cadmium toxicity. EPA notes that integrating DOC into the analysis would be expected in most cases to make the criteria less stringent. Thus, while recognizing the need to consider the applicability of the BLM in future cadmium criteria updates, which would incorporate DOC, the inclusion of DOC in a BLM would be unlikely to make the criteria more stringent or conservative.	Section 2.3.1 Section 2.5 Section 5.1.3

Reviewer	External Peer Reviewer Comments Regarding Charge Question 4	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 2	Salmonids are clearly one of the more sensitive species with regard to Cd toxicity. Not only are they very sensitive, they are commercially important, and possess several species that are listed as endangered and threatened in the US. The proposed criteria are appropriate for freshwater conditions since many of the studies used to derive the criteria focused on freshwater treatments to rainbow trout. However, only one study evaluated Cd toxicity in coho salmon smolts in saltwater conditions, and this was at nearly full seawater strength (28 ppth). Of concern is the fact that many salmonids including strains of *O. mykiss* (steelhead) are anadromous and often come in contact with Cd at lower salinities (5-15 ppth). While the agency should be applauded for normalizing toxicity to hardness to improve freshwater criteria, there is a critical need to understand the impacts of salinity on Cd toxicity particularly in anadromous salmonid species. Of additional concern is the lack of discussion of sublethal impacts of Cd particularly to olfaction (Williams and Gallagher 2013) which significantly alters return rates of salmon (Baldwin et al. 2009). Return metrics are population level endpoints that should supersede standard repro/survival/growth. These should also be topics of discussion with regard to uncertainty.	Additional acceptable estuarine/marine toxicity data were not available for salmonids. Additional text (and references) was added to the appropriate uncertainty sections to emphasize the absence of these data.	Section 5.4.1 Section 5.5.2
Reviewer 2	Lastly, the issue of climate change is largely missing from the document. Acidification (particularly with metal availability) and temperature issues are also likely to impact sensitive species (e.g. salmonids). Sea level rise will also cause saltwater intrusion into salmonid spawning habitats and affect "estuarine/marine" criteria. Evaluation of these stressors should be focal points for future criteria assessment particularly for salmonids. Overall, while the values for freshwater are likely safe for salmonids, the values for estuarine/marine are highly uncertain and deserve further evaluation.	Thank you for your comment. EPA revises the criteria documents based on the best available scientific information at the time of development and based on current conditions in the environment. Criteria documents are then periodically revised to incorporate the latest scientific information based on toxicity and consideration of applicable environmental conditions.	No edits

Reviewer	**External Peer Reviewer Comments Regarding Charge Question 4**	**EPA Response**	**Revision Location in 2015 Draft Cadmium Criteria Document**
Reviewer 3	This seems to be the case if we assume that only aqueous exposures matter. Evidence for dietary toxicity is less compelling than for invertebrates, so for these fish species, the criteria are likely more protective for these species than they are for invertebrates.	EPA concurs with the reviewer about the difficulty of characterizing dietary exposure and establishing critical tissue effects thresholds for bioaccumulated metals. Text has been added to discuss dietary exposure and incorporate the work of other researchers, such as Mebane (2006), who discuss dietary exposure and cadmium bioaccumulation in detail and the uncertainties currently associated with its evaluation. In particular, text was added to detail how cadmium can bioaccumulate in aquatic organisms through multiple exposure routes including ingestion and direct exposure, and how total uptake depends on the cadmium concentration, exposure route and the duration of exposure. Text was also added to clarify that there does not appear to be a consistent relationship between body burden and toxicological effect, and an acceptable tissue effect concentration cannot be defined for aquatic life at this time. Bioaccumulation and effect level data that are available indicate that cadmium is unlikely to accumulate in tissue to levels that would result in adverse effects to aquatic invertebrates or fish at the calculated chronic criterion concentrations. For this reason, the evaluation of direct exposure effects to organisms via water is considered applicable to the development of criteria that is protective of aquatic life.	Section 5.6.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 4	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 4	Yes, I think the criteria as derived will be protective of salmonids. However, I'm concerned about the exclusion of the fountain darter data from the derivation. EPA argues that the acute data should be excluded because the test was fed and that the chronic data should be excluded because the study was only 7 d in duration (i.e., not true chronic). Generally, I agree with both of these decisions, but from my perspective, these rules are in place to prevent the inclusion of data indicating organisms are insensitive due to inappropriate test conditions (i.e., food reducing metal bioavailability, short test durations missing sensitive endpoints). However, this is not the case with the darter data, which indicate this species is very sensitive despite test conditions that would tend to reduce their sensitivity. EPA also seems to infer (p. 86) that the fountain darter data has limited applicability because this species has a limited distribution. However, the genus *Etheostoma* is widespread throughout central and eastern U.S. with a number of listed species at both the state and federal level. Hence these data a representative for a genus that is under considerable threat. Given this, I think it would be important to assess how inclusion of these data would impact derivation of the freshwater Cd WQC.	Text has been added to clarify that data eliminated were not used in criteria derivation because the test organisms were fed and the duration was too long for an acute test and too short for a true ELS test. EPA also added text indicating the genus *Etheostoma* is widespread, with some of species representing those of special concern. It is important that states evaluate the potential occurrence of these species when establishing site-specific standards.	Section 5.8.1 Section 5.8.2

Reviewer	External Peer Reviewer Comments Regarding Charge Question 4	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 4	Page 87: I don't think the statement that dividing the LC50 by two is expected to result in a concentration with effects no different than the control is correct. Dividing the LC50 by two will result in an "LC-low". I agree that across a range of species and toxicants, dividing by two equates to a values that approximates the NOEC. However, it does not equate to an LC0, which is inferred by this statement. Please clarify.	Dividing the FAV by a factor of two to derive a CMC is the standard approach used by the Agency to derive its 304(a) acute criterion recommendations, consistent with the 1985 Guidelines. The FAV is a statistical estimate of the 5th percentile of a set of LC50s. The LC50 is defined as the concentration that kills 50% of the exposed organisms. Thus, by definition, the FAV, as defined in the 1985 Guidelines, is a concentration that would be lethal to 50% of organisms with a sensitivity greater than 95% of genera. Since the FAV is a concentration that may affect 50 percent of the 5th percentile or 50 percent of a sensitive species, this value cannot be considered to be protective of that percentile or that species. Therefore, per the 1985 Guidelines, to derive the CMC EPA divides the FAV by a factor of 2 with the intention of defining a concentration that will not affect the majority of organisms. The rationale for adjusting the FAV to derive the CMC is explained in item 6 on page 17 of the 1985 Guidelines. The basis for this adjustment factor is an analysis of data from 219 acute toxicity tests showing that the mean concentration lethal to 0-10% of the test population was 0.44 times the LC50 or the LC50 divided by 2.27. The data and analysis on which the 2.27 value is based is described in the Federal Register on May 18, 1978 (43 FR 21506-21518). Best professional judgment was used to round the FAV "adjustment factor" of 2.27 to 2 in revisions of the Guidelines that occurred subsequent to the 1987 Federal Register notice. The use of the factor became final EPA guidance in the 1985 Guidelines.	Section 5.1.3

Reviewer	External Peer Reviewer Comments Regarding Charge Question 4	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 5	Not necessarily, although to definitively answer this would take a considerably more thorough review to determine than was presented in the document, or could be done independently in the time available. I note that NMFS (2012) in Oregon concluded the 2001 CMC of 2.0 µg/L could jeopardize some salmonids and that the CCC of 0.25 µg/L would not jeopardize listed salmonids under their prevue. Thus the draft 2015 criterion of 2.2 µg/L would presumably be a concern. Conversely, NMFS (2011) concurred with EPA that Idaho acute and chronic criteria of 1.34 and 0.55 µg/L respectively would not jeopardize listed anadromous salmonids. I did not attempt to reconcile the three documents. However, I think part of the discrepancies may be in the manner of analyses. In the draft document, data from long-term exposures to salmonids that began with sensitive fry life stage are excluded in favor of data from tests that began with eggs or alevins. While all fish have some life stage-sensitivity interaction, with at least salmonids sensitivity increases with size up to at least 0.4g ww, and maybe up to 1g or more (Hansen et al. 2002; Mebane et al. 2012). With other fish, the newly hatched stage may be more sensitive, or life events such as the onset of exogenous feeding may be related to a stressful and sensitive stage (Wang et al. 2014).	Use of the life cycle (LC) tests over the early life stage (ELS) tests is consistent with the 1985 Guidelines. Furthermore, there is no consistent pattern of early life stage tests being more sensitive than life cycle tests for salmonids However, to account for this discrepancy, ELS tests were used to calculate revised SMCV in instances where they were more sensitive than the LC tests (e.g., *Salmo trutta*).	Section 3.1.2 Section 5.2.2

Reviewer	External Peer Reviewer Comments Regarding Charge Question 4	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 5	There are some instances of inappropriate averaging using resistant life stages. Bull trout at the most sensitive (~1g) were averaged with results of test with yearling brook trout to produce a nonsense genus mean acute value of 126 µg/L. Stephan et al. advise against pooling species mean values when they differ by more than a factor of 10; these differed by a factor of 1000X.	This issue was re-examined ion depth based on the peer reviewer's comments. The SMAVs for bull trout and brook trout do differ by more than a factor of 10 (factor of 708X), most likely due the different sensitivities of the fish used to initiate the tests. The freshwater and estuarine/marine acute databases also include several genera where two or more widely different SMAVs (>10x factor) are available for estimating the GMAV. In this case the 1985 Guidelines recommend that some or all of the values probably should not be used in calculations. To resolve this issue, only the more sensitive SMAV (primarily due to a more sensitive life stage tested) was used to calculate the GMAV, thereby ensuring protection of the genus. It is important to note that the FAV can be lowered to protect the most sensitive SMAV for a commercially or recreationally important species to be conservative. This was the case for the acute freshwater value for both the 2001 AWQC and the current 2015 draft criteria update.	Table 7 Table 10 Section 5.1.3 Section 5.4.1

Reviewer	External Peer Reviewer Comments Regarding Charge Question 4	EPA Response	Revision Location in 2015 Draft Cadmium Criteria Document
Reviewer 5	The draft document evaluates protection of listed species by rolling up species data to a hardness-normalized species mean acute value (SMAV) and comparing that with the criteria. Because the accuracy of hardness-normalization is uncertain, but the criteria values can be calculated with certainty for any hardness, a more informative way to evaluate the data with listed species is to compare the criteria values for the conditions of each test of interest with listed species to the effects magnitude of effects to listed species at a given criteria. If the test concentrations causing an adverse effect are close to criteria concentrations, such as if the EC50s were within a factor of 2 (or maybe 2.5 to 3 to be on the safe side), then evaluate the actual adverse effects observed at the criteria concentrations. The SMAV approach involves a lot of data manipulation and may lose sensitive life stages or strains.	The criteria document provides the available toxicity data for listed species. A separate document is in development that addresses the detailed analyses of protection of Listed salmonid species. Additionally, states and tribes have the opportunity to use the toxicity data provided in this document, as appropriate, to their address their specific situation.	Section 5.8

2.5 OTHER COMMENTS PROVIDED

Reviewer	Comments	EPA Response	Revision Location
Reviewer 4	Additional Minor Comments Page 11: Note that Cd does not form complexes with Ca as stated, but rather competes with Ca for uptake and Ca channels. Please correct.	Text was revised as suggested.	Section 2.3
Reviewer 4	Page 11: While Atli and Canli did observe a reduction in NKA activity in their study, it's a significant overstatement to say disruption of Na homeostasis is a mechanism of action for Cd. To the best of my knowledge, it hasn't been observed in any other study that has investigated this potential mechanism.	Text was revised as suggested.	Section 2.3
Reviewer 4	Page 11: If Cd inhibits catalase, glutathione reductase, SOD, etc., it seems to me this is direct inhibition of anti-oxidant processes, not indirect as stated.	Text was revised as suggested.	Section 2.3
Reviewer 4	Page 12: Regarding the relationship between Cd tissue burdens and toxicity, see also the analysis by Adams et al. (2011).	EPA recognizes the difficulty in characterizing dietary exposure and establishing critical tissue effects thresholds associated with bioaccumulated metals (the identified paper has been reviewed and text has been added to the document).	Section 5.6.1
Reviewer 4	Page 50: *Tigriopus* is a copepod, not a mysid, as indicated in the second paragraph.	Text was revised as suggested.	Section 3.2.1
Reviewer 4	Page 58: Please specific at the top of p. 58 which two freshwater ACRs were used in the calculation of the marine ACR.	Text was revised to be clearer in the selection of ACRs used to calculate the FACR.	Section 3.2.2 Section 5.5.1
Reviewer 4	Table 18: Change the test duration for the Borgmann studies to 42 d rather than 6 w to make the units consistent with the rest of the table.	Text was revised as suggested.	Table 18
Reviewer 4	Page 83: It should be mentioned that both BCFs and BAFs are inversely related to exposure concentration which explains much of the variation in BCFs/BAFs (McGeer et al. 2003, DeForest et al. 2007).	Text was revised as suggested.	Section 5.6

Reviewer	Comments	EPA Response	Revision Location
Reviewer 4	Table 21: Taking a final look through Table 21 I note that EPA has included several species that are not resident to N. America (*Oreochromis spp.*, *Danio rerio*, *Xenopus laevis*). Unless this requirement has changed, they should be removed from the data set.	Naturally/wild reproducing North American species populations are considered for inclusion in the document. Each has been verified as such. Please see the following links for the species mentioned: http://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=67 http://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=505 http://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=468 http://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=466	No edits
Reviewer 5	Unfortunately, the compressed time period for this review (2 weeks, which works out to several hours on evenings and weekends for volunteer reviewers), makes a comprehensive review of a document of this length and complexity infeasible.	Thank you for your comment. EPA appreciates the comments that were provided during the time available for review.	No edits

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