

October 23, 2008

Via Electronic and U.S. Mail

Ms. Jeanine Townsend Clerk to the Board State Water Resources Control Board P.O. Box 100 Sacramento, CA 95812 commentletters@waterboards.ca.gov



Subject: Proposed Amendment to the Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California (the "SIP") to Establish Water Quality Objectives (WQOs) for Cadmium and Related Implementation Methods, CEQA Scoping Comments

Dear Ms. Townsend:

The California Association of Sanitation Agencies (CASA), the Central Valley Clean Water Association (CVCWA), the Southern California Alliance of POTWs (SCAP) and Tri-TAC (collectively, "the Associations") appreciate the opportunity to provide our scoping comments regarding the proposed amendment to the Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California (the "SIP") to establish water quality objectives (WQOs) for cadmium and related implementation methods. The constituency base for the Associations collects, treats and reclaims more than two billion gallons of wastewater each day and serves most of the sewered population of California.

We understand the State Water Board has requested early public comments by affected parties regarding the range of alternatives to be considered and the potential environmental impacts of those alternatives as part of the CEQA Scoping phase of proposed action. The proposed action merits significant attention since it involves the adoption of a statewide water quality objective for cadmium that will pertain to a number of important regulatory actions in California, including NPDES permitting, 303(d) listings and TMDL development. Because the proposed water quality objective for

cadmium is significantly more stringent than the existing objective, its adoption could have considerable impacts on wastewater dischargers throughout the state.

The proposed amendments are also important because, in addition to establishing water quality objectives for cadmium, they would potentially establish implementation procedures for not only cadmium, but all other metals with hardness-based objectives as well. These metals include copper, chromium (III), lead, nickel, silver and zinc. Because these constituents are present in essentially all wastewater discharges, the proposed amendments could potentially have notable impacts throughout the state.

### **Proposed Alternatives**

The notice issued by the State Water Board on June 16, 2008, describes three alternatives regarding adoption of a statewide water quality objective for cadmium, as follows:

- (1) No action Allow the cadmium objectives contained in the CTR to remain in force in California.
- (2) Adopt the USEPA 2001 cadmium objectives for saltwater and fresh water regimes, with the exception that the freshwater cadmium objectives would be based on the default hardness value of 100 mg/L as CaCO<sub>3</sub>.
- (3) Adopt the USEPA 2001 cadmium objectives for saltwater and fresh water regimes. The USEPA fresh water cadmium objectives would be adjusted based on the hardness of the waters to which the objectives pertain. Additionally, an implementation policy would be developed to specify the hardness selection.

Our understanding is that California objectives will only be effective after the United States Environmental Protection Agency issues a rule amending the federal regulations to withdraw the federally applicable criteria from the CTR.<sup>1</sup>

Of the three alternatives described in the State Water Board's June 16, 2008 notice, the Associations have significant concerns regarding the appropriateness and

<sup>&</sup>lt;sup>1</sup> U.S. EPA clarified its process in approving site specific objectives for copper and nickel in San Francisco Bay: "Under the procedures set out in the National Toxics Rule, published December 22, 1992 (see 57 FR 60860, December 22, 1992), and referenced in the CTR, when a state adopts and EPA approves water quality criteria that meet the requirements of the CWA, EPA will issue a rule amending the federal regulations to withdraw the federally applicable criteria. If the State's criteria are no less stringent than the promulgated Federal criteria, EPA will withdraw its criteria without notice and comment rulemaking because additional comment is unnecessary. (68 Fed. Reg. 62744, 62746 (November 6, 2003).)

attainability of Alternative 2. Given that the cadmium criteria are dependent on the hardness of ambient waters (i.e. the conditions that organisms are exposed to), it would be technically and environmentally unsound to adopt an objective that is correct only in the rare case where the ambient hardness was equal to the fixed value upon which the objective would be based (e.g. hardness of 100 mg/L as CaCO<sub>3</sub>). In some waters, the resulting effluent limitations may be insufficiently protective, while in many waters of the state the effluent limitations based on the fixed criteria would be unnecessarily stringent and costly to meet. Neither the costs of monitoring to determine actual hardness conditions, nor the effort to determine appropriate hardness values for interpretation of the objectives, rise to the level of significance to justify such an approach.

Alternative 1 should be selected only if it is shown that new objectives based on best available information would not represent a significant change from the California Toxics Rule (CTR) criteria.

### New Alternative(s) to be Considered

The Associations recommend that the State Water Board add one or more additional alternatives to the list under consideration. The alternative(s) should address the following:

Updated objectives derived through recalculation of the USEPA 2001 criteria using USEPA approved methodologies based on the consideration of additional data not used in the 2001 USEPA criteria derivation. For example, new data is available for freshwater chronic toxicity caused by cadmium. This data meets USEPA data acceptability requirements for criteria derivation, and was used in development of water quality criteria for cadmium in the state of Colorado. These water quality criteria were subsequently approved by the USEPA. Similar work on updating the 2001 USEPA 2001 cadmium criteria with newer data has been performed in Idaho and is being proposed in New Mexico. Use of the additional data available in deriving cadmium objectives for California will allow the state to have more robust objectives that are based on the most recent science. Included with this letter is a technical report that presents the new data that is available and outlines a proposed set of cadmium objectives that incorporate the data.

Objectives expressed as proposed values multiplied by a Water Effect Ratio (WER). The CTR expresses trace metal criteria in California as a value times a WER, consistent with the USEPA Metals Policy (refer to May 2000 CTR (131.38 (b)(1), footnote i). California should incorporate the same approach to improve the site-specific applicability of cadmium trace metals objectives.

Implementation of hardness-based metals criteria using a technically sound approach. Because the proposed criteria for cadmium depend on hardness, it is not possible to adequately evaluate the environmental impacts of adoption of the criteria unless the method of implementation is known. Therefore, if different implementation methods are being considered for adoption, they should each be considered a separate alternative. This is particularly important because the State Water Board has indicated that any implementation method would likely be applied to other hardness-based metals as well.

Further discussion of the technical issues related to these proposed alternatives is provided below.

### **Cadmium Objective Determination**

As stated above in the discussion of alternative proposals, the Associations endorse cadmium objectives comprised of a numeric value, derived from a hardnessadjusted formula where appropriate (e.g. fresh water), multiplied by a Water Effect Ratio, following the approach used in the May 2000 CTR (131.38 (b)(1), footnote i).

Furthermore, cadmium objectives should be based on the latest available data that passes USEPA criteria for data acceptability. At a minimum, the Associations recommend that the proposed cadmium freshwater objective should be based on a recalculation of the USEPA 2001 criteria using available chronic toxicity data for Daphnia. Preferably, we would recommend use of a recent, comprehensive update of the entire cadmium toxicity database.

GEI Consultants, Inc (GEI), Ecological Division, recently revised and updated current water quality objectives for cadmium, based on the USEPA criteria derivation methods. Extensive literature review on acute and chronic cadmium data resulted in many new data points added to the national toxicity database. USEPA methods for criteria derivation were followed to calculate an updated FAV/FCV for cadmium and provide updates to the corresponding equations. These updated equations are a result of the literature review, additional data on new and existing species in the toxicity databases, and reduced variability in the four most sensitive species. The resulting equations, including application of conversion factors for total to dissolved cadmium objectives, would be:

 $\begin{array}{l} \mbox{Acute Cd} = 1.136672 \mbox{-[(ln(hardness)*(0.041838)]} & e^{0.9151[ln(hardness)] \mbox{-}3.2488} \\ \mbox{Acute}_{(trout)} \mbox{Cd} = 1.136672 \mbox{-[(ln(hardness)*(0.041838)]} & e^{0.9151[ln(hardness)] \mbox{-}3.6236} \\ \mbox{Chronic Cd} = 1.101672 \mbox{-[(ln(hardness)*(0.041838)]} & e^{0.7998[ln(hardness)] \mbox{-}4.4255} \\ \end{array}$ 

These equations represent the most up-to-date science and, therefore, the Associations recommend their adoption as cadmium water quality objectives in California, with the appropriate WER adjustment and provisions to allow the equations to be adjusted with site-specific total to dissolved cadmium ratios. A technical report detailing the full basis for these equations is included with this letter.

### <u>Hardness</u>

The method by which hardness-based criteria will be implemented merits considerable attention. Choice of an implementation method will have far-reaching impacts across the state, as essentially all wastewater discharges contain metals. The extent to which these metals may be toxic to aquatic life are evaluated by hardness-based criteria. It is therefore essential to adopt a scientifically sound approach that is appropriately protective of the state's water bodies without being overly stringent. Adoption of an overly stringent implementation method could result in installation of unnecessary wastewater treatment to meet the resulting overly stringent criteria, with significant associated adverse economic and environmental impacts and no additional environmental benefit.

The Associations have conducted a detailed technical analysis of the appropriate hardness to use for implementation of hardness-based metals criteria, and derived a recommended implementation approach. The full analysis is included with this letter, as is a summary of the analysis. The recommended approach ensures that the associated effluent concentration will not cause or contribute to exceedances of criteria in possible blends of effluent and receiving water. This is the case irrespective of whether ambient hardness is less than or greater than effluent hardness or metals concentrations in the receiving water. This approach yields criteria for the effluent, and subsequent effluent limits if necessary, that provide the intended level of protection to aquatic organisms in the whole effluent and possible blends of effluent and receiving water. The results do not depend on a mixing zone for dilution, and no regulatory mixing zone is required to ensure protection of aquatic life in the receiving water.

The approach relies on simultaneous consideration of effluent hardness, receiving water hardness, and blending of effluent and receiving water. Depending on the mathematical properties of the relationship between metal concentration and hardness, certain conclusions can be drawn regarding the effects of hardness and blending. The resulting equations for total recoverable criteria assuming the default WER to derive WQBELs for hardness-dependent metals are given below:

Chronic:

Cadmium, Copper, Chromium (III), Nickel, and Zinc:  $CCC_{eff} = exp\{m_c*ln(hardness_{eff}) + b_c\}$  Lead and Silver:  $CCC_{eff} = \{(m_c/hardness_{R1})^*(hardness_{eff} - hardness_{R1}) + 1\}^*exp\{m_c^*ln(hardness_{R1}) + b_c\}$ 

Acute:

Copper, Chromium (III), Nickel, and Zinc:  $CMC_{eff} = exp\{m_A*ln(hardness_{eff}) + b_A\}$ 

Cadmium, Lead, and Silver:

 $CMC_{eff} = \{(m_A/hardness_{R1})*(hardness_{eff} - hardness_{R1}) + 1\}*exp\{m_A*ln(hardness_{R1}) + b_A\}$ 

Hardness<sub>eff</sub> and hardness<sub>R1</sub> are the effluent and upstream receiving water hardness, respectively, and  $m_A$ ,  $b_A$ ,  $m_C$ , and  $b_c$  are constants that have previously been determined through the criteria calculation process for each of the trace metals. For the case of the chronic criteria for cadmium, copper, chromium (III), nickel, and zinc, and for the case of the acute criteria for copper, chromium (III), nickel and zinc, the criteria is simply the equation in the CTR, calculated using effluent hardness. For the case of the chronic criteria for lead and silver, and for the case of the acute criteria for cadmium, lead, and silver, the criteria depend upon the upstream receiving water hardness and the effluent hardness.

Use of this approach is fully protective of aquatic life in receiving water, and resolves many difficult issues that would otherwise have to be addressed on an individual permit basis. However, in some cases use of the above approach will result in overly stringent criteria. Therefore, an option should be provided to allow dischargers to propose an alternative approach that is sufficiently protective.

Additionally, note that these equations express the CMC and CCC as total recoverable values. A total to dissolved translator would also have to be included when criteria are developed.

#### **Environmental Impacts**

If the Water Board pursues either Alternative 2 or 3, many of our member agencies will face significant compliance challenges. Members of the Associations, particularly in the Central Valley and Southern California areas, have indicated that they would not likely be able to comply with criteria contemplated under Alternatives 2 or 3. Alternative methods of compliance would need to be employed by dischargers, and thus the foreseeable environmental impacts associated with these alternative method need to be evaluated. Specific alternative methods of compliance and reasonably foreseeable environmental impacts in several areas are detailed below.

### <u> Air</u>

It is reasonably foreseeable that dischargers will need to install advanced treatment to achieve significant trace metals removal to comply with cadmium water quality standards, and potentially to comply with water quality standards for other hardness-based metals if an overly stringent implementation policy for hardness-based metals is adopted. While several different treatment options are available, reverse osmosis (RO) is a likely method of treatment. RO is highly energy intensive, resulting in increased electrical demands and associated air quality degradations including the release of atmospheric pollutants and greenhouse gases. It requires approximately 3,750 kWh to incorporate RO treatment for every million gallons of tertiary-treated wastewater. For a typical 20 MGD facility, this would result in an additional 27,375 MWh of energy usage per year. This would result in an annual increase of over 17,000 tons of CO<sub>2</sub>, 7.5 tons of  $NO_x$ , and over 200 pounds of  $SO_2$ .<sup>2</sup> These  $CO_2$  emissions are equivalent to over 2,800 passenger vehicles or 1.7 million gallons of gasoline. It has been estimated that the total volume from POTWs to rivers and effluent dominated waterbodies is approximately 1000 mgd. If all of these POTWs had to install RO treatment on their full flow, it would result in an additional 1,368,750 MWh of energy usage per year, with a resulting annual increase of over 850,000 tons of CO<sub>2</sub>, 375 tons of NO<sub>x</sub>, and over 10,000 pounds of SO<sub>2</sub>. The resulting CO<sub>2</sub> emissions would be the equivalent of putting 140,000 passenger vehicles on the road, or use of 85 million gallons of gasoline annually.

Additionally, when RO is employed, approximately 15 to 20% of the water entering the RO treatment unit is wasted as brine, which cannot be discharged to inland freshwater surface waters. For the inland dischargers that do not have access to a brine line, additional drying and disposal methods must be employed which can also significantly increase atmospheric pollution through additional energy use and transportation.

### Water and Groundwater

Furthermore, as discussed above, if Alternatives 2 or 3 are adopted it is reasonably foreseeable that some dischargers may install RO treatment to comply with metals water quality standards. The resulting brine waste, which cannot be discharged to most inland surface waters, would decrease surface water flow in some basins. Changes to surface water flow patterns could also impact groundwater flow patterns, as some surface waters have a hydraulic connection with ground waters. The State Board needs to fully evaluate the methods of compliance available and their reasonably foreseeable impacts on water and groundwater flows.

<sup>2</sup> Based on average 2002 emissions data from all California power generating facilities.

### **Plant Life and Animal Life**

As discussed above, if Alternatives 2 or 3 are adopted it is reasonably foreseeable that some dischargers may install additional treatment to comply with metals water quality standards. The State Board needs to fully evaluate the methods of compliance available and their reasonably foreseeable impacts on plant life and animal life.

### **Energy**

If Alternative 2 or 3 is adopted, dischargers that are unable to divert flows will need to incorporate advanced treatment capable of reducing metals, potentially resulting in increased electrical demands. As previously discussed, it will require approximately 3,750 kWh to incorporate advanced RO treatment for every million gallons of tertiarytreated wastewater, resulting in an additional 27,375 MWh of energy annually for a single 20 MGD facility or a total of 1,368,750 MWh of energy annually if all POTWs discharging to rivers or effluent dominated waterbodies had to install full RO treatment

### Cost Considerations

Adoption of Alternatives 2 or 3 could have considerable cost implications for dischargers. If RO treatment is necessary, considerable costs would be incurred. Using a Cost Parametric Estimating System, the approximate cost to install RO treatment (with pretreatment using microfiltration) for facilities from 5 to 50 MGD is \$1,055,000 x (Flow, MGD) + \$6,918,000. For a 20 MGD facility, the capital cost is approximately \$28 million. The State Water Board needs to fully explore the potential costs of compliance of implementation of the proposed policy. To the extent that a methodology for determining hardness is included as part of this effort, the State Water Board should evaluate the costs and environmental impacts which may result as a result of the proposed hardness methodologies for all metals that are hardness dependent.

### Legal and Policy Issues

In light of the attainability issues and potential adverse environmental impacts raised by the development of revised water quality objectives, it is critical that the Water Board thoroughly analyze the factors required under Water Code Section 13241, in particular consideration of ability to achieve proposed objective and the economics of compliance and Section 13242, consideration of the means by which the proposed objective would be achieved.

The State Water Board is to regulate to attain the highest water quality that is "reasonable." (Water Code §13000.) The Water Boards are under "an affirmative duty to consider economics when adopting water quality objectives in water quality control

plans." (Memorandum to Regional Water Board Executive Officers from William R. Attwater, Chief Counsel, January 4, 1994 at p.1.) To fulfill this duty, the State Water Board must assess the costs of the proposed WQOs for cadmium, including a review of available information to determine:

- Whether the objective is currently being attained.
- What methods are available to achieve compliance with the objective, if it is not currently being achieved.
- The costs of those methods. (Ibid.)

The Associations question whether an amendment to the SIP is the proper vehicle for adopting statewide water quality objectives. The State Water Board may adopt water quality control plans for waters of the United States. (Water Code §13170.) Such plans are to be developed in accordance with Water Code sections 13241 through 13244, which set forth specific factors to be considered in developing water quality objectives, and require development of an implementation program to achieve objectives. However, the SIP is arguably not a water quality control plan and specifically does not apply to either storm water or combined sewer overflows. The State Water Board should address these issues in its follow up to the CEQA scoping meeting.

Our Associations appreciate the opportunity to make these early comments regarding proposed cadmium objectives and seek to work collaboratively with the State Water Board in the adoption of objectives and implementing provisions that provide reasonable protection for beneficial uses in California.

Sincerely,

Kolurta L'Anson

fin Colston

Roberta Larson, CASA

elou Webst

Debbie Webster, CVCWA

John Pastore, SCAP

Jim Colston, Tri-TAC

Attachments:

- Attachment 1: Summary of Hardness Approach
- Attachment 2: Cadmium Criteria Update

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# Attachment 1:

Summary of Hardness Approach



Figure 1: Metals Criteria Curve Shapes with Reference Straight Lines it Highlight Curvature.

The following are the curve shapes for acute and chronic criteria for the following metals:

Downward: Cadmium (chronic), Chromium (III), Copper, Nickel, Zinc Upward: Cadmium (acute), Lead, Silver (acute)

Both the CTR and SIP state that criteria should be properly adjusted for hardness. Lacking in the CTR and the SIP is a discussion of where hardness should be measured and what value of hardness should be used to determine compliance with water quality criteria but it is generally understood that any water quality-based effluent limit should not cause or contribute to a receiving water WQO exceedance. In instances where an upstream receiving water is exceeding the WQO, it can be assumed that the receiving water is listed as impaired on the 303(d) list and that a TMDL with calculated waste load allocations (WLAs) is in place or is at least being developed to address the impairment. Furthermore, lacking a TMDL, it is still possible to demonstrate that the discharge is not contributing to the exceedance. Therefore, the most critical condition necessary to consider when selecting the appropriate hardness selection for hardness-adjusted trace metal effluent limit calculations under the CTR would be a condition where the receiving water and effluent discharge metal concentrations are both at the WQO calculated using at their respective hardness levels. The process for selecting the appropriate hardness that results in trace metal objectives protective under these conditions differs depending on the metal and its distinctive curve shape.

# Selection of Hardness Values for derivation of water quality –based effluent limitations for trace metals

Mitchell J Mysliwiec; Tom Grovhoug, Larry Walker Associates, Davis, CA

October, 2008

As established in the California Toxics Rule (CTR), the calculation of water quality objectives (WQOs) for some trace metals are dependent on the water column hardness. Toxicity testing has demonstrated that toxic effects associated with these metals is a function of the concentration of dissolved metal and the co-occurring hardness concentration that aquatic organisms are exposed to in receiving waters with increasing toxic effects observed as hardness decreases. The trace metals with hardness-dependent criteria are:

- Cadmium
- Chromium (III)
- Copper
- Lead
- Nickel
- Silver
- Zinc

The CTR provides mathematical formulas to determine WQOs at varying hardness for each of these metals and these formulas can be represented as curves with one of two distinct shapes: either (a) downward facing (concave) or (b) upward facing (convex) as illustrated in Figure 1 A straight line is included for each curve to highlight the "upward" and "downward" curvature.



Figure 1: Metals Criteria Curve Shapes with Reference Straight Lines it Highlight Curvature.

The following are the curve shapes for acute and chronic criteria for the following metals:

Downward: Cadmium (chronic), Chromium (III), Copper, Nickel, Zinc Upward: Cadmium (acute), Lead, Silver (acute)

Both the CTR and SIP state that criteria should be properly adjusted for hardness. Lacking in the CTR and the SIP is a discussion of where hardness should be measured and what value of hardness should be used to determine compliance with water quality criteria but it is generally understood that any water quality-based effluent limit should not cause or contribute to a receiving water WQO exceedance. In instances where an upstream receiving water is exceeding the WQO, it can be assumed that the receiving water is listed as impaired on the 303(d) list and that a TMDL with calculated waste load allocations (WLAs) is in place or is at least being developed to address the impairment. Furthermore, lacking a TMDL, it is still possible to demonstrate that the discharge is not contributing to the exceedance. Therefore, the most critical condition necessary to consider when selecting the appropriate hardness selection for hardness-adjusted trace metal effluent limit calculations under the CTR would be a condition where the receiving water and effluent discharge metal concentrations are both at the WQO calculated using at their respective hardness levels. The process for selecting the appropriate hardness that results in trace metal objectives protective under these conditions differs depending on the metal and its distinctive curve shape.

# Cadmium (chronic), Chromium (III), Copper, Nickel, Zinc

For cadmium (chronic), chromium (III), copper, nickel, zinc (downward facing criteria curves), using effluent hardness will result in a WQO that is protective throughout the receiving water regardless of effluent or receiving hardness. The scatter plot in Figure 2 illustrates the copper CCC calculated at a hardness ranging from 40 to 160 mg/L CaCO<sub>3</sub>. If we assume that the background ambient receiving water (R1) is represented by the 40 mg/L CaCO<sub>3</sub> hardness data point and the effluent is represented by the 160 mg/L CaCO<sub>3</sub> hardness data point, the straight dashed line connecting the two represents the entire range of possible receiving water metal concentrations affected by the discharge due to the blending of the effluent and receiving water, noting that infinite dilution would be required to reach the ambient background levels. The metal concentration across this inclusive range is at or below the calculated CCC. The most critical point in the receiving water is at the point of discharge where the metal concentration equals the criterion. The same holds true if we assume that the background ambient receiving water is represented by the 160 mg/L CaCO3 hardness data point and the effluent is represented by the 40 mg/L CaCO3 hardness data point, where the labels "Point of Discharge" and "Infinite Dilution" would be switched in Figure 2. Therefore, using receiving water hardness at the point of discharge best represented by the effluent hardness for all metals exhibiting a downward facing curve (Cadmium (chronic), Chromium (III), Copper, Nickel, Zinc) will result in sufficiently protective objectives across the entire range of receiving water condition.



Figure 2: Copper Chronic Criterion Typical of all Metals with Downward Facing Criteria Curves.

## Cadmium (acute), Lead, Silver (acute)

For metals represented by upward facing curves (acute cadmium, lead, and silver), a slightly modified approach is required for these metals to ensure that effluent limits will always be protective along the discharge gradient. The scatter plot in Figure 3 illustrates the lead CCC calculated at a hardness ranging from 40 to 160 mg/L CaCO<sub>3</sub>. If we assume that the ambient background receiving water is represented by the 40 mg/L CaCO<sub>3</sub> hardness data point and the effluent is represented by the 160 mg/L CaCO3 hardness data point lower, the straight dashed line connecting the two represents the entire range of possible receiving water metal concentrations based on the blending of the effluent and receiving water. Unfortunately, the metal concentration across this inclusive range is not at or below the calculated CCC indicating that using only effluent hardness to calculate the CCC would not be protective of all possible receiving water conditions. In fact, using effluent hardness alone would only be protective if the receiving water and effluent hardness were equal. Furthermore, use of only the receiving water hardness would only be protective if the upstream hardness was lower than or equal to the effluent levels. The use of a modified approach is necessary to account for the possibility of the receiving water hardness being greater or less than the effluent hardness. For this approach, it is necessary to project a tangent line from the receiving water hardness point on the characteristic curve to a point of intersection with the vertical line extending down from the effluent hardness point on the characteristic curve. This one approach results in criteria that are protective for any combination of effluent and receiving water hardness levels and amount of available dilution. This approach is illustrated in Figure 3 by the straight line tangent to the criteria curve at the ambient background criterion. As is evident in Figure 3, the metal concentration across this inclusive range is at or below the calculated CCC across the entire range of possible effluent/receiving water combinations. The case where ambient background hardness is greater than the effluent hardness is illustrated in Figure 4. The determination of this controlling criteria value requires the use of both effluent and receiving water hardness data in the following formula:

$$CCC_{eff} = \left\{ \frac{m_{c}}{H_{R1}} \cdot (H_{eff} - H_{R1}) + 1 \right\} \cdot exp\{m_{c} \cdot ln(H_{R1}) + b_{c}\}$$
$$CMC_{eff} = \left\{ \frac{m_{A}}{H_{R1}} \cdot (H_{eff} - H_{R1}) + 1 \right\} \cdot exp\{m_{A} \cdot ln(H_{R1}) + b_{A}\}$$

Note that in cases where the effluent hardness is low (generally below 100 mg/L as  $CaCO_3$ ) and the receiving water hardness is much greater than the effluent hardness, the formulas may result in a negative criterion. Under these conditions, a simple criterion for the effluent cannot be calculated without considering the available assimilative capacity of the receiving water. Generally, the condition resulting in negative criteria does not occur.



Figure 3: Lead Chronic Criterion Typical of all Metals with Upward Facing Criteria Curves where Effluent Hardness is Greater than Receiving Water Hardness.



Figure 4: Lead Chronic Criterion Typical of all Metals with Upward Facing Criteria Curves where Effluent Hardness is Less than Receiving Water Hardness.

# **Concerning Upstream WQO Exceedances**

If the receiving water exceeds a WQO upstream of the discharge, using the above method will also ensure that the discharge does not cause or contribute to the exceedance. In fact the above method will result in improved water quality for all blends of effluent and receiving water. For example if the upstream receiving water in the above examples exceeded WQOs by a factor of 1.4, all possible concentrations of effluent and receiving water are plotted in Figure 5. The information in Figure 5 is plotted as percent of criterion and percent effluent in Figure 6. The critical feature of Figure 6 is that for all concentrations of effluent and receiving water, the blend is closer to or below WQOs. The discharge with effluent WQOs based on effluent hardness for downward facing curves (copper) and upward facing curves (lead) does not cause of contribute to exceedances in the receiving water.



Figure 5: Copper and Lead Criteria and In plume Concentrations for Ambient Background Exceeding Criteria by a Factor of 1.4.



Figure 6: Percent of Lowest Criteria for Blends of Effluent and Receiving Water. For the Example of R1 Exceeding WQOs by a Factor of 1.4 and Effluent Meeting Criteria Based.

### Conclusions

For trace metals with concave (downward curved) hardness dependent criteria (cadmium (chronic), chromium (III), copper, nickel, zinc), selecting the effluent hardness as representative point of discharge receiving water hardness will result in effluent criteria protective of receiving water aquatic life regardless of receiving water flowrate or hardness levels. For trace metals with convex (upward curved) hardness dependent criteria (cadmium (acute), lead, silver (acute)), both background ambient hardness and effluent hardness must be utilized to determine the effluent criteria protective of receiving water than the effluent hardness is low and the receiving water affected by the discharge. Where the effluent hardness is low and the receiving water hardness is much greater than the effluent hardness, consideration of the assimilative capacity of the receiving water may be necessary to determine the appropriate effluent criteria. In the case where the background ambient concentrations exceed the criteria, using the above hardness selection will result in effluent criteria such that the discharge will not contribute to the background exceedance.

The proposed hardness selection method is applicable to all discharges and receiving waters. All possible receiving water flowrates are considered from zero upstream flow to an infinite upstream flow. All possible combinations of background ambient hardness and effluent hardness are considered in the proposed method. The proposed method is developed for meeting criteria at the point of discharge (i.e. no dilution credits), but the method could be modified for regulatory mixing zones as applicable, by meeting criteria at the prescribed dilution at the edge of the mixing zone. The proposed method is uniformly applicable to all discharges and results in metals criteria for the effluent that are protective of aquatic life in all areas in the receiving water affected by the discharge.

# Attachment 2:

# Cadmium Criteria Update



GEI consultants

# Water Quality Objectives for Cadmium – Review and Update

Submitted to:

Santa Ana River Dischargers Association; Los Angeles County Sanitation District

Submitted by: GEI Consultants, Inc. **Ecological Division** 5575 South Sycamore Street, Suite 101 Littleton, Colorado 80120







Geotechnical Water Resources Environmental and Ecological Services

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Table 2:	Acute Cd toxicity data added to the acute database (CEC 2004a, 2004b).
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GEI Consultants, Inc. Ecological Division ii

At the request of members of the Santa Ana River Dischargers Association (specifically, San Bernardino, Riverside, Eastern Municipal, Corona, and Yucaipa), as well as the Los Angeles County Sanitation District, GEI Consultants, Inc (GEI), Ecological Division, has evaluated the technical basis for California's current water quality objectives for cadmium (Cd), based on the United States Environmental Protection Agency (EPA) criteria derivation and recalculation procedures (Stephan et al. 1985, EPA 1994). This analysis was initiated using the existing criteria document and national cadmium toxicity databases (EPA 2001), which are the basis for changes in the water quality objectives by the State Water Resources Control Board staff.

The purpose of this analysis was to revise and update acute and chronic Cd objectives using EPA criteria derivation methods. This report is based primarily on a previous technical review and update of the 2001 revised EPA Cd criteria conducted by GEI (formerly Chadwick Ecological Consultants, Inc. CEC 2004a, 2004b).

The first step of the EPA recalculation procedure is a technical review of the most up-to-date EPA ambient water quality criteria (AWQC) documents to determine if 1) suitable and correct data were included in national toxicity databases, and 2) EPA criteria development methods were followed for deriving AWQC. The EPA's *Guidelines for Deriving Numerical Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Stephan et al. 1985), hereafter referred to as the 1985 Guidelines, provide details on the acceptable data and criteria derivation methods, including minimum data requirements for the toxicity database, often referred to as the "eight-family rule" (Stephan et al. 1985). The next step is to update the national toxicity databases, with an emphasis on literature available since the most recently published database. Following the compilation of literature and development of the revised database, each acute and chronic AWQC is recalculated using methods as described by the 1985 Guidelines.

Current Cd objectives in California are based on an EPA report entitled 1995 Updates: Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water (EPA 1996). The EPA revised its aquatic life criteria for Cd on April 12, 2001, with the publication entitled 2001 Update of Ambient Water Quality Criteria for Cadmium (EPA 2001) hereafter referred to as the 2001 Cadmium Document. This document established an updated (from the 1996 document) toxicity database with recommended AWQC to protect freshwater organisms. This 2001 update is the basis for recommended Cd objectives by the SWRCB staff, as outlined in the notice.

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Phase 1 of our evaluation of the 2001 Cadmium Document consisted of a thorough investigation of the data used to calculate the most recent EPA Cd criteria (CEC 2004a). The document (EPA 2001) was critically reviewed for relevance of the toxicological data and adherence to EPA methodology (Stephan et al. 1985). The criteria presented in the 2001 Cadmium Document supersede previous the 1995 AWQC update for Cd (EPA 1996), which was built upon the 1984 criteria document (EPA 1984).

## 2.1 2001 Acute Criteria for Cadmium

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

Table 1: Summary of data from the 2001 Cadmium Document used by EPA in the Cd criteria calculations, but deemed unsuitable and, therefore, deleted from the revised databases.

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Species	Reference	Reason
Acute:		
Salvelinus fontinalis	Carroll et al. 1979	control had higher Cd concentration than $LC_{50}$ , but no response
Daphnia magna	Attar and Maly 1982	previous exposure of test organisms to Cd
Xenopus laevis	Sunderman et al. 1991	pest species; not native to North America

Carroll et al. (1979) examined the toxicity of Cd to brook trout (*Salvelinus fontinalis*) in response to various hardness constituents (i.e., CaCO<sub>3</sub>, MgCO<sub>3</sub>, etc.). The LC<sub>50</sub> value used in the 2001 Cadmium Document came from the test in which the authors used reconstituted soft water. However, the LC<sub>50</sub> (<1.5  $\mu$ g/L) is lower than the measured Cd concentration for the control (2.9  $\mu$ g/L), in which they reported 100 percent survival. Therefore, we determined this set of data possessed inappropriate test conditions and methodology and was removed from the revised acute Cd database.

Additionally, data was used from a study conducted by Attar and Maly (1982) that examined the toxicity of Cd, zinc, and their mixtures to *Daphnia magna*. It was determined these data were unsuitable for use in AWQC derivations because of inappropriate treatment of test organisms. *D. magna* test organisms were cultured in a 430 L polyethylene tub containing a concentrated algae culture. Water quality analyses of the culture water showed that the water

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

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

## 2.2 Existing Chronic Criteria for Cadmium

The 2001 Cadmium Document presents chronic data for 16 genera of freshwater organisms, including seven species of invertebrates and 14 species of fishes. These 21 species satisfy the "eight-family rule" as specified in the 1985 Guidelines. The resultant revised chronic Cd database is the same as the 2001 Cadmium Document, in terms of the number and composition of genera and species, following the Phase 1 review.

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

## 2.2 Existing Chronic Criteria for Cadmium

The 2001 Cadmium Document presents chronic data for 16 genera of freshwater organisms, including seven species of invertebrates and 14 species of fishes. These 21 species satisfy the "eight-family rule" as specified in the 1985 Guidelines. The resultant revised chronic Cd database is the same as the 2001 Cadmium Document, in terms of the number and composition of genera and species, following the Phase 1 review.

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## 3.1 New Acute Cadmium Toxicity Data

A comprehensive literature review of all Cd documents not used in the 2001 Cd update was originally conducted by GEI in 2004 (CEC 2004a). This included a review of all documents published since the 2001 Cadmium Document, as well as those published prior to 2001 that were not used in the criteria derivation. Relevant Cd toxicity documents were obtained and reviewed for relevance of the toxicological data and adherence to EPA methodology (Stephan et al. 1985). Approximately 130 papers were reviewed, including unpublished toxicity data from recent studies conducted on behalf of Thompson Creek Mining Company (TCMC) (CEC 2003), as well as acute and chronic trout toxicity data from the Colorado Division of Wildlife (CDOW) published as "Federal Aid to Fisheries" (i.e., gray literature) reports.

Following review of these studies, we were able to add 21 acute data points from seven studies to the revised acute Cd database (Table 2). Of the seven studies added to the database, four were published prior to the 2001 Cadmium Document. Two of these studies published prior to 2001 were not cited in either Table 1a (Acute toxicity of Cd to freshwater animals) or Table 6a (Other data on effects of Cd on freshwater organisms) of the 2001 Cadmium Document and apparently represent data unknown to EPA.

Suedel et al. (1997) tested the effects of exposure duration, test organism, and test endpoint on the toxicity of Cd to a variety of freshwater species. Suitable acute 48- and 96-hour data points were reported in this study for Ceriodaphnia dubia, D. magna, Pimephales promelas, Hyalella azteca, and Chironomus tentans and were incorporated into the revised acute database. The other study not mentioned in the 2001 Cadmium Document is an internal report published by the CDOW in which brown trout (Salmo trutta) were exposed to various concentrations of Cd sulfate in a static renewal toxicity test (Davies and Brinkman 1994). One acute value for S. trutta was utilized from this study. There are three studies listed in Table 6a ("Other Data") in the 2001 Cadmium Document that we believe provide useful data. One data point for the arctic grayling (Thymallus arcticus) from Buhl and Hamilton (1991) was added to the revised acute Cd database. The data point is listed in Table 6a of the 2001 Cadmium Document because the EPA claims the toxicity test was conducted improperly due to low dissolved oxygen. Indeed, the authors stated there were dissolved oxygen problems in one of their selenite tests; yet, dissolved oxygen levels never fell below 40 percent saturation for their Cd tests. We believe this Cd data point is appropriate for use. Additional data listed in Table 6a of the 2001 Cadmium Document was for Oncorhynchus mykiss data from Davies et al. (1993), with no reason provided for the exclusion. Davies et al. (1993) tested acute and chronic toxicity of Cd to O. mykiss at three different target hardness values (50, 200, and 400 mg/L). The acute values listed in Table 6a are inconsistent

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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L)	LC <sub>50</sub> (µg/L)	Adjusted LC <sub>50</sub> <sup>b</sup>	Reference
Ceriodaphnia dubia	S, M, T	CdCl <sub>2</sub>	17	63.01		Suedel et al. 1997
Daphnia magna	S, M, T	CdCl <sub>2</sub>	17	26.40		Suedel et al. 1997
Pimephales promelas	S, M, T	CdCl <sub>2</sub>	17	4.80	12.96	Suedel et al. 1997
Hyalella azteca*	S, M, T	CdCl <sup>2</sup>	17	2.80		Suedel et al. 1997
Chironomus tentans**	S, M, T	CdCl <sub>2</sub>	17	2,956.00		Suedel et al. 1997
Salmo trutta	F, M, T	CdSO₄	37.6	2.37		Davies and Brinkman 1994
Salmo trutta	F, M, D	CdSO₄	151.4	3.66		Brinkman and Hansen 2004
Salmo trutta	F, M, D	CdSO₄	29.2	1.23		Brinkman and Hansen 2004
Salmo trutta	F, M, D	CdSO₄	67.6	3.9		Brinkman and Hansen 2004
Thymallus arcticus* (juvenile)	S, M, T	CdCl <sub>2</sub>	41	4.00	4.80	Buhl and Hamilton 1991
Oncorhynchus mykiss	R, M, T	CdCl <sub>2</sub>	420 (388-490)	7.40	1.04	Davies et al. 1993
Oncorhynchus mykiss	F, M, T	CdCl <sub>2</sub>	427 (406-444)	5.92	0.82	Davies et al. 1993
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Oncorhynchus mykiss	F, M, T	CdCl <sub>2</sub>	227 (212-243)	6.57	1.63	Davies et al. 1993
Oncorhynchus mykiss	F, M, T	CdCl <sub>2</sub>	46 (45-48)	2.64	2.85	Davies et al. 1993
Oncorhynchus mykiss	F, M, T	CdCl <sub>2</sub>	49 (48-50)	3.08	3.14	Davies et al. 1993
Chironomus plumosus**	S, U	CdCl <sub>2</sub>	80	12,700.00		Fargasova 2003
Daphnia magna	R, M, T	CdCl <sub>2</sub>	50	4.00		CEC 2003
Daphnia magna	R, M, T		100	8.00	4.23	CEC 2003
Daphnia nulgru Daphnia pulex	R, M, T	CdCl <sub>2</sub>	50	16.00	16.00	CEC 2003
Daphnia pulex	R, M, T	CdCl <sub>2</sub>	100	20.00	10.57	CEC 2003

Table 2.	Acute Cd toxicity data added to the acute database (CEC 2004a, 2004b).

S = static, R = renewal, M = measured, U = unmeasured, T = total measured concentration, F = flow-through, and D = dissolved measured concentration

Value adjusted to hardness = 50 using the revised acute slope (0.9207) listed in Table 6.

\* New genus.

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Pimephales promelas	S, M, T	CdCl <sub>2</sub>	17	4.80	12.96	Suedel et al. 1997
Hyalella azteca*	S, M, T	CdCl <sup>2</sup>	17	2.80	7.56	Suedel et al. 1997
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Daphnia magna	R, M, T	CdCl <sub>2</sub>	100	8.00	4.23	CEC 2003
Daphnia nulgrid Daphnia pulex	R, M, T	CdCl <sub>2</sub>	50	16.00	16.00	CEC 2003
Daphnia pulex	R, M, T	CdCl <sub>2</sub>	100	20.00	10.57	CEC 2003

Table 2:	Acute Cd toxicit	y data added to the acute database (CEC 2004a, 2004b).

S = static, R = renewal, M = measured, U = unmeasured, T = total measured concentration, F = flow-through, and D = dissolved measured concentration

Value adjusted to hardness = 50 using the revised acute slope (0.9207) listed in Table 6.

\* New genus.

\*\* New species.

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Species	Common Name	Method	Hardness as CaCO <sub>3</sub> (mg/L)	Test Duration	LC <sub>50</sub> (µg/L)	Adjusted LC <sub>50</sub> (µg/L)	Reference
Salmo trutta	Brown trout	M, F	29.2	96-hr	1.23	2.01	Brinkman and Hansen 2007
Salmo trutta	Brown trout	M, F	67.6	96-hr	3.9	2.96	Brinkman and Hansen 2007
Salmo trutta	Brown trout	M, F	151	96-hr	10.1	3.67	Brinkman and Hansen 2007
Oncorhynchus mykiss	Rainbow trout	M, R	29	96-hr	0.84	1.38	Mebane et al. 2007
Oncorhynchus mykiss	Rainbow trout	M, R	20	96-hr	0.89	2.06	Mebane et al. 2007
Oncorhynchus mykiss	Rainbow trout	M, F	103	96-hr	4.7	2.43	Besser et al. 2007
Chironomus riparius	Midge	, .	140	48-hr	1,106,000	431,083	Gillis and Wood 2007
Cottus bairdi	Mottled sculpin	M, F	103	96-hr	4.6	2.37	Besser et al. 2007
Cottus bairdi	Mottled sculpin	M, F, D	48.7	96-hr	1.92	1.97	CDOW 2007
Rhithrogena hageni	Mayfly	M, F, D	48	96-hr	10,500	10,900	CDOW 2007

Table 3: New acute Cd data from the literature review performed by GEI (2008).

## 3.2 New Chronic Cadmium Toxicity Data

Sixteen chronic data points from six studies were added by the revised chronic database (Table 4) as a result of the literature review in 2004. Two of these studies were published prior to 2001, and were not cited in the 2001 Cadmium Document. Suedel et al. (1997) examined the long-term chronic effect of Cd on several species, in addition to the acute effects previously mentioned. Long-term toxicity tests were conducted for the same five species (*C. dubia*, *D. magna*, *P. promelas*, *H. azteca*, and *C. tentans*) as the acute toxicity tests reported in that study. However, we only added the data for *C. dubia* to the revised chronic Cd database because the test duration for the other species did not meet EPA chronic criteria development standards (Stephan et al. 1985). Additionally, Davies and Brinkman (1994) conducted a long-term toxicity test of Cd on *S. trutta* in soft water that satisfies criteria development standards (Stephan et al. 1985). The reported chronic value from this study was added to the revised chronic database.

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Species	Common Name	Method	Hardness as CaCO <sub>3</sub> (mg/L)	Test Duration	LC₅₀ (µg/L)	Adjusted LC <sub>50</sub> (µg/L)	Reference
Salmo trutta	Brown trout	M, F	29.2	96-hr	1.23	2.01	Brinkman and Hansen 2007
Salmo trutta	Brown trout	M, F	67.6	96-hr	3.9	2.96	Brinkman and Hansen 2007
Salmo trutta	Brown trout	M, F	151	96-hr	10.1	3.67	Brinkman and Hansen 2007
Oncorhynchus mykiss	Rainbow trout	M.R	29	96-hr	0.84	1.38	Mebane et al. 2007
Oncorhynchus mykiss	Rainbow trout	M, R	20	96-hr	0.89	2.06	Mebane et al. 2007
Oncorhynchus mykiss	Rainbow trout	M.F	103	96-hr	4.7	2.43	Besser et al. 2007
Chironomus riparius	Midge		140	48-hr	1,106,000	431,083	Gillis and Wood 2007
Cottus bairdi	Mottled sculpin	M.F	103	96-hr	4.6	2.37	Besser et al. 2007
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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L)	Chronic Value (µg/L)	Adjusted Chronic Value <sup>b</sup>	Reference
Ceriodaphnia dubia	LC	CdCl <sub>2</sub>	17.0	2.00	4.459	Suedel et al. 1997
Salmo trutta	ELS	CdSO <sub>4</sub>	39.8	1.33	1.576	Davies and Brinkman 1994
Daphnia magna	LC		209.2	0.69	0.231	Canton and Slooff 1982
Oncorhynchus mykiss	LC	CdCl <sub>2</sub>	46.2 (45-48)	1.47	1.559	Davies et al. 1993
Oncorhynchus mykiss	LC	CdCl <sub>2</sub>	217.0 (203-240)	3.58	1.203	Davies et al. 1993
Oncorhynchus mykiss	LC	CdCl <sub>2</sub>	413.8 (383-438)	3.64	0.757	Davies <i>et al</i> . 1993
Hyalella azteca	ELS	CdCl <sub>2</sub>	280.0	1.40	0.389	Ingersoli and Kemble 2001
Daphnia magna	LC	CdCl <sub>2</sub>	50.0	3.43	3.430	CEC 2003
Daphnia pulex	LC	CdCl <sub>2</sub>	50.0	1.45	1.450	CEC 2003
Daphnia magna	LC	CdCl <sub>2</sub>	50.0	2.32	2.320	CEC 2003
Daphnia magna	LC	CdCl <sub>2</sub>	50.0	2.80	2.800	CEC 2003
Daphnia magna	LC	CdCl <sub>2</sub>	100.0	2.60	1.553	CEC 2003
Daphnia pulex	LC	CdCl <sub>2</sub>	50.0	2.50	2.500	CEC 2003
Hyalella azteca	EL\$	CdCl <sub>2</sub>	120.0	0.62	0.323	CEC 2003
Hyalella azteca	ELS	CdCl <sub>2</sub>	150.0	0.73	0.323	CEC 2003
Hyalella azteca	ELS	CdCl <sub>2</sub>	120.0	0.50	0.261	CEC 2003

Table 4: Chronic Cd toxicity data added to the chronic database (CEC 2004a, 2004b).

<sup>a</sup> ELS = early life stage and LC = life cycle or partial life cycle.

<sup>b</sup> Value adjusted to hardness = 50 using the revised chronic slope (0.7432) found in Table 8.

As noted earlier, in early 2008, GEI conducted another scientific literature review to update the Cd toxicity database. This search resulted in the addition of data for two species to the chronic database (Table 5).

Species	Common name	Hardness	Chronic Value	Reference
Cottus bairdi	mottled sculpin	103	1.9	Besser et al. 2007
Oncorhynchus mykiss	rainbow trout	29	<0.16	Mebane et al. 2007
Oncorhynchus mykiss	rainbow trout	20	1.9	Mebane et al. 2007

Table 5: New chronic Cd data from the literature review performed by GEI (2008).

### 3.3 Updated Acute and Chronic Cadmium Toxicity Databases

After excluding inappropriate data used in the 2001 Cadmium Document and adding data deemed suitable for inclusion from our literature review, revised acute (Table 6) and chronic (Table 7) databases were compiled. These databases can serve as the basis for the subsequent recalculation of updated Cd water quality objectives. For each species with at least one acute value, the species mean acute value (SMAV) was calculated as the geometric mean of the individual acute values (Stephan *et al.* 1985). Results from all flow-through tests and those in which the concentrations of the test material were measured took precedence over tests using static or renewal methods and unmeasured concentrations (Stephan *et al.* 1985). For each genus with more than one SMAV, the genus mean acute value (GMAV) was calculated as the geometric mean of all available SMAVs for the genus. Otherwise, the GMAV was equal to the SMAV if data for only one species was available (Stephan *et al.* 1985).

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L)	Chronic Value (µg/L)	Adjusted Chronic Value <sup>b</sup>	Reference
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Daphnia magna	LC	CdCl <sub>2</sub>	50.0	3.43	3.430	CEC 2003
Daphnia nagna	LC	CdCl <sub>2</sub>	50.0	1.45	1.450	CEC 2003
Daphnia magna		CdCl <sub>2</sub>	50.0	2.32	2.320	CEC 2003
Daphnia magna		CdCl <sub>2</sub>	50.0	2.80	2.800	CEC 2003
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Species	Common name	Hardness		Reference				
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Table 5: New chronic Cd data from the literature review performed by GEI (2008).

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Daphnia magna		CdCl <sub>2</sub>	50.0	2.80	2.800	CEC 2003
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Daphnia pulex	LC	CdCl <sub>2</sub>	50.0	2.50	2.500	CEC 2003
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Daphnia pulex	LC	CdCl <sub>2</sub>	50.0	1.45	1.450	CEC 2003
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Daphnia magna	LC		50.0	2.80	2.800	CEC 2003
Daphnia magna	LC	CdCl <sub>2</sub>	100.0	2.60	1.553	CEC 2003
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able 5: New Chroni		Hardness	Chronic Value	Reference
Species	Common name	naidiless		
Cottus bairdi	mottled sculpin	103		Besser et al. 2007
Oncorhynchus mykiss	rainbow trout	29	<0.16	Mebane et al. 2007
Oncorhynchus mykiss	rainbow trout	20	1.9	Mebane et al. 2007

Table 5: New chronic Cd data from the literature review performed by GEI (2008).

## 3.3 Updated Acute and Chronic Cadmium Toxicity Databases

After excluding inappropriate data used in the 2001 Cadmium Document and adding data deemed suitable for inclusion from our literature review, revised acute (Table 6) and chronic (Table 7) databases were compiled. These databases can serve as the basis for the subsequent recalculation of updated Cd water quality objectives. For each species with at least one acute value, the species mean acute value (SMAV) was calculated as the geometric mean of the individual acute values (Stephan *et al.* 1985). Results from all flow-through tests and those in which the concentrations of the test material were measured took precedence over tests using static or renewal methods and unmeasured concentrations (Stephan *et al.* 1985). For each genus with more than one SMAV, the genus mean acute value (GMAV) was calculated as the geometric mean of all available SMAVs for the genus. Otherwise, the GMAV was equal to the SMAV if data for only one species was available (Stephan *et al.* 1985).

#### Updated Acute Database 3.3.1

The revised acute Cd AWQC database consists of 70 species (increased from 65) occupying 58 genera (increased from 55) of freshwater organisms Table 6). Only one species and its corresponding genus (X. laevis) in the 2001 Cadmium Document database is not present in the revised acute database. Six species (C. bairdi, R. hageni, T. arcticus, H. azteca, C. tentans, and C. plumosus) were added to the acute database, resulting in four additional genera (Cottus, Rhithrogena, Thymallus, and Hyalella). The revised acute database meets the "eight-family rule." Genus mean acute values range from the most sensitive at 1.91 µg/L for the genus Salvelinus to the least sensitive at 14,880 µg/L for the genus Dendrocoelum. The top four most sensitive genera are all fish, and include Salvelinus (1.91 µg/L), Cottus (2.16  $\mu$ g/L), Salmo (2.88  $\mu$ g/L), and Morone (3.16  $\mu$ g/L).

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family
58	Dendrocoelum lacteum	14,880.09	14,880.09	Planaria	Planariidae
57	Orconectes virilis	<11,193.54	11,097.25	Crayfish	Cambaridae
51	Orconectes immunis		<11,371.23	Crayfish	Cambaridae
56	Rhithrogena hageni	10,899.66	10,899.66	Mayfly	Heptageniidae
55	Oreochromis mossambica	10,068.09	10,068.09	Tilapia	Cichlidae
54	Chironomus riparius*	7,933.19	216,223.17	Midge	Chironomidae
94	Chironomus tentans		7,933.19	Midge	Chironomidae
	Chironomus plumosus		8,260.64	Midge	Chironomidae
53	Gasterosteus aculeatus	5,897.00	5,897.00	Threespine stickleback	Gasterosteidae
52	Gambusia affinis	5,578.08	5,578.08	Mosquitofish	Poeciliidae
51	Ictalurus punctatus	4,994.42	4,994.42	Channel catfish	Ictaluridae
50	Rhyacodrilus montana	4,912.28	4,912.28	Tubificid worm	Tubificidae
49	Lepomis cyanellus	4,812.28	3,595.94	Green sunfish	Centrarchidae
43	Lepomis macrochirus		6,440.04	Bluegill	Centrarchidae
48	Cyprinus carpio	4,547.36	4,547.36	Common carp	Cyprinidae
47	Stylodrilus heringianus	4,228.50	4,228.50	Tubificid worm	Tubificidae
46	Notropis lutrensis	4,051.76	4,051.76	Red shiner	Cyprinidae
45	Spirosperma ferox	3,094.45	2,729.04	Tubificid worm	Tubificidae
40	Spirosperma nikolskyi		3,508.77	Tubificid worm	Tubificidae
44	Varichaeta pacifica	2,962.96	2,962.96	Tubificid worm	Tubificidae
43	Catostomus commersoni	2,827.16	2,827.16	White sucker	Catostomidae
42	Jordanella floridae	2,810.24	2,810.24	Flagfish	Cyprinodontidae
41	Poecilia reticulata	2,569.18	2,569.18	Guppy	Poeciliidae
40	Quistradilus multisetosus	2,495.13	2,495.13	Tubificid worm	Tubificidae
39	Ephemerella grandis	2,248.19	2,248.19	Mayfly	Ephemerellidae
38	Branchiura sowerbyi	1,871.34	1,871.34	Tubificid worm	Tubificidae
37	Crangonyx pseudogracilis	1,700.00	1,700.00	Amphipod	Crangonyctidae
36	Procambarus clarkii	1,659.77	1,659.77	Crayfish	Cambaridae
35	Tubifex tubifex	1,344.34	1,344.34	Tubificid worm	Tubificidae
34	Limnodrilus hoffmeisteri	867.63	867.63	Tubificid worm	Tubificidae
33	Carassius auratus	833.89	833.89	Goldfish	Cyprinidae
32	Asellus bicrenata	548.72	548.72	lsopod	Asellidae
31	Ambystoma gracile	515.81	515.81	Salamander	Ambystomatidae
30	Plumatella emarginata	299.69	299.69	Bryozoan	Plumatellidae
29	Alona affinis	267.59	267.59	Cladoceran	Chydoridae
28	Cyclops varicans	241.62	241.62	Copepod	Cyclopidae

#### Revised acute Cd criteria database. Table 6:

GEI Consultants, Inc. **Ecological** Division

October 2008 Cadmium Objectives - Review and Update

#### Updated Acute Database 3.3.1

The revised acute Cd AWQC database consists of 70 species (increased from 65) occupying 58 genera (increased from 55) of freshwater organisms Table 6). Only one species and its corresponding genus (X. laevis) in the 2001 Cadmium Document database is not present in the revised acute database. Six species (C. bairdi, R. hageni, T. arcticus, H. azteca, C. tentans, and C. plumosus) were added to the acute database, resulting in four additional genera (Cottus, Rhithrogena, Thymallus, and Hyalella). The revised acute database meets the "eight-family rule." Genus mean acute values range from the most sensitive at 1.91  $\mu$ g/L for the genus Salvelinus to the least sensitive at 14,880 µg/L for the genus Dendrocoelum. The top four most sensitive genera are all fish, and include Salvelinus (1.91 µg/L), Cottus (2.16  $\mu g/L),$  Salmo (2.88  $\mu g/L),$  and Morone (3.16  $\mu g/L).$ 

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family
58	Dendrocoelum lacteum	14,880.09	14,880.09	Planaria	Planariidae
57	Orconectes virilis	<11,193.54	11,097.25	Crayfish	Cambaridae
57	Orconectes immunis	,	<11,371.23	Crayfish	Cambaridae
56	Rhithrogena hageni	10,899.66	10,899.66	Mayfly	Heptageniidae
55	Oreochromis mossambica	10,068.09	10,068.09	Tilapia	Cichlidae
54	Chironomus riparius*	7,933.19	216,223.17	Midge	Chironomidae
04	Chironomus tentans		7,933.19	Midge	Chironomidae
	Chironomus plumosus		8,260.64	Midge	Chironomidae
53	Gasterosteus aculeatus	5,897.00	5,897.00	Threespine stickleback	Gasterosteidae
52	Gambusia affinis	5,578.08	5,578.08	Mosquitofish	Poeciliidae
51	Ictalurus punctatus	4,994.42	4,994.42	Channel catfish	Ictaluridae
50	Rhyacodrilus montana	4,912.28	4,912.28	Tubificid worm	Tubificidae
49	Lepomis cyanellus	4,812.28	3,595.94	Green sunfish	Centrarchidae
43	Lepomis macrochirus	í í	6,440.04	Bluegill	Centrarchidae
48	Cyprinus carpio	4,547.36	4,547.36	Common carp	Cyprinidae
47	Stylodrilus heringianus	4,228.50	4,228.50	Tubificid worm	Tubificidae
46	Notropis lutrensis	4,051.76	4,051.76	Red shiner	Cyprinidae
45	Spirosperma ferox	3,094.45	2,729.04	Tubificid worm	Tubificidae
<b> </b> <sup>-</sup>	Spirosperma nikolskyi		3,508.77	Tubificid worm	Tubificidae
44	Varichaeta pacifica	2,962.96	2,962.96	Tubificid worm	Tubificidae
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42	Jordanella floridae	2,810.24	2,810.24	Flagfish	Cyprinodontidae
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38	Branchiura sowerbyi	1,871.34	1,871.34	Tubificid worm	Tubificidae
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35	Tubifex tubifex	1,344.34	1,344.34	Tubificid worm	Tubificidae
34	Limnodrilus hoffmeisteri	867.63	867.63	Tubificid worm	Tubificidae
33	Carassius auratus	833.89	833.89	Goldfish	Cyprinidae
32	Asellus bicrenata	548.72	548.72	Isopod	Asellidae
31	Ambystoma gracile	515.81	515.81	Salamander	Ambystomatidae
30	Plumatella emarginata	299.69	299.69	Bryozoan	Plumatellidae
29	Alona affinis	267.59	267.59	Cladoceran	Chydoridae
29	Cyclops varicans	241.62	241.62	Copepod	Cyclopidae

#### Table 6: Revised acute Cd criteria database.

GEI Consultants, Inc. **Ecological** Division

October 2008 Cadmium Objectives - Review and Update

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51	Ictalurus punctatus	4,994.42	4,994.42	Channel catfish	Ictaluridae
50	Rhyacodrilus montana	4,912.28	4,912.28	Tubificid worm	Tubificidae
49	Lepomis cyanellus	4,812.28	3,595.94	Green sunfish	Centrarchidae
70	Lepomís macrochirus		6,440.04	Bluegill	Centrarchidae
48	Cyprinus carpio	4,547.36	4,547.36	Common carp	Cyprinidae
47	Stylodrilus heringianus	4,228.50	4,228.50	Tubificid worm	Tubificidae
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44	Varichaeta pacifica	2,962.96	2,962.96	Tubificid worm	Tubificidae
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GEI Consultants, Inc. Ecological Division October 2008 Cadmium Objectives - Review and Update

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Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family
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49	Lepomis cyanellus	4,812.28	3,595.94	Green sunfish	Centrarchidae
	Lepomis macrochirus		6,440.04	Bluegili	Centrarchidae
48	Cyprinus carpio	4,547.36	4,547.36	Common carp	Cyprinidae
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46	Notropis lutrensis	4,051.76	4,051.76	Red shiner	Cyprinidae
45	Spirosperma ferox	3,094.45	2,729.04	Tubificid worm	Tubificidae
	Spirosperma nikolskyi		3,508.77	Tubificid worm	Tubificidae
44	Varichaeta pacifica	2,962.96	2,962.96	Tubificid worm	Tubificidae
43	Catostomus commersoni	2,827.16	2,827.16	White sucker	Catostomidae
42	Jordanella floridae	2,810.24	2,810.24	Flagfish	Cyprinodontidae
41	Poecilia reticulata	2,569.18	2,569.18	Guppy	Poeciliidae
40	Quistradilus multisetosus	2,495.13	2,495.13	Tubificid worm	Tubificidae
39	Ephemerella grandis	2,248.19	2,248.19	Mayfly	Ephemerellidae
38	Branchiura sowerbyi	1,871.34	1,871.34	Tubificid worm	Tubificidae
37	Crangonyx pseudogracilis	1,700.00	1,700.00	Amphipod	Crangonyctidae
36	Procambarus clarkii	1,659.77	1,659.77	Crayfish	Cambaridae
35	Tubifex tubifex	1,344.34	1,344.34	Tubificid worm	Tubificidae
34	Limnodrilus hoffmeisteri	867.63	867.63	Tubificid worm	Tubificidae
33	Carassius auratus	833.89	833.89	Goldfish	Cyprinidae
32	Asellus bicrenata	548.72	548.72	Isopod	Asellidae
31	Ambystoma gracile	515.81	515.81	Salamander	Ambystomatida
30	Plumatella emarginata	299.69	299.69	Bryozoan	Plumatellidae
29	Alona affinis	267.59	267.59	Cladoceran	Chydoridae
28	Cyclops varicans	241.62	241.62	Copepod	Cyclopidae

#### Table 6: Revised acute Cd criteria database.

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October 2008 Cadmium Objectives - Review and Update

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family
27	Glossiphonia complanata	210.93	210.93	Leech	Glossiphoniidae
26	Pectinatella magnifica	192.46	192.46	Bryozoan	Pectinatellidae
25	Lumbriculus variegatus	156.13	156.13	Worm	Lumbriculidae
24	Physa gyrina	115.30	115.30	Snail	Physidae
23	Aplexa hypnorum	102.73	102.73	Snail	Physidae
22	Gammarus pseudolimnaeus	77.58	77.58	Amphipod	Gammaridae
21	Lirceus alabamae	54.23	54.23	Isopod	Asellidae
20	Ceriodaphnia dubia	48.15	49.86	Cladoceran	Daphniidae
20	Ceriodaphnia reticulata		46.50	Cladoceran	Daphniidae
19	Moina macrocopa	45.31	45.31	Cladoceran	Moinidae
18	Utterbackia imbecilis	44.90	44.90	Mussel	Unionidae
17	Gila elegans	44.55	44.55	Bonytail	Cyprinidae
16	Xyrauchen texanus	42.13	42.13	Razorback sucker	Catostomidae
15	Lophopodella carteri	41.24	41.24	Bryozoan	Lophopodidae
14	Vilosa vibex	37,18	37.18	Mussel	Unionidae
13	Actinonaia pectorosa	35,59	35.59	Mussel	Unionidae
12	Lampsilis straminea claibornensis	33.00	46.61	Mussel	Unionidae
	Lampsilis teres		23.37	Mussel	Unionidae
11	Pimephales promelas	28.45	28.45	Fathead minnow	Cyprinidae
10	Simocephalus serrulatus	27.79	27.79	Cladoceran	Daphniidae
9	Daphnia magna	27.43	15.36	Colorado pikeminnow	Cyprinidae
-	Daphnia pulex		48.98	Northern pikeminnow	Cyprinidae
8	Ptychocheilus lucius*	25.93	25.93	Cladoceran	Daphniidae
	Ptychocheilus oregonensis		2,070.47	Cladocerán	Daphniidae
7	Hyallela azteca	7.51	7.51	Amphipod	Hyalellidae
6	Thymallus arcticus	4.80	4.80	Arctic grayling	Salmonidae
5	Oncorhynchus kisutch	3.48	5.72	Coho salmon	Salmonidae
	Oncorhynchus tshawytscha		3.98	Chinook salmon	Salmonidae
	Oncorhynchus mykiss		1.85	Rainbow trout	Salmonidae
4	Morone saxatilis	3.16	3.16	Striped bass	Percichthyidae
3	Salmo trutta	2.88	2.88	Brown trout	Salmonidae
2	Cottus bairdi	2.16	2.16	Mottled sculpin	Cottidae
1	Salvelinus fontinalis	1.91	<1.76	Brook trout	Salmonidae
	Salvelinus confluentus		2.08	Bull trout	Salmonidae

#### 3.3.2 Updated Chronic Database

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family
27	Glossiphonia complanata	210.93	210.93	Leech	Glossiphoniidae
26	Pectinatella magnifica	192.46	192.46	Bryozoan	Pectinatellidae
25	Lumbriculus variegatus	156.13	156.13	Worm	Lumbriculidae
24	Physa gyrina	115.30	115.30	Snail	Physidae
23	Aplexa hypnorum	102.73	102.73	Snail	Physidae
22	Gammarus pseudolimnaeus	77.58	77.58	Amphipod	Gammaridae
21	Lirceus alabamae	54.23	54.23	Isopod	Asellidae
20	Ceriodaphnia dubia	48.15	49.86	Cladoceran	Daphniidae
~~~	Ceriodaphnia reticulata		46.50	Cladoceran	Daphniidae
19	Moina macrocopa	45.31	45.31	Cladoceran	Moinidae
18	Utterbackia imbecilis	44.90	44.90	Mussel	Unionidae
17	Gila elegans	44.55	44.55	Bonytail	Cyprinidae
16	Xyrauchen texanus	42.13	42.13	Razorback sucker	Catostomidae
15	Lophopodella carteri	41.24	41.24	Bryozoan	Lophopodidae
14	Vilosa vibex	37.18	37.18	Mussel	Unionidae
13	Actinonaia pectorosa	35.59	35.59	Mussel	Unionidae
12	Lampsilis straminea claibornensis	33.00	46.61	Mussel	Unionidae
-,-	Lampsilis teres		23.37	Mussel	Unionidae
11	Pimephales promelas	28.45	28.45	Fathead minnow	Cyprinidae
10	Simocephalus serrulatus	27.79	27.79	Cladoceran	Daphniidae
9	Daphnia magna	27.43	15.36	Colorado pikeminnow	Cyprinidae
	Daphnia pulex		48.98	Northern pikeminnow	Cyprinidae
8	Ptychocheilus lucius*	25.93	25.93	Cladoceran	Daphniidae
	Ptychocheilus oregonensis		2,070.47	Cladoceran	Daphniidae
7	Hyallela azteca	7.51	7.51	Amphipod	Hyalellidae
6	Thymallus arcticus	4.80	4.80	Arctic grayling	Salmonidae
5	Oncorhynchus kisutch	3.48	5.72	Coho salmon	Salmonidae
	Oncorhynchus tshawytscha		3.98	Chinook salmon	Salmonidae
	Oncorhynchus mykiss		1.85	Rainbow trout	Salmonidae
4	Morone saxatilis	3.16	3.16	Striped bass	Percichthyidae
3	Salmo trutta	2.88	2.88	Brown trout	Salmonidae
2	Cottus bairdi	2.16	2.16	Mottled sculpin	Cottidae
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Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family
27	Glossiphonia complanata	210.93	210.93	Leech	Glossiphoniidae
26	Pectinatella magnifica	192.46	192.46	Bryozoan	Pectinatellidae
20	Lumbriculus variegatus	156.13	156.13	Worm	Lumbriculidae
24	Physa gyrina	115.30	115.30	Snail	Physidae
24	Aplexa hypnorum	102.73	102.73	Snail	Physidae
22	Gammarus pseudolimnaeus	77.58	77.58	Amphipod	Gammaridae
22	Lirceus alabamae	54.23	54.23	Isopod	Asellidae
21	Ceriodaphnia dubia	48.15	49.86	Cladoceran	Daphniidae
20	Ceriodaphnia dubia	40.10	46.50	Cladoceran	Daphniidae
19	Moina macrocopa	45.31	45.31	Cladoceran	Moinidae
19	Utterbackia imbecilis	44.90	44,90	Mussel	Unionidae
18	Gila elegans	44.55	44.55	Bonytail	Cyprinidae
16	Xyrauchen texanus	42.13	42.13	Razorback sucker	Catostomidae
15	Lophopodella carteri	41.24	41.24	Bryozoan	Lophopodidae
13	Vilosa vibex	37.18	37.18	Mussel	Unionidae
14	Actinonaia pectorosa	35.59	35.59	Mussel	Unionidae
13	Lampsilis straminea claibornensis	33.00	46.61	Mussel	Unionidae
12	Lampsilis teres	00.00	23.37	Mussel	Unionidae
11	Pimephales promelas	28.45	28.45	Fathead minnow	Cyprinidae
10	Simocephalus serrulatus	27.79	27.79	Cladoceran	Daphniidae
9	Daphnia magna	27.43	15.36	Colorado pikeminnow	Cyprinidae
9	Daphnia magna Daphnia pulex	21.40	48.98	Northern pikeminnow	Cyprinidae
8	Ptychocheilus lucius*	25.93	25.93	Cladoceran	Daphniidae
0	Ptychocheilus oregonensis		2,070.47	Cladoceran	Daphniidae
7	Hvallela azteca	7.51	7.51	Amphipod	Hyalellidae
6	Thymallus arcticus	4.80	4.80	Arctic grayling	Salmonidae
5	Oncorhynchus kisutch	3.48	5.72	Coho salmon	Salmonidae
5	Oncorhynchus tshawytscha		3.98	Chinook salmon	Salmonidae
	Oncorhynchus mykiss		1.85	Rainbow trout	Salmonidae
4	Morone saxatilis	3.16	3.16	Striped bass	Percichthyidae
3	Salmo trutta	2.88	2.88	Brown trout	Salmonidae
2	Cottus bairdi	2.16	2.16	Mottled sculpin	Cottidae
1	Salvelinus fontinalis	1.91	<1.76	Brook trout	Salmonidae
	Salvelinus confluentus		2.08	Bull trout	Salmonidae

#### 3.3.2 Updated Chronic Database

Rank	Species	GMAV (µg/L)	SMAV (µg/L)	Common Name	Family
27	Glossiphonia complanata	210.93	210.93	Leech	Glossiphoniidae
26	Pectinatella magnifica	192.46	192.46	Bryozoan	Pectinatellidae
25	Lumbriculus variegatus	156.13	156.13	Worm	Lumbriculidae
24	Physa gyrina	115.30	115.30	Snail	Physidae
23	Aplexa hypnorum	102.73	102.73	Snail	Physidae
22	Gammarus pseudolimnaeus	77.58	77.58	Amphipod	Gammaridae
21	Lirceus alabamae	54.23	54.23	Isopod	Asellidae
20	Ceriodaphnia dubia	48.15	49.86	Cladoceran	Daphniidae
20	Ceriodaphnia reticulata		46,50	Cladoceran	Daphniidae
19	Moina macrocopa	45.31	45.31	Cladoceran	Moinidae
18	Utterbackia imbecilis	44.90	44.90	Mussel	Unionidae
17	Gila elegans	44,55	44.55	Bonytail	Cyprinidae
16	Xyrauchen texanus	42.13	42.13	Razorback sucker	Catostomidae
15	Lophopodella carteri	41.24	41.24	Bryozoan	Lophopodidae
14	Vilosa vibex	37.18	37.18	Mussel	Unionidae
13	Actinonaia pectorosa	35.59	35.59	Mussel	Unionidae
12	Lampsilis straminea claibornensis	33.00	46.61	Mussel	Unionidae
12	Lampsilis teres		23.37	Mussel	Unionidae
11	Pimephales promelas	28.45	28.45	Fathead minnow	Cyprinidae
10	Simocephalus serrulatus	27.79	27.79	Cladoceran	Daphniidae
9	Daphnia magna	27.43	15.36	Colorado pikeminnow	Cyprinidae
Ŷ	Daphnia pulex		48.98	Northern pikeminnow	Cyprinidae
8	Ptychocheilus lucius*	25.93	25.93	Cladoceran	Daphniidae
Ŷ	Ptychocheilus oregonensis		2,070.47	Cladoceran	Daphniidae
7	Hyallela azteca	7.51	7.51	Amphipod	Hyalellidae
6	Thymallus arcticus	4.80	4.80	Arctic grayling	Salmonidae
5	Oncorhynchus kisutch	3.48	5.72	Coho salmon	Salmonidae
-	Oncorhynchus tshawytscha		3.98	Chinook salmon	Salmonidae
	Oncorhynchus mykiss		1.85	Rainbow trout	Salmonidae
4	Morone saxatilis	3.16	3.16	Striped bass	Percichthyidae
3	Salmo trutta	2.88	2.88	Brown trout	Salmonidae
2	Cottus bairdi	2.16	2.16	Mottled sculpin	Cottidae
1	Salvelinus fontinalis	1.91	<1.76	Brook trout	Salmonidae
	Salvelinus confluentus		2.08	Buil trout	Salmonidae

#### 3.3.2 Updated Chronic Database

Rank	Species	GMCV (µg/L)	SMCV (µg/L)	Common Name	Family
17	Oreochromis aurea	>22.19	>22.19	Blue tilapia	Cichlidae
16	Aeolosoma headleyi	20.42	20.42	Oligochaete	Aeolosomatidae
15	Lepomis macrochirus	15.99	15.99	Bluegill.	Centrarchidae
14	Pimephales promelas	15.09	15.09	Fathead minnow	Cyprinidae
13	Ceriodaphnia dubia	11.66	11.66	Cladoceran	Daphniidae
12	Micropterus dolomieui	8.19	8.19	Smallmouth bass	Centrarchidae
11	Esox lucius	8.15	8.15	Northern pike	Esocidae
10	Catostomus commersoni	7.86	7.86	White sucker	Catostomidae
9	Jordanella floridae	5.34	5.34	Flagfish	Cyprinidontidae
8	Aplexa hypnorum	4.85	4.85	Snail	Physidae
7	Salmo salar	4.73	8.28	Atlantic salmon	Salmonidae
1	Salmo trutta		2.70	brown trout	Salmonidae
6	Salvelinus fontinalis	4.66	2.66	Brook trout	Salmonidae
v	Salvelinus namaycush		8.15	Lake trout	Salmonidae
5	Chironomus tentans	2.53	2.53	Midge	Chironomidae
4	Oncorhynchus kisutch	2.31	4.30	Coho salmon	Salmonidae
т.	Oncorhynchus mykiss		1.05	Rainbow trout	Salmonidae
	Oncorhynchus tshawytscha		2.72	Chinook salmon	Salmonidae
3	Daphnia magna	1.33	0.49	Cladoceran	Daphniidae
-	Daphnia pulex		3.57	Cladoceran	Daphniidae
2	Cottus bairdi	1.07	1.07	Mottled sculpin	Cottidae
1	Hyalella azteca	0.26	0.26	Amphipod	Hyalellidae

Table 7: Updated chronic Cd criteria data	abase.
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<sup>1</sup> Used in coldwater calculations.
 <sup>2</sup> Used in warmwater calculations.
Rank	Species	GMCV (µg/L)	SMCV (µg/L)	Common Name	Family
17	Oreochromis aurea	>22.19	>22.19	Blue tilapia	Cichlidae
16	Aeolosoma headleyi	20.42	20.42	Oligochaete	Aeolosomatidae
15	Lepomis macrochirus	15.99	15.99	Bluegill	Centrarchidae
14	Pimephales promelas	15.09	15.09	Fathead minnow	Cyprinidae
13	Ceriodaphnia dubia	11.66	11.66	Cladoceran	Daphniidae
12	Micropterus dolomieui	8.19	8.19	Smallmouth bass	Centrarchidae
11	Esox lucius	8.15	8.15	Northern pike	Esocidae
10	Catostomus commersoni	7.86	7.86	White sucker	Catostomidae
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2	Cottus bairdi	1.07	1.07	Mottled sculpin	Cottidae
1	Hyalella azteca	0.26	0.26	Amphipod	Hyalellidae

7: Up chronic Cd criteria database Tak

<sup>1</sup> Used in coldwater calculations.
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Rank	Species	GMCV (µg/L)	SMCV (µg/L)	Common Name	Family
17	Oreochromis aurea	>22.19	>22.19	Blue tilapia	Cichlidae
16	Aeolosoma headleyi	20.42	20.42	Oligochaete	Aeolosomatidae
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13	Ceriodaphnia dubia	11.66	11.66	Cladoceran	Daphniidae
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2	Cottus bairdi	1.07	1.07	Mottled sculpin	Cottidae
1	Hyalella azteca	0.26	0.26	Amphipod	Hyalellidae

Undated chronic Cd criteria database. Table 7

<sup>1</sup> Used in coldwater calculations. <sup>2</sup> Used in warmwater calculations.

Rank	Species	GMCV (µg/L)	SMCV (µg/L)	Common Name	Family
17	Oreochromis aurea	>22.19	>22.19	Blue tilapia	Cichlidae
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14	Pimephales promelas	15.09	15.09	Fathead minnow	Cyprinidae
13	Ceriodaphnia dubia	11.66	11.66	Cladoceran	Daphniidae
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3	Daphnia magna	1.33	0.49	Cladoceran	Daphniidae
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1	Hyalella azteca	0.26	0.26	Amphipod	Hyalellidae

Table 7: Updated chronic Cd criteria data	apase.
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<sup>1</sup> Used in coldwater calculations. <sup>2</sup> Used in warmwater calculations.

# 4.1 Updating the Acute Hardness Relationship

When enough data are available to show that the toxicity of a substance is related to a water quality characteristic for two or more species, the relationship is accounted for using an analysis of covariance (Stephan *et al.* 1985). This appears to be the case for the relationship between Cd toxicity and water hardness. The 2001 Cadmium Document normalized data and used analysis of covariance (Stephen *et al.* 1985) to obtain the acute hardness slope.

Definitive acute values were available for 12 species over a range of hardness values such that the highest hardness was at least three times the lowest, and the highest was also at least 100 mg/L higher than the lowest. Only acute tests initiated with individuals less than 24-hour old neonates were used to estimate the hardness slope for *D. magna*. The individual species slopes ranged from 0.1086 (*D. magna*) to 2.03 (*P. promelas*), and the pooled slope was 1.17. However, the EPA decided that there was too much variability associated with the slopes for *D. magna* and *P. promelas*. Therefore, only the Chapman *et al.* manuscript data were used to compute the slope for *D. magna* (1.18) and only adult data were used to compute the slope for *P. promelas* (1.22). When the adjusted data set was used, the resultant pooled slope was 1.0166. This value was used by EPA to adjust all acute values to a common hardness (50 mg/L) and is also included in the final acute equation.

Reviewing data used to calculate the acute hardness slope in the 2001 Cadmium Document and adding data from the revised acute database allowed development of a revised acute hardness relationship (Table 8). One major conflict with data selection for the 2001 Cadmium Document acute hardness relationship and that used by GEI is EPA's decision to limit fathead minnow Cd vs. hardness data to adults, when only the toxicity data of the more sensitive age classes (juvenile and fry) were used in the SMAV calculations. EPA justified this apparent conflict because excluding juvenile and fry hardness related data decreased undesirable variability within the species and pooled slope. Yet in this situation, when data for multiple age classes are available, we believe data used to calculate the hardness relationship should be more consistent with data used to calculate the SMAV. This approach should be honored (even if data are more variable) as long as resulting slopes are within the range of other species. Therefore, instead of only adult data (slope = 1.220,  $R^2 = 0.70$ ), juvenile data for fathead minnow (slope = 0.9210,  $R^2 = 0.29$ ) were used in the revised pooled acute hardness slope. Davies et al. (1993) provided 6 data points for O. mykiss that increased the range of water hardness tested for this species, making it possible to add this previously unused species to the revised acute hardness slope calculations. Data points for O. mykiss from four other studies were also added to the hardness relationship database.

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Table 8: Updated acute Cd hardness slope.	l hardness	slope. SMAS	H	species mean acute slope	ite slope.						Γ
						Normalized		<u> </u>	<u>ب</u>	04100	2
Species	Hardness (mg/L)	Geomean (hardness)	Normalized	(hg/L)	(acute)	acute	Reference	(norm hard)	(norm acute)	CHINC	۲
l imnodrilus hoffmeisteri	5.3		0.19	170.00		0.27	Chapman <i>et al.</i> 1982	-	-1.324	1	-
l impodrilus hoffmeisteri	152.0	28.38	5.36	2,400.00	638.75	3.76	Williams <i>et al.</i> 1985	1.678	1.324	0.7888	;
Tubitav tubitav	128.0		2.89	3,200.00		2.66	Reynoldson <i>et al.</i> 1996	1.061	0.978		
Tubitex tubitex	128.0		2.89	1,700.00		1.41	Reynoldson et al. 1996	1.061	0.346		
Tublev	5.3	44.28	0.12	320.00	1,202.96	0.27	Chapman <i>et al.</i> 1982	-2.123	-1.324	0.6238	0.93
Vilosa vihex	40.0		0.46	30.00		0.49	Keller as cited in U.S. EPA 2001	-0.768	-0.714		
Viince vihev	186.0	86.26	2.16	125.00	61.24	2.04	Keller as cited in U.S. EPA 2001	0.768	0.714	0.9286	1
Viiusa viiusa Danhnia magna	51.0		0.50	9.60		.0.51	Chapman et al. Manuscript	-0.839	-1.178		
Dephris magna	104.0		1.02	33.00		1.69	Chapman et al. Manuscript	-0.127	0.026		
Darhain magna	105.0		1.03	34.00		1.74	Chapman et al. Manuscript	-0.117	0.056		
Dathris magna	107.0		1.93	63.00		3.22	Chapman et al. Manuscript	0.512	0.673		
Daphria magna	0 602	118.05	2.05	49.00	32.14	2.50	Chapman et al. Manuscript	0.571	0.422	1.1824	0.91
Daphris mayna	57.0		0.60	47.00		0.53	Bertram and Hart 1979	-0.508	-0.636		
Danhnia pulax Danhnia milax	240.0		2.53	319.00		3.59	Elnabarawy et al. 1986	0.930	1.279		
Danhnia nulex	120.0		1.27	80.00		06.0	Hall et al. 1986	0.237	-0.104		
Danhnia nulex	120.0		1.27	100.00		1.13	Hall et al. 1986	0.237	0.119		
Danhnia nulex	53.5		0.56	70.10		0.79	Stackhouse and Benson 1988	-0.571	-0.236		
Danhnia pulex	85.0		06.0	66.00		0.74	Roux et al. 1993	-0.108	-0.296		
Danhnia milay	85.0		06.0	00.66		1.12	Roux et al. 1993	-0.108	0.109		
Danhnia pulov	85.0	94.71	06.0	70.00	88.74	0.79	Roux et al. 1993	5.52	-0.237	1.0633	0.79
Decomprise pulso	2110		4.05	26.00		5.27	Hamilton and Buhi 1990	1.398	1.661		
Oncomprise is the antice of a	343.0		6.58	57.00		11.55	Hamilton and Buhl 1990	1.884	2.446		
Oncorhynchus tshawytscha	23.0		0.44	1.80		0.36		-0.819	-1.009		
Oncorhvnchus tshawvtscha	23.0		0.44	3.50		0.71	Chapman 1975, 1978	-0.819	-0.344		
Oncorhynchiis tshawytscha	25.0		0.48	1.41		0.29	Chapman 1982	-0.735	-1.253		
Oncorhvnchus tshawvtscha	21.0	52.14	0.40	1.10	4.94	0.22	Finlayson and Verrue 1982	-0.909	-1.501	1.2576	0.95
Carassius auratus	20.0		0.50	2,340.00		0.64	Pickering and Henderson 1966	-0.686	-0.440		
Carassius auratus	20.0		0.50	2,130.00		0.59	McCarty et al. 1978	-0.686	-0.534		
Carassius auratus	140.0		3.53	46,800.00		12.88	McCarty et al. 1978	1.260	2.555		
Carassius auratus	44.4	39.71	1.12	748.00	3,634.43	0.21	Phipps and Holcombe 1985	0.112	-1.581	1.4608	76.0
Pimenhales promelas (juvenile)	44.0		0.87	13.20		0.40	Spehar and Fiandt 1986	-0.138	606.0-	ļ	
Pimenhales promelas (iuvenile)	290.0		5.74	60.00		1.83	Schubauer-Berigan et al. 1993	1.748	0.605		

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Table 8: Indated actite Cd hardness slope.	hardness	slope. SMAS	- 11	species mean acute slope	ite slope.						ſ
								h	<u>_</u>		
Species	Hardness (mg/L)	Geomean (hardness)	Normalized hardness	LC50/EC50 (µg/L)	Geomean (acute)	Normalized	Reference	(norm hard)	(norm acute)	SMAS	έz –
	C		010	170.00		0.27	Chapman et al. 1982	-1.678	-1.324		;
Limnodrilus hoffmeister	0.3 4 F.0 O	00 00	U. 13 5 36	2 400 00	638.75	3.76	Williams et al. 1985	1.678	1.324	0.7888	-
Limnodrius normeister	0.201	00.04	0.00	3 200 00		2.66	Revnoldson et al. 1996	1.061	0.978		
I ubitex tubitex	0.021		2.03	1 700.00		1.41	Reynoldson et al. 1996	1.061	0.346		
Tublex tublex	F 2	80 11	0 10	320.00	1 202.96	0.27	Chapman et al. 1982	-2.123	-1.324	0.6238	0.93
I ubitex tubitex	0.0	44,20	0.46	30.00		0.49	Keller as cited in U.S. EPA 2001	-0.768	-0.714		Τ
VIIOSA VIDEX Vilosa vihev	186.0	86.26	2.16	125.00	61.24	2.04	Keller as cited in U.S. EPA 2001		-	0.9286	:
Vilusa vibez Danhnia magna	51.0		0.50	9.90		0.51	Chapman et al. Manuscript	-+	-1.178	-+	
Danhala marma	104.0		1.02	33.00		1.69	Chapman et al. Manuscript	-0.127	0.026		
Darhnia magna	105.0		1.03	34.00		1.74	Chapman et al. Manuscript	-0.117	0.056	-	┓
Dathin magna	197.0		1.93	63.00		3.22	Chapman et al. Manuscript	0.512	0.673		
Dahnia magna Dahnia magna	0.600	118.05	2.05	49.00	32.14	2.50	Chapman et al. Manuscript	0.571	0.422	1.1824	0.91
Denhole pridev	57.0		0.60	47.00		0.53	Bertram and Hart 1979	-0.508	-0.636		
Denhula purex	240.0		2.53	319.00		3.59	Elnabarawy et al. 1986	0.930	1.279		
Danhnia purok Danhnia pulex	120.0		1.27	80.00		06.0	Hall et al. 1986	0.237	-0.104		
Donhria pulov	120.0		1.27	100.00		1.13	Hall et al. 1986	0.237	0.119		
Dahaia pura	53.5		0.56	70.10		0.79	Stackhouse and Benson 1988	-0.571	-0.236		Ì
Daphina pulex Daphie nulex	85.0		0.90	66.00		0.74	Roux et al. 1993	-0.108	-0.296		- 1
Darhaia putav	85.0		06.0	00'66		1.12	Roux et al. 1993	-0.108	0.109		
Daphic pulsy	85.0	94.71	0.90	70.00	88.74	0.79	Roux et al. 1993	5.52	-0.237	1.0633	0.79
Daprinia puiek	2110	>	4.05	26.00		5.27	Hamilton and Buhi 1990	1.398	1.661		
Oncontructus tshawytscha	343.0		6.58	57.00		11.55	Hamilton and Buhl 1990	1.884	2.446		
Oncorhurchus tshawutscha	23.0		0.44	1.80		0.36	Chapman 1975, 1978	-0.819	-1.009		
Oncorhinchile tehaningcha	23.0		0.44	3.50		0.71	Chapman 1975, 1978	-0.819	-0.344		T
Oncorhinohis tshawrtscha	25.0		0.48	1.41		0.29	Chapman 1982	-0.735	-1.253		
Oncorhynchus tshawrtscha	21.0	52.14	0.40	1.10	4.94	0.22	Finlayson and Verrue 1982	-0.909	-1.501	1.2576	0.95
Coroceire atratic	20.0		0.50	2,340.00		0.64	Pickering and Henderson 1966	-0.686	-0.440		
Carassius auratus	20.0		0.50	2,130.00		0.59	McCarty et al. 1978	-0.686	-0.534		
Carassius auratus	140.0		3.53	46,800.00		12.88	McCarty et al. 1978	1.260	2.555	0007	
Carassius auratus	44.4	39.71	1.12	748.00	3,634.43	0.21	Phipps and Holcombe 1985	0.112	-1.581	1.4608	10.0
Pimenhales prometas (juvenije)	-		0.87	13.20		0.40	Spehar and Fiandt 1986	-0.138	-0.909		
Pimenhales promelas (juvenile)	290.0		5.74	60.00		1.83	Schubauer-Berigan et al. 1993	1.748	0.605		-

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Table 8: Updated acute Cd nargness slope.	Lidi Uliess	SUDE SURVO	o - sheries mean acars along					-		-	
				C L		Mornalizad		<u>۔</u>	5	O M M O	2
Species	Hardness (mg/L)	Geomean (hardness)	Normalized	LC <sub>50</sub> /EC <sub>50</sub> (µg/L)	(acute)	acute	Reference	(norm hard)	(norm acute)	CHINO	۲
l immodulus hoffmaistari	53		0.19	170.00		0.27	Chapman <i>et al.</i> 1982	-	-1.324		1
Limitodrike hoffmaisteri	152.0	28.38	5.36	2,400.00	638.75	3.76	Williams et al. 1985	1.678	1.324	0.7888	1
T. HEROLINGS HOUMANDA	128.0		2.89	3.200.00		2.66	Reynoldson et al. 1996	1.061	0.978		
Tublex tublex	128.0		2.89	1,700.00		1.41	Reynoldson et al. 1996	1.061	0.346		
	5.3	44 2R	0.12	320.00	1,202.96	0.27	Chapman et al. 1982	-2.123	-1.324	0.6238	0.93
Tublex tublex	40.0		0.46	30.00		0.49	Keller as cited in U.S. EPA 2001	-0.768	-0.714		
VIIOSA VIOSA	186.0	86.26	2.16	125.00	61.24	2.04	Keller as cited in U.S. EPA 2001	0.768	0.714	0.9286	ł
Viiusa viusa Danhnia magna	51.0		0.50	9.90		0.51	Chapman et al. Manuscript	-0.839	-1.178		
Danhaja magna	104.0		1.02	33.00		1.69	Chapman et al. Manuscript	-0.127	0.026		
Darhnia magna	105.0		1.03	34.00		1.74	Chapman et al. Manuscript	-0.117	0.056		Τ
Darhaia magrid	197.0		1.93	63.00		3.22	Chapman et al. Manuscript	0.512	0.673		
Darhria magna	209.0	118.05	2.05	49.00	32.14	2.50	Chapman et al. Manuscript	0.571	0.422	1.1824	0.91
Danhara magna	57.0		0.60	47.00		0.53	Bertram and Hart 1979	-0.508	-0.636		
Danhnia putav	240.0		2.53	319.00		3.59	Elnabarawy et al. 1986	0.930	1.279		
Danhaia putos	120.0		1.27	80.00		06.0	Hall et al. 1986	0.237	-0.104		
Deptification	120.0		1.27	100.00		1.13	Hall et al. 1986	0.237	0.119		
Daprina purex	F3 F		0.56	70.10		0.79	Stackhouse and Benson 1988	-0.571	-0.236		
Dapinia puex	85 D		06.0	66.00		0.74	Roux et al. 1993	-0.108	-0.296		
Uaprina pulex	0000			00 66		1.12	Roux et al. 1993	-0.108	0.109		
Daphnia pulex	00.0	04 71		20.00	88.74	0.79	Roux et al. 1993	5.52	-0.237	1.0633	0.79
Daphnia pulex	00.0	34.4	4.05	26.00		5.27	Hamilton and Buhi 1990	1.398	1.661		
Oncorhynchus tsnawytscha	0.112		9 2 2 2 2 2 2 2 2 3	57 00		11.55	Hamilton and Buhl 1990	1.884	2.446		
Oncornyncnus Isriawyiscria	23.0		0.44	1.80		0.36	Chapman 1975, 1978	-0.819	-1.009		
Oncontrigitorius tarianytastia	23.0		0.44	3.50		0.71	Chapman 1975, 1978	-0.819	-0.344		
Oricorrigitcius israwyiscus	25.0		0.48	1.41		0.29	Chapman 1982	-0.735	-1.253		ŀ
Oncorting terral terrangleoria	210	52.14	0.40	1.10	4.94	0.22	Finlayson and Verrue 1982	-0.909	-1.501	1.2576	0.95
Oncomprishing the prismy sound	20.02		0.50	2,340.00		0.64	Pickering and Henderson 1966	-0.686	-+		
Caraceire auratus	20.0		0.50	2,130.00		0.59	McCarty et al. 1978	-0.686	_		
	140.0		3.53	46,800.00		12.88	McCarty et al. 1978	1.260	2.555		
Caraceire auratus	44.4	39.71	1.12	748.00	3,634.43	0.21	Phipps and Holcombe 1985	0.112	-1.581	1.4608	/c.u
Dimenhales nmme(as (invenile)	44.0		0.87	13.20		0.40	Spehar and Fiandt 1986	-0.138	-0.909		
Pimephales prometas (iuvenile)	290.0		5.74	60.00		1.83	Schubauer-Berigan et al. 1993	1.748	0.605		

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Species         Hardness (mgU)         Recompanies (mgU)         Hardness (mgU)         Recompanies (mgU)         Monumatised (mgU)         Monumatis	Table 8: Updated acute Cd hardness slope.	hardness	slope. SMAS		= species mean acute slope.	ite slope.						ſ
Tradition         Tradition <t< th=""><th></th><th>Landaroo</th><th>Gormoan</th><th>Normalizad</th><th>1 C/EC</th><th>Geomean</th><th>Normalized</th><th></th><th><u>ء</u></th><th>ے ا</th><th>0110</th><th>2</th></t<>		Landaroo	Gormoan	Normalizad	1 C/EC	Geomean	Normalized		<u>ء</u>	ے ا	0110	2
5.3         0.19         170.00         6.23. f         Chapman et al. 1965         1.678         1.324         0.7868           1820         283. 6         23000         635. 75         3.76         Nullams et al. 1965         1.61         0.734         1.724         0.7868           1820         289         3,700.00         635. 75         5.66         Reynoldson et al. 1965         1.061         0.744         0.748         0.748         0.748         0.748         0.748         0.758         0.748         0.758         0.748         0.748         0.748         0.748         0.748         0.758         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.748         0.74	Species	(mg/L)	(hardness)	hardness	(hg/L)	(acute)	acute	Reference	(norm hard)	(norm acute)	CAMC	Ł
152 0         28-36         2,400.00         638.75         3.76         Williams et al. 1965         1.078         1.324         0.378           128.0         2.86         3.2000         1.301         Reynoldson et al. 1965         1.061         0.378         0.374           5.3         4.4.28         0.12         32.000         1.202.96         0.27         Chapman et al. 1965         1.037         0.578         0.774         0.578         0.774         0.574         0.526           5.3         44.28         0.12         32.000         1.202.96         0.21         Chapman et al. 1962         .2.133         0.626         0.778         0.774         0.226           5.10         1.02         33.00         1.69         Chapman et al. Manuscript         0.617         0.206           1197         106.0         1.12         23.00         3.2.14         2.50         Chapman et al. Manuscript         0.617         0.206           1197         1070         3.1         2.26         Chapman et al. Manuscript         0.617         0.203         1.784           1197         1070         3.1         2.26         Chapman et al. Manuscript         0.617         0.203         1.784         0.714         0.204	Limnodrilus hoffmeisteri	5.3		0.19	170.00		0.27	Chapman <i>et al.</i> 1982	-1.678	-1.324		
128.0         228.0         3.200.00         2.056         Reynoldson et al. 1966         1.061         0.978         0.978           5.3.3         44.26         0.14         Rewnoldson et al. 1962         1.061         0.346         0.714         0.346           5.3.3         44.26         0.16         30.00         1.202.96         0.27         Rewnoldson et al. 1982         2.173         1.340         0.714         0.246           65.0         2.16         125.00         61.20         51.0         1.0.5         ENAPAGENT et al. 1982         0.714         0.246           610.0         51.0         1.02         30.00         1.202.96         0.27         Chapman et al. Manuscript         0.714         0.226           105.0         1.03         34.00         1.12         2.04         Kalmascript         0.714         0.226           105.0         1.18.0         5.00         3.2.00         32.14         2.50         Chapman et al. Manuscript         0.616         4.71         0.266         0.656         0.656         0.656         0.714         0.227         0.616           105.0         118.05         2.60         47.00         3.271         0.666         0.656         0.656         0.656 <td>Limnodrilus hoffmeisteri</td> <td>152.0</td> <td>28.38</td> <td>5.36</td> <td>2,400.00</td> <td>638.75</td> <td>3.76</td> <td>Williams et al. 1985</td> <td>1.678</td> <td>1.324</td> <td>0.7888</td> <td>ł</td>	Limnodrilus hoffmeisteri	152.0	28.38	5.36	2,400.00	638.75	3.76	Williams et al. 1985	1.678	1.324	0.7888	ł
128.0         1.28.0         1.70.00         1.41         Reynoldson et al. 1992         1.051         0.346           5.3         44.28         0.12         320.00         1.202.96         0.27         Relaman et al. 1992         2.123         0.6238           5.3         44.28         0.12         320.00         61.24         2.04         Keller as cited in U.S. EPA 2011         0.778         0.714         0.926           51.0         86.56         2.16         125.00         61.24         2.04         Keller as cited in U.S. EPA 2011         0.718         0.714         0.926           51.0         86.50         0.50         9.00         1.74         Chepman et al. Manuscript         0.173         0.023           197.0         1.130         53.00         1.74         2.50         0.141         0.025         0.058         1.174         0.025         0.058         1.174         0.025         0.058         1.174         0.025         0.058         1.102         0.025         0.016         0.227         0.016         0.271         0.026         0.056         0.174         0.025         0.058         1.102         0.025         0.016         0.271         0.026         0.174         0.025         0.016	Tubifex tubifex	128.0		2.89	3,200.00		2.66		1.061	0.978		
5.3         44.28         0.12         320.00         1,202.56         0.27         Chapman et al. 1982         2.123         1.324         0.528         1           16.0         86.26         0.50         61.30         0.51         Chapman et al. Manuscript         .0.714         0.228           16.0         86.26         9.30         61.30         0.51         Chapman et al. Manuscript         .0.736         .0.714         0.228           16.0         10.0         1.02         33.00         1.14         0.51         Chapman et al. Manuscript         .0.127         0.028           197.0         197.0         198         5.00         3.40         3.2.14         2.50         Chapman et al. Manuscript         .0.127         0.028           200.0         13.0         3.40         3.2.14         2.50         Chapman et al. Manuscript         0.51         0.428           201.0         120.0         127         100.00         3.2.1         2.50         Chapman et al. Manuscript         0.51         0.414           201.0         17.0         0.58         Ehabmany et al. 1896         0.571         0.268         1.1824           201.0         120.0         0.56         0.50         0.50         <	Tubifex tubifex	128.0	-	2.89	1,700.00		1.41	Reynoldson <i>et al.</i> 1996	1.061	0.346		
400         046         30,00         61,24         Keller as clied in U.S. EPA 2001         0.714         0.296           165,0         66,26         2.16         155,00         61,24         Zent         Keller as clied in U.S. EPA 2001         0.714         0.296           104,0         1030         34,00         1,25         7.00         0.127         0.026           105,0         1030         34,00         1,74         Chapman et al. Manuscript         -0.117         0.026           105,0         118,05         2.03         300         32,14         2.50         Chapman et al. Manuscript         -0.117         0.026           177,0         180,5         0.50         47.00         32,14         2.50         Chapman et al. Manuscript         -0.127         0.026           77,0         0.50         47.00         32,14         2.50         Chapman et al. Manuscript         -0.127         0.026           77,0         0.50         17,37         9.010         1.180,5         0.510         0.126         0.514         1.184           70,0         17,27         0.026         1.17         0.026         0.231         1.026         0.236         1.184           70,0         1127	Tubifex tubifex	5.3	44.28	0.12	320.00	1,202.96	0.27	Chapman <i>et al.</i> 1982	-2.123	-1.324	0.6238	0.93
166.0         66.26         2.16         125.00         61.24         2.04         Keller as cided in U.S. EPA 2001         0.768         0.717         0.026           161.0         0.50         1.03         34.00         1.65         Chapman et al. Manuscript         -0.173         0.026           165.0         1.03         34.00         1.74         Chapman et al. Manuscript         -0.171         0.026           1787.0         1.03         34.00         7.10         3.22         Chapman et al. Manuscript         -0.171         0.057         0.457           1787.0         1.970         32.14         Chapman et al. Manuscript         -0.171         0.057         0.457           187.0         187.0         32.14         Chapman et al. Manuscript         -0.172         0.023         1.184           187.0         187.0         319.00         32.4         4.50         0.53         Enabarawy et al. 1986         0.340         1.724           120.0         1.277         100.00         1.127         Roux et al. 1986         0.237         0.104         1.924           120.0         1.270         0.58         Finabarawy et al. 1986         0.237         0.104         1.924           120.0         9.471	Vilosa vibex	40.0		0.46	30.00		0.49	EPA	-0.768	-0.714		
51.0         0.50         9.90         0.51         Chapman et al. Manuscript         -0.839         -1.78           104.0         1.02         33.00         1.74         Chapman et al. Manuscript         -0.127         0.026         -1.78           197.0.         1.03         33.00         1.74         Chapman et al. Manuscript         -0.171         0.057         0.026         -1.78           197.0.         1.80         5.300         32.14         2.50         Chapman et al. Manuscript         0.571         0.673            209.0         118.05         2.05         48.00         32.14         2.50         Chapman et al. Manuscript         0.571         0.673            209.0         18.05         2.05         48.00         32.14         2.50         Chapman et al. Manuscript         0.571         0.673                                    <	Vilosa vibex	186.0	86.26	2.16	125.00	61.24	2.04	EPA	0.768	0.714	0.9286	1
104.0         1.02         33.00         1.64         Chapman et al. Manuscript         -0.127         0.026           105.0         1.03         34.00         1.74         Chapman et al. Manuscript         -0.171         0.026           105.0         1.03         33.00         32.14         2.50         Chapman et al. Manuscript         0.571         0.422         1.1824           209.0         118.05         2.05         49.00         32.14         2.50         Chapman et al. Manuscript         0.571         0.422         1.1824           270.0         1270         0.56         47.00         32.14         2.50         Chapman et al. Manuscript         0.571         0.422         1.1824           240.0         127         10.00         32.14         2.50         Chapman et al. Manuscript         0.571         0.423         0.196           240.0         0.56         70.10         0.53         Bertam and Hart 1976         0.571         0.237         0.196         0.591         1.1804           25.0         0.56         70.10         0.73         Norus et al. 1996         0.237         0.196         0.571         0.237         0.196         0.571         0.237         0.104         1.163	Daphnia magna	51.0		0.50	9.90		0.51	Chapman et al. Manuscript	-0.839	-1.178		
105.0         1.03         34.00         1.74         Chapman et al. Manuscript         -0.117         0.056           197.0         1.83         63.00         32.14         Chapman et al. Manuscript         -0.117         0.057         0.673           57.0         1.805         0.505         0.505         0.506         0.512         0.673           57.0         1.805         0.506         3.50         1.253         Betram and Hart 1976         0.506         0.636           240.0         2.53         319.00         3.59         Elnebarawy et al. 1986         0.237         0.104           240.0         1.27         80.00         0.35         Betram and Hart 1976         0.237         0.104           240.0         0.50         0.50         0.50         0.53         Betram and Hart 1976         0.237         0.104           240.0         0.55         0.10         0.74         Roux et al. 1986         0.237         0.104           240.0         0.50         0.50         0.50         0.50         0.237         0.104           240.0         0.50         0.50         0.50         0.50         0.236         0.537         0.104           246         0.50	Daphnia magna	104.0		1.02	33.00		1.69	Chapman et al. Manuscript	-0.127	0.026		
167.0         1.83         63.00         3.22         Chapman et al. Manuscript         0.571         0.673         0.472         1.1824           2060         118.05         2.05         49.00         32.14         2.50         Chapman et al. Manuscript         0.571         0.472         1.1824           270         0.60         319.00         3.59         Entrama and Hart 1976         0.571         0.423         1.1824           270         1.27         80.00         3.59         Entrama and Hart 1976         0.571         0.416         1.127           270         1.201         1.27         100.00         1.13         Hall et al. 1986         0.237         0.108         0.199           5.35         0.056         70.10         0.74         Rux et al. 1985         0.237         0.108         0.199           5.35         0.090         66.00         0.74         Rux et al. 1983         0.101         0.237         0.108         0.109           85.0         94.71         0.90         66.00         88.74         0.79         Rux et al. 1983         0.571         0.237         1.063           85.0         94.71         0.90         86.00         70.00         88.74         0.79 </td <td>Daphnia magna</td> <td>105.0</td> <td></td> <td>1.03</td> <td>34.00</td> <td></td> <td>1.74</td> <td>Chapman et al. Manuscript</td> <td>-0.117</td> <td>0.056</td> <td></td> <td></td>	Daphnia magna	105.0		1.03	34.00		1.74	Chapman et al. Manuscript	-0.117	0.056		
a         206.0         118.05         2.05         49.00         32.14         2.50         Chapman et al Manuscript $0.571$ $0.422$ 1.1824           57.0         77.0         0.50         47.00         3.53         Bentram and Hart 1976         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         0.50         <	Daohnia magna	197.0		1.93	63.00		3.22	Chapman et al. Manuscript	0.512	0.673		
57.00.6047.000.53Bertram and Hart 19790.5080.6360.636240.02.53319.003.59Elmabarawy et al. 19860.2370.104127120.01.2780.000.09Hall et al. 19860.2370.1041120.01.2780.000.99Hall et al. 19860.2370.1041120.01.27100.001.12Roux et al. 19850.5710.2060.26685.094.710.9086.000.74Roux et al. 19930.7080.29685.094.710.9088.740.79Roux et al. 19930.7080.10985.094.710.9088.740.79Roux et al. 19930.1080.10985.094.710.9088.740.79Roux et al. 19930.1080.10985.094.710.9088.740.79Roux et al. 19930.1080.10985.094.710.9088.740.79Roux et al. 19931.3641.06185.094.710.9087.71.100.791.1661.06385.094.710.9087.40.79Roux et al. 19931.3641.06185.094.100.9087.40.791.1571.0631.05485.094.100.901.151.1561.1671.0691.1611.07985.11480.791.150.791.1671.0791.0761.25	Daohnia magna	209.0	118.05	2.05	49.00	32.14	2.50	Chapman et al. Manuscript	0.571	0.422	1.1824	0.91
240.0 $2.53$ $319.00$ $3.56$ Emabarawy et al. 1986 $0.320$ $1.279$ $1.279$ $120.0$ $1.27$ $80.00$ $0.56$ $1.27$ $100.00$ $1.13$ Hall et al. 1986 $0.237$ $0.104$ $1.27$ $120.0$ $1.27$ $100.00$ $1.13$ Hall et al. 1986 $0.237$ $0.104$ $1.27$ $85.0$ $0.56$ $70.10$ $0.74$ Roux et al. 1993 $0.108$ $0.237$ $0.108$ $85.0$ $94.71$ $0.90$ $99.00$ $87.4$ $0.74$ Roux et al. 1993 $0.108$ $0.109$ $85.0$ $94.71$ $0.90$ $86.00$ $87.4$ $0.74$ Roux et al. 1993 $0.108$ $0.108$ $85.0$ $94.71$ $0.90$ $86.00$ $87.4$ $0.74$ Roux et al. 1993 $0.108$ $0.108$ $85.0$ $94.71$ $0.90$ $86.00$ $88.74$ $0.74$ Roux et al. 1993 $0.108$ $0.108$ $85.0$ $94.71$ $0.90$ $86.00$ $88.74$ $0.74$ Roux et al. 1993 $0.108$ $0.108$ $85.0$ $94.71$ $0.90$ $86.00$ $88.74$ $0.74$ $1.983$ $2.446$ $0.757$ $85.0$ $94.71$ $0.90$ $86.00$ $0.74$ $1.84$ $2.446$ $0.754$ $2.446$ $85.0$ $0.44$ $1.80$ $0.71$ $2.90$ $1.84$ $2.46$ $0.754$ $2.46$ $85.0$ $9.16$ $0.74$ $1.90$ $0.72$ $7.1975$ $1.975$ $1.253$ $1.256$ $85.0$ $9$	Daphnia pulex	57.0		0.60	47.00		0.53	Bertram and Hart 1979	-0.508	-0.636		
120.0 $1.27$ $80.00$ $0.30$ $0.30$ Hall et al. 1986 $0.237$ $0.104$ $0.132$ $120.0$ $1.27$ $100.00$ $1.13$ Hall et al. 1986 $0.231$ $0.119$ $0.731$ $53.5$ $0.56$ $70.10$ $0.70$ $8.tokhouse and Benson 1988$ $0.571$ $0.236$ $0.70$ $85.0$ $8.70$ $0.990$ $66.00$ $0.74$ $Roux et al. 1993$ $0.071$ $0.236$ $0.236$ $85.0$ $94.74$ $0.90$ $86.00$ $8.74$ $0.74$ $Roux et al. 1993$ $0.0108$ $0.236$ $85.0$ $94.74$ $0.90$ $86.00$ $88.74$ $0.76$ $Roux et al. 1993$ $0.710$ $0.236$ $85.0$ $94.74$ $0.90$ $88.74$ $0.77$ $Roux et al. 1993$ $0.52$ $0.237$ $1.0633$ $85.0$ $94.74$ $0.90$ $88.74$ $0.76$ $Roux et al. 1993$ $0.56$ $0.281$ $0.236$ $85.0$ $94.74$ $0.90$ $88.74$ $0.76$ $Roux et al. 1993$ $0.52$ $0.237$ $1.0633$ $85.0$ $94.74$ $0.90$ $88.74$ $0.76$ $Roux et al. 1993$ $0.52$ $0.237$ $1.0633$ $85.0$ $94.74$ $0.90$ $88.74$ $0.76$ $Roux et al. 1993$ $0.710$ $0.796$ $0.281$ $85.0$ $94.74$ $0.76$ $0.74$ $0.76$ $0.76$ $0.76$ $0.736$ $1.267$ $85.0$ $0.44$ $0.22$ $1.157$ $0.71$ $0.87$ $0.84$ $0.76$ $0.736$	Daphnia pulex	240.0		2.53	319.00		3.59	Elnabarawy et al. 1986	0.930	1.279	ĺ	
120.0 $1.27$ $100.00$ $1.13$ Hall et al. 1986 $0.237$ $0.119$ $0.236$ $0.109$ $53.5$ $0.56$ $70.10$ $0.76$ $70.10$ $0.74$ Roux et al. 1993 $0.571$ $-0.296$ $0.236$ $85.0$ $85.0$ $94.71$ $0.90$ $66.00$ $0.74$ Roux et al. 1993 $-0.108$ $0.109$ $0.109$ $85.0$ $94.71$ $0.90$ $99.00$ $80.74$ $0.79$ Roux et al. 1993 $-0.108$ $0.109$ $85.0$ $94.71$ $0.90$ $99.00$ $80.74$ $0.79$ Roux et al. 1993 $-0.108$ $0.109$ $85.0$ $94.71$ $0.90$ $80.00$ $80.74$ $0.79$ Roux et al. 1993 $-0.108$ $0.109$ $85.0$ $94.71$ $0.90$ $80.00$ $80.74$ $0.79$ Roux et al. 1993 $-0.108$ $-0.237$ $1.0633$ $85.0$ $94.71$ $0.90$ $80.70$ $80.74$ $0.79$ Roux et al. 1993 $-0.108$ $-0.236$ $85.0$ $94.71$ $0.90$ $80.74$ $0.79$ Roux et al. 1993 $-0.108$ $-0.237$ $1.0633$ $85.0$ $94.71$ $0.90$ $80.74$ $0.79$ $1.155$ Hamilton and Buhl 1990 $1.84$ $2.466$ $85.0$ $0.44$ $1.80$ $0.71$ $1.55$ Hamilton and Buhl 1990 $1.84$ $2.466$ $85.0$ $0.44$ $1.41$ $0.72$ Chapman 1975, 1978 $-0.319$ $-1.601$ $85.0$ $52.14$ $0.40$ $1.41$ $0.22$ Fhapwara et al. 1978<	Daphnia pulex	120.0		1.27	80.00		06.0	Hall et al. 1986	0.237	-0.104		
(3.5) $(0.56)$ $(0.10)$ $(0.74)$ Stackhouse and Benson 1988 $(-0.216)$ $(-0.236)$ $(8.5.0)$ $(0.90)$ $(66.00)$ $(0.74)$ $(0.02)$ $(0.010)$ $(-0.296)$ $(-0.108)$ $(-0.296)$ $(8.5.0)$ $(9.7)$ $(0.90)$ $(99.00)$ $(0.74)$ $(0.010)$ $(0.103)$ $(-0.108)$ $(-0.296)$ $(8.5.0)$ $(9.7)$ $(0.90)$ $(99.00)$ $(8.74)$ $(0.74)$ $(0.74)$ $(0.93)$ $(-0.108)$ $(-0.23)$ $(-0.23)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(-0.10)$ $(1.6)$ $(-0.10)$ $(-0.10)$ $(-0.10$	Daphnia putex	120.0		1.27	100.00		1.13	Hall et al. 1986	0.237	0.119		
85.0 $0.90$ $66.00$ $0.74$ Roux et al. 1993 $-0.106$ $-0.296$ $85.0$ $9.7.1$ $0.90$ $99.00$ $88.74$ $0.72$ Roux et al. 1993 $5.52$ $0.237$ $1.0633$ $85.0$ $94.71$ $0.90$ $99.00$ $88.74$ $0.72$ Roux et al. 1993 $5.52$ $0.237$ $1.0633$ $85.0$ $94.71$ $0.90$ $70.00$ $88.74$ $0.79$ Roux et al. 1993 $5.52$ $0.237$ $1.0633$ $1 shawytscha$ $211.0$ $4.05$ $26.00$ $81.74$ $5.27$ Hamilton and Buhl 1990 $1.384$ $2.446$ $1 shawytscha$ $23.0$ $0.44$ $1.80$ $0.36$ Chapman 1975, 1978 $0.819$ $-0.36$ $1 shawytscha$ $23.0$ $0.44$ $3.50$ $0.71$ $0.29$ $0.814$ $-0.819$ $1 shawytscha$ $23.0$ $0.44$ $3.50$ $0.71$ $0.29$ $-0.36$ $-0.319$ $1 shawytscha$ $23.0$ $0.44$ $3.50$ $0.71$ $0.29$ $-0.919$ $-0.34$ $1 shawytscha$ $27.0$ $0.24$ $0.71$ $0.29$ $-0.019$ $-0.735$ $-1.209$ $1 shawytscha$ $27.0$ $0.44$ $3.50$ $0.71$ $-0.919$ $-0.735$ $-1.253$ $1 shawytscha$ $21.0$ $5.214$ $0.40$ $1.10$ $-0.23$ $-0.735$ $-1.253$ $1 shawytscha$ $21.0$ $0.50$ $2.100$ $0.74$ $-0.735$ $-0.735$ $-1.253$ $1 shawytscha$ $21.0$ $0.50$ $2.34$	Daphnia pulex	53.5		0.56	70.10		0.79	Stackhouse and Benson 1988	-0.571	-0.236		
85.0 $0.90$ $99.00$ $88.74$ $0.12$ Roux et al. 1993 $-0.108$ $0.109$ $0.103$ $85.0$ $94.71$ $0.90$ $70.00$ $88.74$ $0.79$ $Roux et al. 1993$ $5.52$ $-0.237$ $10633$ $157auxy/scha$ $211.0$ $4.05$ $26.00$ $88.74$ $0.79$ $Roux et al. 1993$ $5.52$ $-0.237$ $10633$ $157aux/scha$ $211.0$ $4.05$ $26.00$ $88.74$ $0.79$ $Roux et al. 1993$ $1.661$ $-0.108$ $0.109$ $157aux/scha$ $23.0$ $6.58$ $57.00$ $11.55$ Hamilton and Buhl 1990 $1.884$ $2.446$ $23.0$ $0.44$ $1.80$ $0.44$ $3.50$ $0.71$ $Chapman 1975, 1978$ $-0.819$ $-1.009$ $157aux/scha$ $23.0$ $0.44$ $3.50$ $0.71$ $Chapman 1975, 1978$ $-0.735$ $-1.253$ $-1.253$ $157aux/scha$ $23.0$ $0.44$ $3.50$ $0.71$ $0.29$ $Chapman 1982$ $-0.735$ $-1.253$ $-1.253$ $157aux/scha$ $25.0$ $0.44$ $3.50$ $0.71$ $0.29$ $Chapman 1982$ $-0.735$ $-1.253$ $-1.253$ $157aux/scha$ $20.0$ $0.48$ $1.41$ $0.40$ $0.110$ $0.34$ $-0.735$ $-1.253$ $-1.253$ $157aux/scha$ $20.0$ $5.74$ $0.3634.43$ $0.22$ $Einlayson and Verrue 1982-0.735-1.253-1.25311us20.020.02.140.000.540.64R.06-0.40Daphnia pulex85.006.066.000.74Roux et al. 1993-0.108-0.296$	Daphnia pulex	85.0		06.0	66.00		0.74	Roux et al. 1993	-0.108	-0.296		
85.0         94.71         0.90         70.00         88.74         0.79         Roux et al. 1993         5.52         -0.237         1.0633           211.0         211.0         4.05         26.00         88.74         0.75         Hamilton and Buhl 1990         1.398         1.661         7           343.0         6.58         57.00         11.55         Hamilton and Buhl 1990         1.884         2.446         7           23.0         0.44         1.80         0.36         Chapman 1975, 1978         -0.619         -1.009         7           23.0         0.44         1.80         0.71         Chapman 1975, 1978         -0.819         -0.344         7           23.0         0.48         1.41         0.29         Chapman 1975, 1978         -0.819         -1.009           21.0         52.14         0.40         1.41         0.29         Chapman 1982         -0.735         -1.253         7           220.0         22.14         0.40         1.10         4.94         0.22         Finlayson and Verrue 1982         -0.735         -1.253         7           20.0         22.14         0.40         1.103         0.54         0.54         0.54         0.54         0.56	Daphnia pulex	85.0		06.0	00.66		1.12	Roux et al. 1993	-0.108	0.109		
211.0 $4.05$ $26.00$ $5.27$ Hamilton and Buhl 1990 $1.388$ $1.661$ $1.661$ $343.0$ $6.58$ $57.00$ $1.155$ Hamilton and Buhl 1990 $1.884$ $2.446$ $2.446$ $23.0$ $0.44$ $1.80$ $0.36$ $0.36$ Chapman 1975, 1978 $0.819$ $-0.819$ $1.009$ $23.0$ $0.44$ $3.50$ $0.36$ $0.71$ Chapman 1975, 1978 $-0.819$ $-0.344$ $2.446$ $23.0$ $0.44$ $3.50$ $0.44$ $3.50$ $0.71$ Chapman 1975, 1978 $-0.735$ $-1.253$ $25.0$ $0.48$ $1.41$ $0.29$ $0.71$ Chapman 1975, 1978 $-0.736$ $-1.253$ $-1.253$ $21.0$ $52.14$ $0.40$ $1.10$ $4.94$ $0.22$ Finlayson and Verrue 1982 $-0.736$ $-1.253$ $-1.253$ $20.0$ $52.14$ $0.40$ $1.10$ $4.94$ $0.22$ Finlayson and Verrue 1982 $-0.736$ $-1.253$ $-1.253$ $21.0$ $52.14$ $0.40$ $1.10$ $4.94$ $0.22$ Finlayson and Verrue 1982 $-0.736$ $-1.253$ $-1.253$ $20.0$ $20.0$ $2.340.00$ $0.29$ $0.244$ $0.22$ Finlayson and Verrue 1982 $-0.740$ $-1.253$ $20.0$ $1.40.0$ $0.50$ $2.130.00$ $0.54$ $12.88$ McCarty et al. 1978 $-0.536$ $-0.440$ $140.0$ $1.40.0$ $3.534.43$ $0.21$ Phipps and Holcombe 1985 $-1.581$ $1.460$ $140.0$ $0.87$ $1.320$	Daphnia pulex	85.0	94.71	0:00	70.00	88.74	0.79	Roux et al. 1993	5.52	-0.237	1.0633	0.79
343.0 $6.58$ $57.00$ $11.55$ Hamilton and Buhl 1990 $1.884$ $2.446$ $2.446$ $23.0$ $0.44$ $1.80$ $0.36$ Chapman 1975, 1978 $0.819$ $-1.009$ $-1.603$ $23.0$ $0.44$ $3.50$ $0.36$ Chapman 1975, 1978 $-0.819$ $-0.819$ $-1.009$ $23.0$ $0.44$ $3.50$ $0.74$ $0.71$ Chapman 1975, 1978 $-0.819$ $-0.344$ $25.0$ $0.48$ $1.41$ $0.40$ $1.10$ $4.94$ $0.22$ Einlayson and Verrue 1982 $-0.735$ $-1.253$ $21.0$ $52.14$ $0.40$ $1.10$ $4.94$ $0.22$ Einlayson and Verrue 1982 $-0.740$ $1.2576$ $20.0$ $52.14$ $0.40$ $1.10$ $4.94$ $0.50$ $2.340.00$ $0.64$ Pickering and Henderson 1966 $-0.686$ $-0.740$ $20.0$ $52.14$ $0.50$ $2.340.00$ $0.59$ $McCarty et al. 1978$ $-0.686$ $-0.534$ $-1.2576$ $21.0$ $3.53$ $46.800.00$ $0.544.3$ $0.21$ Pinps and Holcombe 1985 $0.112$ $-1.501$ $-1.501$ $14.0$ $3.571$ $1.12$ $748.00$ $3.634.43$ $0.21$ Pinps and Holcombe 1985 $0.112$ $-1.581$ $1.4608$ $14.4$ $39.71$ $1.12$ $748.00$ $0.80$ $-0.81$ $-0.138$ $-0.138$ $-0.909$ $-1.501$ $140.0$ $-14.0$ $-1.22$ $-1.581$ $-1.581$ $-1.581$ $-1.581$ $-1.581$ $-1.581$ $14.4$ $-1.12$	Oncorhynchus tshawytscha	211.0		4.05	26.00		5.27	Hamilton and Buhl 1990	1.398	1.661		
23.0 $0.44$ $1.80$ $0.36$ Chapman 1975, 1978 $-0.819$ $-1.009$ $-1.006$ 23.0 $0.44$ $3.50$ $0.24$ $0.71$ Chapman 1975, 1978 $-0.819$ $-0.344$ $-0.344$ 25.0 $0.48$ $1.41$ $0.40$ $1.10$ $4.94$ $0.29$ Chapman 1982 $-0.735$ $-1.253$ $-1.2576$ 21.0 $52.14$ $0.40$ $1.10$ $4.94$ $0.22$ Finlayson and Verrue 1982 $-0.909$ $-1.501$ $1.2576$ 20.0 $21.0$ $52.14$ $0.40$ $1.10$ $4.94$ $0.22$ Finlayson and Verrue 1982 $-0.909$ $-1.501$ $1.2576$ 20.0 $21.0$ $0.50$ $2.340.00$ $0.64$ Pickering and Henderson 1966 $-0.686$ $-0.440$ $-0.440$ 20.0 $2.130.00$ $2.130.00$ $0.59$ McCarty et al. 1978 $-0.686$ $-0.534$ $-0.440$ $140.0$ $3.53$ $46,800.00$ $3.634.43$ $0.21$ Phipps and Holcombe 1985 $0.112$ $-1.581$ $1.4608$ $140.0$ $3.57$ $1.320$ $3.634.43$ $0.21$ Phipps and Holcombe 1985 $0.112$ $-1.581$ $1.4608$ $140.0$ $0.87$ $1.320$ $0.60$ $0.712$ $-1.581$ $1.4608$ $110$ $2.00$ $0.87$ $1.320$ $0.40$ $1.83$ $0.9138$ $-0.9138$ $-0.9138$ $120.0$ $2.748$ $0.21$ $0.712$ $-1.581$ $-1.581$ $-1.581$ $-1.581$ $-1.581$ $120.0$ $0.87$ $0.90$ $-1.$	Oncorhynchus tshawytscha	343.0		6.58	57.00		11.55	Hamilton and Buhl 1990	1.884	2.446		
23.0 $0.44$ $3.50$ $0.71$ Chapman 1975, 1978 $-0.819$ $-0.344$ $-0.346$ 25.0 $0.48$ $1.41$ $0.29$ $0.735$ $1.253$ $-1.253$ $-1.253$ 21.0 $52.14$ $0.40$ $1.10$ $4.94$ $0.22$ Finlayson and Verrue 1982 $-0.909$ $-1.501$ $1.2576$ 20.0 $20.0$ $0.50$ $2.340.00$ $0.64$ Pickering and Henderson 1966 $-0.686$ $-0.440$ $-0.440$ 20.0 $2.730.00$ $0.50$ $2.130.00$ $0.59$ McCarty et al. 1978 $-0.686$ $-0.534$ $140.0$ $3.53$ $46.800.00$ $3.634.43$ $0.21$ Phipps and Holcombe 1985 $0.112$ $-1.561$ $1.4608$ $44.4$ $39.71$ $1.12$ $748.00$ $3.634.43$ $0.21$ Phipps and Holcombe 1985 $0.112$ $-1.581$ $1.4608$ $44.0$ $0.87$ $13.20$ $0.40$ $3.634.43$ $0.21$ Phipps and Holcombe 1985 $0.112$ $-1.581$ $1.4608$ $11e$ $290.0$ $5.74$ $60.00$ $3.634.43$ $0.21$ Phipps and Holcombe 1985 $0.112$ $-1.581$ $1.4608$ $11e$ $2.30.0$ $0.87$ $13.20$ $0.40$ $0.40$ $0.40$ $0.9138$ $-0.909$ $0.909$ $20.0$ $2.748$ $0.00$ $3.634.43$ $0.21$ Phipps and Holcombe 1985 $0.112$ $-1.581$ $1.4608$ $20.0$ $0.87$ $1.3.20$ $0.40$ $0.40$ $0.909$ $-0.909$ $0.909$ $20.0$ $2.74$ <td< td=""><td>Oncorhynchus tshawytscha</td><td>23.0</td><td></td><td>0.44</td><td>1.80</td><td></td><td>0.36</td><td>Chapman 1975, 1978</td><td>-0.819</td><td>-1.009</td><td></td><td></td></td<>	Oncorhynchus tshawytscha	23.0		0.44	1.80		0.36	Chapman 1975, 1978	-0.819	-1.009		
25.0         0.48         1.41         0.29         Chapman 1982         -0.735         -1.253         -1.253           21.0         52.14         0.40         1.10         4.94         0.22         Finlayson and Verrue 1982         -0.909         -1.501         1.2576           20.0         52.14         0.40         1.10         4.94         0.22         Finlayson and Verrue 1982         -0.909         -1.501         1.2576           20.0         20.0         2.340.00         0.64         Pickering and Henderson 1966         -0.686         -0.400         1.2576           20.0         2.730.00         0.59         McCarty et al. 1978         -0.686         -0.534         1.2576           140.0         3.53         46.800.00         3.634.43         0.21         Phipps and Holderson 1966         -0.686         -0.534         1.4608           44.4         39.71         1.12         748.00         3.634.43         0.21         Phipps and Holcombe 1985         0.112         1.581         1.4608           nile)         44.0         0.87         13.20         0.40         Shehar and Fiandt 1986         -0.138         -0.909         9.9909           20.0         5.74         60.00         3.634.43	Oncorhynchus tshawytscha	23.0		0.44	3.50		0.71	- 1	-0.819	-0.344		
21.0         52.14         0.40         1.10         4.94         0.22         Finlayson and Verrue 1982         -0.909         -1.501         1.2576           20.0         0.50         2,340.00         0.64         Pickering and Henderson 1966         -0.686         -0.440         1.2576           20.0         0.50         2,130.00         0.59         McCarty et al. 1978         -0.686         -0.534         model           20.0         3.53         46,800.00         0.59         McCarty et al. 1978         -0.686         -0.534         model           44.4         39.71         1.12         748.00         3,634.43         0.21         Phipps and Holcombe 1985         0.112         -1.581         1.4608           nile)         44.0         0.87         13.20         0.40         Spehar and Flandt 1986         -0.138         -0.909         -1.581         1.4608           nile)         20.0         5.74         60.00         3,634.43         0.21         Phipps and Holcombe 1985         0.112         -1.581         1.4608	Oncorhynchus tshawytscha	25.0		0.48	1.41		0.29	Chapman 1982	-0.735	-1.253		
20.0         0.50         2,340.00         0.64         Pickering and Henderson 1966         -0.686         -0.440           20.0         0.50         2,130.00         0.59         McCarty et al. 1978         -0.686         -0.534         Pickering and Henderson 1966         -0.534         Pickering and Henderson 1966         -0.534         Pickering and Henderson 1978         -0.586         -0.534         Pickering and Henderson 1966         -0.534         Pickering and Henderson 1978         -0.565         Pickering and Henderson 1966         -0.555         Pickering and Henderson 1978         -0.561         1.4608           44.4         39.71         1.12         748.00         3.634.43         0.21         Phipps and Holcombe 1985         0.112         -1.581         1.4608           44.0         0.87         13.20         0.40         Spehar and Flandt 1986         -0.138         -0.909         Pictore           290.0         5.74         60.00         1.83         Schubauer-Berligan et al. 1993         1.748         0.605         Pictore	Oncorhynchus tshawytscha	21.0	52.14	0.40	1.10	4.94	0.22	Finlayson and Verrue 1982	-0.909	-1.501	1.2576	0.95
20.0         0.50         2,130.00         0.59         McCarty et al. 1978         -0.686         -0.534         -0.634         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.681         -0.534         -0.534         -0.681         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.534         -0.513         -0.513         -0.513         -0.513         -0.513         -0.503         -0.513         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503         -0.503 <t< td=""><td>Carassius auratus</td><td>20.0</td><td></td><td>0.50</td><td>2,340.00</td><td></td><td>0.64</td><td>Pickering and Henderson 1966</td><td>-0.686</td><td>-0.440</td><td></td><td></td></t<>	Carassius auratus	20.0		0.50	2,340.00		0.64	Pickering and Henderson 1966	-0.686	-0.440		
140.0         3.53         46,800.00         12.88         McCarty et al. 1978         1.260         2.555         1.4608           44.4         39.71         1.12         748.00         3,634.43         0.21         Phipps and Holcombe 1985         0.112         -1.581         1.4608           44.0         0.87         13.20         0.40         Spehar and Flandt 1986         -0.138         -0.909           290.0         5.74         60.00         1.83         Schubauer-Berigan et al. 1993         1.748         0.605	Carassius auratus	20.0		0.50	2,130.00		0.59	McCarty et al. 1978	-0.686	-0.534		
44.4         39.71         1.12         748.00         3.634.43         0.21         Phipps and Holcombe 1985         0.112         -1.581         1.4608           44.0         0.87         13.20         0.40         Spehar and Flandt 1986         -0.138         -0.909         1.400           290.0         5.74         60.00         1.83         Schubauer-Berigan et al. 1993         1.748         0.605	Carassius auratus	140.0		3.53	46,800.00		12.88	McCarty et al. 1978	1.260	2.555		1
44.0         0.87         13.20         0.40         Spehar and Fiandt 1986         -0.138           290.0         5.74         60.00         1.83         Schubauer-Berigan et al. 1993         1.748	Carassius auratus	44.4	39.71	1.12	748.00	3,634.43	0.21	Phipps and Holcombe 1985	0.112	-1.581	1.4608	0.57
290.0 5.74 60.00 1.83 Schubauer-Berigan et al. 1993 1.748	Pimephales promelas (juvenile)	44.0		0.87	13.20		0.40	Spehar and Fiandt 1986	-0.138	-0.909		
	Pimephales prometas (juvenite)	290.0		5.74	60.00		1.83	Schubauer-Berigan et al. 1993	1.748	0.605	1	

GEI Consultants, Inc. Ecological Division

October 2008 Cadmium Objectives - Review and Update

						Mamalinad		<u>u</u>	Ľ		
Species	(mg/L)	(hardness)	hardness		(acute)	acute	Reference	(norm hard)	(norm acute)	SMAS	¥
Pimephales promelas (frv)	17.0		0.34	4.80		0.15	Suedel et al. 1997	-1.089	-1.920		
Pimephales prometas (frv)	60.09		1.19	210.00		6.41	Rifici et al. 1996	0.172	1.858		
Pimephales prometas (frv)	60.09		1.19	180.00		5.50	Rifici et al. 1996	0.172	1.704		
Pimephales prometas (fry)	40.0		0.79	21.50		0.66	Spehar 1982	-0.233	-0.421		
Pimephales prometas (fry)	48.0		0.95	11.70		0.36	Spehar 1982	-0.051	-1.029		
Pimephales prometas (fry)	39.0		0.77	19.30		0.59	Spehar 1982	-0.258	-0.529		
Pimephales prometas (frv)	45.0		0.89	42.40		1.29	Spehar 1982	-0.115	0.258		
Pimephales promelas (fry)	47.0		0.93	54.20		1.65	Spehar 1982	-0.072	0.504		
Pimephales prometas (fry)	44.0		0.87	00.6	32.75	0.89	Spehar 1982	-0.138	-0.122	0.9210	0.29
Pimephates prometas (fry)	20.0	50.49	0.26	1,270.00		0.34	Pickering and Henderson 1966	-1.335	-1.088		
Poecilia reticulata	105.0		1.38	3,800.00		1.01	Canton and Slooff 1982	0.323	0.008		
Poecilia reticulata	209.2	76.02	2.75	11,100.00	3,769.67	2.94	Canton and Slooff 1982	1.012	1.080	0.8752	0.95
Poecília reticulata	34.5		0.57	1.00		0.33	Hughes 1973	-0.565	-1.096		
Morone saxatilis	34.5		0.57	2.00		0.67	Hughes 1973	-0.565	-0.402		
Morone saxatilis	40.0		0.66	4.00		1.34	Palawski et al. 1985	-0.417	0.291	•	
Morone saxatilis	285.0	60.69	4.70	10.00	2.99	3.34	Palawski et al. 1985	1.547	1.207	0.8089	0.72
Morone saxatilis	20.0		0.17	2,840.00		0.20	Pickering and Henderson 1966	-1.790	-1.631		
Lepomis cyanellus	360.0		3.00	66,000.00		4.55	Pickering and Henderson 1966	1.100	1.515		
Lepomis cyanellus	85.5		0.71	11,520.00		0.79	Carrier and Beitinger 1988b	-0.338	-0.230		
Lepomis cyanellus	335.0	119.84	2.80	20,500.00	14,504,98	1.41	Jude 1973	1.028	0.346	0.8986	0.88
Lepomis macrochirus	20.0		0.56	1,940.00		0.46	Pickering and Henderson 1966	-0.585	-0.786		
Lepomis macrochirus	18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
Lepomis macrochirus	18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
Lepomis macrochirus	207.0		5.77	21,100.00		4.95	Eaton 1980	1.752	1.600		
Lepomis macrochirus	44.4	35.89	1.24	6,470.00	4,258.80	1.52	Phipps and Holcombe 1985	0.213	0.418	0.9531	0.95
Oncorhynchus mykiss	420.0		6.93	7.40		4.04	Davies et al. 1993	1.935	1.397		
Oncorhynchus mykiss	427.0		7.04	5.92		3.23	Davies et al. 1993	1.952	1.174		
Oncorhynchus mykiss	217.0		3.58	4.20		2.29	Davies et al. 1993	1.275	0.830		
Oncorhynchus mykiss	227.0		3.74	6.57		3.59	Davies et al. 1993	1.320	1.278		
Oncorhynchus mykiss	46.0		0.76	2.64		1.44	Davies et al. 1993	-0.276	0.366		
Oncorhynchus mykiss	49.0		0.81	3.08		1.68	Davies et al. 1993	-0.213			
Oncorhynchus mykiss	23.0		0.38	1.30		0.71	Chapman 1975, 1978	-0.969	-+		
Oncorhynchus mykiss	23.0		0.38	1.00		0.55	Chapman 1978	-0.969	-0.605		
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Pimephales promelas (iry)17.0Pimephales promelas (iry)60.0Pimephales promelas (iry)60.0Pimephales promelas (iry)40.0Pimephales promelas (iry)48.0Pimephales promelas (iry)39.0Pimephales promelas (iry)45.0		hardness	(hg/L)	Geomean (acute)	Normalized acute	Reference	(norm hard)	(norm acute)	SMAS	R²
		0.34	4.80		0.15	Suedel et al. 1997	-1.089	-1.920		
		1.19	210.00		6.41	Rifici et al. 1996	0.172	1.858		
		1.19	180.00		5.50	Rifici et al. 1996	0.172	1.704		
		0.79	21.50		0.66	Spehar 1982	-0.233	-0.421		
		0.95	11.70		0.36	Spehar 1982	-0.051	-1.029		
		0.77	19.30		0.59	Spehar 1982	-0.258	-0.529		
		0.89	42.40	-	1.29	Spehar 1982	-0.115	0.258		
Pimephales promelas (fry) 47.0		0.93	54.20		1.65	Spehar 1982	-0.072	0.504		
Pimephales promelas (fry) 44.0		0.87	00'6	32.75	0.89	Spehar 1982	-0.138	-0.122	0.9210	0.29
Pimephales promelas (frv) 20.0	50.49	0.26	1,270.00		0.34	Pickering and Henderson 1966	-1.335	-1.088		
		1.38	3,800.00		1.01	Canton and Slooff 1982	0.323	0.008		
Poecilia reticulata 209.2	76.02	2.75	11,100.00	3,769.67	2.94	Canton and Slooff 1982	1.012	1.080	0.8752	0.95
Poecilia reticulata 34.5		0.57	1.00		0.33	Hughes 1973	-0.565	-1.096		
		0.57	2.00		0.67	Hughes 1973	-0.565	-0.402		
Morone saxatilis 40.0		0.66	4.00	-	1.34	Palawski et al. 1985	-0.417	0.291		
Morone saxatilis 285.0	60.69	4.70	10.00	2.99	3.34	Palawski et al. 1985	1.547	1.207	0.8089	0.72
		0.17	2,840.00		0.20	Pickering and Henderson 1966	-1.790	-1.631		
SD		3.00	66,000.00		4.55	Pickering and Henderson 1966	1.100	1.515		_
Lepomis cyanellus 85.5		0.71	11,520.00		0.79	Carrier and Beitinger 1988b	-0.338	-0.230		
	119.84	2.80	20,500.00	14,504.98	1.41	Jude 1973	1.028	0.346	0.8986	0.88
Lepomis macrochirus 20.0		0.56	1,940.00		0.46	Pickering and Henderson 1966	-0.585	-0.786		
Lepomis macrochirus 18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
Lebomis macrochirus 18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
Lepomis macrochirus 207.0		5.77	21,100.00		4.95	Eaton 1980	1.752	1.600		
Lepomis macrochirus 44.4	35.89	1.24	6,470.00	4,258.80	1.52	Phipps and Holcombe 1985	0.213	0.418	0.9531	0.95
Oncorhynchus mykiss 420.0		6.93	7.40		4.04	Davies et al. 1993	1.935	1.397		
Oncorhvnchus mykiss 427.0		7.04	5.92		3.23	Davies et al. 1993	1.952	1.174		
Oncorhvnchus mvkiss 217.0		3.58	4.20		2.29	Davies et al. 1993	1.275	0.830		
		3.74	6.57		3.59	Davies et al. 1993	1.320	1.278		
Oncorhynchus mykiss 46.0		0.76	2.64		1.44	Davies et al. 1993	-0.276	0.366		
Oncorhynchus mykiss 49.0		0.81	3.08		1.68	Davies et al. 1993	-0.213	0.520		
Oncorhynchus mykiss 23.0		0.38	1.30		0.71	Chapman 1975, 1978	-0.969	-0.342		
Oncorhynchus mykiss 23.0		0.38	1.00		0.55	Chapman 1978	-0.969	-0.605		
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Species	Hardness (mg/L)	Geomean (hardness)	Normalized hardness	LC <sub>50</sub> /EC <sub>50</sub> (µg/L)	Geomean (acute)	Normalized	Reference	(norm hard)	(norm acute)	SMAS	R
Dimonhalas nromalas (fru)	17.0		0.34	4.80		0.15	Suedel et al. 1997	-1.089	-1.920		
Pimonholos promotos (frv)	80.0		1.19	210.00		6.41	Rifici et al. 1996	0.172	1.858		
Pimenhales prometas (fn/)	80.0		1.19	180.00		5.50	Rifici et al. 1996	0.172	1.704		
Pimenhales promodas (frv)	40.0		0.79	21.50		0.66	Spehar 1982	-0.233	-0.421		
Pimenhales prometas (frv)	48.0		0.95	11.70		0.36	Spehar 1982	-0.051	-1.029		-
Pimenhales prometas (ftv)	39.0		0.77	19.30		0.59	Spehar 1982	-0.258	-0.529		
Pimenhales nromelas (frv)	45.0		0.89	42.40		1.29	Spehar 1982	-0.115	0.258		
Pimenhales prometas (frv)	47.0		0.93	54.20		1.65	Spehar 1982	-0.072	0.504		
Pimeohales promelas (frv)	44.0		0.87	00.6	32.75	0.89	Spehar 1982	-0.138	-0.122	0.9210	0.29
Pimephales promelas (fry)	20.0	50.49	0.26	1,270.00		0.34	Pickering and Henderson 1966	-1.335	-1.088		
Poecilia reticulata	105.0		1.38	3,800.00		1.01	Canton and Slooff 1982	0.323	0.008		L
Poecilia reticulata	209.2	76.02	2.75	11,100.00	3,769.67	2.94	Canton and Slooff 1982	1.012	1.080	0.8752	C6.U
Poecilia reticulata	34.5		0.57	1.00		0.33	Hughes 1973	-0.565	-1.096	,	
Morone saxatilis	34.5		0.57	2.00		0.67	Hughes 1973	-0.565	-0.402		
Morone saxatilis	40.0		0.66	4.00		1.34	Palawski et al. 1985	-0.417	0.291		
Morone saxatilis	285.0	60.69	4.70	10.00	2.99	3.34	Palawski et al. 1985	1.547	1.207	0.8089	0.72
Morone savatilis	20.0		0.17	2,840.00		0.20	Pickering and Henderson 1966	-1.790	-1.631		
l enomis cvanellus	360.0		3.00	66,000.00		4.55	Pickering and Henderson 1966	1.100	1.515		
Leponne dy unonue	85.5		0.71	11,520.00		0.79	Carrier and Beitinger 1988b	-0.338	-0.230		
Leponno vyanonuo	335.0	119.84	2.80	20.500.00	14,504.98	1.41	Jude 1973	1.028	0.346	0.8986	0.88
Lepuille cyaneilue	20.0	-	0.56	1,940.00		0.46	Pickering and Henderson 1966	-0.585	-0.786		
Leponia macrochinis	18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
Leponie macmohinis	18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
l enomis mecnochirus	207.0		5.77	21,100.00		4.95	Eaton 1980	1.752	1.600		
Lepomis macrochirus	44.4	35.89	1.24	6,470.00	4,258.80	1.52	Phipps and Holcombe 1985	0.213	0.418	0.9531	0.95
Oncorhvnchus mykiss	420.0		6.93	7.40		4.04	Davies et al. 1993	1.935	1.397		
Oncortworking mukiss	427.0		7.04	5.92		3.23	Davies et al. 1993	1.952	1.174	_	
Oncomprisition mukies	217.0		3.58	4.20		2.29	Davies et al. 1993	1.275	0.830		
Oncorhvnchus mykiss	227.0	-	3.74	6.57		3.59	Davies et al. 1993	1.320	$\rightarrow$		
Oncorhvnchus mvkiss	46.0		0.76	2.64		1.44	Davies et al. 1993	-0.276	-+		
Oncorhvnchus mvkiss	49.0		0.81	3.08		1.68	Davies et al. 1993	-0.213	-		_
Oncorhvnchus mvkiss	23.0		0.38	1.30		0.71	Chapman 1975, 1978	-0 969			
Oncorhvnchus mvkiss	23.0		0.38	1.00		0.55	Chapman 1978	-0.969	-0.605		
				-	1					October 2008	-2.008

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Species	Hardness (mg/L)	Geomean (hardness)	Normalized hardness	LC <sub>50</sub> /EC <sub>50</sub> (µg/L)	Geomean (acute)	Normalized acute	Reference	in (norm hard)	In (norm acute)	SMAS	۲ <sup>۲</sup>
Dimenhales nrometas (frv)	17.0		0.34	4.80		0.15	Suedel et al. 1997	-1.089	-1.920		
Pimenhales prometas (frv)	80.0		1.19	210.00		6.41	Rifici et al. 1996	0.172	1.858		
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Pimenhales promelas (frv)	40.0		0.79	21.50		0.66	Spehar 1982	-0.233	-0.421		
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Pimenhales prometas (frv)	45.0		0.89	42.40		1.29	Spehar 1982	-0.115	0.258		
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Pimephales promelas (frv)	44.0		0.87	9.00	32.75	0.89	Spehar 1982	-0.138	-0.122	0.9210	0.29
Pimephales promelas (frv)	20.0	50.49	0.26	1,270.00		0.34	Pickering and Henderson 1966	-1.335	-1.088		
Poecilia reticulata	105.0		1.38	3,800.00		1.01	Canton and Slooff 1982	0.323	0.008		
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Poecília reticulata	34.5		0.57	1.00		0.33	Hughes 1973	-0.565	-1.096	,	
Morone saxatilis	34.5	1	0.57	2.00		0.67	Hughes 1973	-0.565	-0.402		
Morone saxatilis	40.0		0.66	4.00		1.34	Palawski et al. 1985	-0.417	0.291		į
Morone saxatilis	285.0	60.69	4.70	10.00	2.99	3.34	Palawski et al. 1985	1.547	1.207	0.8089	0.72
Morone saxatilis	20.0		0.17	2,840.00		0.20	Pickering and Henderson 1966	-1.790	-1.631		
Lepomis cvanellus	360.0		3.00	66,000.00		4.55	Pickering and Henderson 1966	1.100	1.515		
Lepomís cvanellus	85.5		0.71	11,520.00		0.79	Carrier and Beitinger 1988b	-0.338	-0.230		
Lepomis cvanellus	335.0	119.84	2.80	20,500.00	14,504.98	1.41	Jude 1973	1.028	-	0.8986	0.88
Lebomis macrochirus	20.0		0.56	1,940.00		0.46	Pickering and Henderson 1966	-0.585	- +		
Lebomis macrochirus	18.0		0.50	2,300.00		0.54	Bishop and McIntosh 1981	-0.690	-0.616		
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Lepomis macrochirus	44.4	35.89	1.24	6,470.00	4,258.80	1.52	Phipps and Holcombe 1985	0.213	0.418	0.9531	0.95
Oncorhynchus mykiss	420.0		6.93	7.40		4.04	Davies et al. 1993	1.935	1.397		
Oncorhvnchus mvkiss	427.0		7.04	5.92		3.23	Davies et al. 1993	1.952	1.174		
Oncorhvnchus mvkiss	217.0		3.58	4.20		2.29	Davies et al. 1993	1.275	0.830		
Oncorhynchus mykiss	227.0		3.74	6.57		3.59	Davies et al. 1993	1.320			
Oncorhvnchus mvkiss	46.0		0.76	2.64		1.44	Davies et al. 1993	-0.276	-		
Oncorhvnchus mykiss	49.0		0.81	3.08		1.68	Davies et al. 1993	-0.213	-+		
Oncorhynchus mykiss	23.0		0.38	1.30		0.71	Chapman 1975, 1978	-0.969	-		
Oncorhynchus mykiss	23.0		0.38	1.00		0.55	Chapman 1978	696.0-	-0.605		
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	Hardness	Geomean	Normalized LCso/ECso Geomean	LC50/EC50	Geomean	Normalized	Reference	(norm	(norm	SMAS	ۍ ۲
Species	(mg/L)	(hardness)	hardness	(hg/L)	(acute)	acute		hard)	acute)		
	0.70		0.51	1 75		0.96	Davies 1976	-0.671	-0.045		
Oncornynchus mykiss	0.10		0.73	3.00		1.64	Phipps and Holcombe 1985	-0.312	0.494		
Oncorhynchus mykiss	<b>+</b> +.+		2.0	2000		0.30	Stratus Consulting 1999	-0.681	-0.947		
Oncorhynchus mykiss	30.7		1.C.U	1.1.0		0.00		<b>2</b> 02 0	1 260		
Oncorhvnchus mykiss	29.3		0.48	0.47		0.26	Stratus Consulting 1999	-0.121	000.1-		Ţ
Onorthinghie millie	317		0.52	0.51		0.28	Stratus Consulting 1999	-0.649	-1.278		
	000		0.50	0.38		0.21	Stratus Consulting 1999	-0.697	-1.572		1
Uncornyncnus mykiss	<b>4</b> .00		970			0 2 0	Stratus Consulting 1999	-0.704	-0.350		
Oncorhynchus mykiss	30.0		0.43	62.1				700.0	0110	0.7670	890
Oncorhvnchus mykiss	89.3	60.64	1.47	2.85	1.83	1.56	Stratus Consulting 1999	1.30/	0.446	0.101.0	200
	12.5		0.80	1.40		0.51	Spehar and Carlson 1984	-0.229	-0.680		
Saimo trutta			0.60	2 37		0.86	Davies and Brinkman 1994	-0.374	-0.153		
Salmo trutta	0.10		000			0 AE	Brinkman and Hansen 2004	-0.627	-0.809		
Salmo trutta	29.2		0.53	1.23		0.40		0.040	0 345		
Colmo tu tto	67.6		1.24	3.90		1.41	Brinkman and Hansen 2004	717.0	0.040		
	151 4	51 G8	77.6	10 10	2.76	3.66	Brinkman and Hansen 2004	1.018	1.297	1.2671	0.91
Salmo trutta	101.4	00.40					Revised pooled acute slope = 0.9151	oled acut	e slope	= 0.9151	0.69

October 2008 Cadmium Objectives - Review and Update

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Socioe	Hardness		Normalized LC50/EC50	LC <sub>50</sub> /EC <sub>50</sub>	G	Normalized	Reference	uorm	(norm	SMAS	<b>R</b> 2
abecies	(mg/L)	(hardness)	hardness	(hg/L)	(acute)	acrite		hard)	acute)		
Canada matrice	31.0		0.51	1.75		0.96	Davies 1976	-0.671	-0.045		
Oncontryncias mynas	2110		0.73	3.00		1.64	Phipps and Holcombe 1985	-0.312	0.494		
Oncomprished in priss	200		051	0 71		0.39	Stratus Consulting 1999	-0.681	-0.947		
Uncornyncitus mykiss	- 00		0.00			0.26	Stratus Consulting 1999	-0.727	-1.360		
Oncorhynchus mykiss	23.3		0.40	÷.		0000	Stratus Consulting 1999	-0.649	-1.278		
Oncorhynchus mykiss	31.7		0.52	1C.U		0.40					
Oncorhinchits mukiss	30.2		0.50	0.38	1	0.21	Stratus Consulting 1999	-0.697	-1.5/Z		
Circontynoriad mynes	30.0		0.49	1 29		0.70	Stratus Consulting 1999	-0.704	-0.350		
Oncompricing mykiss		000	1 17	2 85	1.83	1.56	Stratus Consulting 1999	0.387	0.442	0.7679	0.68
<b>Uncornynchus mykiss</b>	03.3	40.00				0 51	Snehar and Carlson 1984	-0.229	-0.680		
Salmo trutta	43.5		U.8U	1.40		10.0		120.0	0.152		Γ
Salmo trutta	37.6		0.69	2.37		0.86	Davies and Brinkman 1994	-0.014			
Salmo trutta	292		0.53	1.23		0.45	Brinkman and Hansen 2004	-0.627	-0.809		
	1 0 1 0 0 1 0		1 24	3.90		1.41	Brinkman and Hansen 2004	0.212	0.345		
Salmo Irutta	0.10			07.07	95.0	2 56	Brinkman and Hansen 2004	1.018	1.297	1.2671	0.91
Salmo trutta	151.4	54.68	2.11	10.10	z./۵	3.00				0.0464	0.60
							Kevised pooled acute stope - 0.3 131	olea acul	e siope	- 0.3 13 1	20.0

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	Hardness	Geomean	Normalized	LC <sub>50</sub> /EC <sub>50</sub>	G	Normalized	Reference	(norm	(norm	SMAS	ъ Г
Species	(mg/L)	(hardness)	hardness	(hg/L)	(acute)	acute		hard)	acute)		
Oucorhinchiic miliice	31.0		0.51	1.75		96.0	Davies 1976	-0.671	-0.045		
Oncontrynchus mykiss	74.4		0.73	3.00		1.64	Phipps and Holcombe 1985	-0.312	0.494		
Oncomprising myrics	2U2		0.51	0.71		0.39	Stratus Consulting 1999	-0.681	-0.947		
	2003		0.48	0.47		0.26	Stratus Consulting 1999	-0.727	-1.360		
Oncorrighterius rightiss	C 10	Ĩ	0.52	0.51		0.28	Stratus Consulting 1999	-0.649	-1.278		
Oncorriging inguiss	000		0.50	0.38		0.21	Stratus Consulting 1999	-0.697	-1.572		
Uncomynenus mykiss	2.00		0.40	1 20		0.70	Stratus Consulting 1999	-0.704	-0.350		- 1
Oncornynchus mykiss	0.00	EO EA	1 47	2.85	1.83	1.56	Stratus Consulting 1999	0.387	0.442	0.7679	0.68
Uncomynchus mykiss	42.5	<b>1</b> 0.00	0.80	1 40		0.51	Spehar and Carlson 1984	-0.229	-0.680		
Saimo trutta	27.6		0.69	2.37		0.86	Davies and Brinkman 1994	-0.374	-0.153		
Saimo trutta	0.10		0.53	1 23		0.45	Brinkman and Hansen 2004	-0.627	-0.809		
Saimo trutta	67.6 67.6		1 24	3 90		1.41	Brinkman and Hansen 2004	0.212	0.345		
Saimo trutta	151.1	£1 68	<u>11 c</u>	10 10	2.76	3.66	Brinkman and Hansen 2004	1.018	1.297	1.2671	0.91
Sanno Iruua	t 12	201-0		2			Revised pooled acute slope = 0.9151	oled acut	e slope	= 0.9151	0.69

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	Hardness	Geomean	Normalized LC50/EC50	LC50/EC50	Geomean	Normalized	Reference	(norm	(norm	SMAS	۳2 ۲
Species	(mg/L)	(hardness)	hardness	(hg/L)	(acute)	acute		hard)	acute)		T
Orthon the mediate	34.0		0.51	1.75		0.96	Davies 1976	-0.671	-0.045		
Oncompricing myxiss	0.10 A A A		0.73	3.00		1.64	Phipps and Holcombe 1985	-0.312	0.494		
Uncorrigination in the second			0.54	0 71		0.39	Stratus Consulting 1999	-0.681	-0.947		
Oncornynchus mykiss	30.7		0.0	- 10		0.26	Stratus Consulting 1999	-0.727	-1.360		
Oncorhynchus mykiss	29.3		0.40	1+10		04.0	Cutato Concerno 2	0.640	-1 278		
Oncorhvnchus mykiss	31.7		0.52	0.51		0.28	Stratus Consuluing 1999	100.0-			Ţ
Operative husies	30.2		0.50	0.38		0.21	Stratus Consulting 1999	-0.697	-1.572		
			0.49	1 29		0.70	Stratus Consulting 1999	-0.704	-0.350		
Oncornynchus mykiss			1.1	30 0	1 83	1 56	Stratus Consulting 1999	0.387	0.442	0.7679	0.68
Oncorhynchus mykiss	89.3	60.04	1.47	×.00	3			0000	0 ARO		
Salmo trutta	43.5		0.80	1.40		0.51	Spehar and Carlson 1964	-0.223	000.0-		
Salmo trutta	37.6		0.69	2.37		0.86	Davies and Brinkman 1994	-0.374	-0.153		
Comp trutto	20.2		0.53	1.23		0.45	Brinkman and Hansen 2004	-0.627	-0.809		T
Saino uuua	57 E		1 24	3.90		1.41	Brinkman and Hansen 2004	0.212	0.345		
	0, 10	51 60	0 77	10 10	276	3.66	Brinkman and Hansen 2004	1.018	1.297	1.2671	0.91
Salmo trutta	4.101	04'00	7.77	2		22.2	Revised monled acute slobe = 0.9151	oled acut	te slope	= 0.9151	0.69
		i									-

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## 4.2 Updated Acute Cadmium Objectives

The recalculated FAV was then determined using the GMAVs for the four most sensitive genera in the revised acute database. Calculations followed the EPA methods for criteria derivation (Stephan et al. 1985), and are presented in Table 9. The revised FAV at a hardness of 50 mg/L is 2.785  $\mu$ g/L, which results in a final acute equation of e<sup>0.9151[ln(hardness)]-3.2488</sup> and criteria maximum concentration (CMC), or acute objective, of 1.393  $\mu$ g/L for Cd. This value is slightly higher than the FAV reported in the 2001 Cadmium Document (2.763  $\mu$ g/L), and is higher than the SMAVs for many, but not all, commercially important trout. To further protect trout, the 2001 Cadmium Document replaced the FAV with the SMAV of rainbow trout in the criterion calculation, which resulted in a FAV of 2.014  $\mu$ g/L. This value was higher than the SMAV for the brook trout, yet lower than all other SMAVs in the 2001 Cadmium Document database. Following this approach, but in an effort to be more protective, we lowered the revised FAV to the lowest GMAV (*Salvelinus*) of 1.915  $\mu$ g/L to better protect trout (Table 9). The revised "trout-specific" equation becomes e0.9151[ln(hardness)]-3.6236 and a CMC if 0.9573  $\mu$ g/L, again at hardness of 50 mg/L, using the lowered "trout" FAV.

Rank	Genus	GMAV	In GMAV	(In GMAV)^2	P = R/(N+1)	√P
4	Morone	3.159	1.1502	1.3229	0.0678	0.2604
3	Salmo	2.883	1.0590	1.1215	0.0508	0.2255
2	Cottus	2.374	0.8647	0.7477	0.0339	0.1841
1	Salvelinus	1.915	0.6495	0.4218	0.0169	0.1302
		Sum	3.7234	3.6140	0.1695	0.8002

Table 9: Recalculation of the final acute values for Cd using the updated acute database. N = 58 genera, R = sensitivity rank in database, P = rank / N+1.

### Calculations:

Acute Criterion  $S^{2} = \sum (\ln GMAV)^{2} - (\sum \ln GMAV)^{2}/4 = 3.6140 - (3.7234)^{2}/4 = 15.7167$ 

 $\Sigma P - (\Sigma \sqrt{P})^2/4$ 

$$\begin{split} L &= [\Sigma \ln GMAV - S(\Sigma \sqrt{P})]/4 = [3.7234 - 3.9644 \ (0.8002)]/4 = 0.1378 \\ A &= S \ (\sqrt{0.05}) + L = (3.9644)(0.2236) + 0.1378 = 1.0243 \end{split}$$

Final Acute Value =  $FAV = e^A = 2.785$ CMC =  $\frac{1}{2}$  FAV = 1.3925 Pooled Slope = 0.9151

In (Criterion Maximum Intercept)

=  $\ln$ CMC - [pooled slope × ln (standardized hardness level)] =  $\ln (1.3925) - [0.9151 \times \ln (50)]$ 

= -3.2488

Recalculated Acute Cadmium Criterion =  $e^{0.9151 [\ln (hardness)] - 3.2488}$ @ Hardness 100 = 2.626 µg/L S = 3.96440.1695 -  $(0.8002)^2/4$ 

Lowered to protect trout FAV = 1.9146 CMC = 0.9573

> $= \ln(0.9573) - [0.9151 \times \ln(50)]$ = -3.6236

Criterion to protect trout =  $e^{0.9151[in(hardness)]-3.6236}$ @ Hardness 100 = 1.805 µg/L

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## 4.2 Updated Acute Cadmium Objectives

The recalculated FAV was then determined using the GMAVs for the four most sensitive genera in the revised acute database. Calculations followed the EPA methods for criteria derivation (Stephan et al. 1985), and are presented in Table 9. The revised FAV at a hardness of 50 mg/L is 2.785  $\mu$ g/L, which results in a final acute equation of e<sup>0.9151[ln(hardness)]-3.2488</sup> and criteria maximum concentration (CMC), or acute objective, of 1.393  $\mu$ g/L for Cd. This value is slightly higher than the FAV reported in the 2001 Cadmium Document (2.763  $\mu$ g/L), and is higher than the SMAVs for many, but not all, commercially important trout. To further protect trout, the 2001 Cadmium Document replaced the FAV with the SMAV of rainbow trout in the criterion calculation, which resulted in a FAV of 2.014  $\mu$ g/L. This value was higher than the SMAV for the brook trout, yet lower than all other SMAVs in the 2001 Cadmium Document database. Following this approach, but in an effort to be more protective, we lowered the revised FAV to the lowest GMAV (*Salvelinus*) of 1.915  $\mu$ g/L to better protect trout (Table 9). The revised "trout-specific" equation becomes e0.9151[ln(hardness)]-3.6236 and a CMC if 0.9573  $\mu$ g/L, again at hardness of 50 mg/L, using the lowered "trout" FAV.

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2	Cottus	2.374	0.8647	0.7477	0.0339	0.1841
1	Salvelinus	1.915	0.6495	0.4218	0.0169	0.1302
	Garronnac	Sum	3,7234	3.6140	0.1695	0.8002

Table 9: Recalculation of the final acute values for Cd using the updated acute database. N = 58 genera, R = sensitivity rank in database, P = rank / N+1.

### Calculations:

Acute Criterion  $S^{2} = \sum (\ln GMAV)^{2} - (\sum \ln GMAV)^{2}/4 = 3.6140 - (3.7234)^{2}/4 = 15.7167$   $\sum P - (\sum \sqrt{P})^{2}/4$ 

S = 3.96440.1695 - (0.8002)<sup>2</sup>/4

 $L = [\Sigma \ln GMAV - S(\Sigma \sqrt{P})]/4 = [3.7234 - 3.9644 (0.8002)]/4 = 0.1378$ A = S ( $\sqrt{0.05}$ ) + L = (3.9644)(0.2236) + 0.1378 = 1.0243

Final Acute Value = $FAV = e^A = 2.785$ CMC = $\frac{1}{2}$ FAV = 1.3925 Pooled Slope = 0.9151	FAV = 1.9146 CMC = 0.9573
In (Criterion Maximum Intercept) = $\ln$ CMC - [pooled slope × ln (standardized hardness level)] = $\ln (1.3925) - [0.9151 \times \ln (50)]$ = -3.2488	$= \ln(0.9573) - [0.9151 \times \ln(50)]$ = -3.6236
Recalculated Acute Cadmium Criterion = $e^{0.9151 [lm (hardness)] - 3.2488}$ (a) Hardness 100 = 2.626 µg/L	Criterion to protect trout = $e^{0.9151[in(hardness)]-3.6236}$ @ Hardness 100 = 1.805 µg/L

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Lowered to protect trout

#### 4.2 Updated Acute Cadmium Objectives

The recalculated FAV was then determined using the GMAVs for the four most sensitive genera in the revised acute database. Calculations followed the EPA methods for criteria derivation (Stephan et al. 1985), and are presented in Table 9. The revised FAV at a hardness of 50 mg/L is 2.785  $\mu$ g/L, which results in a final acute equation of  $e^{0.9151[ln(hardness)]}$ -

 $^{3.2488}$  and criteria maximum concentration (CMC), or acute objective, of 1.393  $\mu$ g/L for Cd. This value is slightly higher than the FAV reported in the 2001 Cadmium Document (2.763 µg/L), and is higher than the SMAVs for many, but not all, commercially important trout. To further protect trout, the 2001 Cadmium Document replaced the FAV with the SMAV of rainbow trout in the criterion calculation, which resulted in a FAV of 2.014  $\mu$ g/L. This value was higher than the SMAV for the brook trout, yet lower than all other SMAVs in the 2001 Cadmium Document database. Following this approach, but in an effort to be more protective, we lowered the revised FAV to the lowest GMAV (Salvelinus) of 1.915 µg/L to better protect trout (Table 9). The revised "trout-specific" equation becomes e0.9151[ln(hardness)]-3.6236 and a CMC if 0.9573 µg/L, again at hardness of 50 mg/L, using the lowered "trout" FAV.

Rank	Genus	GMAV	In GMAV	(In GMAV)^2	P = R/(N+1)	√P
4	Morone	3.159	1.1502	1.3229	0.0678	0.2604
3	Salmo	2.883	1.0590	1.1215	0.0508	0.2255
2	Cottus	2.374	0.8647	0.7477	0.0339	0.1841
1	Salvelinus	1.915	0.6495	0.4218	0.0169	0.1302
		Sum	3.7234	3.6140	0.1695	0.8002

Recalculation of the final acute values for Cd using the updated acute database. Table 9: N = 58 genera, R = sensitivity rank in database, P = rank / N+1.

### **Calculations:**

Acute Criterion

 $S^{2} = \sum (\ln GMAV)^{2} - (\sum \ln GMAV)^{2}/4 = 3.6140 - (3.7234)^{2}/4 = 15.7167$  $\Sigma P - (\Sigma \sqrt{P})^2/4$ 

S = 3.9644

 $L = [\Sigma \ln GMAV - S(\Sigma \sqrt{P})]/4 = [3.7234 - 3.9644 (0.8002)]/4 = 0.1378$  $A = S (\sqrt{0.05}) + L = (3.9644)(0.2236) + 0.1378 = 1.0243$ 

Final Acute Value =  $FAV = e^{A} = 2.785$  $CMC = \frac{1}{2}$  FAV = 1.3925 Pooled Slope = 0.9151

In (Criterion Maximum Intercept)

=  $\ln CMC$  - [pooled slope × ln (standardized hardness level)]  $= \ln (1.3925) - [0.9151 \times \ln (50)]$ 

= -3.2488

Recalculated Acute Cadmium Criterion =  $e^{0.9151 [ln (hardness)] - 3.2488}$ @ Hardness 100 = 2.626 μg/L

 $0.1695 - (0.8002)^2/4$ 

 $= \ln(0.9573) - [0.9151 \times \ln(50)]$ = -3.6236

Criterion to protect trout =  $e^{0.9151[in(hardness)]-3.6236}$ @ Hardness  $100 = 1.805 \ \mu g/L$ 

Lowered to protect trout

FAV = 1.9146

CMC = 0.9573

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## 4.2 Updated Acute Cadmium Objectives

The recalculated FAV was then determined using the GMAVs for the four most sensitive genera in the revised acute database. Calculations followed the EPA methods for criteria derivation (Stephan et al. 1985), and are presented in Table 9. The revised FAV at a hardness of 50 mg/L is 2.785  $\mu$ g/L, which results in a final acute equation of e<sup>0.9151[ln(hardness)]-<sup>3.2488</sup> and criteria maximum concentration (CMC), or acute objective, of 1.393  $\mu$ g/L for Cd. This value is slightly higher than the FAV reported in the 2001 Cadmium Document (2.763  $\mu$ g/L), and is higher than the SMAVs for many, but not all, commercially important trout. To further protect trout, the 2001 Cadmium Document replaced the FAV with the SMAV of rainbow trout in the criterion calculation, which resulted in a FAV of 2.014  $\mu$ g/L. This value was higher than the SMAV for the brook trout, yet lower than all other SMAVs in the 2001 Cadmium Document database. Following this approach, but in an effort to be more protective, we lowered the revised FAV to the lowest GMAV (*Salvelinus*) of 1.915  $\mu$ g/L to better protect trout (Table 9). The revised "trout-specific" equation becomes e0.9151[ln(hardness)]-3.6236 and a CMC if 0.9573  $\mu$ g/L, again at hardness of 50 mg/L, using the lowered "trout" FAV.</sup>

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### Calculations:

Acute Criterion  $S^{2} = \sum (\underline{\ln GMAV})^{2} - (\sum \underline{\ln GMAV})^{2}/4 = \underline{3.6140} - (\underline{3.7234})^{2}/4 = 15.7167$   $\Sigma P - (\sum \sqrt{P})^{2}/4$ 

 $L = [\Sigma \ln GMAV - S(\Sigma \sqrt{P})]/4 = [3.7234 - 3.9644 \ (0.8002)]/4 = 0.1378$  $A = S \ (\sqrt{0.05}) + L = (3.9644)(0.2236) + 0.1378 = 1.0243$ 

Final Acute Value =  $FAV = e^A = 2.785$ CMC =  $\frac{1}{2}$  FAV = 1.3925 Pooled Slope = 0.9151

In (Criterion Maximum Intercept)

=  $\ln$ CMC - [pooled slope × ln (standardized hardness level)] =  $\ln (1.3925) - [0.9151 \times \ln (50)]$ 

= -3.2488

Recalculated Acute Cadmium Criterion =  $e^{0.9151 [\ln (hardness)] - 3.2488}$ @ Hardness 100 = 2.626 µg/L S = 3.96440.1695 -  $(0.8002)^2/4$ 

Lowered to protect trout FAV = 1.9146 CMC = 0.9573

> $= \ln(0.9573) \cdot [0.9151 \times \ln(50)]$ = -3.6236

Criterion to protect trout =  $e^{0.9151[\ln(hardness)]-3.6236}$ @ Hardness 100 = 1.805 µg/L

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

The revised and updated chronic hardness relationship was derived by reviewing data used to calculate the chronic hardness slope calculation in the 2001 Cadmium Document and adding data from the updated chronic database (Table 10). The revised pooled chronic slope was derived from 13 individual data points (increased from 7) that encompasses four species (increased from three). Individual species slopes ranged from 0.4779 (*O. mykiss*) to 1.0034 (*P. promelas*). The Davies et al. (1993) toxicity tests for *O. mykiss* increased the range of hardness values tested. Target values ranged from 50 mg/L to 400 mg/L enabling us to add this previously unused species to the chronic hardness slope adtabase. Analysis of covariance determined the individual species slopes of the revised chronic slope database are not different (p = 0.72). Therefore, all data were grouped and the pooled slope of this revised database is 0.7998. This slope is used to standardize all chronic toxicity values to a common hardness and in the final equation to compute the chronic AWQC at a given hardness.

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Table 10: Updated chronic Cd hardness s	hronic Cd h	ardness sl	ope. SMCS	= specie	s mean ch	lope. SMCS = species mean chronic slope.					ſ
Species	Hardness (mg/L)	Hardness Geomean (mg/L) (hard)	Normalized hardness	Chronic value	Geomean (chronic)	Normalized chronic	Reference	Ln (norm hard)	Ln (norm acute)	SMCS	R²
Contraction strategies	000		168	0.67		2.15	Canton and Slooff 1982	0.5206	0.7654		
Daphria magna	53.0		0.43	1.52		0.49	Chapman et al. Manuscript	-0.8524	-0.7180		
Dophria magna	103.0		0.83	0.21		0.68	Chapman et al. Manuscript	-0.1879	-0.3853		
Daphria magna	0.001	124.30	168	0.44	0.31	1.40	Chapman et al. Manuscript	0.5197	0.3380	0.9659	0.89
Dapilita Ilayia Salmo fritta	30.8	221-21	0.52	1.33		0.25	Davies and Brinkman 1994	-0.65	-1.38		
Salmo trutta	44.0		0.58	6.67		1.27	Eaton et al. 1978	-0.55	-0.24		
Colmo trutto	250.0	75 93	3 29	16.49	5.27	3.13	Brown et al. 1994	1.19	1.14	0.9931	0.65
Sairrio trutta	2010	0000	0.10	15 02		2.14	Pickering and Gast 1972	0.76	0.76		-
Pimephales promelas	201.0	1010	t 17	10.00	21.43	0.47	Spehar and Flandt 1986	-0.76	-0.76	1.0034	1
Pimephales prometas	0 44 0	40.48	0.06	1 47	-	0.49	Davies et al. 1993	-1.36	-0.72		
Oncornyncnus mykiss	947.0		1 21	3.58		1.19	Davies et al. 1993	0.19	0.17		
Oncomynenus mykiss	A13.8		231	3.64		1.21	Davies et al. 1993	0.84	0.19		
Oncorhynchus mykiss	250.0	179.46	1 39	4.31	3.01	1.43	Brown et al. 1994	0.33	0.36	0.4779	0.86
ontoninà indua mana	2.207						Revised pooled chronic slope =	oled chroni	c slope =	0.7998	0.72

nic Cd hardness slope. SMCS = species mean chronic slope. Lindatod I ;

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				Chronic				٤	5		,
Species	Hardness (mg/L)	Hardness Geomean (mg/L) (hard)	Normalized hardness	value	Geomean (chronic)	Normalized chronic	Reference	(norm hard)	(norm acute)	SMCS	<u>ب</u>
				1-1-2-1-		0.1E	Canton and Slooff 1982	0.5206	0.7654		
Daphnia magna	209.2		1.68	U.D/		r. 10		╈	0 1100		
Danhnia magna	53.0		0.43	1.52		0.49	Chapman et al. Manuscript	-†	-0.7100		
Dontrio morno	103.0		0.83	0.21		0.68	Chapman et al. Manuscript	-0.1879	-0.3853		
Dapinia magna	0.000	00 101	1 50	0.44	0.31	1.40	Chapman et al. Manuscript	0.5197	0.3380	0.9659	0.89
Daphnia magna	209.0	124.30	00.4		5	0.05	Davies and Brinkman 1994	-0.65	-1.38		
Salmo trutta	39.8		0.52	1.33		04.0			100		
Selmo trutta	44.0		0.58	6.67		1.27	Eaton et al. 1978	-0.00	-0.24		
	250.0	75.03	3 29	16.49	5.27	3.13	Brown et al. 1994	1.19	1.14	0.9931	0.65
Saimo trutta	0.002		440	AE 02		2.14	Pickering and Gast 1972	0.76	0.76		!
Pimephales promelas	201.0		2.14	40.32		i		0.76	-0.76	1 0034	I
Pimenhales prometas	44.0	94.04	0.47	10.00	21.43	0.47	Spehar and Flandt 1980	-0.70	0.10	1222	
Construction promotes	46.7		0.26	1.47		0.49	Davies et al. 1993	-1.36	-0.72		
Officiality internal internas	1010		101	3.58		1.19	Davies et al. 1993	0.19	0.17		
Oncornyncnus mykiss	0.11Z			20.0				0.84	0 19		
Oncorhynchus mykiss	413.8		2.31	3.64		1.2.1	Lavies el al. 1993	5.5		04440	0.00
Oncorhynchus mykiss	250.0	179.46	1.39	4.31	3.01	1.43	Brown et al. 1994	0.33	0.30	0,41.0	0.00
							Revised po	Revised pooled chronic slope =	c slope =	0.7998	0.72

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slope. SMCS = species mean chronic slope.

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Table 10: Updated chronic Cd hardness s	ronic Cd h			= specie:	s mean ch	lope. SMCS = species mean chronic slope.					ſ
				Chronic				٤	5		
Species	Hardness (mg/L)	Hardness Geomean (mg/L) (hard)	Normalized hardness	value (ua/L)	Geomean (chronic)	Normalized chronic	Reference	(norm hard)	(norm acute)	SMCS	يد ۲
	0000		1 68	0.67		2.15	Canton and Slooff 1982	0.5206	0.7654		-
Daphnia magna	203.2		001				Chapman of al Manuscript	-0.8524	-0.7180		
Daphnia magna	53.0		0.43	1.52		U.43			0.0050		T
Denhnia madna	103.0		0.83	0.21		0.68	Chapman et al. Manuscript	-0.18/9	-0.3833		
		124 30	168	0.44	0.31	1.40	Chapman et al. Manuscript	0.5197	0.3380	0.9659	0.89
Dapnnia magna	203.0	00.121				0.05	Davies and Brinkman 1994	-0.65	-1.38		
Salmo trutta	39.8		0.52	1.33		0.2 <sup>.0</sup>					
Salmo trutta	44 0		0.58	6.67		1.27	Eaton et al. 1978	-0.55 -	-0.24		
	000	75.03	3 20	16.49	5.27	3.13	Brown et al. 1994	1.19	1.14	0.9931	0.65
Salmo trutta	0.007	0000		15.00		214	Dickering and Gast 1972	0.76	0.76		
Pimephales promelas	201.0		Z. 14	76.04		<b>-</b> - <b>j</b>		010	0.76	1 0024	
Dimenhales prometas	44.0	94.04	0.47	10.00	21.43	0.47	Spehar and Fiandt 1986	0/.0-	-0.70	+000-1	
Contraction of the matrice	16.2		0.26	1.47		0.49	Davies et al. 1993	-1.36	-0.72		
Officiality interest of the			+ 24	3 58		1 19	Davies et al. 1993	0.19	0.17		
Oncornynchus mykiss	211.0			22.2			A 1 1000	18.0	0 19		
Oncorhvnchus mykiss	413.8		2.31	3.64		1.21	Davies et al. 1990	10.0	2.0	01110	
Oncorhynchus mykiss	250.0	179.46	1.39	4.31	3.01	1.43	Brown et al. 1994	0.33	0.30	0.4778	00.0
ourourburner and more							Revised pooled chronic slope =	oled chroni	c slope =	0.7998	0.72

slone SMCS = species mean chronic slope. 170 .

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Table 10: Updated chronic Cd hardness s	ronic Cd h			= specie:	s mean ch	ope. SMCS = species mean chronic slope.				ŀ	ſ
				Chronic		:		٦	٦		ĥ
Species	Hardness (mg/L)	Geomean (hard)	Normalized hardness	value (uq/L)	Geomean (chronic)	Normalized chronic	Reference	(norm hard)	(norm acute)	SMCS	₩
Destroit mores	000		168	0.67		2.15	Canton and Slooff 1982	0.5206	0.7654		
	2.00.2		0.13	1 50		0.49	Chapman et al. Manuscript	-0.8524	-0.7180		
Daphnia magna	0.00		500	0.04		0.68	Channan et al. Manuscript	-0.1879	-0.3853		
Daphnia magna	103.0		0.00					0 E107	03380	0.9659	0.89
Daphnia magna	209.0	124.30	1.68	0.44	0.31	1.40	Chapman et al. Manuscript	0.0131	2000.0	2000	}
Salmo trutta	39.8		0.52	1.33		0.25	Davies and Brinkman 1994	-0.65	8 <u>9</u>		Ţ
Calino tutta	14.0		0.58	6.67		1.27	Eaton et al. 1978	-0.55	-0.24		
Sairing tratta				01.01	10.3	2 4 3	Brown at al 1094	1.19	1.14	0.9931	0.65
Salmo trutta	250.0	15.93	3.23	10.43	1.51	2		0.76	0.76		
Dimentales prometes	201.0		2.14	45.92		2.14	Pickering and Gast 19/2	0/.0	2		
	44.0	04.04	0.47	10.00	21.43	0.47	Spehar and Fiandt 1986	-0.76	-0.76	1.0034	1
Pimepriales prometas		to:to	30.0	1 17		0 49	Davies et al. 1993	-1.36	-0.72		
Oncorhynchus mykiss	40.2		07.0			10	Davias at al 1993	0.19	0.17		
Oncorhynchus mykiss	217.0		17.1	0.00							
Oncorhynchus mykiss	413.8		2.31	3.64		1.21	Davies et al. 1993	0.84	0.18		
Oncomprising in the middle	250.0	179.46	1 39	4.31	3.01	1.43	Brown et al. 1994	0.33	0.36	0.4779	0.86
Oricorrigination in parso	2.00.2						Revised pooled chronic slope =	oled chronic	c slope =	0.7998	0.72

slone SMCS = species mean chronic slope. Jucee ć

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# 4.4 Updated Chronic Cadmium Objectives

The recalculated FCV was then determined using the GMCVs for the four most sensitive genera in the revised chronic database. Calculations followed the EPA methods for criteria derivation (Stephan et al. 1985) and are presented in Table 11. The recalculated FCV is 0.2734  $\mu$ g/L, whereas the FCV from the 2001 Cadmium Document was 0.162  $\mu$ g/L. This results in a final chronic equation of e<sup>0.7998 [In(hardness)]-4.4255</sup> for Cd. At a hardness of 100 mg/L, the revised chronic Cd objective based upon this equation is 0.476  $\mu$ g/L.

Rank	Genus	GMCV	In GMCV	(in GMCV)^2	P = R/(N+1)	<u></u>
4	Oncorhynchus	2.308	0.8365	0.6997	0.2222	0.4714
3	Daphnia	1.326	0.2821	0.0796	0.1667	0.4082
- 3	Cottus	1.066	0.0638	0.0041	0.1111	0.3333
	Hyalella	0.264	-1.3316	1.7733	0.0556	0.2357
		Sum	-0.1493	2.5566	0.5556	1.4487

 Table 11:
 Recalculation of the final chronic values for Cd using the updated chronic database

 (N = 17 genera, R = sensitivity rank in database, P = rank / N+1).

## Calculations:

**Chronic Criterion** 

 $S^{2} = \frac{\sum (\ln GMCV)^{2} - (\sum \ln GMCV)^{2}/4}{\sum P - (\sum \sqrt{P})^{2}/4} = \frac{2.5566 - (-0.1493)^{2}/4}{0.5556 - (1.4487)^{2}/4} = 82.6070$ 

S = 9.0888

$$\begin{split} L &= [\Sigma lnGMCV - S(\Sigma \sqrt{P})]/4 = [-0.1493 - 9.0888 (1.4487)]/4 = -3.3290 \\ A &= S(\sqrt{0.05}) + L = (9.0888)(0.2236) + -3.3290 = -1.2967 \\ Final Chronic Value = FCV = e^{A} = 0.2734 \\ Pooled Slope = 0.7998 \end{split}$$

 $\ln (\text{Final Chronic Intercept}) = \ln \text{FCV} - [\text{chronic slope} \times \ln(\text{standardized hardness level})] \\= \ln (0.2734) - [0.7998 \times \ln (50)] \\= -4.4255$ 

Recalculated Chronic Cadmium Criterion =  $e^{0.7998 [ln (hardness)] -4.4255}$ 

@ Hardness 100 = 0.476 µg/L
### 4.4 Updated Chronic Cadmium Objectives

The recalculated FCV was then determined using the GMCVs for the four most sensitive genera in the revised chronic database. Calculations followed the EPA methods for criteria derivation (Stephan et al. 1985) and are presented in Table 11. The recalculated FCV is  $0.2734 \mu g/L$ , whereas the FCV from the 2001 Cadmium Document was  $0.162 \mu g/L$ . This results in a final chronic equation of  $e^{0.7998 [ln(hardness)] - 4.4255}$  for Cd. At a hardness of 100 mg/L, the revised chronic Cd objective based upon this equation is  $0.476 \mu g/L$ .

Rank	Genus	GMCV	In GMCV	(In GMCV)^2	P = R/(N+1)	√P
4	Oncorhynchus	Oncorhynchus 2.308		0.6997	0.2222	0.4714
3	Daphnia	1.326	0.2821	0.0796	0.1667	0.4082
2	Cottus	1.066	0.0638	0.0041	0.1111	0.3333
<u> </u>	Hvalella	0.264	-1.3316	1.7733	0.0556	0.2357
	1, , , u o	Sum	-0.1493	2.5566	0.5556	1.4487

Table 11: Recalculation of th	e final chronic values for Cd using the updated chronic database
(N = 17 genera, R =	sensitivity rank in database, P = rank / N+1).

#### Calculations:

**Chronic Criterion** 

 $S^{2} = \frac{\sum (\ln GMCV)^{2} - (\sum \ln GMCV)^{2}/4}{\sum P - (\sum \sqrt{P})^{2}/4} = \frac{2.5566 - (-0.1493)^{2}/4}{0.5556 - (1.4487)^{2}/4} = 82.6070$ 

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 $\ln (\text{Final Chronic Intercept}) = \ln \text{FCV} - [\text{chronic slope} \times \ln(\text{standardized hardness level})] \\= \ln (0.2734) - [0.7998 \times \ln (50)] \\= -4.4255$ 

Recalculated Chronic Cadmium Criterion =  $e^{0.7998 [\ln (hardness)] - 4.4255}$ 

(*a*) Hardness  $100 = 0.476 \, \mu g/L$ 

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Rank	Genus	GMCV	In GMCV	(In GMCV)^2	P = R/(N+1)	√P	
4	Oncorhynchus	2.308	0.8365	0.6997	0.2222	0.4714	
3	Daphnia	1.326	0.2821	0.0796	0.1667	0.4082	
2	Cottus	1.066	0.0638	0.0041	0.1111	0.3333	
1	Hyalella	0.264	-1.3316	1.7733	0.0556	0.2357	
		Sum	-0.1493	2.5566	0.5556	1.4487	

Table 11:	Recalculation of the final chronic values for Cd using the updated chronic database
	(N = 17 genera, R = sensitivity rank in database, P = rank / N+1).

### Calculations:

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 $L = [\Sigma lnGMCV - S(\Sigma \sqrt{P})]/4 = [-0.1493 - 9.0888 (1.4487)]/4 = -3.3290$ A = S ( $\sqrt{0.05}$ ) + L = (9.0888)(0.2236) + -3.3290 = -1.2967 Final Chronic Value = FCV = e<sup>A</sup> = 0.2734 Pooled Slope = 0.7998

ln (Final Chronic Intercept) = ln FCV - [chronic slope × ln(standardized hardness level)]= ln (0.2734) - [0.7998 × ln (50)]= -4.4255

Recalculated Chronic Cadmium Criterion =  $e^{0.7998 [ln (hardness)] - 4.4255}$ 

(*a*) Hardness  $100 = 0.476 \, \mu g/L$ 

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#### Calculations:

**Chronic Criterion** 

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 $\begin{array}{ll} \mbox{In (Final Chronic Intercept)} &= \ln \mbox{FCV} - \mbox{[chronic slope $\times$ ln(standardized hardness level)]} \\ &= \ln \ (0.2734) - \mbox{[0.7998 $\times$ ln (50)]} \\ &= -4.4255 \end{array}$ 

Recalculated Chronic Cadmium Criterion =  $e^{0.7998 [in (hardness)] - 4.4255}$ 

(a) Hardness  $100 = 0.476 \, \mu g/L$ 

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## 5.0 Summary

EPA methods for criteria derivation were followed to calculate an updated FAV/FCV for Cd and provide updates to the corresponding equations. This produced a revised FAV (2.785  $\mu$ g/L) that is higher than the FAV reported in the 2001 document (2.763  $\mu$ g/L). The revised FCV (0.273 g/L) was also higher than the FCV from the 2001 document (0.162  $\mu$ g/L). In both cases, the changes are a result of the literature review, additional data on new and existing species in the toxicity databases, and reduced variability in the four most sensitive species. The resulting equations, including application of the EPA conversion factors, would be:

Acute Cd = 1.136672-[(ln(hardness)\*(0.041838)] e<sup>0.9151[ln(hardness)]-3.2488</sup> Acute<sub>(trout)</sub> Cd = 1.136672-[(ln(hardness)\*(0.041838)] e<sup>0.9151[ln(hardness)]-3.6236</sup> Chronic Cd = 1.101672-[(ln(hardness)\*(0.041838)] e<sup>0.7998[ln(hardness)]-4.4255</sup>

On behalf of the SARDA members and L.A. County Sanitation District, we recommend adoption of these updated final acute and chronic equations for Cd water quality objectives. Table 12 summarizes the calculated acute and chronic concentrations at different hardnesses, with comparisons to the outdated 2001 values, including application of conversion factors for total to dissolved objectives.

Table 12: Summary of acute objectives and chronic objectives at various hardness values for Cd. All values are reported in µg/L.

		Hardness (mg/L)										
Equations		25	50	75	100	150	200	250	300	350	400	
2001 E	PA Update											
СМС	= $1.136672$ -[(ln(hardness)*(0.041838)] e <sup>1.0166[ln(hardness)]-3.924</sup>	0.52	1.03	1.52	2.01	2.99	3.95	4.90	5.85	6.80	7.74	
ccc	= 1.101672-[(In(hardness)*(0.041838)] e <sup>0.7409[in(hardness)]-4.719</sup>	0.09	0.15	0.20	0.25	0.33	0.40	0.46	0.53	0.59	0.64	
GEI Re	vision/Update											
СМС	= 1.136672-[(ln(hardness)*(0.041838)] e <sup>0.9151[in(hardness)]-3.2488</sup>	0.74	1.35	1.93	2.48	3.53	4.53	5.50	6.44	7.37	8.27	
CMCª	= 1.136672-[(ln(hardness)*(0.041838)] e <sup>0.9151[ln(hardness)]-3.6236</sup>	0.51	0.93	1.33	1.70	2.43	3.11	3.78	4.43	5.06	5.69	
ccc	= 1.101672-[(In(hardness)*(0.041838)] e <sup>0.7998[In(hardness)]-4.4255</sup>	0.15	0.26	0.35	0.43	0.59	0.73	0.86	0.99	1.11	1.23	

\* FAV lower to protect a commercially important species.

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CMCª	= $1.136672 \cdot [(\ln(hardness)^*(0.041838)])$ $e^{0.9151[\ln(hardness)] - 3.6236}$	0.51	0.93	1.33	1.70	2.43	3.11	3.78	4.43	5.06	5.69	
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