



# **Proposed updates to Aquatic Life Toxics Criteria, WAC 173- 201A-240**

## **Technical Support Document**

### **Water Quality Program**

Washington State Department of Ecology  
Olympia, Washington

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<b>Eastern</b>	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
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Washington State Department of Ecology  
Headquarters  
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DEPARTMENT OF  
**ECOLOGY**  
State of Washington

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## Abbreviations and Acronyms

µg/L	micrograms per liter
ACR	Acute to chronic ratio
BCF	Bioconcentration factor
BE	Biological evaluation
BiOp	Biological opinion
BLM	Biotic ligand model
CaCO <sub>3</sub>	Calcium carbonate
CCC	Criterion continuous concentration
CF	Conversion factor
CFR	Code of Federal Regulations
CMC	Criterion maximum concentration
CWA	Clean Water Act
DOC	Dissolved organic carbon
EIM	Environmental Information Management
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FACR	Final acute to chronic ratio
FAV	Final acute value
FW	Freshwater
GMAV	Genus mean acute value
GSD	Genus Sensitivity Distribution
LAA	Likely to adversely affect
LC50	Lethal Concentration 50

LOER	Lowest observed effect residue
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MLR	Multiple linear regression model
NLAA	Not likely to adversely affect
NMFS	National Marine Fisheries Service
NOER	No observed effect residue
ODEQ	Oregon Department of Environmental Quality
PPA	Performance Partnership Agreement
SMAC	Species mean acute value
SW	Saltwater
TOC	Total organic carbon
USFWS	United States Fish and Wildlife Services
WAC	Washington Administrative Code

## Executive Summary

The Department of Ecology is proposing to amend chapter 173-201A Washington Administrative Code (WAC) Water Quality Standards for Surface Waters of the State of Washington. These proposed changes include revising the aquatic life toxics criteria in WAC 173-201A-240. The purpose of this document is to provide background and technical analysis for the proposed aquatic life toxics criteria.

We compared Environmental Protection Agency (EPA) nationally recommended aquatic life toxics criteria against Washington's current criteria to determine if updates are needed. If updates were deemed necessary, we evaluated previous Endangered Species Act (ESA) consultations from the National Marine Fisheries Service (NMFS) and United States Fish and Wildlife Service (USFWS) Biological Opinions (BiOps) from Idaho and Oregon to determine whether additional considerations are needed to protect ESA-listed species in Washington. We used information from Oregon and Idaho BiOps for similarly listed species in Washington to determine if Washington's endangered species and their populations need additional protection. We also used the Swinomish Tribe Biological Evaluation by EPA to inform decisions to update criteria.

We considered available ESA consultation information for this rule update because the process and goals for evaluating species protection is different for NMFS and USFWS compared to EPA. The aim of EPA's aquatic life criteria is to protect 95% of genera. The ESA consultation process evaluates protection of endangered species populations by evaluating impacts to individual species of a population. If population modeling indicates that the proposal could lead to harm of a species population (referred to as "jeopardy"), then the criteria will be disapproved.

Previous ESA consultations in Oregon and Idaho have indicated that EPA's recommendations for some aquatic life toxics may not adequately protect ESA listed species in Washington. If select toxics were not deemed "approvable" through ESA consultation, we evaluated new scientific data, alternative methods to calculate criteria, and new modeling tools as remedies to providing additional protection to aquatic life species. In instances where EPA recommendations are not likely to provide protection for endangered species populations, we used an alternative method to derive more protective criteria.

EPA recommends deriving criteria using the 5<sup>th</sup> percentile of the toxicity data distribution. We derived the 1<sup>st</sup> percentile of the toxicity data distribution to provide additional protection that equates to protection of 99% of genera 99% of the time. More stringent protection levels were applied when previous BiOps indicated endangered species vulnerability to extinction at toxic concentrations equal to EPA's national recommendations and when new science alone did not provide adequate protection. While EPA's national recommendations are generally protective and endangered species are usually not more chemically sensitive, there are instances where a higher protection level is needed to prevent populations from extinction.

Decisions for each toxic are provided in this document alongside information on previous ESA consultations in Region 10 states, criteria calculations, new science, and proposed numeric values.

## BACKGROUND

Updating the aquatic life toxics criteria is a high priority for Ecology and was included in the Five-Year Work Plan developed as part of the 2010 triennial review. Ecology decided it would be most beneficial for our state to wait until final Endangered Species Act (ESA) consultations and subsequent EPA approvals had been completed for adjacent states before moving forward with adopting aquatic life toxics criteria in order to increase the likelihood they would meet ESA considerations and be approved by EPA. Ecology decided to move forward with developing human health toxics criteria as a higher priority, to be followed by aquatic life toxics criteria when there was more certainty which EPA-recommended criteria would be approvable through ESA consultation. The decision to prioritize human health criteria updates ahead of aquatic life toxics criteria was made, in part, because of significant delays in the several ESA consultations for EPA's nationally recommended aquatic life toxics criteria in other states.

More recently, updates to aquatic life toxics criteria were outlined in our performance partnership agreement (PPA) with EPA in 2021 and in our most recent [triennial review report](#)<sup>2</sup> submitted to EPA in April 2022. During the triennial review, we received overwhelming public support for updating rules for aquatic life toxics criteria based on new information and approaches to aquatic life protection. As part of this process, we considered and received feedback on several approaches to a rulemaking. Based on feedback, we decided to proceed with updating all necessary aquatic life toxics criteria in a single rulemaking. This decision is influenced in part by ongoing litigation for EPA to evaluate and potentially promulgate aquatic life toxics criteria for Washington.

We anticipated that a single rulemaking of all aquatic life toxics criteria will be more efficient than multiple rulemakings. Stakeholders, Tribes, and other interested parties will be able to engage in the full scope of aquatic life toxic criteria considerations within one rulemaking, without Ecology placing one toxic substance or group of substances on an earlier rule schedule than others.

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<sup>2</sup> <https://apps.ecology.wa.gov/publications/summarypages/2210002.html>

# INTRODUCTION

## Overview

Under Clean Water Act (CWA) regulations, any revisions to a state's surface water quality standards must be approved by EPA and may be subject to review of potential impacts to endangered species. The last major update to Washington's aquatic life toxics criteria was in 1992 in response to impending federal promulgation, called the National Toxics Rule, for states that had insufficient protections for certain toxic substances. Ecology chose to adopt most aquatic life toxics criteria that were recommended by EPA prior to this promulgation, and EPA approved updates to some of Washington's aquatic life toxics criteria in 1993. Washington has made minor updates to their aquatic life criteria as recently as 2007. Since the National Toxics Rule of 1992, EPA has added additional toxic substances to their list of recommended criteria and provided several updates to previously established criteria.

In this rulemaking, we compared EPA's nationally recommended aquatic life toxics criteria against Washington's current criteria to determine if updates are needed. We also considered any draft EPA criteria that may not be finalized before the rule proposal phase of this rulemaking. Furthermore, we evaluated previous ESA consultations from the NMFS' and USFWS' Biological Opinions (BiOps) from other Pacific Northwest states (i.e., Idaho and Oregon) to determine whether additional considerations are needed to protect ESA-listed species in Washington. We also used the Swinomish Tribe Biological Evaluation by EPA to inform our decisions.

EPA Region 10 states have submitted updates to their aquatic life toxics criteria over the past few decades, but EPAs required ESA Section 7 consultations with the National Oceanographic and Atmospheric Administration National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) have been significantly delayed for several states (such as Oregon and Idaho). EPA's consideration of Oregon's aquatic life toxics criteria adopted in 2004 was significantly delayed as the federal agencies worked through ESA consultation. In 2013, EPA disapproved several aquatic life criteria that the Oregon Environmental Quality Commission (ODEQ) adopted in 2004. Since 2013, ODEQ adopted and EPA approved revisions to several of the disapproved criteria. EPA's approvals of Idaho's aquatic life criteria likewise were stalled, leaving the state-adopted aquatic life criteria unusable for CWA actions for several years.

Previous ESA consultations for EPA nationally recommended criteria in Idaho and Oregon have indicated some aquatic life toxics may not adequately protect ESA listed species in Washington. If select toxics were not deemed "approvable" through ESA consultation in Idaho and Oregon for similarly listed species in Washington, then we evaluated new scientific data, alternative methods to calculate criteria, and the new modeling tools as remedies to provide full protection to endangered species and their populations.

## Clean Water Act – Water Quality Standards

The CWA was established to regulate discharges of pollutants into water of the United States and regulate quality standards for surface waters. Under Section 303(c) of the CWA and federal

implementing regulations at 40 Code of Federal Regulations (CFR) § 131.4, states and authorized Tribes have the primary responsibility for reviewing, establishing, and revising water quality standards. Water quality standards consist primarily of the designated uses of a waterbody or waterbody segment, the water quality criteria that protect those designated uses, and an antidegradation policy to protect high quality waters.

EPA has compiled a list of nationally recommended water quality criteria for the protection of aquatic life and human health in surface waters. These criteria are published pursuant to Section 304(a) of the CWA and provide guidance for states and Tribes to establish water quality standards and provide the foundation for controlling the release of pollutants and identifying impaired waters. The state water quality standards are federally approved by EPA and describe the level of protection for Waters of the State.

All state-adopted water quality standards are required to be submitted to EPA for review and approval (or disapproval). If EPA does not approve state water quality standards, then they are required to promulgate federal water quality standards for states that do not adopt standards (unless the state resubmits a revised rule package to EPA). The following outlines the steps and timing of the federal action:

1. Ecology submits the adopted rule to EPA.
2. EPA reviews the submittal for acceptability under the CWA.
3. EPA has 60 days to approve or 90 days to disapprove the State's rule.

EPA is required to evaluate potential impacts of the state-adopted aquatic life criteria to endangered species. EPA writes a Biological Evaluation (BE) that describes effects that the rule package (i.e., the "action") may have on endangered species. If EPA's approval of the rule is likely to adversely affect endangered species (LAA), EPA will request ESA Section 7(a)(2) consultation with NMFS and USFWS to determine if the action would jeopardize those species. Alternatively, EPA can designate the proposal as not likely to adversely affect (NLAA) endangered species. If a LAA determination is made, USFWS and NMFS write BiOps that analyze the effects of the rule to ESA listed species. The conclusion of the BiOps will state if any part of the rule is likely to jeopardize the continued existence of a listed species or harm critical habitat. A jeopardy call can lead to a disapproval of a rule or portion of a rule if EPA cannot conclude that the rule is protective of the applicable designated uses, which include consideration of ESA-listed species. BiOps can include conservation recommendations or reasonable and prudent actions to minimize any "take" of listed species. A likely to adversely affect determination with no jeopardy means that effects to endangered species are measurable, observable, and likely to occur, but will not affect the continued existence of the species at the population level or landscape scale (i.e., critical habitat).

## Endangered Species Act Consultation

### Background

The Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 *et seq.*), as amended, establishes a national program for conserving threatened and endangered species of fish, wildlife, plants, and the habitat on which they depend. Section 7(a)(2) of the ESA requires federal agencies to

ensure, in consultation with the USFWS and the NMFS, as appropriate, that their actions are not likely to jeopardize the continued existence of endangered or threatened species or adversely modify or destroy their designated critical habitats. This is called “jeopardy.” Section 7(a)(4) of the ESA requires federal agencies to confer with USFWS and NMFS, as appropriate, in cases where the agency or the Services have determined that a proposed or ongoing Federal action is likely to jeopardize the continued existence of species proposed to be listed under section 4 of the ESA or result in the destruction or adverse modification of critical habitat proposed to be designated for such species.

The USFWS also encourages federal agencies to confer on actions that may affect a proposed species or proposed critical habitat. In such cases, conference concurrence determinations or conference opinions can be adopted as formal concurrences or biological opinions, respectively, after a proposed species is listed or the critical habitat is designated.

In accordance with policy and regulation, the jeopardy analysis relies on four components:

1. The *Status of the Species*, which evaluates the species’ rangewide condition, the factors responsible for that condition, and its survival and recovery needs.
2. The *Environmental Baseline*, which evaluates the condition of the species in the action area, the factors responsible for that condition, and the relationship of the action area to the survival and recovery of the species.
3. The *Effects of the Action*, which determines the direct and indirect impacts of the proposed Federal action and the effects of any interrelated or interdependent activities on the species.
4. *Cumulative Effects*, which evaluates the effects of future, non-Federal activities in the action area on the species.

The jeopardy call is made by evaluating the effects of the proposed federal action in the context of the species’ current status, taking into account any cumulative effects, to determine if implementation of the proposed action is likely to cause an appreciable reduction in the likelihood of both the survival and recovery of the species in the wild.

Both the BE (written by EPA) and the BiOps (written by USFWS and NMFS) contain a discussion of the effects of each water quality standard adopted by the state and submitted to EPA. These analyses could result in three potential effect outcomes for each standard: (1) no effect; (2) not likely to adversely affect (NLAA); or (3) likely to adversely affect (LAA).

The following sections provide information on the outcomes of ESA consultation for Oregon, Idaho, and information from EPA’s BE of the Swinomish Indian Tribal Community following their submittal of aquatic life toxics criteria.

## Oregon

Oregon Department of Environmental Quality (ODEQ) submitted revised water quality standards for aquatic life toxics criteria on July 8, 2004. The updated criteria incorporated EPA recommended criteria for toxic pollutants that were current at the time. USFWS received a letter from EPA requesting formal consultation on January 16, 2008. The BiOp for Oregon’s 2004 submittal was completed in 2012. Table 1 and Table 2 provides a summary of the results

of Oregon's ESA consultation for the adoption of EPA recommended criteria in 2012 and the toxics criteria that had jeopardy calls (or likely to adversely affect endangered species; USFWS, 2012; NMFS, 2012). Oregon's endangered species list is different from Washington, but the two states do share common endangered species such as the Chinook salmon. Thus, we only used ESA consultation information for similarly listed species in Washington.



Table 1. Oregon aquatic life toxics criteria submitted in 2004.

Substance	Freshwater Acute Criteria (µg/L)		Freshwater Chronic Criteria (µg/L)		Saltwater Acute Criteria (µg/L)		Saltwater Chronic Criteria (µg/L)	
	Previous	Proposed	Previous	Proposed	Previous	Proposed	Previous	Proposed
<b>Aluminum</b>	N/A	750	N/A	87	-	-	-	-
<b>Ammonia (@pH 8 &amp; 20C)</b>	6	5.6 (salmonids) 8.4 (no salmonids)	0.76 (salmonids) 1.08 (no salmonids)	1.7	-	-	-	-
<b>Lindane</b>	2	0.95		-		-		-
<b>Cadmium*</b>	3.9	2.0	1.1	0.25	43	40	9.3	8.8
<b>Chromium III*</b>	17000	570	210	74		-		-
<b>Chromium VI*</b>	16	16	11	11	1100	1100	50	50
<b>Copper*</b>	18	13	12	9	2.9	4.8	2.9	3.1
<b>Dieldrin</b>	2.5	0.24	0.0019	0.056		-		-
<b>Endosulfan (alpha)</b>	N/A	0.22	N/A	0.056	N/A	0.034	N/A	0.0087
<b>Endosulfan (beta)</b>	N/A	0.22	N/A	0.0056	N/A	0.034	N/A	0.0087
<b>Endrin</b>	0.18	0.086	0.0023	0.036		-		-
<b>Heptachlor epoxide</b>	N/A	0.52	N/A	0.0038	N/A	0.053	N/A	0.0036
<b>Lead*</b>	82	65	3.2	2.5	140	210	5.6	8.1
<b>Nickel*</b>		470		52		74		8.2
<b>Pentachlorophenol (@pH 7.8)</b>	20	19	13	15	13	13	N/A	7.9
<b>Selenium</b>	260	12.82 (selenate) 185.9 (selenite)	35	5.0	410	290	54	71
<b>Silver*</b>	4.1	3.2	0.12	0.10	2.3	1.9		-
<b>Tributyltin</b>	N/A	0.46	N/A	0.063	N/A	0.37	N/A	0.01
<b>Zinc*</b>	120	120	110	120	95	90	86	81

\* Hardness of 100 mg/L

Table 2. Summary of the ESA consultation results for Oregon’s 2004 submittal of aquatic life criteria (LAA = likely to adversely affect; NLAA = not likely to adversely affect; USFWS, 2012; NMFS, 2012). Some criteria have been updated since Oregon last submitted aquatic life criteria updates (i.e., aluminum, cadmium, copper, selenium, ammonia).

Chemical	Freshwater Acute	Freshwater Chronic	Saltwater Acute	Saltwater Chronic
<b>Aluminum</b>	LAA*	LAA*	N/A	N/A
<b>Arsenic</b>	NLAA	LAA	N/A	N/A
<b>Cadmium</b>	LAA*	LAA	NLAA	NLAA
<b>Chromium III</b>	LAA	LAA	N/A	N/A
<b>Chromium VI</b>	LAA	LAA	NLAA	NLAA
<b>Copper</b>	LAA*	LAA*	NLAA	NLAA
<b>Lead</b>	LAA	LAA	NLAA	NLAA
<b>Nickel</b>	LAA	LAA	NLAA	NLAA
<b>Selenium</b>	LAA	LAA	NLAA	LAA
<b>Silver</b>	LAA	N/A	NLAA	N/A
<b>Zinc</b>	LAA	LAA	NLAA	NLAA
<b>Ammonia</b>	LAA	LAA	N/A	N/A
<b>Dieldrin</b>	NLAA	NLAA	N/A	N/A
<b>Endosulfan (alpha)</b>	NLAA	NLAA	NLAA	NLAA
<b>Endosulfan (beta)</b>	NLAA	NLAA	NLAA	NLAA
<b>Endrin</b>	NLAA	NLAA	N/A	N/A
<b>Heptachlor Epoxide</b>	NLAA	NLAA	NLAA	NLAA
<b>Lindane (gamma-BHC)</b>	NLAA	NLAA	N/A	N/A
<b>Pentachlorophenol</b>	LAA	LAA	NLAA	NLAA
<b>Tributyltin</b>	NLAA	NLAA	NLAA	NLAA

\* Criterion also received subsequent Jeopardy call by USFWS or NMFS

## Idaho

Idaho submitted revised aquatic life toxics criteria on April 11, 2006. These criteria were approved by EPA in 2007, subject to ESA consultation. The BiOp from NMFS and USFWS were completed in 2014 and 2015, respectively. Tables 3 and 4 provide the revised aquatic life toxics criteria submitted by Idaho and the results of ESA consultation, indicating which criteria received a likely to adversely affect endangered species determination or jeopardy calls (NMFS, 2014; USFWS, 2015). Idaho’s endangered species list is different from Washington, but the two states do share common endangered species such as the bull trout. Thus, we only used ESA consultation information for similarly listed species in Washington.

Table 3. Ambient water quality criteria for toxic pollutants submitted for consultation in EPA's 1999 Assessment and revisions by the State of Idaho (NMFS, 2014; USFWS, 2015).

Substance	Freshwater Acute Criteria (µg/L)		Freshwater Chronic Criteria (µg/L)	
	Previous	Proposed	Previous	Proposed
<b>Arsenic</b>	360	340	190	150
<b>Cadmium*</b>	-	-	-	-
<b>Copper</b>	17	17	11	11
<b>Cyanide</b>	22	22	5.2	5.2
<b>Lead</b>	65	65	2.5	2.5
<b>Mercury</b>	2.1	2.1	0.012	0.012
<b>Selenium</b>	20	20	5	5
<b>Zinc</b>	114	120	105	120
<b>Chromium III</b>	550	570	180	74
<b>Chromium VI</b>	15	16	10	11
<b>Nickel</b>	1400	470	160	52
<b>Silver</b>	3.4	3.4	N/A	N/A
<b>Endosulfan (alpha and beta)</b>	0.22	2.0	0.056	89
<b>Aldrin</b>	3	0.00014	-	0.000050
<b>Chlordane</b>	2.4	0.00057	0.0043	0.00081
<b>4,4-DDT</b>	1.1	0.00059	0.001	0.00022
<b>Dieldrin</b>	2.5	0.00014	0.0019	0.000054
<b>Endrin</b>	0.18	0.81	0.0023	0.060
<b>Heptachlor</b>	0.52	0.00021	0.0038	0.000079
<b>Lindane (gamma-BHC)</b>	2	0.063	0.08	1.8
<b>Polychlorinated biphenyls (PCBs)</b>	N/A	0.000045	0.014	0.000064
<b>Pentachlorophenol</b>	20	6.2	13	3.0
<b>Toxaphene</b>	0.73	0.00075	0.0002	0.00028

\*Consultation completed in 2011

Table 4. Summary of the Endangered Species Act consultation results for Idaho’s aquatic life criteria (LAA = likely to adversely affect; NLAA = not likely to adversely affect; NMFS, 2014; USFWS, 2015).

Chemical	Freshwater Acute	Freshwater Chronic
Arsenic	NLAA	LAA*
Chromium III	NLAA	NLAA
Chromium VI	NLAA	LAA
Copper	LAA*	LAA*
Lead	NLAA	LAA*
Mercury	NLAA	LAA*
Nickel	LAA*	LAA*
Selenium	NLAA	LAA*
Silver	LAA	N/A
Zinc	LAA*	LAA*
Aldrin	NLAA	NLAA
Chlordane	NLAA	NLAA
Cyanide	LAA*	LAA*
4,4-DDT	NLAA	NLAA
Dieldrin	NLAA	NLAA
Endosulfan (alpha)	NLAA	NLAA
Endosulfan (beta)	NLAA	NLAA
Heptachlor	NLAA	NLAA
Lindane (γ-BHC)	NLAA	NLAA
Pentachlorophenol	NLAA	NLAA
Polychlorinated biphenyls	N/A	NLAA
Toxaphene	NLAA	NLAA

\* Criterion also received subsequent Jeopardy call by USFWS or NMFS

## Swinomish Indian Tribal Community

The Swinomish Indian Tribal Community (Swinomish Tribe) submitted aquatic life toxics criteria to EPA for review and approval under the CWA on February 8, 2017. The Swinomish Tribe revised the aquatic life toxics criteria submittal, and the Swinomish Senate adopted the revisions into their water quality standards on April 8, 2019. The revised water quality standards were submitted to EPA on April 30, 2019. EPA’s biological evaluation of the Swinomish Tribe aquatic life toxics criteria was completed on June 22, 2022 (USEPA, 2022a). EPA has subsequently submitted the biological evaluation of the Swinomish Tribe’s updates to USFWS and NMFS for ESA consultation. Table 5 summarizes EPA’s BE.

EPA did not evaluate some of the Swinomish Tribe aquatic life toxics criteria, including freshwater chronic arsenic, freshwater acute and chronic chloride, freshwater acute and chronic cyanide, and freshwater and saltwater acute and chronic mercury. The criteria that

were not consulted on were found by NMFS and/or USFWS to likely adversely affect salmonid species in Idaho or Oregon or were predicted to cause effects based on new science.

Table 5. Biological evaluation results for the Swinomish Tribe (LAA = likely to adversely affect; NLAA = not likely to adversely affect; USEPA, 2022a).

Chemical	Freshwater Acute	Freshwater Chronic	Saltwater Acute	Saltwater Chronic
<b>Arsenic</b>	NLAA	Not evaluated	NLAA	LAA
<b>Chromium III</b>	NLAA	NLAA	-	-
<b>Chromium VI</b>	NLAA	LAA	LAA	LAA
<b>Copper</b>	NLAA	NLAA	NLAA	NLAA
<b>Iron</b>	-	LAA	-	-
<b>Lead</b>	NLAA	NLAA	NLAA	NLAA
<b>Mercury</b>	Not evaluated	Not evaluated	Not evaluated	Not evaluated
<b>Nickel</b>	LAA	NLAA	NLAA	NLAA
<b>Selenium</b>	NLAA	NLAA	NLAA	LAA
<b>Silver</b>	NLAA	-	NLAA	-
<b>Zinc</b>	LAA	LAA	NLAA	NLAA
<b>Acrolein</b>	NLAA	NLAA	-	-
<b>Aldrin</b>	NLAA	-	NLAA	-
<b>Carbaryl</b>	NLAA	NLAA	NLAA	-
<b>Chlordane</b>	NLAA	NLAA	NLAA	NLAA
<b>Chloride</b>	Not evaluated	Not evaluated	-	-
<b>Chlorine</b>	NLAA	NLAA	LAA	NLAA
<b>Chlorpyrifos</b>	NLAA	NLAA	NLAA	NLAA
<b>Cyanide</b>	Not evaluated	Not evaluated	NLAA	NLAA
<b>Demeton</b>	-	NLAA	-	NLAA
<b>Diazinon</b>	NLAA	NLAA	NLAA	NLAA
<b>Dieldrin</b>	NLAA	NLAA	NLAA	NLAA
<b>Endosulfan (alpha &amp; beta)</b>	NLAA	NLAA	NLAA	NLAA
<b>gamma-BHC (Lindane)</b>	NLAA	-	NLAA	-
<b>Guthion</b>	-	NLAA	-	NLAA
<b>Heptachlor</b>	NLAA	NLAA	NLAA	NLAA
<b>Heptachlor epoxide</b>	NLAA	NLAA	NLAA	NLAA
<b>Hydrogen sulfide</b>	-	LAA	-	LAA
<b>Malathion</b>	-	NLAA	-	NLAA
<b>Methoxychlor</b>	-	NLAA	-	NLAA
<b>Mirex</b>	-	NLAA	-	NLAA
<b>Nonylphenol</b>	LAA	NLAA	LAA	LAA
<b>4,4-DDT</b>	NLAA	NLAA	NLAA	NLAA
<b>Parathion</b>	NLAA	NLAA	-	-
<b>Pentachlorophenol</b>	NLAA	NLAA	LAA	NLAA

Chemical	Freshwater Acute	Freshwater Chronic	Saltwater Acute	Saltwater Chronic
<b>Polychlorinated biphenyls</b>	-	NLAA	-	NLAA
<b>Toxaphene</b>	NLAA	NLAA	NLAA	NLAA
<b>Tributyltin</b>	NLAA	NLAA	NLAA	NLAA

The Swinomish Tribe water quality submission was approved by EPA on August 4, 2023, with the exceptions noted above that EPA did not act upon (USEPA, 2023). However, formal ESA consultation was not completed by NMFS and USFWS. Rather, Section 7(d) of the Endangered Species Act and Habitat Conservation Plans was used to allow for implementation of the Swinomish Tribe water quality criteria. The USFWS specifically states the following regarding section 7(d):

“The Services' Interagency Consultation Handbook provides limited guidance regarding the application of section 7(d) during the consultation process other than to state that the section 7(d) restriction is triggered by the determination of "may affect." The Consultation Handbook also states that "Not all irreversible and irretrievable commitments of resources are prohibited. The formulation or implementation of any reasonable and prudent alternative must be foreclosed by the resource commitment to violate section 7(d). Thus, resource commitments may occur as long as the action agency retains sufficient discretion and flexibility to modify its action to allow formulation and implementation of an appropriate reasonable and prudent alternative." Destroying potential alternative habitat within the project area, for example, could violate section 7(d).”

Because formal ESA consultation was not completed, we will continue to use EPA’s 2022 BE for the Swinomish Tribe to provide ancillary support for decision-making in this rulemaking.

## Litigation

### Determination of Consistency with Clean Water Act

In October 2013, Northwest Environmental Advocates (NWEA) petitioned EPA to use its CWA authority to determine that Washington needed new or revised aquatic life toxics criteria and to promulgate such criteria for Washington. EPA denied this petition in 2017, and in September 2020, NWEA filed a lawsuit in federal court challenging EPA’s denial. On December 29, 2021, the U.S. District Court ruled that EPA’s denial of the rulemaking petition was unreasonable and ordered EPA to determine whether Washington’s aquatic life criteria are consistent with the CWA or if they need to be revised (NWEA vs. EPA, 2021, Case No. C20-1362 MJP).

Following issuance of the order, EPA and NWEA negotiated a proposed modification to the order which the Court granted in August 2022. The modified order required EPA to evaluate the following nine pollutants by June 2023: arsenic, cadmium, copper, cyanide, mercury, selenium, nickel, acrolein, and aluminum, and determine whether they are consistent with CWA requirements and protect the applicable designated uses of Washington’s surface waters. The modified order further directed EPA to evaluate the following additional eight pollutants by June 2026: chromium III, DDT and metabolites, endosulfan, endrin, tributyltin, zinc, lead, and

nonylphenol. If any of Washington’s criteria for these 17 toxics are determined to be inconsistent with CWA requirements, the CWA requires EPA to promulgate new or revised criteria for Washington that meets such requirements, unless the state adopts and submits new or revised criteria that EPA approves first.

In May 2023, EPA determined that Washington’s existing criteria for arsenic, cadmium, copper, cyanide, mercury, nickel, and selenium are not protective of the applicable designated use and that Washington lacks aquatic life criteria for acrolein and aluminum where information indicates that Washington needs criteria for those pollutants to protect applicable designated uses.

## **Endangered Species Act Consultation on Cyanide**

The Center for Biological Diversity filed a lawsuit in federal court alleging that EPA failed to ensure its approval of Washington’s cyanide criteria will not jeopardize the survival and recovery of endangered and threatened species or adversely modify habitat (Center for Biological Diversity vs. EPA, Case 1:22-cv-00486-BAH, 8/08/23). The litigation is ongoing and its outcome uncertain. However, if the court reaches the merits of the case or the parties settle, EPA may be required to consult on Washington’s existing cyanide criteria under the Endangered Species Act.

## **Rulemaking Strategy**

We are updating our aquatic life toxics criteria to ensure consistency with CWA recommendations, protect endangered species, and avoid federal promulgation stemming from litigation. In this rulemaking, we are using information from previous ESA consultations in Oregon and Idaho to determine whether to adopt EPA CWA recommendations or adopt state-specific criteria that will be protective of Washington’s listed endangered species. The biological opinions from Oregon and Idaho provided information on protection levels needed for full protection for similarly listed endangered species in Washington. In addition, we used a recently completed EPA biological evaluation for aquatic life toxics criteria for the Swinomish Tribe to inform endangered species protection levels. The methods section below describes the decision-making process for developing criteria and the specific approach for protecting endangered species and their populations.

## **Endangered and Threatened Species in Washington**

The following aquatic species are federally listed endangered and threatened in Washington:

- Chinook salmon and critical habitat
- Sockeye salmon
- Coho salmon
- Steelhead
- Chum salmon
- Bocaccio and critical habitat
- Yelloweye rockfish

- Humpback whale
- Southern resident killer whale and critical habitat
- Bull trout and critical habitat
- Marbled murrelet
- Green sturgeon
- Eulachon smelt



# METHODS

## Standard EPA Derivation Methods

EPA is tasked with developing aquatic life toxics criteria that protect aquatic life from the harmful effects of toxic chemicals. EPA uses derivation methods that can be broken down into four steps:

1. Calculate species mean acute/chronic values,
2. Calculate genus mean acute/chronic values,
3. Rank the genus mean acute/chronic values, and
4. Determine the 5<sup>th</sup> percentile of the genus sensitivity distribution (GSD) and divide by a factor of two to yield protective acute criteria, while chronic criteria are based directly on the 5<sup>th</sup> percentile of the GSD.

A more detailed procedure can be found in EPA 1985 guidance on developing aquatic life toxics criteria (Stephan et al. 1985). These EPA standard derivation methods aim to protect 95% of aquatic genera 99% of the time. In the 1985 EPA guidance document, EPA states that because aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places is not deemed necessary. If data are available for a large and diverse number of taxa, a reasonable level of protection will be provided if all except a small fraction of taxa are protected.

One notable issue with EPA methods is when endangered species and their populations are especially sensitive and fall outside national protection levels or new toxicity data has been generated and not yet incorporated into EPA national criteria. In other instances, studies with endangered species have examined toxicity using surrogates or endpoints that are not considered using standard EPA derivation methods (such as indirect effects on prey items of endangered species) and are the cause of jeopardy calls during ESA consultation.

During ESA consultation, EPA's BE considers all toxicity data and indirect effects of toxic chemicals to endangered species at the individual level. EPA's BEs consider direct effects to growth, survival, and reproduction, but can also consider endpoints other than growth, survival, or reproduction (non-apical endpoints) that can be quantitatively linked to population-level effects. A BE can also assess impacts to the prey of a listed species to determine potential effects to listed species. The BE can consider tissue data, bioaccumulation potential, and ambient water concentrations to predict toxicity to prey. NMFS and USFWS consider if and how effects documented in EPA's BE results in population-level effects to inform Jeopardy and Non-Jeopardy calls. The difference in approach between EPA methods for developing aquatic life toxics criteria and ESA consultation methods has led to several issues in adopting EPA 304(a) recommendations in Pacific Northwest states.

## Alternative Aquatic Life Toxics Derivation Method

If Washington adopts EPA 304(a) recommendations for aquatic life toxics criteria that through the ESA Consultation process are not shown to be protective of endangered and threatened species and their populations, we anticipate that we will not receive federal approval as

demonstrated in other Pacific Northwest states with similarly listed species (such as Oregon and Idaho). EPA's nationally recommended aquatic life criteria for some toxics have been determined in previous federal BiOps by NMFS and USFWS to jeopardize or adversely affect certain ESA-listed species that exist in Washington (NMFS, 2012; NMFS, 2014; USFWS 2012; USFWS, 2015).

We evaluated alternative methods to develop criteria, in addition to using new scientific data since the last EPA updates, to calculate more stringent criteria than EPA's national recommendations for some criteria to ensure that the criteria would be protective of endangered species and their populations. The alternative method (i.e., 1<sup>st</sup> percentile derivation procedure) described is used to address extinction susceptibility of Washington's endangered species populations and are not a result of a particular species chemical sensitivity. However, the outcome of using this method is improved protection for all aquatic species.

We decided to set state-specific criteria for certain pollutants where Oregon and Idaho BiOps concluded that EPA recommendations for those pollutants would likely adversely affect or jeopardize ESA-listed species and their populations that also exist in Washington. The first step in developing state-specific criteria for select pollutants in the proposed rule was to evaluate the new science since EPA last updated the national criteria to determine if incorporating new science into the criteria derivation would adequately protect endangered species in Washington. When developing state-specific criteria using new science only, we used standard EPA methods (Stephan et al. 1985) to incorporate new science and calculate the new criteria. The newly calculated criteria based on new science alone was compared to the information in the Idaho and Oregon BiOps for similarly listed endangered species in Washington to determine if new science alone provided adequate protection.

When new science did not provide adequate protection for endangered species, we applied a more conservative derivation process than EPA methods recommend in their 1985 guidance document for criteria development. We used the 1<sup>st</sup> percentile of the toxicity data distribution to derive a more conservative criterion value that will protect a greater proportion of species. Deriving the 1<sup>st</sup> percentile of the toxicity data distribution results in a protection level of 99% of genera 99% of the time, which translates to greater overall protection to all aquatic species, including susceptible populations of endangered species. The general procedure for evaluating pollutants in this rule was as follows:

1. Match EPA recommendations if there were no LAA determinations or jeopardy calls for similarly listed species in Idaho and Oregon.
2. If there were LAA determinations or jeopardy calls in Idaho and Oregon for similarly listed species in Washington, then evaluate the new science since EPA last updated national recommendations.
3. If new science met protection levels described in the Idaho and Oregon BiOps, then use the new science to derive the criteria.
4. If criteria based on new science did not provide adequate protection, then derive the 1<sup>st</sup> percentile of the toxicity data distribution.

We reviewed EPA national recommendations for aquatic life toxics and identified several of Washington's aquatic life toxics criteria that need to be updated. Table 6 shown below

compares the year numeric aquatic life toxics were last updated by Washington and when EPA last updated their CWA recommendations. Table 7 below lists criteria that are not included in Washington’s water quality standards for aquatic life toxics but are recommended by EPA. Updates to Washington’s aquatic life toxics criteria were placed in six different categories:

1. We are proposing taking no action (“No change”). No action means that Washington aquatic life criteria are identical to EPA CWA recommendations and there are no ESA consultation jeopardy calls.
2. We are proposing adopting EPA CWA recommendations (“EPA recommendation”).
3. We are proposing not adopting criteria with EPA CWA recommendations into Washington’s standards (“Do not adopt”).
4. We are proposing new criterion specific to Washington with no EPA CWA recommendations (“New state-specific criteria”) or we are proposing criteria with EPA recommendations but have used a state-specific approach (“State-specific criteria”).
5. We are proposing updated criteria for select toxics with ESA jeopardy calls or likely to adversely affect determinations that incorporate new science since EPA last updated the criteria (“New science”).
6. We are proposing updated criteria for select toxics with ESA jeopardy calls that incorporate new science since EPA last updated the criteria and uses the 1st percentile of the toxicity data distribution to derive the protective value (“New science and 1st percentile”). In instances where likely to adversely affect determinations were made for a pollutant and the new science was incorporated into the new criteria but resulted in a greater criterion, the 1st percentile was applied to increase protection levels.

These different strategies are outlined for each toxic chemical in the Strategy for Aquatic Life Toxics section below.

Table 6. Washington’s current list and adoption year of aquatic life toxics criteria compared with EPA’s last update.

Toxic Substance	Year WA Last Updated	Year EPA Last Updated
<b>4,4’-DDT (and metabolites)</b>	1988*	1980
<b>Aldrin</b>	1988*	1980
<b>Ammonia</b>	2003	2013
<b>Arsenic</b>	1992	1995
<b>Cadmium</b>	1997	2016
<b>Chlordane</b>	1988*	1980
<b>Chloride (dissolved)</b>	1992	1988
<b>Chlorine (total)</b>	1988	1986
<b>Chlorpyrifos</b>	1988*	1986
<b>Chromium III</b>	1992	1995
<b>Chromium VI</b>	1992	1995
<b>Copper</b>	1997	2007
<b>Cyanide</b>	2003*	1985
<b>Dieldrin</b>	1988*	1995

Toxic Substance	Year WA Last Updated	Year EPA Last Updated
Endosulfan	1988*	1980
Endrin	1988*	1995
Heptachlor	1988*	1980
Hexachlorocyclohexane (gamma-BHC; Lindane)	1988*	1995
Lead	1992	1984
Mercury	1997	1995
Nickel	1997	1995
Parathion	1988*	1995
Pentachlorophenol (PCP)	1992	1995
Polychlorinated Biphenyls (PCBs)	1988*	1986
Selenium	1997	2016
Silver	1992	1980
Toxaphene	1988*	1986
Zinc	1992	1995

\*Record of identical criteria in 1988 standards but not in 1981. Criteria may have been incorporated between 1982 and 1988.

Table 7. Toxic substances listed in EPA national recommended 304(a) criteria and year last updated for which Washington has no numeric criteria.

Toxic Substance	Year EPA Last Updated
Acrolein	2009
Aluminum	2018
Boron	1986
Carbaryl	2012
Demeton	1985
Diazinon	2005
Guthion	1986
Heptachlor Epoxide	1981
Iron	1986
Malathion	1986
Methoxychlor	1986
Mirex	1986
Nonylphenol	2005
Perfluorooctanoic Acid (PFOA)	2022 (draft)
Perfluorooctane Sulfonate (PFOS)	2022 (draft)
Sulfide-hydrogen sulfide	1986
Tributyltin	2004

## Evaluating Scientific Articles for Criteria Derivation

### Databases

We evaluated new science in calculating state-specific criteria. We used the [EPA ECOTOX database](https://cfpub.epa.gov/ecotox/)<sup>3</sup> to obtain new scientific articles for incorporation into criteria development. We restricted the ECOTOX database to look at new science from the year before EPA published their last update for a toxic to present day. We searched for articles from the year before EPA last updated criteria because of delays in publishing and time taken to complete updates. During this process we discovered that the ECOTOX database is not updated to present day for most toxics. We therefore requested information from the ECOTOX database coordinator on when the ECOTOX database was last updated for the toxics with state-specific criteria (see Table 8).

We used this information to evaluate the open literature, primarily using Google Scholar, for additional scientific articles from the time ECOTOX was last updated to March 2023. Search terms for individual toxics in the open literature included “<insert chemical name> LC50”, “<insert chemical name> EC50”, “<insert chemical name> NOEC”, “<insert chemical name> LOEC”, and “<insert chemical name> EC20.”

Table 8. ECOTOX database latest updates for chemicals selected for state-specific criteria.

Chemical	Most Recent Literature Search
Arsenic	January 2020
Cadmium	January 2013
Chromium VI	February 2013
Lead	July 2010
Nickel	June 2013
Silver	October 2008
Zinc	November 2014
Chlorine	June 2012
Cyanide	November 2013
Nonylphenol	February 2016
Pentachlorophenol	February 2016

### Study Acceptability

After obtaining a list of potential articles that could be used to update select aquatic life toxics criteria, each one had to be individually evaluated for data quality and assurance. EPA does not have clear guidelines for the inclusion of scientific articles into criteria derivation but does have some general guidance that can be used from their 1985 guidelines. We used the 1985 EPA guidance in addition to standard method test acceptability requirements. Below are the criteria used to evaluate scientific studies for the inclusion into criteria development. Articles that did

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<sup>3</sup> <https://cfpub.epa.gov/ecotox/>

not meet these requirements were disqualified and removed from consideration. The test acceptability and data requirements were as follows:

- Study must include control treatment(s)
- Control survival should meet standard methods (generally greater than 90%)
- Water quality of dilution water and/or test conditions must be reported
- If chemical toxicity is based on water quality (e.g., hardness), then that parameter must be reported
- Appropriate dilution water was used for test species
- Study should use replicates of test concentrations (at least two)
- Technical grade chemicals were used and reported
- Formulated mixtures and emulsifiable concentrations cannot be used
- For volatile, hydrolysable, and degradable chemicals, only flow through tests are acceptable unless initial test concentrations were used to calculate threshold values
- Feeding should not occur during acute studies (few exceptions)
- Studies should not use brine shrimp as test species
- Test species must be a non-invasive North American species (**invasive species with established populations were not considered in this rule because they do not represent native fauna of Washington, there is a significant amount of time and resources used to eradicate these species, and they are generally less sensitive than native species thereby precluding their use as a surrogate**)
- Test organisms must not be previously exposed to a test chemical
- Do not use a study if total organic carbon or particulate matter exceeded 5 milligrams per liter (mg/L) in dilution waters
- Test with cladocerans should use organisms less than 24 hours old
- Tests with single celled organisms should not be used
- Acute values reported as “greater than” should not be used when they represent one of the four lowest genus mean acute values
- Toxicity values should not be averaged for same species if studies used different life stages with the most sensitive species used for criteria calculations
- Toxicity values from species were rejected when other species within a genus were approximately 10X more sensitive (i.e., 10-fold difference in toxicity values resulted in rejection of the less sensitive species)
- Chronic studies must use a flow-through test design and measured chemical concentrations using analytical methods (exception for cladocerans)
- Acute studies can use static, static-renewal, or flow through test designs, and measuring chemical concentrations is optional
- Hierarchy of studies were given for test design: flow through > static renewal > static (if multiple studies existed for same species, studies were rejected if the more representative test design was used)
- Hierarchy of studies were given for studies measuring chemical concentrations versus unmeasured concentrations

Appendix A of this document includes the studies considered in this rulemaking and reasons for removing studies from consideration for criteria derivation. References for studies that were obtained from Google Scholar are reported in the reference section.

## Metal Reporting

For metals where new scientific information was used, we reported all metal concentrations as total recoverable as per EPA guidelines for consistency in calculating the criterion maximum concentration (CMC) or acute criterion and criteria continuous concentration (CCC) or chronic criterion. When a toxicity value such as median lethal concentration (LC50), which describes the amount of a toxic chemical that kills 50% of organisms, was reported as a dissolved metal, the dissolved concentration was back-calculated to total metal concentrations using EPA's metal conversion factors (Table 9). If a study reported both dissolved and total metal concentrations, total metal concentrations were used for this analysis. The CMC and CCC based on total metal concentrations were translated to dissolved metal concentrations using EPA's conversion factors. The final criteria values were reported as dissolved metal concentrations.

Table 9. EPA acute and chronic conversion factors (CF) for metals (Kinerson et al. 1996).

Metal	Acute CF	Chronic CF
<b>Arsenic</b>	1.000	1.000
<b>Cadmium*</b>	0.944	0.909
<b>Chromium III</b>	0.316	0.860
<b>Chromium VI</b>	0.982	0.962
<b>Copper</b>	0.960	0.960
<b>Lead*</b>	0.791	0.791
<b>Mercury</b>	0.85	-
<b>Nickel</b>	0.998	0.997
<b>Silver</b>	0.85	-
<b>Zinc</b>	0.978	0.986

\*Conversion factors for cadmium and lead are hardness dependent. The values shown are with a hardness of 100 mg/L as calcium carbonate (CaCO<sub>3</sub>).

# RESULTS

## Summary Table of Proposal

Table 10 provides a summary of our proposed freshwater acute, freshwater chronic, saltwater acute, and saltwater chronic aquatic life toxics criteria. For each criterion, we have also provided a comparison to EPA national recommended criteria when applicable.

Table 10. Proposed acute and chronic aquatic life toxics criteria for freshwater (FW) and saltwater (SW) and EPA recommendations. MLR = multiple linear regression.

Chemical	FW Acute (µg/L)		FW Chronic (µg/L)		SW Acute (µg/L)		SW Chronic (µg/L)	
	WA	EPA	WA	EPA	WA	EPA	WA	EPA
<b>Aluminum</b>	MLR Model (West: 510 <sup>#</sup> ) (East: 820 <sup>#</sup> )	MLR Model	MLR model (West: 270 <sup>#</sup> ) (East: 480 <sup>#</sup> )	MLR Model	-	-	-	-
<b>Arsenic</b>	300	340	130	150	27	69	12	36
<b>Cadmium</b>	1.3*	1.8*	0.41*	0.72*	33	33	7.9	7.9
<b>Chromium III</b>	570*	570*	74*	74*	-	-	-	-
<b>Chromium VI</b>	18	16	4.5	11	1100	1100	50	50
<b>Copper</b>	MLR model (West: 2.0 <sup>#</sup> ) (East: 2.5 <sup>#</sup> )	BLM model	MLR Model (West: 1.6 <sup>#</sup> ) (East: 1.8 <sup>#</sup> )	BLM Model	4.8	4.8	3.1	3.1
<b>Iron</b>	-	-	-	1000	-	-	-	-
<b>Lead</b>	65*	65*	2.5*	2.5*	210	210	8.1	8.1
<b>Mercury</b>	1.4	1.4	0.012	0.77	1.8	1.8	0.025	0.94
<b>Nickel</b>	34*	470*	5.6*	52*	74	74	8.2	8.2
<b>Selenium</b>	EPA's tissue & water criteria	EPA's tissue & water criteria	EPA's tissue & water criteria	EPA's tissue & water criteria	290	290	71	71
<b>Silver</b>	0.52*	3.2*	0.21	-	2.2	1.9	0.87	-
<b>Zinc</b>	57*	120*	39*	120*	90	90	81	81



Chemical	FW Acute (µg/L)		FW Chronic (µg/L)		SW Acute (µg/L)		SW Chronic (µg/L)	
	WA	EPA	WA	EPA	WA	EPA	WA	EPA
<b>4,4''-DDT (and metabolites)</b>	1.1	1.1	0.001	0.001	0.13	0.13	0.001	0.001
<b>6PPD-quinone</b> (N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone)	0.008	-	-	-	-	-	-	-
<b>Acrolein</b>	3	3	3	3	-	-	-	-
<b>Aldrin</b>	3	3	0.0019	-	1.3	1.3	0.0019	-
<b>Carbaryl</b>	2.1	2.1	2.1	2.1	1.6	1.6	-	-
<b>Chlordane</b>	2.4	2.4	0.0043	0.0043	0.09	0.09	0.004	0.004
<b>Chloride</b>	860000	860000	230000	23000	-	-	-	-
<b>Chlorine</b>	19	19	11	11	13	13	7.5	7.5
<b>Chlorpyrifos</b>	0.083	0.083	0.041	0.041	0.011	0.011	0.0056	0.0056
<b>Cyanide</b>	12	22	2.7	5.2	1	1	1	1
<b>Demeton</b>	-	-	0.1	0.1	-	-	0.1	0.1
<b>Diazinon</b>	0.17	0.17	0.17	0.17	0.82	0.82	0.82	0.82
<b>Dieldrin</b>	0.24	0.24	0.056	0.056	0.71	0.71	0.0019	0.0019
<b>Endosulfan (alpha)</b>	0.22	0.22	0.056	0.056	0.034	0.034	0.0087	0.0087
<b>Endosulfan (beta)</b>	0.22	0.22	0.056	0.056	0.034	0.034	0.0087	0.0087
<b>Endrin</b>	0.086	0.086	0.036	0.036	0.037	0.037	0.0023	0.0023
<b>gamma-BHC</b>	0.95	0.95	0.08	-	0.16	0.16	-	-
<b>Guthion</b>	-	-	0.01	0.01	-	-	0.01	0.01
<b>Heptachlor</b>	0.52	0.52	0.0038	0.0038	0.053	0.053	0.0036	0.0036
<b>Heptachlor epoxide</b>	-	0.52	-	0.0038	-	0.053	-	0.0036
<b>Malathion</b>	-	-	0.1	0.1	-	-	0.1	0.1
<b>Methoxychlor</b>	-	-	0.3	0.3	-	-	0.3	0.3
<b>Mirex</b>	-	-	0.001	0.001	-	-	0.001	0.001
<b>Nonylphenol</b>	28	28	6.6	6.6	7	7	1.7	1.7
<b>Parathion</b>	0.065	0.065	0.013	0.013	-	-	-	-

Chemical	FW Acute (µg/L)		FW Chronic (µg/L)		SW Acute (µg/L)		SW Chronic (µg/L)	
	WA	EPA	WA	EPA	WA	EPA	WA	EPA
<b>Pentachlorophenol</b>	9.4 <sup>^</sup>	19 <sup>^</sup>	4.7 <sup>^</sup>	15 <sup>^</sup>	13	13	6.7	7.9
<b>Polychlorinated biphenyls</b>	2	-	0.014	0.014	10	-	0.03	0.03
<b>PFOS</b>	EPA's water & tissue criteria	EPA's water & tissue criteria	EPA's water & tissue criteria	EPA's water & tissue criteria	550	550	-	-
<b>PFOA</b>	EPA's water & tissue criteria	EPA's water & tissue criteria	EPA's water & tissue criteria	EPA's water & tissue criteria	7000	7000	-	-
<b>Sulfide-hydrogen sulfide</b>	-	-	-	2	-	-	-	2
<b>Toxaphene</b>	0.73	0.73	0.002	0.002	0.21	0.21	0.002	0.002
<b>Tributyltin</b>	0.46	0.46	0.072	0.072	0.42	0.42	0.0074	0.0074

\* Based on hardness of 100 mg/L

# 5<sup>th</sup> percentile default criteria from statewide dataset

<sup>^</sup> Based on a pH of 7.8

## Strategy for Aquatic Life Toxics Criteria

Table 11. Strategy for each freshwater (FW) and saltwater (SW) aquatic life toxics criterion considered in this rulemaking. Detail on each strategy can be found in the Alternative Aquatic Life Toxics Method section described above.

Chemical	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Aluminum</b>	EPA recommendation	EPA recommendation	-	-
<b>Arsenic</b>	New science & 1 <sup>st</sup> percentile	New science & 1 <sup>st</sup> percentile	New science & 1 <sup>st</sup> percentile	New science & 1 <sup>st</sup> percentile
<b>Cadmium</b>	EPA recommendation with modification	1 <sup>st</sup> percentile	EPA recommendation	EPA recommendation
<b>Chromium III</b>	EPA recommendation	EPA recommendation	-	-
<b>Chromium VI</b>	New science	New science	No change	No change

Chemical	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Copper</b>	State-specific criteria	State-specific criteria	No change	No change
<b>Iron</b>	-	Do not adopt	-	-
<b>Lead</b>	No change	No change	EPA recommendation	EPA recommendation
<b>Mercury</b>	EPA recommendation	No change	No change	No change
<b>Nickel</b>	New science	New science	No change	No change
<b>Selenium</b>	EPA recommendation	EPA recommendation	No change	No change
<b>Silver</b>	New science	New state-specific criteria	New science	New state-specific criteria
<b>Zinc</b>	New science	New science	No change	No change
<b>4,4'-DDT (and metabolites)</b>	No change	No change	No change	No change
<b>6PPD-quinone</b> (N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone)	New state-specific criteria	-	-	-
<b>Acrolein</b>	EPA recommendation	EPA recommendation	-	-
<b>Aldrin</b>	EPA recommendation	No change	EPA recommendation	No change
<b>Carbaryl</b>	EPA recommendation	EPA recommendation	EPA recommendation	-
<b>Chlordane</b>	No change	No change	No change	No change
<b>Chloride</b>	No change	No change	-	-
<b>Chlorine</b>	No change	No change	No change	No change
<b>Chlorpyrifos</b>	No change	No change	No change	No change
<b>Cyanide</b>	New science & 1 <sup>st</sup> percentile	New science & 1 <sup>st</sup> percentile	No change	No change
<b>Demeton</b>	-	EPA recommendation	-	EPA recommendation
<b>Diazinon</b>	EPA recommendation	EPA recommendation	EPA recommendation	EPA recommendation
<b>Dieldrin</b>	EPA recommendation	EPA recommendation	No change	No change
<b>Endosulfan (alpha &amp; beta)</b>	No change	No change	No change	No change
<b>Endrin</b>	EPA recommendation	EPA recommendation	No change	No change
<b>gamma-BHC</b>	EPA recommendation	No change	No change	-

Chemical	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Guthion</b>	-	EPA recommendation	-	EPA recommendation
<b>Heptachlor</b>	No change	No change	No change	No change
<b>Heptachlor epoxide</b>	Do not adopt	Do not adopt	Do not adopt	Do not adopt
<b>Malathion</b>	-	EPA recommendation	-	EPA recommendation
<b>Methoxychlor</b>	-	EPA recommendation	-	EPA recommendation
<b>Mirex</b>	-	EPA recommendation	-	EPA recommendation
<b>Nonylphenol</b>	EPA recommendation	EPA recommendation	EPA recommendation	EPA recommendation
<b>Parathion</b>	No change	No change	-	-
<b>Pentachlorophenol</b>	New science	New science	New science	New science
<b>Polychlorinated biphenyls</b>	No change	No change	No change	No change
<b>PFOA</b>	EPA recommendation	EPA recommendation	EPA recommendation	-
<b>PFOS</b>	EPA recommendation	EPA recommendation	EPA recommendation	-
<b>Sulfide-hydrogen sulfide</b>	-	Do not adopt	-	Do not adopt
<b>Toxaphene</b>	No change	No change	No change	No change
<b>Tributyltin</b>	EPA recommendation	EPA recommendation	EPA recommendation	EPA recommendation

## Metals

This section provides a summary of recommended criteria for metals, which we have listed in alphabetical order. The frequency of exceedance for acute criteria is a 1-hour average concentration not to be exceeded more than once every three years on average. The frequency of exceedance for chronic criteria is a 4-day average concentration not to be exceeded more than once every three years on average. Exceptions to these frequencies of exceedances are otherwise noted in table footnotes (such as selenium).

Some metal's criteria are based on hardness. EPA presents the metals that are dependent on hardness at 100 mg/L on their [recommended aquatic life toxics criteria webpage](#)<sup>4</sup>. We are presenting Washington's current criteria and the proposed criteria at 100 mg/L as well. However, most datasets that EPA used to calculate criteria are based on 50 mg/L. Therefore, the tables containing species mean acute values (SMAVs) and genus mean acute values (GMAVs) presented throughout this document are normalized for 50 mg/L (except for cadmium), similar to EPA documents, and converted using the hardness dependent equation to criteria based on 100 mg/L. Any criteria that are dependent on hardness or pH and were updated in this proposed rulemaking have an accompanying equation that was updated as well.

## Aluminum

### Summary of Criteria Recommendations and Changes

Washington does not have aluminum criteria for aquatic life (Table 12). EPA first recommended aluminum criteria in 1988 and finalized the multiple linear regression (MLR)-based criteria for aluminum in 2018 (USEPA, 2018). EPA recommendations for aluminum consists of a model-based approach for criteria based on water chemistry data (i.e., pH, dissolved organic carbon, hardness). The MLR model is presented as a regression equation that uses water body specific inputs to calculate criteria. We recommend adopting EPA recommendations for aluminum using the MLR model. We have calculated default criteria using state-specific data that can be used when site-specific water chemistry data are not available. The default freshwater acute criterion is 510 µg/L for western Washington and 820 µg/L for eastern Washington (boundaries for eastern and western are defined in the methodology below and in WAC 222-16-010). The freshwater chronic default criterion is 270 µg/L for western Washington and 480 µg/L for eastern Washington. Criteria calculated using concurrently sampled pH, hardness, and DOC for a specific water body supersede the default criteria, regardless of whether the default criteria are higher or lower.

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<sup>4</sup> <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table>

Table 12. Comparison of Washington’s current freshwater (FW) and saltwater (SW) aluminum acute and chronic criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	Multiple Linear Regression Model	Multiple Linear Regression Model	-	-
<b>Proposed</b>	West: 510# East: 820# (Multiple Linear Regression Model; 1-hour)	West: 270# East: 480# (Multiple Linear Regression Model; 4-day)	-	-

# Represents the 5<sup>th</sup> percentile default criteria. The boundary between east and west designations is found in WAC 222-16-010.

## Endangered Species Consultation

The previous 2012 Oregon and 2014/2015 Idaho Biological Opinions (BiOps) were completed prior to EPA’s recommendation of the aluminum MLR model. However, more recently EPA promulgated the aluminum MLR model in Oregon (USEPA, 2022b), and both NMFS and USFWS concluded that the aluminum MLR model did not result in jeopardy to Oregon’s endangered species (NMFS, 2020).

## Criteria Calculations

### Methodology for Default Criteria

The default criteria were calculated using concurrently sampled pH, hardness, and dissolved organic carbon data from Washington’s EIM database and the Federal Water Quality (WQ) Portal. Data from EIM and the federal WQ Portal was downloaded in March 2023. We also examined concurrently sampled total organic carbon (TOC), hardness, and pH and conductivity, pH, and DOC. We calculated conversion factors to translate TOC to DOC and conductivity to hardness as detailed below.

The data qualifiers and management decisions are presented in Appendix B of this document. Data was reviewed for quality with respects to the intended use of the aquatic life toxics rulemaking. We reviewed sampling locations, the study’s purpose, outlier values and units, reported QA levels, and field collection comments. Records not meeting the intended use of the aquatic life toxics rulemaking were removed (see Appendix B).

The final count of concurrent samples is 3,337 events across 646 unique locations (Figure 1). Each of the 3,337 concurrent samples were entered into the EPA Aluminum MLR calculator. We then compiled the 3,337 calculated criteria values for waterbodies throughout the state and calculated the 5<sup>th</sup> percentile of those 3,337 different criteria to be representative of the default criteria. The 5<sup>th</sup> percentile of the criteria distribution represents a conservative criteria value that is intended to protect the majority of waters with regulated discharge of aluminum. We

considered ecoregional default values (e.g., EPA level III ecoregions), but we had limited geospatial representation in some ecoregions and therefore developed default values for western and eastern Washington. Eastern and western Washington is defined by definitions in WAC 222-16-010 (Figure 2). More specifically, "**Eastern Washington**" means the geographic area in Washington east of the crest of the Cascade Mountains from the international border to the top of Mt. Adams, then east of the ridge line dividing the White Salmon River drainage from the Lewis River drainage and east of the ridge line dividing the Little White Salmon River drainage from the Wind River drainage to the Washington-Oregon state line. "**Western Washington**" means the geographic area of Washington west of the Cascade crest and the drainages defined in Eastern Washington. We had 367 unique sample locations with 2,210 samples in western Washington and 279 unique locations with 1,127 samples in eastern Washington.

A 5<sup>th</sup> percentile default criteria was used to provide protection of all aquatic species. In EPA's Biological Evaluation of Oregon's freshwater aluminum water quality criteria that was promulgated by EPA, EPA states that the 10<sup>th</sup> percentile of outputs should be protective in the majority of cases but circumstances may warrant use of a more stringent model output such as consideration of an endangered species (USEPA, 2019). EPA found that a 10<sup>th</sup> percentile default ecoregional aluminum criterion yielded <90% protection for some ecoregions and that the 5<sup>th</sup> percentile of measured numeric values in Oregon will be protective of the vast majority of cases in Oregon (USEPA, 2019).

Oregon had adequate data to develop ecoregional default values whereas Washington developed an east and west default value due to limited dispersion of concurrent sampling sites throughout the state. Thus, a higher level of protection at the 5<sup>th</sup> percentile default criteria is appropriate because individual ecoregions and watershed water chemistry is not accounted for using a default value but rather becomes integrated into the dataset. The 5<sup>th</sup> percentile default value is more protective of waters with higher bioavailability of aluminum and endangered species.

Permittees will have the opportunity to collect their own site-specific chemistry data to calculate site-specific criteria that may afford a higher criteria value than the 5<sup>th</sup> percentile default criteria. If site-specific criteria are less than the 5<sup>th</sup> percentile default criteria, permittees will need to use the site-specific information to determine effluent limits.

## MLR Locations

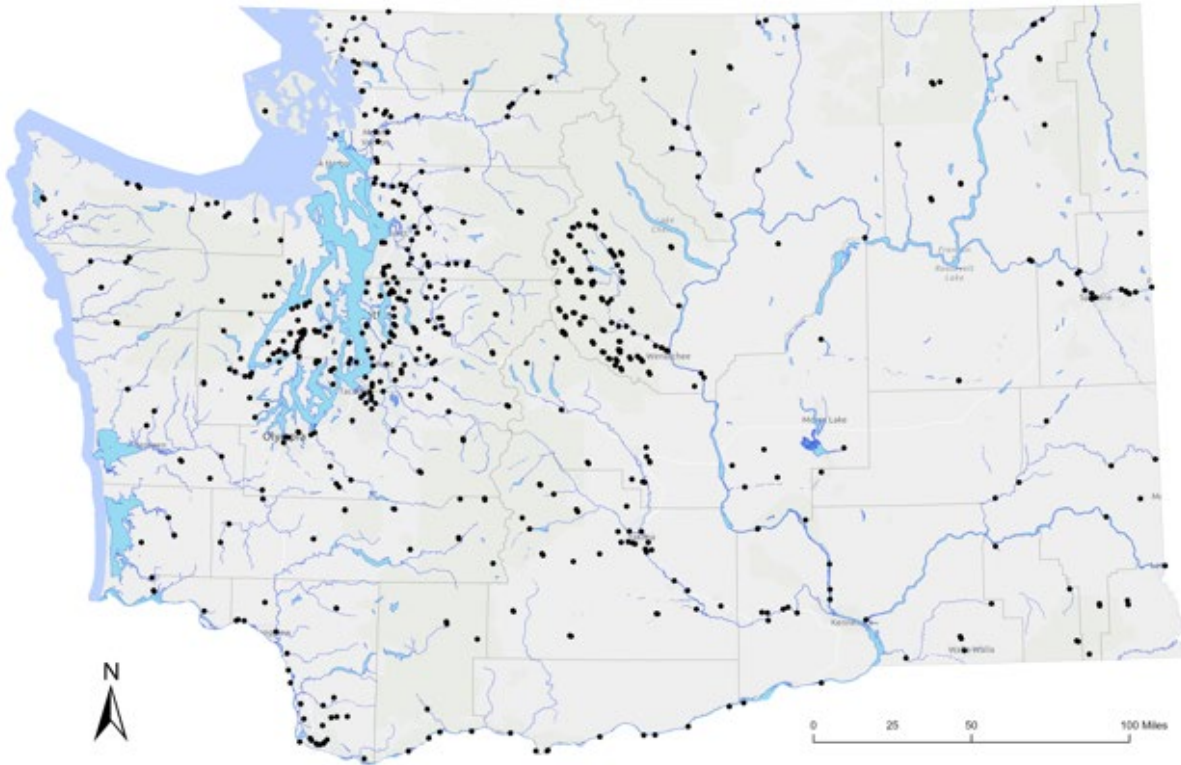


Figure 1. Locations in Washington with concurrently sampled pH, hardness, and dissolved organic carbon. Some hardness samples were calculated from conductivity and some dissolved organic carbon samples were calculated for total organic carbon.





Figure 2. Boundary defined between eastern and western Washington in WAC 222-16-010.

## Conversion Factors

### Total Organic Carbon to Dissolved Organic Carbon

We also examined instances where we had concurrently sampled TOC, hardness, and pH since 2000 to add additional sampling events and increase representation of waterbodies throughout the state. We developed a conversion factor to translate TOC to DOC. We downloaded all the concurrently sampled TOC and DOC data in May 2023 and calculated the ratio of DOC to TOC, or the proportion of TOC that is DOC. For the TOC conversion factor, we used the 10<sup>th</sup> percentile of all the different ratios for statewide data. We used a conservative value (i.e., 10<sup>th</sup> percentile) aimed to protect all state aquatic life (i.e., the lower the DOC value the lower the criteria value), to account for uncertainty in the conversion, and to be protective of the majority of state waters.

After converting TOC to DOC, 105 sampling events were added to our MLR dataset (105 sample events out of the 3,337 total sampling events). The statewide conversion factor, based on the 10<sup>th</sup> percentile of the ratio of DOC to TOC, is 0.81 (see example below). The TOC to DOC conversion factor is comparable to Oregon’s conversion factor of 0.83 (ODEQ, 2021), EPA’s reported conversion value in the copper criteria document of 0.86 (USEPA, 2007), and Massachusetts’ value of 0.86 (MassDEP, 2021).

Example:

TOC = 10 mg/L

DOC = 10 mg/L (TOC) x 0.81 (conversion factor) = 8.1 mg/L

### Conductivity to Hardness

We also examined instances where we had concurrently sampled conductivity, hardness, and pH since 2000 to add additional sampling events and increase representation of waterbodies throughout the state. We developed a conversion factor to translate conductivity to hardness (Figure 3). We downloaded all the concurrently sampled conductivity and hardness measurements data in August 2023. For the specific conductance versus hardness dataset, we first took the natural log of the values before running a linear regression between the two variables to improve model fit. The natural-log transformed data were used to establish the conversion equation used to estimate total hardness from conductivity. When we converted conductivity to hardness, 910 sampling events were added to our MLR dataset (910 sample events out of the 3,337 total sampling events). The linear regression equation that was used to convert conductivity to hardness is as follows:

$$\text{LN}(\text{Hardness}) = 1.0108 * \text{LN}(\text{conductivity}) - 0.9233$$

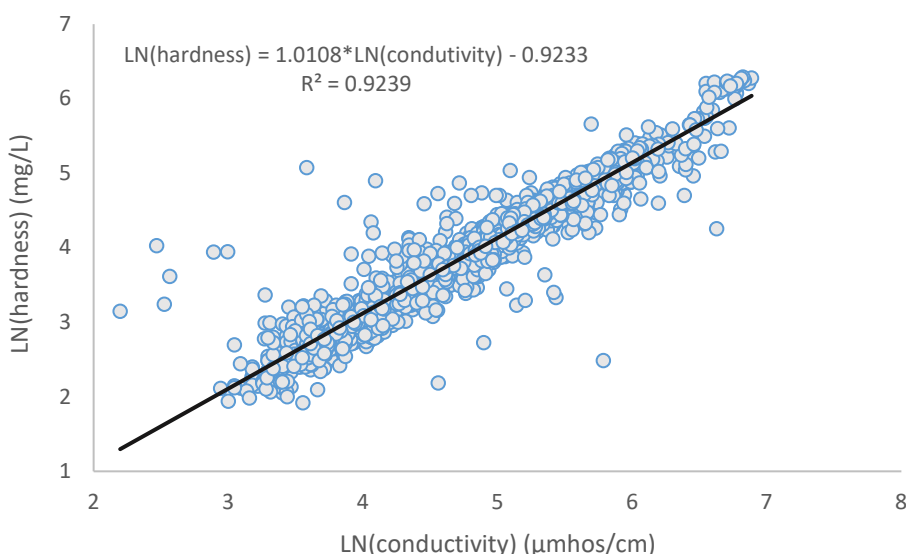


Figure 3. Relationship between hardness and conductivity (in micromhos per centimeter (µmhos/cm) for concurrent sampling throughout Washington.

### Freshwater Acute and Chronic Criteria

The default freshwater acute aluminum criterion of 510 µg/L applies to western Washington and 820 µg/L is applicable to eastern Washington. The default freshwater chronic aluminum criterion is 270 µg/L for western Washington and 480 µg/L for eastern Washington are based on concurrent sampling from Ecology’s EIM database and the federal WQ Portal.

If site-specific water quality information exists for a water body, that information must be used to develop site-specific aluminum criteria. A permittee is expected to work with the permit writer to determine adequate sampling data. In the absence of site-specific water chemistry data, the aluminum default criteria apply.

# Arsenic

## Summary of Criteria Recommendations and Changes

The proposed arsenic criteria (based on arsenic III) for freshwater and saltwater are more stringent than EPA recommendations to account for endangered species protection concerns (Table 13). New science since EPA last updated the arsenic freshwater criteria in 1995 (USEPA, 1996) and the saltwater criteria in 1984 (USEPA, 1985) was incorporated into the proposed criteria. Additionally, the 1<sup>st</sup> percentile of the toxicity data distribution was used to calculate the proposed freshwater and saltwater criteria for arsenic to ensure protection of endangered species in Washington. The EPA recommended freshwater chronic arsenic criterion was implicated in previous BiOps for causing indirect effects to freshwater endangered species (i.e., bull trout and sturgeon).

The revised arsenic criteria are aimed at improving protection for endangered species. However, BiOps and toxicity data indicate that some freshwater prey species (i.e., gammarid and mayflies) of endangered species may be negatively affected over chronic durations at 100 µg/L arsenic. We support the derived chronic criteria of 130 µg/L as protective of endangered species for the reasons described within this section and additional analyses provided in the Endangered Species Act Consultation section for Idaho. Fish species have diversity in their range of diet and are not strictly dependent on gammarid or mayfly populations for their food source. Other environmental factors, organism life history, and water quality play a role in realistic exposure scenarios that may mediate toxicity compared with controlled laboratory studies.

An important point in setting arsenic criteria is that it is based on arsenic III toxicity data which is one inorganic form of arsenic (USEPA, 1985). The EPA approved analytical method for arsenic is based on total recoverable inorganic arsenic, which includes both arsenic III and arsenic V. Arsenic III is known to be more acutely toxic than arsenic V (USEPA, 1985; Spehar et al. 1980; Suhendrayatna and Maeda, 1999; Jeyasingham and Ling, 2000; Hughes, 2002; Suhendrayatna et al. 2002; Irving et al. 2008). The analytical method cannot distinguish between different oxidation states (USEPA, 1985). This means the criteria may be overly protective when based on the total recoverable method because we are measuring both arsenic III and arsenic V in the environment, but only arsenic III is used to derive the criteria. Therefore, any compliance monitoring for permitting purposes may be overestimating arsenic levels because of the inclusion of both inorganic species, arsenic III and arsenic V. When based on the total recoverable method, the criteria may be overly protective (USEPA, 1986). Given these factors combined, we support a freshwater chronic criterion value of 130 µg/L for arsenic because of the conservatism built into the criteria.

The proposed saltwater arsenic criteria are intended to protect endangered species and are more conservative than EPA recommendations. The Swinomish Tribe BE suggested that the EPA recommended saltwater chronic arsenic criteria may not be protective of individuals of endangered species in Washington (USEPA, 2022a). The Swinomish BE analysis was based on existing data and results compiled by EPA and may be subject to change if re-evaluated with updated datasets. The Swinomish Tribe BE back-calculated tissue residue concentrations from

the chronic criterion using a bioconcentration factor (BCF) that resulted in a tissue concentration of 1.6 mg/kg ww. They used this criteria-based value and compared it to bioaccumulation studies that reported no observed effect residues of 0.07 to 0.20 mg/kg. The newly proposed saltwater chronic criterion of 12 µg/L translates to a tissue residue of 0.53 mg/kg.

While we contend that translating water concentration thresholds to tissue residue is a useful exercise, there is a very high degree of uncertainty. Back-calculating tissue residue concentrations from a water quality criterion has high uncertainty because BCFs are site and species specific, and the chronic based criterion is based on several different species with different physiologies. The BCF used for back-calculation was not specific to the endangered species listed in Washington and may need updated using more relevant aquatic species compared with the BCF used in the Swinomish BE analysis. Furthermore, the toxicity studies used threshold tissue concentrations representative of no observed effect residues (NOERs). Typically, threshold values are calculated by taking the mean value of NOERs and the lowest observed effect residue (LOER). By using the NOER, the threshold value is being overestimated because no observed effects may occur at higher residue levels. Most often the NOERs are a product of the toxicity test design and not true threshold values. Given all these factors combined, we support a saltwater chronic criterion value of 12 µg/L for arsenic as protective of endangered species in Washington.

Table 13. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic arsenic criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	360 <sup>^</sup> (1-hour)	190 <sup>^</sup> (4-day)	69 <sup>^</sup> (1-hour)	36 <sup>^</sup> (4-day)
<b>EPA</b>	340 <sup>^</sup> (1-hour)	150 <sup>^</sup> (4-day)	69 <sup>^</sup> (1-hour)	36 <sup>^</sup> (4-day)
<b>Proposed</b>	300 <sup>^</sup> (1-hour)	130 <sup>^</sup> (4-day)	27 <sup>^</sup> (1-hour)	12 <sup>^</sup> (4-day)

<sup>^</sup> Presented as the dissolved fraction

## Endangered Species Act Consultation

### Idaho

A jeopardy call was listed for arsenic freshwater chronic criterion of 150 µg/L in Idaho BiOps (NMFS, 2014; USFWS, 2015). The Idaho USFWS BiOp implicates indirect effects of arsenic on sturgeon, bull trout, and other salmonids through the bioaccumulation of arsenic from invertebrate prey species. Washington has bull trout and green sturgeon listed on their endangered and threatened species list. Thus, the effects described in the Idaho BiOp are relevant to Washington. The Idaho USFWS BiOp specifically states:

“Bioaccumulation of arsenic in invertebrate organisms (that serve as prey for salmonids like the bull trout) to concentrations harmful to salmonids is likely to occur in streams with dissolved arsenic concentrations below the proposed chronic criterion; inorganic arsenic in the diet of rainbow trout is associated with reduced growth, organ damage and other adverse physiological effects (Cockell et al. 1991, p. 518; Hansen et al. 2004, pp. 1902-1910; Erickson et al. 2010, pp. 122,123). For those reasons, we expect that arsenic concentrations below the proposed chronic criteria are likely to contaminate the prey base within bull trout critical habitat to an extent that precludes it from being adequate to support normal growth and reproduction in the bull trout. For that reason, the proposed chronic criterion for arsenic is likely to significantly impair the capability of bull trout critical habitat to provide an abundant food base (PCE 3) for the bull trout over a significant portion of the range of designated critical habitat.”

“We also assume that sturgeon sensitivity to arsenic is at least as sensitive as for the rainbow trout. With rainbow trout, dietary arsenic has been linked to reduced growth at about 20 mg/kg dw and higher (see *Dietary Toxicity*, section 2.5.2.2 above), and these concentrations in benthic invertebrates have been measured in field conditions with water concentrations much lower than the proposed 150 µg/L chronic criterion for arsenic (Table 5). The observed effects of arsenic contamination in salmonids include altered feeding behavior, and reduced body weight, reproductive success, and survival. Absent information specific to the effects of the proposed arsenic criteria on white sturgeon prey species, we are assuming that information on the effects of the proposed arsenic criteria on bull trout prey species also applies to white sturgeon prey species.”

These claims are further substantiated in the Idaho BiOp from Irving et al. (2008) and Canivet et al. (2001) that found arsenic III thresholds for growth effects at 100 µg/L and mortality of gammarid amphipods and mayflies at 100 µg/L. They conclude that because invertebrates accumulate arsenic from sediments and biofilms, arsenic accumulations in aquatic invertebrates have been implicated in reduced growth and tissue damage in salmonids and are likely to cause adverse effects to bull trout. However, Maeda et al. (1990) concluded that methylated arsenic in organisms increase in higher trophic levels, while total arsenic bioaccumulation decreases with an order of magnitude with each trophic level. The work by Maeda et al. (1990) suggests that threshold effects using inorganic or total arsenic should not be evaluated in terms of arsenic accumulation to higher trophic levels as was done in the USFWS BiOp for the chronic arsenic criterion. The threshold effects cited in the USFWS for gammarids and mayflies at 100 µg/L should not be extrapolated to higher trophic organisms (i.e., salmonids) that prey on these invertebrates.

Idaho’s USFWS jeopardy call for the freshwater arsenic chronic criterion of 150 µg/L uses studies from Cockell et al. (1991), Hansen et al. (2004), and Erickson et al. (2010) as a basis for their determination. These articles have several uncertainties and should be reconsidered in the assessment of endangered species protection compared with surface water quality criteria. Cockell et al. (1991) directly spiked fish diets to determine effect levels. The translation between spiked diet and water column concentrations are unknown for this study, rendering it difficult to conclude whether a diet-based study is relevant to evaluating surface water quality standards based on water column concentrations. Furthermore, the Hansen et al. (2004) study

used field-collected sediments that contained several different metals, rendering it difficult to discern between effects related to arsenic versus other metals. Finally, Erickson et al. (2010) exposed earthworms to very high arsenic concentrations that would rarely be found in the environment and it is unclear if the effects would be evident at concentrations similar to the freshwater chronic arsenic criteria of 130 ug/L (an order of magnitude lower than test concentrations).

## **Swinomish Tribe Biological Evaluation**

The Swinomish BE represents EPA's evaluation of proposed actions and does not represent NMFS/USFWS positions or conclusions of formal ESA consultation (USEPA, 2022a). However, the results of EPA's BE can be used to inform potential adverse effects that would be recognized in formal ESA consultation. In the Swinomish BE, the arsenic marine chronic criterion resulted in a likely to adversely affect (LAA) determination. The Swinomish BE specifically states:

“The marine chronic arsenic criterion of 36 µg/L multiplied by the bioconcentration factor from the criteria document of 44 L/kg yields a tissue screening concentration (TSC) of 1.6 mg/kg wb/ww. Two NOERs were found and compared to the TSC. The first is 0.14 mg/kg from a brook trout exposure that assessed physiological effects (Harper, Farag, Hogstrand, & MacConnell, 2009); the second study EPA reviewed provides a range of 0.07 to 0.20 mg/kg based on mortality in lake trout swim up fry (Fitzsimons, Huestis, & Williston, 1995). The available residue-effects data indicates exposure to arsenic at chronic criteria levels appears likely to result in bioaccumulation of arsenic to levels associated with toxicity to aquatic species.”

The BCF of 44 L/kg used in the Swinomish BE was developed using existing data and results compiled by EPA and may be subject to change if re-evaluated with updated datasets. We do not wish to update the Swinomish BE but other datasets suggest that a BCF of 44 may be an overestimate and that aquatic life based BCFs presented in USEPA (1985) arsenic criteria document may be more appropriate for comparative purposes. The results of using a lower BCF value in this assessment will likely yield a lower magnitude of effects to endangered species.

## **Criteria Calculations**

### **Freshwater Acute Arsenic Criterion**

The data used to derive the freshwater acute arsenic criterion is presented in Table 14. New studies that met data acceptability requirements are presented in Table 15. Studies used in previous EPA derivations but not used in this derivation are found in Table 16. The proposed freshwater acute criterion for arsenic was derived using 17 GMAVs and the 1<sup>st</sup> percentile of the toxicity data distribution. Calculation results are as follows:

Final acute value (FAV) = 596.2

CMC = 298.1

**Acute criterion (total) = 300 µg/L (rounded to two significant digits)**

**Conversion factor (total to dissolved fraction) = 1.00**

Acute criterion (dissolved) =  $300 \times 1.00 = 300 \mu\text{g/L}$  (rounded to two significant digits)

Table 14. Freshwater acute toxicity data used for criteria derivation.

Rank	GMAV ( $\mu\text{g/L}$ )	Species	SMAV ( $\mu\text{g/L}$ )
1	874	<i>Gammarus pseudolimnaeus</i>	874
2	1175	<i>Simocephalus vetulus</i>	1700
		<i>Simocephalus serrulatus</i>	812
3	1600	<i>Hyalella azteca</i>	1600
4	1634	<i>Ceriodaphnia reticulata</i>	1511
		<i>Ceriodaphnia dubia</i>	1768
5	2533	<i>Daphnia magna</i>	3841
		<i>Daphnia pulex</i>	1670
6	7100	<i>Chironomus dilutus</i>	7100
7	13700	<i>Thymallus arcticus</i>	13700
8	14065	<i>Pimephales promelas</i>	14065
9	14960	<i>Salvelinus fontinalis</i>	14960
10	18100	<i>Ictalurus punctatus</i>	18100
11	18513	<i>Oncorhynchus mykiss</i>	16026
		<i>Oncorhynchus kisutch</i>	18500
		<i>Oncorhynchus tshawytscha</i>	21400
12	20130	<i>Jordanella floridae</i>	20130
13	22040	Plecoptera	22040
14	24500	<i>Aplexa hypnorum</i>	24500
15	28100	<i>Danio rerio</i>	28100
16	41760	<i>Lepomis macrochirus</i>	41760
17	97000	<i>Tanytarus dissimilis</i>	97000

Table 15. New freshwater acute studies that met data acceptability requirements since EPA last updated arsenic criteria (S = static, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L)	Used in Derivation?	Reference
<b>Oncorhynchus mykiss</b>	S, U	16000	Yes.	Buhl 1991
<b>Oncorhynchus mykiss</b>	S, M	15300	Yes.	Tisler & Zagorc-Koncan 2002
<b>Oncorhynchus tshawytscha</b>	S, U	21400	Yes.	Hamilton & Buhl 1990
<b>Oncorhynchus kisutch</b>	S, U	18500	Yes.	Buhl 1991
<b>Chironomus dilutis</b>	S, M	7100	Yes.	Liber et al. 2011
<b>Thymallus arcticus</b>	S, U	13700	Yes.	Buhl 1991
<b>Daphnia pulex</b>	S, M	2566	Yes.	Shaw et al. 2007
<b>Ceriodaphnia dubia</b>	S, U	1768	Yes.	Hocket & Mount 1996
<b>Daphnia magna</b>	S, U	2500	Yes.	Tisler & Zagorc-Koncan 2002
<b>Danio rerio</b>	S, M	28100	Yes.	Tisler & Zagorc-Koncan 2002
<b>Hyalella azteca</b>	S, M	1600	Yes.	Liber et al. 2011
<b>Oncorhynchus mykiss</b>	FT, M	20200	Yes.	Rankin & Dixon 1994



Table 16. Freshwater acute studies not used from previous EPA criteria derivations (FT = flow-through, M = measured test concentrations).

Species	Method	LC50 (µg/L)	Reason	Reference
<b>Carassius auratus</b>	FT, M	26040	Non-north American species	USEPA, 1985

### Freshwater Chronic Arsenic Criterion

There was inadequate freshwater chronic arsenic data to calculate criteria using the eight-family method. The FACR (final acute to chronic ratio) of 4.594 was used to calculate the freshwater chronic arsenic criterion. This ACR is the same as the EPA derived ACR from the 1995 updates to aquatic life (USEPA, 1996). Calculation results are as follows:

FAV = 596.2

FACR = 4.594

CCC = 129.9 µg/L

**Chronic criterion (total) = 130 µg/L (rounded to two significant digits)**

**Conversion factor (total to dissolved fraction) = 1.00**

**Chronic criterion (dissolved) = 130 x 1.00 = 130 µg/L (rounded to two significant digits)**

### Saltwater Acute Arsenic Criterion

The data used to derive the saltwater arsenic criteria is presented in Table 17. New studies that met data acceptability requirements since EPA's last update in 1984 are found in Table 18. The proposed saltwater acute criterion for arsenic was derived using 12 GMAVs and the 1<sup>st</sup> percentile of the toxicity data distribution. Calculation results are as follows:

FAV = 54.3

CMC = 27.2 µg/L

**Acute criterion (total) = 27 µg/L (rounded to two significant digits)**

**Conversion factor (total to dissolved fraction) = 1.00**

**Acute criterion (dissolved) = 27 x 1.00 = 27 µg/L (rounded to two significant digits)**

Table 17. Saltwater acute toxicity data used for criteria derivation.

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
<b>1</b>	232	Cancer magister	232
<b>2</b>	508	Acartia clausi	508
<b>3</b>	1564	Crassostrea gigas Crassostrea virginica	326 7500
<b>4</b>	1740	Mysidopsis bahia	1740
<b>5</b>	>3000	Mytilus edulis	>3000

6	3490	Argopecten irradians	3490
7	8227	Ampelisca abdita	8227
8	10120	Neanthes arenaceodentata	10120
9	12700	Cyprinodon variegatus	12700
10	14950	Apeltes quadracus	14950
11	16030	Menidia menidia	16033
12	16737	Fundulus heteroclitus	16737

Table 18. New saltwater acute studies that met data acceptability requirements since EPA last updated arsenic criteria (R = static renewal, U = unmeasured test concentrations).

Species	Method	LC50 (µg/L)	Used in Derivation?	Reference
<b>Fundulus heteroclitus</b>	R, U	16737	Yes.	Shaw et al. 2007

### Saltwater Chronic Arsenic Criterion

There was inadequate saltwater chronic arsenic data to calculate criteria using the eight-family method. The ACR of 4.594 was used to calculate the saltwater chronic arsenic criterion. This ACR is the same as the EPA derived ACR from the 1995 updates to aquatic life (USEPA, 1996). Calculation results are as follows:

FAV = 54.3

FACR = 4.594

CCC = 11.8 µg/L

**Chronic criterion (total) = 12 µg/L (rounded to two significant digits)**

**Conversion factor (total to dissolved fraction) = 1.00**

**Chronic criterion (dissolved) = 12 x 1.00 = 12 µg/L (rounded to two significant digits)**

## Cadmium

### Summary of Criteria Recommendations and Changes

The proposed freshwater acute and chronic cadmium criteria are more stringent than EPA recommendations (Table 19). The freshwater cadmium criteria are intended to provide additional protection to endangered species (specifically bull trout). Saltwater cadmium criteria match EPA recommendations, and there are no known endangered species concerns. Recent litigation has vacated EPA's freshwater chronic cadmium criteria and remanded the freshwater acute cadmium criteria (Center for Biological Diversity v. United States Environmental Protection Administration et al, No. 4:2022cv00138 - Document 39 (D. Ariz. 2023)).

Table 19. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic cadmium criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	3.7* <sup>^</sup> (1-hour)	1.0* <sup>^</sup> (4-day)	42 <sup>^</sup> (1-hour)	9.3 <sup>^</sup> (4-day)
<b>EPA</b>	1.8* <sup>^</sup> (1-hour)	0.72* <sup>^</sup> (vacated) (4-day)	33 <sup>^</sup> (1-hour)	7.9 <sup>^</sup> (4-day)
<b>Proposed</b>	1.3* <sup>^</sup> (1-hour)	0.41* <sup>^</sup> (4-day)	33 <sup>^</sup> (1-hour)	7.9 <sup>^</sup> (4-day)

\* Hardness based criteria (numeric value shown based on 100 mg/L)

<sup>^</sup> Presented as the dissolved fraction

## Endangered Species Act Consultation

### Oregon

A jeopardy call was listed for EPA’s 2001 cadmium freshwater acute (2.0 µg/L) in the Oregon BiOps, while likely to cause adverse effects were reported for the chronic criteria of 0.25 µg/L (Table 2). The Oregon BiOps (NMFS, 2012; USFWS, 2012) specifically state:

“The LC10 developed using direct data for bull trout exposure to cadmium is 1.24 µg/L (at 100 mg/L CaCO<sub>3</sub>) for juvenile fish (Table 4-8). This result means that the proposed acute standard for cadmium would likely cause a reduction in bull trout survival of more than 10% of the exposed population every 3 years during the 25-year term of the proposed action.”

“Hansen et al. (2002, p. 171) concluded that bull trout exposed to cadmium at concentrations equivalent to 0.21 µg/L (at 100 mg/L CaCO<sub>3</sub>) experienced a 12.4% reduction in growth (weight) from the control after 55 days of exposure, while bull trout exposed to a much higher concentration of cadmium [equivalent to 0.9 µg/L (at 100 mg/L CaCO<sub>3</sub>)] experienced a 12.9% reduction in growth from the control. These results are somewhat ambiguous, as testing done at a concentration between these amounts [at 0.46 µg/L (at 100 mg/L CaCO<sub>3</sub>)] showed only a 9% reduction in weight. We conclude that a reduction in bull trout growth of about 13% (a reasonable worst case) is likely to occur every 3 years during the 25-year term of the proposed action when bull trout are subject to chronic exposure to cadmium at the proposed standard.”

“The available evidence for indicates that listed species exposed to waters equal to the acute or chronic criteria concentrations will suffer acute and chronic toxic effects including mortality (high intensity), reduced growth (moderately-high-intensity), impairment of essential behaviors related to successful rearing and migration (moderate intensity), physiological trauma (moderate intensity), and reproductive failure (moderate intensity).”

While the Oregon BiOps from USFWS and NOAA clearly suggest a potential for adverse effects of the EPA 2001 freshwater acute and chronic cadmium criteria, the chronic criterion (0.25 µg/L) was accepted by EPA and incorporated into Oregon’s aquatic life toxics criteria. One

potential reason for this acceptance is the inconsistent dose response curve in Hanson et al. (2002) that served as the basis for the “likely to adversely affect” determination for the chronic criterion, suggesting a questionable data set.

The 2016 EPA recommended freshwater chronic cadmium criterion of 0.72 µg/L has not undergone ESA consultation in other Pacific Northwest states.

### **Swinomish Tribe Biological Evaluation**

The Swinomish BE concluded no effects of their submission of a freshwater acute cadmium criterion of 1.3 µg/L (hardness of 100 mg/L) and chronic cadmium criterion of 0.55 µg/L (hardness of 100 mg/L; USEPA, 2022a). The Swinomish submittal for cadmium aligns with previously approved Idaho freshwater acute (1.34 µg/L) and chronic (0.60 µg/L) cadmium criteria.

## **Criteria Calculations**

### **Freshwater Acute Cadmium Criterion**

The proposed freshwater acute cadmium criterion uses the same derivation methods as EPA’s recommendations (USEPA, 2016). The freshwater acute cadmium criterion is based upon the commercially important rainbow trout (*Oncorhynchus mykiss*). EPA found that the rainbow trout SMAV was less than the 5<sup>th</sup> percentile of the GMAV toxicity distribution for the freshwater acute data set, necessitating the use of rainbow trout SMAV to derive criteria. Rather than using the geometric mean of acute toxicity values for rainbow trout to derive the acute criterion, we used the 20<sup>th</sup> percentile of available acute toxicity data for rainbow trout to add increased protection for endangered species. We sought to align our proposed freshwater acute cadmium criterion with Idaho’s and Swinomish approved criterion of 1.3 µg/L to ensure protection of endangered species. We did not find new freshwater acute toxicity studies since EPA last updated the cadmium criteria that would lower the GMAV.

Table 20 shows the calculated 20<sup>th</sup> percentile of 30 rainbow trout LC50 values from the acute toxicity dataset presented in EPA’s 2016 cadmium recommendations (USEPA, 2016). The 20<sup>th</sup> percentile was used to align with Idaho and the Swinomish Tribe freshwater acute cadmium criteria that has been demonstrated to be protective of endangered species and approved through ESA consultation. Calculation results are as follows:

$$\text{CMC} = 1.376 \text{ } \mu\text{g/L (hardness of 100 mg/L)}$$

$$\text{CMC} = e^{(0.9789 \times \ln(\text{hardness}) - 4.189)} \times \text{CF}$$

Where CF (conversion factor from total to dissolved fraction) =  $1.136672 - [(\ln \text{ hardness}) \times (0.041838)]$

$$\text{FAV} = 2.7518$$

$$\text{CMC} = \text{FAV} / 2 = 2.7518 / 2 = 1.376 \text{ } \mu\text{g/L}$$

Acute criterion (total) = 1.4 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Acute criterion (dissolved) = 1.3 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 20. Rainbow trout acute toxicity values used for criteria derivation (from USEPA, 2016).

Acute Value (µg/L)	Normalized Acute Value (µg/L)*	Reference
1.75	5.506	Davies 1976
1.3	5.479	Chapman 1978
1.0	4.214	Chapman 1978
3.0	6.641	Phipps and Holcombe 1985
1.88	3.565	Stubblefield 1990
2.66	5.569	Davies et al. 1993
3.15	1.567	Davies et al. 1993
3.02	6.070	Davies et al. 1993
6.12	2.779	Davies et al. 1993
2.79	9.371	Davies and Brinkman 1994
8.54	3.376	Davies and Brinkman 1994
13.4	4.873	Davies and Brinkman 1994
2.09	7.265	Davies and Brinkman 1994
10.5	3.886	Davies and Brinkman 1994
10.0	3.637	Davies and Brinkman 1994
0.71	2.255	Stratus Consulting 1999
0.47	1.563	Stratus Consulting 1999
0.51	1.570	Stratus Consulting 1999
0.38	1.227	Stratus Consulting 1999
1.29	4.191	Stratus Consulting 1999
2.85	3.183	Stratus Consulting 1999
3.7	3.594	Besser et al. 2007
5.2	5.051	Besser et al. 2007
3.061	2.945	Calfee et al. 2014
5.115	4.786	Calfee et al. 2014
2.933	2.745	Calfee et al. 2014
3.929	3.780	Calfee et al. 2014
4.808	5.003	Calfee et al. 2014

Acute Value (µg/L)	Normalized Acute Value (µg/L)*	Reference
3.135	3.045	Calfee et al. 2014
5.401	5.400	Wang et al. 2014
20 <sup>th</sup> percentile of Normalized Acute Values	<b>2.7518 (FAV)</b>	
<b>Acute criterion</b>	<b>1.376 (CMC)</b>	

\* Normalized to hardness of 100 mg/L

### Freshwater Chronic Cadmium Criterion

The proposed freshwater chronic cadmium criterion was calculated from the 2016 EPA toxicity dataset and used the 1<sup>st</sup> percentile of the toxicity data distribution (Table 9 from USEPA, 2016).

FCV = 0.4618 µg/L (hardness of 100 mg/L)

$$CCC = e^{(0.7977 \times \ln(\text{hardness}) - 4.446)} \times CF$$

Where CF (conversion factor from total to dissolved fraction) =  $1.101672 - [(\ln \text{hardness}) \times (0.041838)]$

**Chronic criterion (total) = 0.4527 µg/L** (hardness of 100 mg/L; rounded to two significant digits)

**Chronic criterion (dissolved) = 0.41 µg/L** (hardness of 100 mg/L; rounded to two significant digits)

### Saltwater Acute and Chronic Cadmium Criteria

Washington’s saltwater acute and chronic cadmium criteria are outdated and do not match EPA recommendations. We propose to match EPA recommendations for the saltwater acute and chronic cadmium criteria. There are no known ESA consultation issues in other Region 10 states.

## Chromium III

### Summary of Criteria Recommendations and Changes

There are no known concerns regarding protection of endangered species in Washington using EPA recommendations for chromium III. We propose to adopt criteria that align with EPA recommendations (Table 21).

Table 21. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic chromium III criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	550* <sup>^</sup> (1-hour)	180* <sup>^</sup> (4-day)	-	-

<b>EPA</b>	570* <sup>^</sup> (1-hour)	74* <sup>^</sup> (4-day)	-	-
<b>Proposed</b>	570* <sup>^</sup> (1-hour)	74* <sup>^</sup> (4-day)	-	-

\* Hardness based criteria (numeric value shown based on 100 mg/L)

<sup>^</sup> Presented as the dissolved fraction

## Endangered Species Act Consultation

There were no jeopardy calls for the freshwater acute (574 µg/L) and chronic (74 µg/L) chromium III criteria in Oregon (USFWS, 2012; NMFS, 2012). Furthermore, the Swinomish BE indicated a not likely to adversely affect (NLAA) determination for freshwater acute and chronic chromium III EPA recommendations (USEPA, 2022a).

## Chromium VI

### Summary of Criteria Recommendations and Changes

The proposed freshwater chromium VI criteria accounts for endangered species protection levels for species in Washington by incorporating the new science available since EPA last updated the freshwater criteria in 1995 (Table 22; USEPA, 1996).

While there were no jeopardy calls for chromium VI in Idaho or Oregon, the information presented as well as the Swinomish BE suggests that endangered species and their populations in Washington may be at risk at EPA recommendations. We therefore, decided to use new science available and the 1<sup>st</sup> percentile of the toxicity data distribution to derive chromium VI criteria. No changes were necessary for saltwater criteria because Washington’s saltwater criteria are identical to EPA recommendations, and there are no endangered species protection issues highlighted in previous ESA consultations in Oregon.

Table 22. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic chromium VI criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	15 <sup>^</sup> (1-hour)	19 <sup>^</sup> (4-day)	1100 <sup>^</sup> (1-hour)	50 <sup>^</sup> (4-day)
<b>EPA</b>	16 <sup>^</sup> (1-hour)	11 <sup>^</sup> (4-day)	1100 <sup>^</sup> (1-hour)	50 <sup>^</sup> (4-day)
<b>Proposed</b>	18 <sup>^</sup> (1-hour)	4.5 <sup>^</sup> (4-day)	No change	No change

<sup>^</sup> Presented as the dissolved fraction

## Endangered Species Act Consultation

### Idaho

The Idaho USFWS BiOp reported a likely to adversely affect (LAA) determination for the freshwater chronic chromium VI criterion (11 µg/L) for bull trout and white sturgeon but did not result in a jeopardy call (USFWS, 2015; Table 4). The information presented in Idaho BiOps presented concerns for Washington's endangered species. The USFWS Idaho BiOp specifically states:

"Given the information discussed above that long-term exposure to chromium (VI) at the proposed chronic criterion level may cause reduced growth of juvenile bull trout, and depending on the magnitude of the growth reduction, reduced overwinter survival, the Service concludes that individual juvenile bull trout may be adversely affected by the proposed chronic chromium criterion. However, these effects are not likely to occur at a population level given the other above studies involving the chronic exposure effects of chromium that resulted in reduced salmonid growth only at chromium concentrations well above the proposed chronic criterion for chromium (VI) of 11 µg/L."

"Given the information discussed above that long-term exposure to chromium (VI) at the proposed chronic criterion levels may cause reduced growth of juvenile bull trout, and depending on the magnitude of the growth reduction, reduced overwinter survival, the Service concludes that individual juvenile Kootenai River white sturgeon may be adversely affected by the proposed chronic criterion for chromium (VI). However, these effects are not likely to occur at a population level given the other above studies involving the chronic exposure effects of chromium that resulted in reduced salmonid growth only at chromium concentrations well above the proposed chronic criterion for chromium (VI) of 11 µg/L."

### Oregon

The Oregon USFWS BiOps reported likely to adversely affect determinations but did not result in jeopardy for ESA listed species in Oregon (NMFS, 2012). The determinations present concerns for Washington's endangered species. The NMFS BiOp states:

"Based on this principle and the considerations of the shortcomings and implications of laboratory-derived toxicity tests, the relative percent mortality analysis, and the ecological consequences for field-exposed fishes, listed species exposed to waters equal to the acute criterion concentration may not suffer acute toxic effects, but will suffer chronic toxic effects."

"The available evidence for chromium (III) and chromium (VI), respectively, indicates that listed species exposed to waters equal to the acute or chronic criteria concentrations will suffer acute and chronic toxic effects including mortality (moderate intensity, for chromium III, and low intensity for chromium VI) and reduced growth (moderately-high-intensity, for chromium III and chromium VI)."

"In summary, the available evidence for saltwater chromium (VI) indicates that listed species exposed to waters equal to the acute and chronic criteria concentrations will suffer



acute or chronic toxic effects including mortality (moderate intensity) and sublethal effects (moderately-high-intensity).”

### Swinomish Tribe Biological Evaluation

The Swinomish biological evaluation found that there would likely be indirect effects to prey species for ESA listed species in Washington from exposure to the freshwater chronic and saltwater acute and chronic chromium VI criteria (USEPA, 2022a). EPA also references previous Oregon and Idaho BiOps mentioned previously:

“EPA acknowledges that in the Oregon toxic consultation, NMFS determined some adverse effects from the acute chromium VI criteria were possible, but EPA defers to the more recent assessments in the Idaho consultation. Further, Chinook, steelhead, and bull trout exposure to the chromium VI at the criterion level in fresh waters of action area is unlikely due to the lack of current and anticipated sources of chromium VI.”

### Criteria Calculations

#### Freshwater Acute Chromium VI Criterion

The data used to derive the freshwater acute chromium VI criterion is presented in Table 23. New studies that met data acceptability requirements are presented in Table 24. Studies used in previous EPA derivations but not used in this derivation are found in Table 25. The proposed freshwater acute criterion for chromium VI was derived using 43 GMAVs. Calculation results are as follows:

FAV = 36.01

CMC = 18.01

**Acute criterion (total) = 18 µg/L (rounded to two significant digits)**

**Conversion factor (total to dissolved fraction) = 0.982**

**Acute criterion (dissolved) = 18.01 x 0.982 = 17.69 µg/L**

**Acute criterion (dissolved) = 18 µg/L (rounded to two significant digits)**

Table 23. Freshwater acute toxicity data used for criteria derivation.

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
1	28.94	Daphnia magna	23.07
		Daphnia pulex	36.3
2	29	Pseudosida ramosa	29
3	36.35	Simocephalus serrulatus	40.9
		Simocephalus vetulus	32.3
4	67.1	Gammarus pseudolimaeus	67.1
5	80.87	Ceriodaphnia reticulata	45.1
		Ceriodaphnia dubia	145
6	125	Thamnocephalus platyurus	125

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
7	170	Notodiaptomus conifer	170
8	177	Lecane papuana	177
9	300	Chironomus plumosus	300
10	456	Lampsilis siliquoidea	456
11	583	Amphipod	583
12	630	Hyalella azteca	630
13	650	Plumatella emarginata	650
14	919	Margaritifera falcata	919
15	1000	Culicoides furens	1000
16	1440	Pectinatella magnifica	1440
17	1560	Lophodella carteri	1560
18	2841	Bryocamptus zschokkei	1850
		Bryocamptus pygmaeus	3480
		Bryocamptus minutus	3560
19	3516	Tubifex tubifex	3516
20	3820	Attheyella crassa	3820
21	4000	Salmo salar	4000
22	23010	Physa heterostropha	23010
23	30450	Morone saxatilis	30450
24	32000	Xyrauchen texanus	32000
25	36300	Perca flavescens	36300
26	38000	Culex quinquefasciatus	38000
27	46000	Etheostoma nigrum	46000
28	47180	Pimephales notatus	54225
		Pimephales promelas	41050
29	49600	Ericymba buccata	49600
30	51250	Campostoma anomalum	51250
31	57300	Tanytarsus dissimilis	57300
32	59000	Salvelinus fontinalis	59000
33	61000	Chironomus tentans	61000
34	66000	Ptychocheilus Lucius	66000
35	67610	Notropis atherinoides	48400
		Notropis chrysocephalus	85600
		Notropis stramineus	74600
36	69000	Oncorhynchus mykiss	69000
37	72600	Promoxis annularis	72600
38	81000	Gila elegans	81000
39	123500	Lepomis cyanellus	114700
		Lepomis macrochirus	132900
40	140000	Enallagma aspersum	140000

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
41	151950	Gambusia affinis	151950
42	176000	Orconectes rusticus	176000
43	1870000	Neophasganophora capitata	1870000

Table 24. New freshwater acute studies that met data acceptability requirements since EPA last updated chromium VI criteria (S = static, R = static renewal, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L)	Used in Derivation?	Reference
<b>Ceriodaphnia dubia</b>	S, M	145	Yes.	Baral et al. 2006
<b>Ceriodaphnia dubia</b>	S, U	81.11	No. Other studies using the same species measured test concentrations.	Hockett 1996
<b>Pimephales promelas</b>	S, M	22464	No. FT, M available.	Baral et al. 2006
<b>Gambusia affinis</b>	R, U	151950	Yes.	Begum et al. 2006
<b>Tubifex tubifex</b>	S, U	2910	Yes.	Fargasova 1999
<b>Notodiaptomus conifer</b>	S, U	170	Yes.	Gutierrez et al. 2010
<b>Lecane hamata</b>	S, U	4410	No. LC50 10x higher than other species within genus.	Perez-Legaspi & Rico-Martinez 2001
<b>Lecane luna</b>	S, U	3260	No. LC50 10x higher than other species within genus.	Perez-Legaspi & Rico-Martinez 2001
<b>Lecane quadridentata</b>	S, U	4500	No. LC50 10x higher than other species within genus.	Perez-Legaspi & Rico-Martinez 2001
<b>Culex quinquefasciatus</b>	S, U	38000	Yes.	Sorenson et al. 2006
<b>Salmo salar</b>	R, M	4000	Yes.	Grande 1983
<b>Thamnocephalus platyurus</b>	S, U	125	Yes.	Centeno et al. 1995
<b>Chironomus plumosus</b>	S, U	300	Yes.	Vedamanikan & Shazilli 2008
<b>Culicoides furens</b>	S, U	1000	Yes.	Vedamanikan & Shazilli 2008
<b>Ptychocheilus lucius</b>	S, U	66000	Yes.	Buhl 1997
<b>Gila elegans</b>	S, U	81000	Yes.	Buhl 1997
<b>Xyrauchen texanus</b>	S, U	32000	Yes.	Buhl 1997

Species	Method	LC50 (µg/L)	Used in Derivation?	Reference
<b>Bryocamptus pygmaeus</b>	R, U	3480	Yes.	Di Marzio et al. 2009
<b>Bryocamptus minutus</b>	R, U	3560	Yes.	Di Marzio et al. 2009
<b>Bryocamptus zschokkei</b>	R, U	1850	Yes.	Di Marzio et al. 2009
<b>Attheyella crassa</b>	R, U	3820	Yes.	Di Marzio et al. 2009
<b>Tubifex tubifex</b>	S, U	5490	Yes.	Maestre et al. 2009
<b>Oncorhynchus mykiss</b>	R, U	12300	No. Other studies used flow-through design using the same species.	Kazlauskiene 1994
<b>Tubifex tubifex</b>	S, U	2720	Yes.	Rathore et al. 2002
<b>Pseudosida ramosa</b>	S, U	29	Yes.	Freitas & Rocha 2013
<b>Lecane papuana</b>	S, M	177	Yes.	Garza-Leon et al. 2021
<b>Lampsilis siliquoidea</b>	R, M	456	Yes.	Wang et al. 2017
<b>Margaritifera falcata</b>	R, M	919	Yes.	Wang et al. 2017

Table 25. Freshwater acute studies not used from previous EPA derivations.

Species	LC50 (µg/L)	Reason	Reference
<b>Poecilia reticulata</b>	30000	Non-North American species	USEPA, 1996
<b>Carassius auratus</b>	19500	Non-North American species	USEPA, 1996

### Freshwater Chronic Chromium VI Criterion

There was inadequate freshwater chronic chromium VI data to calculate criteria using the eight-family method. The ACR of 2.917 was previously used to calculate the freshwater chronic chromium VI criterion as presented in 1995 updates to aquatic life (USEPA, 1996). Additional chronic chromium VI ACRs were available since last EPA updates (Table 26). The newly calculated ACR used to derive the chronic chromium VI criteria is 7.691. Calculation results are as follows:

FAV = 36.01

FACR = 7.691

CCC = 4.682 µg/L

**Chronic criterion (total) = 4.7 µg/L (rounded to two significant digits)**

**Conversion factor (total to dissolved fraction) = 0.962**

**Chronic criterion (dissolved) = 4.682 x 0.962 = 4.5 µg/L (rounded to two significant digits)**

Table 26. Acute to chronic ratios (ACR) used in chronic criterion derivation.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Daphnia pulex</b>			5.92	5.92	1996 EPA doc
<b>Simocephalus vetulus</b>			5.267	5.267	1996 EPA doc
<b>Simocephalus serrulatus</b>			2.055	2.055	1996 EPA doc
<b>Ceriodaphnia reticulata</b>			1.13	1.13	1996 EPA doc
<b>Pimephales promelas</b>			18.55 <sup>A</sup>	18.55 <sup>A</sup>	1996 EPA doc
<b>Daphnia carinata</b>	423	71	5.96	5.96	Hickey 1989
<b>Daphnia magna</b>	224	50	4.48		Hickey 1989
<b>Daphnia magna</b>	290	17.7	16.4	8.572	Diamantino et al. 2000

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Ceriodaphnia dubia</b>	53	5	10.6	10.6	Hickey 1989
<b>Notodiaptomus conifer</b>	170	5.30	32.06	32.06	Gutierrez et al. 2010
<b>Hypsiboas pulchellus</b>	29600	1732	17.09	17.09	Natale et al. 2006
<b>Pseudosida ramosa</b>	29	1.73	16.74	16.74	Frietas and Rocha 2013
<b>Lecane papuana</b>	177	62.58	2.83	2.83	Garza-Leon et al. 2021
<b>Lampsilis siliquoidea</b>	456	26.15	17.44	17.44	Wang et al. 2017
<b>Geometric mean</b>				7.691	

\* Geometric mean of ACRs were calculated for similar species preceding the final acute chronic ratio calculation

<sup>A</sup> Previously excluded in 1995 update because was 10x greater than other species but new studies suggest it is within an acceptable range for inclusion into FACR calculations.

### Saltwater Acute and Chronic Chromium VI Criteria

No changes are proposed to the saltwater acute and chronic chromium VI criteria. Washington’s current saltwater chromium VI criteria are identical to EPA recommendations, and there are no known ESA consultation issues in other Region 10 states.

## Copper

### Summary of Criteria Recommendations and Changes

Washington’s current rules have freshwater copper criteria based on hardness (Table 27). EPA recommends freshwater copper criteria using a model-based approach called the biotic ligand model (BLM) which is dependent on 12 different water quality inputs to determine the bioavailable fraction of copper. Washington proposes to use a different model-based approach for freshwater copper criteria using a multiple linear regression (MLR) model. Conceptually, this approach is simply a refinement of the current hardness-based approach, but considers three water quality parameters (hardness, pH, and dissolved organic carbon) compared to one. The MLR model is presented as a regression equation that uses water body specific inputs to calculate criteria. The copper MLR model has been published in the scientific literature. Furthermore, EPA has indicated that they are moving towards MLR based models for metals criteria in their Cooperative Research and Development Agreement (CRADA) project. Given the lack of data for the 12 parameters needed to run the BLM model throughout Washington, we propose using the copper MLR model for which we have adequate water quality information to develop default values. We propose a default freshwater copper acute criterion of 2.0 µg/L for western Washington and 2.5 µg/L for eastern Washington (boundaries for eastern and western are defined in the methodology below and in WAC 222-16-010). The freshwater default chronic copper criterion is 1.6 µg/L for western Washington and 1.8 µg/L for eastern Washington.

These default criteria are based on the 5<sup>th</sup> percentile of the MLR criteria for the respective west and east boundaries (Table 27). Criteria calculated using concurrently sampled pH, hardness, and DOC for a specific water body supersede the default criteria, regardless of whether the default criteria are higher or lower.

Table 27. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic copper criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	Hardness-based (1-hour)	Hardness-based (4-day)	4.8 (1-hour)	3.1 (4-day)
<b>EPA</b>	Biotic Ligand Model (1-hour)	Biotic Ligand Model (4-day)	4.8 (1-hour)	3.1 (4-day)
<b>Proposed</b>	West: 2.0 <sup>#</sup> East: 2.5 <sup>#</sup> (Multiple Linear Regression Model; 1-hour)	West: 1.6 <sup>#</sup> East: 1.8 <sup>#</sup> (Multiple Linear Regression Model; 4-day)	No change	No change

<sup>#</sup> Represent 5<sup>th</sup> percentile default criteria values. The boundary between east and west designations is defined in WAC 222-16-010.

### Copper MLR vs Copper BLM Models

The copper MLR offers several advantages compared with the BLM. EPA highlights these points in the aluminum MLR technical document (USEPA, 2018):

“The EPA decided to use an empirical MLR approach in this aluminum criteria update rather than a BLM model due to: 1) the relative simplicity and transparency of the model, 2) the relative similarity to the available BLM model outputs, and 3) the decreased number of input data on water chemistry needed to derive criteria at different sites.”

The copper MLR model is relatively new in that it was published in 2017 (Brix et al. 2017). EPA’s CRADA project aim is to develop a simplified modeling frameworks for predicting the bioavailability of metals. This translates to developing MLR models for other metals in the future ([Metals CRADA Phase 1 Report | US EPA<sup>5</sup>](#)). Comparisons between the performance of MLR and BLM copper models have been completed. In an updated version of the copper MLR model, Brix et al. (2021) found performance between the two models were generally comparable. Brix et al. (2021) noted differences in performance on a species-specific basis and differences in criteria depending on water chemistry.

In an analysis to evaluate community protection levels by the copper MLR model, Mebane et al. (2023) compared the MLR-based chronic criteria from Brix et al. (2021) to an independently

<sup>5</sup> <https://www.epa.gov/wqc/metals-crada-phase-1-report>



compiled chronic criteria dataset and concluded the Brix et al. (2021) copper MLR model generated criteria protective of the 95<sup>th</sup> percentile level as intended by EPA's 1985 guidelines for deriving aquatic life toxics criteria. Mebane et al. (2023) also compared the MLR-based chronic copper criterion with field and experimental ecosystem studies with copper and found the MLR-based criteria were largely protective and performed better than the hardness-based or BLM-based criteria. Mebane et al. (2023) concludes:

“Considering the state of the science, model performance, water quality goals to protect freshwater environments, USEPA policy directions, transparency, and simplicity, the MLR is the best candidate model presently available for statewide criteria updates.”

## Criteria Calculations

### Methodology for Default Criteria

The default criteria were calculated using concurrently sampled pH, hardness, and dissolved organic carbon data from Washington's EIM database and the federal WQ Portal. Data from EIM and the federal WQ Portal were downloaded in March 2023. We also examined concurrently sampled total organic carbon (TOC), hardness, and pH as well as conductivity, pH, and DOC. We calculated conversion factors to translate TOC to DOC and conductivity to hardness as detailed below.

The data qualifiers and management decisions are presented in Appendix B. Data were reviewed for quality with respects to the intended use of the aquatic life toxics rulemaking. We reviewed sampling locations, the study purpose, outlier values and units, reported QA levels, and field collection comments. Records not meeting the intended use of the aquatic life toxics rulemaking were removed. The final count of concurrent samples was 3,337 events across 646 unique locations (Figure 1). Each of the 3,337 concurrent samples were entered into the MLR-based copper equation.

We then compiled the 3,337 calculated criteria values for waterbodies throughout the state and calculated the 5<sup>th</sup> percentile of those 3,337 different criteria to be representative of the default criteria. The 5<sup>th</sup> percentile of the criteria distribution represents conservative criteria values that are intended to protect the majority of waters with regulated discharge of copper. We considered ecoregional default values (e.g., EPA level III ecoregions), but we had limited geospatial representation in some ecoregions and therefore developed default values for western and eastern Washington. Eastern and western Washington is defined by definitions in WAC 222-16-010 (Figure 2). More specifically, "**Eastern Washington**" means the geographic area in Washington east of the crest of the Cascade Mountains from the international border to the top of Mt. Adams, then east of the ridge line dividing the White Salmon River drainage from the Lewis River drainage and east of the ridge line dividing the Little White Salmon River drainage from the Wind River drainage to the Washington-Oregon state line. "**Western Washington**" means the geographic area of Washington west of the Cascade crest and the drainages defined in Eastern Washington. We had 367 unique sample locations with 2,210 samples in western Washington and 279 unique locations with 1,127 samples in eastern Washington.

A 5<sup>th</sup> percentile default criteria was used to provide protection of all aquatic species. Washington developed west and east default values due to limited dispersion of concurrent sampling sites throughout the state that precluded the ability to develop ecoregional or watershed specific default criteria values. A 5<sup>th</sup> percentile default criteria is appropriate because individual ecoregions and watershed water chemistry are not accounted for using a default value but rather becomes integrated into the dataset. The 5<sup>th</sup> percentile default value is more protective of waters with higher bioavailability of copper.

The default acute copper criteria of 2.0 (west) and 2.5 (east) ug/L are similar to the calculated CMC (i.e., acute criterion) of 2.3 ug/L presented in the copper BLM technical support document and the most sensitive SMAV of 2.37 ug/L for *Daphnia pulicaria* (USEPA, 2007) under normalized BLM conditions: temperature = 20°C, pH = 7.5, DOC = 0.5 mg/L, Ca = 14.0 mg/L, Mg = 12.1 mg/L, Na = 26.3 mg/L, K = 2.1 mg/L, SO<sub>4</sub> = 81.4 mg/L, Cl = 1.90 mg/L, Alkalinity = 65.0 mg/L and S = 0.0003 mg/L. The calculated CCC (i.e., chronic criterion) in the copper BLM technical support document was 1.45 ug/L (under normalized BLM conditions; USEPA, 2007), which was similar to the 5<sup>th</sup> percentile default value proposed of 1.6 (west) and 1.8 (east) ug/L. Ultimately, protective levels of copper are dictated by water quality conditions and are subject to site-specific conditions, making direct comparisons difficult between BLM and MLR calculated criteria.

Permittees will have the opportunity to collect their own site-specific chemistry data to calculate site-specific criteria that may afford higher criteria values than the 5<sup>th</sup> percentile default criteria. If site-specific criteria are less than the 5<sup>th</sup> percentile default criteria, permittees will need to use the site-specific information to determine effluent limits.

## Conversion Factors

### Total Organic Carbon to Dissolved Organic Carbon

We also examined instances where we had concurrently sampled total organic carbon (TOC), hardness, and pH since 2000 to add additional sampling events and increase representation of water bodies throughout the state. We developed a conversion factor to translate TOC to DOC. We downloaded all concurrently sampled TOC and DOC data as of May 2023 and calculated the ratio of DOC to TOC or the proportion of TOC that is DOC. For the TOC conversion factor, we used the 10<sup>th</sup> percentile of all ratios for statewide data. We used a conservative value (i.e., 10<sup>th</sup> percentile) because it results in more protective criteria (i.e., the lower the DOC concentration the lower the criteria value) and the goal of default criteria are to be protective of the majority of state waters. When we converted TOC to DOC, 105 sampling events were added to our MLR dataset (105 sample events out of the total 3,337 total sampling events). The statewide conversion factor based on the 10<sup>th</sup> percentile of the ratio of DOC to TOC is 0.81 (see example below). The TOC to DOC conversion factor is similar to Oregon's conversion factor of 0.83 (ODEQ, 2021), the EPA national value of 0.86 (USEPA, 2007), and Massachusetts value of 0.86 (MassDEP, 2021).

Example:

TOC = 10 mg/L

DOC = 10 mg/L x 0.81 = 8.1 mg/L

## Conductivity to Hardness

We also examined instances where we had concurrently sampled conductivity, hardness, and pH since 2000 to add additional sampling events and increase representation of water bodies throughout the state. We developed a conversion factor to translate conductivity to hardness (Figure 4). We downloaded all the concurrently sampled conductivity and hardness measurements data in August 2023. For the specific conductance versus hardness dataset, we first took the natural log of the values before developing a linear regression model between the two variables to improve model fit. The natural-log transformed data were used to establish the conversion equation used to estimate total hardness from conductivity. When we converted conductivity to hardness 910 sampling events were added to our MLR dataset (910 sample events out of the total 3,337 total sampling events). The linear regression equation that was used to convert conductivity to hardness is as follows:

$$\text{LN}(\text{Hardness}) = 1.0108 * \text{LN}(\text{conductivity}) - 0.9233$$

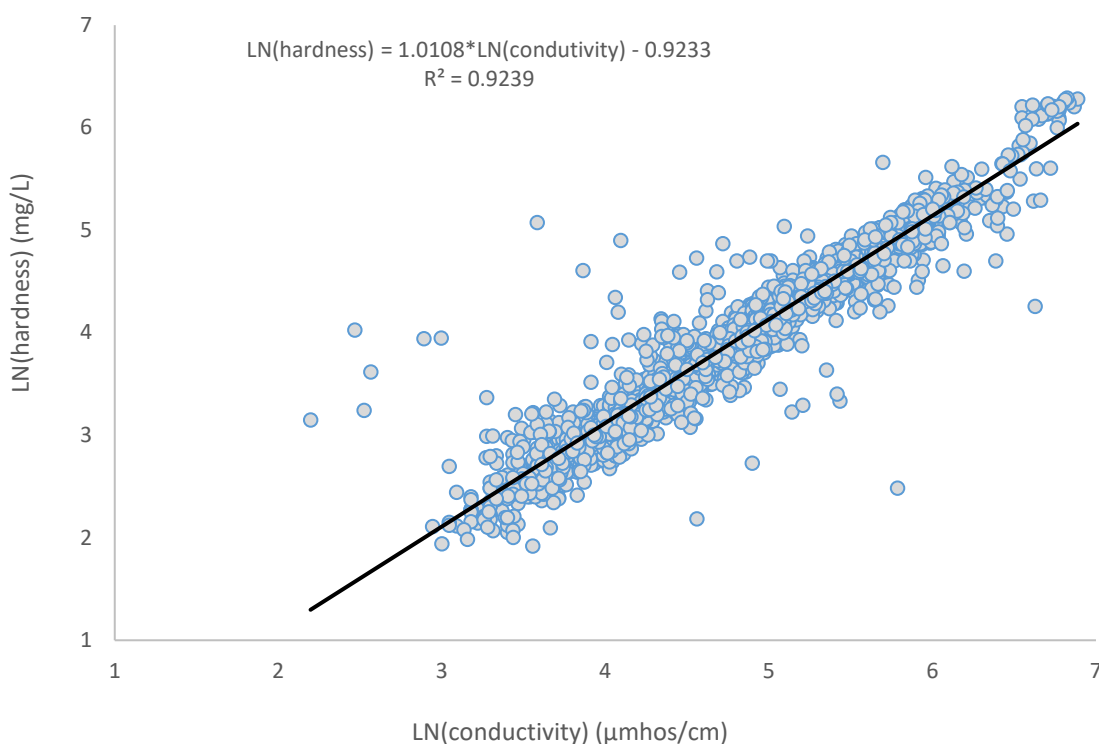


Figure 4. Relationship between hardness and conductivity (in micromhos per centimeter (µmhos/cm) for concurrent sampling throughout Washington.

## Default Criteria

The default freshwater acute copper criterion is 2.0 µg/L for western Washington and 2.5 µg/L for eastern Washington. The default chronic copper criterion is 1.6 µg/L for western Washington and 1.8 µg/L for eastern Washington. The default criteria are based on data concurrently sampled in Ecology's EIM database and the federal WQ Portal. If site-specific water quality information exists for a water body, that information must be used to develop

site-specific copper criteria. In the absence of site-specific water chemistry data, the default copper criteria apply.

### Freshwater Acute Copper Criteria

The freshwater acute copper criterion is represented by the higher value calculated from the two equations:

Equation 1) Acute criteria (empirical) =  $e^{(0.700 \cdot \ln(\text{DOC}) + 0.579 \cdot \ln(\text{hardness}) + 0.778 \cdot \text{pH} - 6.738)}$ , and

Equation 2) Acute criteria (reverse ACR) =  $e^{(0.855 \cdot \ln(\text{DOC}) + 0.221 \cdot \ln(\text{hardness}) + 0.216 \cdot \text{pH} - 1.183)}$ .

Equation 1 represents the acute copper MLR model presented in Brix et al. 2021. Equation 2 represents a reverse ACR based equation in which the ACR of 2.49 is applied to the chronic copper MLR model presented in Brix et al. 2021. The reverse ACR based equation is calculated by application of the ACR to the chronic criterion followed by division by two to be consistent with EPA methods for CMC calculations.

This approach was necessary because at low hardness and low DOC, low pH and low DOC, and high DOC and low hardness, the acute empirical model generates criteria lower than the chronic empirical model (examples presented in Figure 5). This is due to differences in the DOC, hardness, and pH slopes in the empirical acute model versus the empirical chronic model. To resolve these slope related issues, we developed rule language that uses the empirical acute model to the intersection of the acute empirical model and the applications of the reverse ACR based model at which point the reverse ACR based model becomes applicable (red dotted line in Figure 6). In other words, the applicable model for the acute criterion is whichever acute model is higher (the empirical based model or the reverse ACR based model). This method ensures the acute criterion is always greater than the chronic criteria. This concept is discussed in an upcoming publication (Brix et al. in prep).

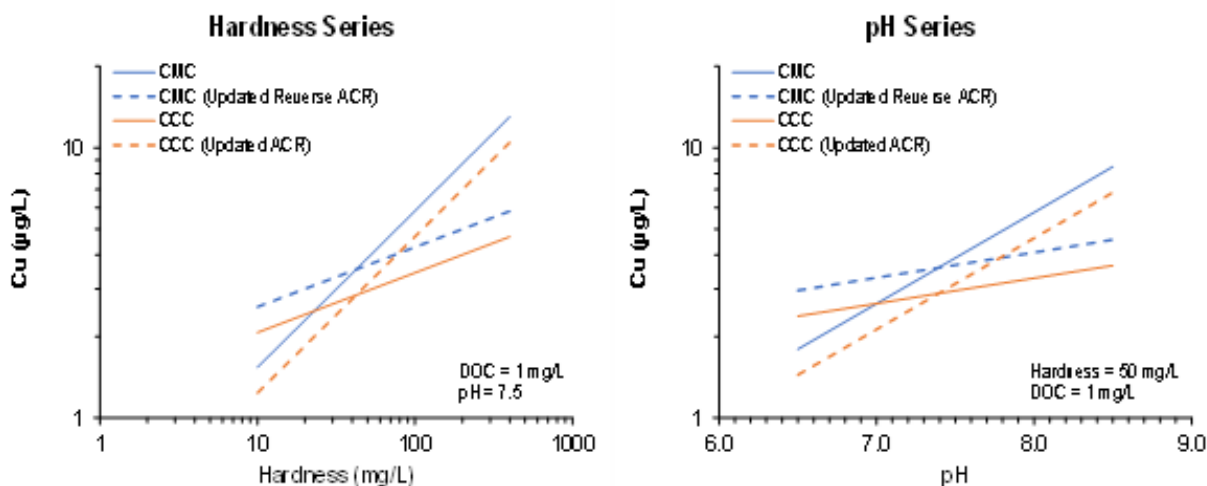


Figure 5. Demonstration of how the empirical based models (CMC and CCC), updated ACR, and the reverse ACR models function at different pH, hardness, and dissolved organic carbon levels.

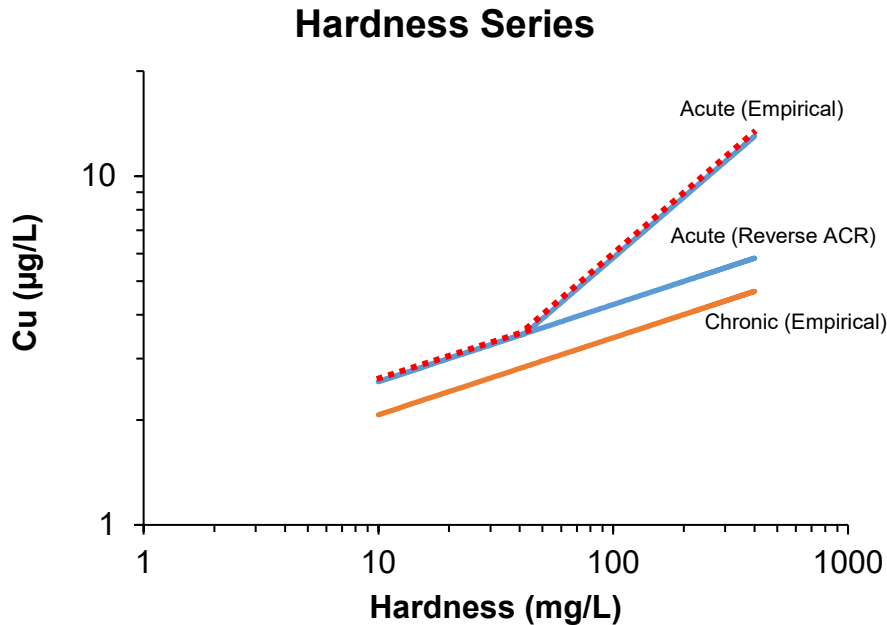


Figure 6. Depiction of how the acute MLR models functions in relation to the chronic MLR model. The proposed copper acute copper criterion states two separate equations, whichever is greater. Equation 1 represents the empirical acute based MLR model, while equation 2 represents the reverse ACR based model. The red dotted line depicts how the acute MLR model functions on the basis of these two models.

Table 28. Acute to chronic ratios used in the development of the copper multiple linear regression equation that are representative of data presented in Brix et al. 2021.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Ceriodaphnia dubia</b>	28.42	7.90	3.60		Belanger et al. 1989
	63.33	19.36	3.27		Belanger et al. 1989
	17.97	9.17	1.96		Carlson et al. 1986
	25	12	2.1		Wang et al. 2011
	157	40	3.9		Wang et al. 2011
	267	41	6.5	3.27	Wang et al. 2011
<b>Cottus bairdii</b>	83	29.35	2.8	2.80	Besser et al. 2007
<b>Daphnia magna</b>	26	12.58	2.07		Chapman et al. Manuscript
	33.76	19.89	1.7		Chapman et al. Manuscript

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
	69	6.06	11.39		Chapman et al. Manuscript
	10.1	8.6	1.2		Villavicencio et al. 2011
	9.9	7.9	1.3		Villavicencio et al. 2011
	22.7	11.5	2.0		Villavicencio et al. 2011
	13.2	8.6	1.5		Villavicencio et al. 2011
	10.7	9.7	1.1		Villavicencio et al. 2011
	5.9	5.4	1.1		Villavicencio et al. 2011
	13.3	12.1	1.1		Villavicencio et al. 2011
	22.4	10.5	2.1		Villavicencio et al. 2011
	16.9	10.5	1.6		Villavicencio et al. 2011
	12	6.3	1.9		Villavicencio et al. 2011
	28	9.3	3.0		Villavicencio et al. 2011
	30.2	16	1.9		Villavicencio et al. 2011
	15.9	14.3	1.1		Villavicencio et al. 2011
	27.4	13.4	2.0		Villavicencio et al. 2011
	64.4	29.8	2.2		Villavicencio et al. 2011
	36.8	3.2	11.5		Villavicencio et al. 2011
	40.9	8.8	4.6	2.08	Villavicencio et al. 2011
<b>Daphnia pulex</b>	25.74	2.83	9.1		Winner 1985
	27.6	7.07	3.9		Winner 1985
	28.8	9.16	3.14	4.80	Winner 1985
<b>Oncorhynchus mykiss</b>	80	27.77	2.88		Seim et al. 1984
	58	40	1.5		Besser et al. 2007
	8.9	5.2	1.7		Cremazy et al. 2017
	12.7	6.6	1.9		Cremazy et al. 2017
	19.7	5	3.9		Cremazy et al. 2017
	5.9	5.5	1.1		Cremazy et al. 2017

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
	8.5	8.2	1.0		Cremazy et al. 2017
	41.3	33	1.3		Cremazy et al. 2017
	139.2	99	1.4		Cremazy et al. 2017
<b>Oncorhynchus tshawytscha</b>	33.1	5.92	5.59	5.59	Chapman 1975, 1982
<b>Salvelinus fontinalis</b>	198.7	141.0	1.4	1.40	Hansen et al. 2000, 2002
<b>Villosa iris</b>	15	10	1.5		Wang et al. 2011
	32	8.8	3.6		Wang et al. 2011
	72	38	1.9	2.20	Wang et al. 2011
<b>Cyprinodon variegatus</b>	368	249	1.48	1.48	Hughes et al. 1989
<b>Geometric mean</b>				2.49	

Table 29. Acute to chronic ratios not used for copper.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Reason not used	Reference
<b>Ceriodaphnia dubia</b>	18	12	15	ACR is approximately 5 times greater than other ACRs for this species	Besser et al. 2007
<b>Daphnia magna</b>	8.8	9.2	0.96	ACR is <1	Villavicencio et al. 2011
<b>Daphnia magna</b>	3.6	8.5	0.42	ACR is <1	Villavicencio et al. 2011
<b>Daphnia magna</b>	3.1	10.2	0.30	ACR is <1	Villavicencio et al. 2011

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Reason not used	Reference
<b>Lymnaea stagnalis</b>	20	1.8	11.1	ACR species mean is approximately 10x greater than lowest species mean ACR	Brix et al. 2011
<b>Oncorhynchus mykiss</b>	29	31	0.94	ACR is <1	Cremazy et al. 2017
<b>Oncorhynchus mykiss</b>	46	49	0.94	ACR is <1	Cremazy et al. 2017
<b>Oncorhynchus mykiss</b>	12.7	16	0.79	ACR is <1	Cremazy et al. 2017
<b>Oncorhynchus mykiss</b>	6.7	18	0.37	ACR is <1	Cremazy et al. 2017
<b>Pimephales promelas</b>	88.3	5.1	17.3	ACR approximately 10x greater than lowest species mean ACR	Spehar and Fiandt, 1986

### Freshwater Chronic Copper Criteria

The copper MLR based equation was used to calculate the default copper criteria and can be used to determine site-specific chronic criteria (Brix et al. 2021). The equation is as follows:

$$\text{Chronic criteria} = e^{(0.855 \cdot \ln(\text{DOC}) + 0.221 \cdot \ln(\text{hardness}) + 0.216 \cdot \text{pH} - 1.402)}$$

### Saltwater Acute and Chronic Copper Criteria

No changes are proposed to the saltwater acute and chronic copper criteria. Washington’s current saltwater copper criteria are identical to EPA recommendations, and there are no known ESA consultation issues in other Region 10 states.

## Iron

### Summary of Criteria Recommendations and Changes

We propose to not adopt EPA recommended freshwater chronic iron criterion (Table 30). The EPA iron criterion does not meet the minimum data requirements for the eight-family method or alternative methods. The EPA iron criterion of 1000 µg/L is based on few field studies outlined in an EPA document from 1976 (USEPA, 1976) and does not follow EPA 1985 guidelines (Stephan et al. 1985). Furthermore, it is difficult to develop statewide iron criteria because of



the variable natural iron concentrations in water bodies throughout Washington. Washington will continue to use their narrative criteria to protect against toxic and aesthetic effects of iron.

Table 30. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic iron criteria with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	1000	-	-
<b>Proposed</b>	-	-	-	-

## Lead

### Summary of Criteria Recommendations and Changes

Washington’s freshwater and saltwater lead criteria are identical to EPA’s recommendations (Table 31). There were LAA determinations for freshwater acute and chronic lead criteria in Oregon for bull trout but there were no jeopardy calls. The new science and 1<sup>st</sup> percentile resulted in higher freshwater criteria values than EPA recommendations. Therefore, we propose no changes to Washington’s freshwater and saltwater lead criteria.

Table 31. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic lead criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	65* <sup>^</sup> (1-hour)	2.5* <sup>^</sup> (4-day)	210 <sup>^</sup> (1-hour)	8.1 <sup>^</sup> (4-day)
<b>EPA</b>	65* <sup>^</sup> (1-hour)	2.5* <sup>^</sup> (4-day)	210 <sup>^</sup> (1-hour)	8.1 <sup>^</sup> (4-day)
<b>Proposed</b>	No change	No change	No change	No change

\* Hardness based criteria (numeric value shown based on 100 mg/L)

<sup>^</sup> Presented as the dissolved fraction

## Mercury

### Summary of Criteria Recommendations and Changes

The only action for mercury criteria proposed is the adoption of the mercury freshwater acute criterion recommended by EPA (Table 32). EPA recommendations for mercury freshwater and saltwater chronic criteria are significantly higher than Washington’s criteria. Idaho’s mercury freshwater chronic criterion received a jeopardy call and was identical to Washington’s current criteria. EPA has indicated that they are working on updating their aquatic life toxics national

recommendations for mercury. We have decided to wait until EPA’s new recommendations to revise chronic criteria for mercury.

Table 32. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic mercury criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	2.1* (1-hour)	0.012^ (4-day)	1.8* (1-hour)	0.025^ (4-day)
<b>EPA</b>	1.4* (1-hour)	0.77* (4-day)	1.8* (1-hour)	0.94* (4-day)
<b>Proposed</b>	1.4* (1-hour)	No change	No change	No change

\* Presented as dissolved fraction

^ Presented as total recoverable fraction

## Endangered Species Act Consultation

### Idaho

There was a jeopardy call in the Idaho USFWS BiOp for the freshwater mercury chronic criterion of 0.012 µg/L (USFWS, 2015). The Idaho USFWS BiOp specifically states:

“The common occurrence of mercury tissue concentrations in the tissue of fish exceeding a threshold concentration for reproductive or neurologic harm considered applicable to bull trout (0.3 mg/kg ww) while water concentrations of mercury were considerably less than the proposed 12 ng/L chronic aquatic life criterion indicates that the proposed chronic criterion would not be sufficient to protect all fish species. As no species-specific information were available for bull trout, we consider this general “fish: endpoint to apply to bull trout as well.”

“Based on the above information, implementation of the proposed chronic criterion for mercury is likely to adversely affect growth, reproduction, and behavior in the bull trout throughout its distribution in Idaho. Considering that the state of Idaho harbors 44 percent of all streams and 34 percent of all lakes and reservoirs occupied by the bull trout rangewide, these effects are considered to be significant. These effects are likely to impede (1) maintaining/increasing the current distribution of the bull trout, (2) maintaining/increasing the current abundance of the bull trout, and (3) achieving stable/increasing trends in bull trout populations.”

## Nickel

### Summary of Criteria Recommendations and Changes

The proposed freshwater nickel criteria accounts for endangered species protection levels by incorporating new science available since EPA last updated the freshwater criteria in 1995

(Table 33; USEPA, 1996). The proposed freshwater nickel criteria are more stringent than EPA recommendations. Although jeopardy calls were specific to the freshwater chronic criterion for species relevant to Washington, new science was used to update the freshwater acute criterion. The freshwater chronic criterion is dependent on the acute criterion because it uses an ACR to derive the criterion value. Furthermore, we decided it was necessary to incorporate the new science for nickel because of the abundance of new data that demonstrates there are more sensitive species than previously used in the 1995 derivation (USEPA, 1996). No changes were necessary for saltwater criteria because Washington’s saltwater nickel criteria are identical to EPA recommendations and there are no endangered species protection issues highlighted in previous ESA consultations in other Region 10 states.

Table 33. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic nickel criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	1415* <sup>^</sup> (1-hour)	157* <sup>^</sup> (4-day)	74 <sup>^</sup> (1-hour)	8.2 <sup>^</sup> (4-day)
<b>EPA</b>	470* (1-hour)	52* (4-day)	74 <sup>^</sup> (1-hour)	8.2 <sup>^</sup> (4-day)
<b>Proposed</b>	34* <sup>^</sup> (1-hour)	5.6* <sup>^</sup> (4-day)	No change	No change

\* Hardness based criteria (numeric value shown based on 100 mg/L)

<sup>^</sup> Presented as the dissolved fraction

## Endangered Species Act Consultation

### Idaho

There were likely to adversely affect (LAA) determinations for ESA listed species for nickel in Idaho (NMFS, 2014; USFWS, 2015). However, no jeopardy calls were made for similarly listed species in Washington. The Idaho BiOps (NMFS, 2014; USFWS, 2015) specifically state:

“Based on the research results referenced above, the Service concludes that the proposed approval of the chronic aquatic life criteria for nickel is likely to adversely affect the bull trout via effects to one component (amphipods) of its prey base. Given the variety of prey species in the diet of the bull trout, this adverse effect is not likely to cause a significant adverse effect to the bull trout.”

“Based on the above analysis, the Service concludes that the proposed approval of the chronic aquatic life criterion for nickel is likely to adversely affect PCE 3 of bull trout critical habitat via effects to one component (amphipods) of its prey base. However, given the variety of prey species in the diet of the bull trout, this adverse effect is not likely to cause a significant adverse effect to the capability of bull trout critical habitat in Idaho to provide for an abundant prey base for the bull trout.”

## Oregon

There were likely to adversely affect (LAA) determinations for the nickel freshwater acute and chronic criteria to bull trout in Oregon. However, no jeopardy calls were made for similarly listed species in Washington. The Oregon BiOps (USFWS, 2012; NMFS, 2012) specifically state:

“Based on model results relying upon rainbow trout response data for exposure to nickel at the proposed chronic criterion concentration, we conclude that chronic exposure of bull trout to nickel at the proposed chronic standard is likely to kill up to 151 adult bull trout, and injure/reduce the fitness (via reduced growth) of up to 1,370 individual adult bull trout per 3- year period over the 25-year term of the proposed action in surface waters along 820.6 miles of bull trout habitat within the action area.”

“We are unable to quantify the exact number of bull trout eggs that may be affected as it is not possible to accurately inventory this life stage within the action area at this time. However, we assume that some small portion of eggs will be adversely affected every 3 years during the 25- year term of the proposed action along 260.8 miles of bull trout spawning and rearing habitat exposed to nickel concentrations at the proposed chronic criterion because modeling indicates a probable 7.9% of fecundity in bull trout when exposed at the proposed criterion.”

“In summary, a number of toxicity studies reported concentrations that are less than the acute criterion concentration for nickel, which implies that listed species exposed to waters equal to criteria concentrations will suffer acute toxic effects. Conversely, a number of toxicity studies reported concentrations that are greater than the acute and chronic criteria concentrations for nickel, which implies that listed species exposed to waters equal to criteria concentrations may not suffer acute or chronic toxic effects. When the available information is equivocal, NMFS gives the benefit of the doubt in its analysis to the listed species. Based on this principle and the considerations of the shortcomings and implications of laboratory-derived toxicity tests, the relative percent mortality analysis, and the ecological consequences for field-exposed fishes, listed species exposed to waters equal to the acute or chronic criteria concentrations will suffer acute toxic effects, but may not suffer chronic toxic effects.”

“Several studies have determined that mortality of salmonid embryos occurs over longer-term exposures to concentrations that are below the chronic criterion. For example, Birge *et al.* (1978) determined a 30-day LC50 for rainbow trout embryos of 50 µg/L at a water hardness between 93 mg/L and 105 mg/L. The corresponding lethal threshold (LC1) was estimated to be approximately 0.6 µg/L. Birge and Black (1980; as cited in Eisler 1998, hardness not reported) determined an LC10 of 11 µg/L for rainbow trout embryos exposed from fertilization through hatching. In Eisler’s (1998b) review, LC50s were reported of 60 µg/L and 90 µg/L at water hardness of 125 and 174 mg/L, respectively, for rainbow trout embryos that were exposed from fertilization through hatching. These results and the review by Birge *et al.* (1981) suggest that adverse effects are likely to occur to embryos exposed to nickel concentrations that are lower than the proposed chronic criterion.”

## Swinomish Tribe Biological Evaluation

EPA’s BE concluded that its proposed approval of the Swinomish Tribe’s adoption of EPA’s 1995 CWA recommendations for nickel is likely to adversely affect (LAA) for ESA listed species in Washington through indirect effects (USEPA, 2022a).

### Criteria Calculations

#### Freshwater Acute Nickel Criterion

The data used to derive the freshwater acute nickel criterion is presented in Table 34. New studies that met data acceptability requirements are presented in Table 35. Studies used in previous EPA derivations but not used in this derivation are found in Table 36. The proposed freshwater acute criterion for nickel was derived using 28 GMAVs. Calculation results are as follows:

$$FAV = 38.17 \text{ (hardness of 50 mg/L)}$$

$$CMC = 19.09 \text{ } \mu\text{g/L (hardness of 50 mg/L)}$$

$$CMC = e^{(0.846 \times \ln(\text{hardness}) - 0.3604)} \times CF$$

Where CF (conversion factor from total to dissolved fraction) = 0.998

Acute criterion (total) = 34.31  $\mu\text{g/L}$  (hardness of 100 mg/L)

Acute criterion (dissolved) = 34  $\mu\text{g/L}$  (hardness of 100 mg/L; rounded to two significant digits)

Table 34. Freshwater acute toxicity data used for criteria derivation reported as total recoverable nickel.

Rank	GMAV* ( $\mu\text{g/L}$ )	Species	SMAV* ( $\mu\text{g/L}$ )
1	29.05	Leptoxis ampla	29.05
2	58.32	Ceriodaphnia dubia	58.32
3	81.94	Neocloeon triangulifer	81.94
4	264.9	Somatogyrus sp.	264.9
5	275.5	Hamiota perovalis	275.5
6	335.6	Tubifex tubifex	335.6
7	385.4	Hyalella azteca	385.4
8	416	Physa gyrina	416
9	448.9	Villosa nebulosa	448.9
10	1089	Daphnia publicaria	2042
		Daphnia magna	1033
		Daphnia pulex	612
11	4312	Ambloplites rupestris	4312
12	4636	Ephemerella subvaria	4636
13	6163	Danio rerio	6163
14	6707	Pimephales promelas	6707
15	8697	Morone americana	12790

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
		Morone saxatilis	5914
<b>16</b>	12180	Anguilla rostrata	12180
<b>17</b>	12548	Oncorhynchus mykiss	12548
<b>18</b>	12756	Lepomis gibbosus	12756
<b>19</b>	12770	Amnicola sp.	12770
<b>20</b>	13000	Gammarus sp.	13000
<b>21</b>	14100	Nais sp.	14100
<b>22</b>	21200	Damselfly (unidentified sp.)	21200
<b>23</b>	30200	Caddisfly (unidentified sp.)	30200
<b>24</b>	40460	Acroneuria lycorias	40460
<b>25</b>	43231	Chironomus riparius Chironomus dilutes	32800 56979
<b>26</b>	43250	Fundulus diaphanus	43250
<b>27</b>	53915	Gambusia affinis	53915
<b>28</b>	66100	Crangonyx pseudogracilis	66100

\* Normalized to hardness of 50 mg/L

Table 35. New freshwater acute studies that met data acceptability requirements since EPA last updated nickel criteria (S = static, R = static renewal, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Pimephales promelas</b>	R, M	3928	106	2080	No. Other studies with the same species used flow-through design.	Lynch et al. 2016
<b>Neocloeon triangulifer</b>	S, M	147	100	81.94	Yes.	Soucek et al. 2020
<b>Hyalella azteca</b>	S, M	917.8	100	510.6	Yes.	Wang et al. 2020
<b>Hyalella azteca</b>	S, M	75.15	18	208.7	Yes.	Borgman et al. 2005
<b>Hyalella azteca</b>	S, M	133.3	124	53.73	Yes.	Borgman et al. 2005
<b>Oncorhynchus mykiss</b>	FT, M	20842	91	9724	Yes.	Brix et al. 2004
<b>Tubifex tubifex</b>	S, U	537	80	335.6	Yes.	Fargasova 1999
<b>Ceriodaphnia dubia</b>	S, M	81.16	50	81.16	Yes.	Keithly et al. 2004
<b>Ceriodaphnia dubia</b>	S, M	148.3	113	65.62	Yes.	Keithly et al. 2004
<b>Ceriodaphnia dubia</b>	S, M	261.5	161	81.22	Yes.	Keithly et al. 2004
<b>Ceriodaphnia dubia</b>	S, M	400.8	253	79.21	Yes.	Keithly et al. 2004
<b>Hyalella azteca</b>	S, M	3051	98	1557	Yes.	Keithly et al. 2004
<b>Ceriodaphnia dubia</b>	S, U	29.3	80	19.69	Yes.	Hockett et al. 1996
<b>Hyalella azteca</b>	S, M	2000	120	953.6	Yes.	Liber et al. 2011
<b>Chironomus dilutus</b>	S, M	119500	120	56978	Yes.	Liber et al. 2011

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Chironomus riparius</b>	S, M	79500	367.8	14696	Yes.	Powlesland 1986
<b>Gambusia affinis</b>	S, U	68000	60	53915	Yes.	Kallangoudar & Patil 1997
<b>Oncorhynchus mykiss</b>	R, U	1280	250	256	No. Other studies with same species used flow through design and measured concentrations.	Kazlausk et al. 1994
<b>Danio rerio</b>	R, M	13146	141	5469	Yes.	Alsop et al. 2011
<b>Danio rerio</b>	R, M	16694	141	6945	Yes.	Alsop et al. 2013
<b>Danio rerio</b>	R, M	>10000	142	>4132	No. Greater than value when other more definitive data exists.	Griffitt 2008
<b>Daphnia pulex</b>	R, M	1480	142	612	Yes.	Griffitt 2008
<b>Ceriodaphnia dubia</b>	R, M	19640	142		No. LC50 10x higher than other studies using the same species.	Griffitt 2008
<b>Daphnia magna</b>	S, M	1503	92.5	893.2	Yes.	Lari et al. 2017
<b>Hamiota perovalis</b>	R, U	313	43	275.5	Yes.	Gibson et al. 2018
<b>Villosa nebulosa</b>	R, U	510	43	448.9	Yes.	Gibson et al. 2018
<b>Leptoxis ampla</b>	R, U	33	43	29.05	Yes.	Gibson et al. 2018
<b>Somatogyrus sp.</b>	R, U	301	43	264.9	Yes.	Gibson et al. 2018

\* Normalized to a hardness of 50 mg/L



Table 36. Freshwater acute studies not used from previous EPA criteria derivations.

Species	SMAV *(µg/L)	Reason	Reference
<b>Poecilia reticulata</b>	9661	Non-North American species	USEPA, 1996
<b>Carassius auratus</b>	21320	Non-North American species	USEPA, 1996
<b>Cyprinus carpio</b>	9839	Non-North American species	USEPA, 1996

### Freshwater Chronic Nickel Criterion

There was inadequate freshwater chronic nickel data to calculate criteria using the eight-family method. The FACR of 17.99 was previously used to calculate the freshwater chronic nickel criterion as presented in 1995 updates to aquatic life (USEPA, 1996). Additional chronic nickel ACRs were available since EPA's last update. The newly calculated FACR used to derive the chronic nickel criterion is 12.29 (Table 37). Calculation results are as follows:

$$FAV = 38.17 \text{ (hardness of 50 mg/L)}$$

$$FACR = 12.29$$

$$CCC = 3.106 \text{ (hardness of 50 mg/L)}$$

$$CCC = e^{(0.846 \times \ln(\text{hardness}) - 2.176)} \times CF$$

Where CF (conversion factor from total to dissolved fraction) = 0.997

Chronic criterion (total) = 5.584 µg/L (hardness of 100 mg/L)

Chronic criterion (dissolved) = 5.6 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 37. Acute to chronic ratios (ACR) used in chronic criterion derivation.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Daphnia magna</b>	1800	14.77	122.4*		EPA 1986 doc
<b>Daphnia magna</b>	1920	123.1	15.60		EPA 1986 doc
<b>Daphnia magna</b>	4970	356.6	13.94	14.75	EPA 1986 doc
<b>Pimephales promelas</b>	27930	526.1	53.03		EPA 1986 doc
<b>Pimephales promelas</b>	5186	217.3	23.87	35.60	EPA 1986 doc
<b>Mysidopsis bahia</b>	508	92.74	5.478	5.478	EPA 1986 doc
<b>Ceriodaphnia dubia</b>	7.2	148	20.56		Keithly et al. 2004

Species	Acute Value (ug/L)	Chronic Value (ug/L)	ACR*	Species Mean ACR	Reference
<b>Ceriodaphnia dubia</b>	4.2	261	62.14		Keithly et al. 2004
<b>Ceriodaphnia dubia</b>	7.5	400	53.33	40.84	Keithly et al. 2004
<b>Neocloeon triangulifer</b>	8	147	18.38	18.38	Soucek et al. 2020
<b>Bufo terrestris</b>	0.77	2.984	3.875	3.875	Fort et al. 2006
<b>Gastrophyne carolinesis</b>	0.1131	1.149	10.16	10.16	Fort et al. 2006
<b>Geometric mean</b>				12.29	

\* Not used because varies significantly from other ACRs of the same species

### Saltwater Acute and Chronic Nickel Criteria

No changes are proposed to the saltwater acute and chronic nickel criteria. Washington’s current saltwater nickel criteria are identical to EPA recommendations, and there are no known ESA consultation issues in other Region 10 states.

## Selenium

### Summary of Criteria Recommendations and Changes

EPA updated their freshwater selenium criteria in 2016 that includes both fish tissue and water column elements (Table 38; USEPA, 2016b). Washington’s current selenium criteria are based on water column only exposures. EPA’s updated criteria are based on chronic exposure to selenium and are intended to protect the entire aquatic community. The new freshwater selenium criteria are based on levels of hierarchy by which particular types of fish tissue has precedent over other types of fish tissue, and fish tissue supersedes water column concentrations under steady state conditions. Further discussion on assumptions related to steady-state conditions are in the rulemaking [Draft Implementation Plan](#)<sup>6</sup>.

We propose to adopt EPA recommendations for freshwater selenium criteria and make no changes to Washington’s saltwater acute and chronic selenium criteria (Table 38). We made slight modifications to the EPA recommended footnotes for the selenium freshwater criteria but they are conceptually similar. We are not aware of endangered species concerns for Washington’s ESA-listed species related to EPA recommended criteria for selenium.

<sup>6</sup> <https://fortress.wa.gov/ecy/publications/summarypages/2410008.html>

Table 38. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic selenium criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute	FW Chronic	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	20 µg/L	5 µg/L	290	71
<b>EPA</b>	15.1 mg/kg dry weight (egg-ovary) <sup>1,2</sup> 8.5 mg/kg dry weight (whole-body) <sup>1,3</sup> 11.3 mg/kg dry weight (muscle) <sup>1,3</sup> 1.5 µg/L (lentic) <sup>4</sup> 3.1 µg/L (lotic) <sup>4</sup> $WQC_{int} = WQC_{30\text{-day}} - C_{bkgnd} (1 - f_{int}) / f_{int}$ <sup>4,5</sup>		290	71
<b>Proposed</b>	15.1 mg/kg dry weight (egg-ovary) <sup>1</sup> 8.5 mg/kg dry weight (whole-body) <sup>2</sup> 11.3 mg/kg dry weight (muscle) <sup>2</sup> 1.5 µg/L (lentic) <sup>3</sup> 3.1 µg/L (lotic) <sup>3</sup> $WQC_{int} = WQC - C_{bkgnd} (1 - f_{int}) / f_{int}$ <sup>3,4</sup>		No change	No change

<sup>1</sup> Egg-ovary supersedes any whole-body, muscle, or water column element when fish egg-ovary concentrations are measured, except as noted in footnote 3. Tissue criterion is not to be exceeded.

<sup>2</sup> Fish whole-body or muscle tissue supersedes the water column element when both fish tissue and water concentrations are measured, except as noted in footnote 3. Tissue criterion is not to be exceeded.

<sup>3</sup> Water column values are based on dissolved total selenium in water and are derived from fish tissue values via bioaccumulation modeling. When selenium inputs are increasing, water column values are the applicable criterion element in the absence of steady-state condition fish tissue data. Water column criteria are based on a 30-day average concentrations, except for  $WQC_{int}$  (see footnote 4). Water column criteria are not to be exceeded more than once every three years on average.

<sup>4</sup> Where  $WQC_{int}$  is the intermittent exposure concentration in µg/L; WQC is the applicable water column element, for either lentic or lotic waters;  $C_{bkgnd}$  is the average daily background concentration occurring during the remaining time, integrated over 30 days;  $f_{int}$  is the fraction of any 30-day period during which elevated selenium concentrations occur, with  $f_{int}$  assigned a value  $\geq 0.033$  (corresponding to one day). Intermittent exposure criteria averaging period is the number of days per month with an elevated concentration.

## Silver

### Summary of Criteria Recommendations and Changes

The proposed freshwater silver criteria accounts for endangered species protection levels by incorporating new science available since EPA last updated the criteria in 1980 (Table 39; USEPA, 1980). The proposed freshwater acute silver criterion is more stringent than EPA recommendations. EPA does not have a recommendation for a freshwater chronic silver criterion, but during our review of new science, we found adequate data available to calculate a

chronic criterion. We updated the saltwater acute silver criterion in order to calculate a saltwater chronic criterion using the newly established FACR.

Table 39. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic silver criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	3.4* <sup>^</sup> (1-hour)	-	1.9 <sup>^</sup> (instantaneous)	-
<b>EPA</b>	3.2* <sup>^</sup> (instantaneous)	-	1.9 <sup>^</sup> (instantaneous)	-
<b>Proposed</b>	0.52* <sup>^</sup> (1-hour)	0.21* <sup>^</sup> (4-day)	2.2 (1-hour)	0.87 (4-day)

\* Hardness based criteria (numeric value shown based on 100 mg/L)

<sup>^</sup> Presented as the dissolved fraction

## Endangered Species Act Consultation

### Oregon

There were likely to adversely affect (LAA) determinations for the silver freshwater acute (3.2 µg/L at 100 mg/L hardness) and chronic (0.10 µg/L at 100 mg/L hardness) criteria in Oregon (USFWS, 2012) for bull trout, a species that is also on Washington’s endangered species list. There was no jeopardy call. The Oregon BiOps specifically state:

“The available evidence for silver indicates that listed species exposed to waters equal to the acute or chronic criteria concentrations will suffer acute and chronic toxic effects including mortality (moderately-high-intensity), reduced growth (moderate intensity), and sublethal effects (moderate intensity).”

“Since the proposed acute standard is 72% less than the LC10 acute concentration for silver, we conclude that while some adverse effects may occur to the bull trout, these effects are likely to be sub-lethal and not cause a significant disruption of breeding, feeding, migrating, or sheltering behavior during each 3-year period during the 25-year term of the proposed action.”

“We conclude that bull trout exposure to the proposed chronic criterion concentration of silver is likely to cause mortality of 263 adult bull trout during each 3-year period over the 25-year term of the proposed action, and injure another 1,371 individual adult bull due to reduced growth and fitness each 3-year period over the 25-year term of the proposed action in surface waters along 820.6 miles of bull trout habitat within the action area.”

## Criteria Calculations

### Freshwater Acute Silver Criterion

The data used to derive the freshwater acute silver criterion is presented in Table 40. New studies that met data acceptability requirements are presented in Table 41. Studies used in

previous EPA derivations but not used in this derivation are found in Table 42. The proposed freshwater acute criterion for silver was derived using 20 GMAVs. Calculation results are as follows:

$$\text{FAV} = 0.3686 \text{ (hardness of 50 mg/L)}$$

$$\text{CMC} = 0.1843 \text{ } \mu\text{g/L (hardness of 50 mg/L)}$$

$$\text{CMC} = e^{(1.72 \times \ln(\text{hardness}) - 8.420)} \times \text{CF}$$

Where CF (conversion factor from total to dissolved fraction) = 0.85

Acute criterion (total) = 0.6071  $\mu\text{g/L}$  (hardness of 100 mg/L)

Acute criterion (dissolved) = 0.52  $\mu\text{g/L}$  (hardness of 100 mg/L; rounded to two significant digits)

Table 40. Freshwater acute toxicity data used for criteria derivation reported as total recoverable silver.

Rank	GMAV* ( $\mu\text{g/L}$ )	Species	SMAV* ( $\mu\text{g/L}$ )
1	0.3620	Ceriodaphnia dubia	0.3620
2	0.7840	Daphnia magna	0.7840
3	2.565	Danio rerio	2.565
4	2.930	Hyalella azteca	2.930
5	3.222	Rhinichthys oscuius	3.222
6	3.351	Cottus bairdi	3.351
7	5.390	Gammarus pseudolimnaeus	5.390
8	7.421	Pimephales promelas	7.421
9	8.772	Oncorhynchus mykiss	8.772
10	10.66	Jordanella floridae	10.66
11	10.84	Leptophlebia sp.	10.84
12	18.32	Ictalurus punctatus	18.32
13	29	Hydra sp.	29
14	63.29	Nephelopsis obscura	63.29
15	93.94	Lepomis macrochirus	93.94
16	122.6	Lepomis macrochirus	122.6
17	241	Aplexa hypnorum	241
18	379.0	Chironomus tentans	379.0
19	3788	Tanytarsus dissimiliis	3788
20	4612	Philodina acuticornis	4612

\* Normalized to 50 mg/L hardness

Table 41. New freshwater acute studies that met data acceptability requirements since EPA last updated silver criteria (S = static, R = static renewal, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Daphnia magna</b>	R, M	0.26	150	0.039	Yes.	Bianchini et al. 2002
<b>Daphnia magna</b>	R, M	0.18	115	0.043	Yes.	Bianchini et al. 2002
<b>Ceriodaphnia dubia</b>	R, M	0.5	90	0.18	Yes.	Bielmyer et al. 2002
<b>Pimephales promelas</b>	FT, M	30	103	8.66	Yes.	Birge et al. 1984
<b>Pimephales promelas</b>	R, M	7.8	48	8.37	No. Other studies with the same species used flow through design.	Erickson et al. 1998
<b>Daphnia magna</b>	S, M	0.58	49	0.60	Yes.	Erickson et al. 1998
<b>Hydra sp.</b>	S, M	29	50	29	Yes.	Brooke et al. 1986
<b>Nepheleopsis obscura</b>	S, M	59	48	63.29	Yes.	Brooke et al. 1986
<b>Leptophlebia sp.</b>	S, M	8.7	44	10.84	Yes.	Brooke et al. 1986
<b>Pimephales promelas</b>	R, M	5.412	80	2.411	No. Other studies with the same species used flow through design.	Diamond et al. 1997
<b>Pimephales promelas</b>	R, M	8.471	80	3.774	No. Other studies with the same species used flow through design.	Diamond et al. 1997
<b>Pimephales promelas</b>	R, M	7.882	80	3.512	No. Other studies with the same species used flow through design.	Diamond et al. 1997

Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Pimephales promelas</b>	R, M	5.294	80	2.359	No. Other studies with the same species used flow through design.	Diamond et al. 1997
<b>Ceriodaphnia dubia</b>	R, M	1.294	80	4.263	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
<b>Ceriodaphnia dubia</b>	R, M	1.294	80	4.263	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
<b>Ceriodaphnia dubia</b>	R, M	1.059	80	3.488	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
<b>Ceriodaphnia dubia</b>	R, M	0.8235	80	2.713	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
<b>Pimephales promelas</b>	S, M	2.43	50	2.43	No. Other studies with the same species used flow through design.	Karen et al. 1999
<b>Pimephales promelas</b>	S, M	2.24	100	0.68	No. Other studies with the same species used flow through design.	Karen et al. 1999
<b>Pimephales promelas</b>	S, M	2.79	200	0.26	No. Other studies with the same species used flow through design.	Karen et al. 1999
<b>Daphnia magna</b>	R, M	0.844	100	0.26	Yes.	Karen et al. 1999
<b>Daphnia magna</b>	R, M	1.009	200	0.31	Yes.	Karen et al. 1999

Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Pimephales promelas</b>	FT, M	16	38	25.65	Yes.	LeBlanc et al. 1984
<b>Oncorhynchus mykiss</b>	R, M	14.7	140	2.501	No. Other studies with same species used flow through design.	Mann et al. 2004
<b>Oncorhynchus mykiss</b>	FT, M	13.3	130	2.571	Yes.	Morgan and Wood, 2004
<b>Ceriodaphnia dubia</b>	S, M	0.92	70	0.52	Yes.	Rodgers et al. 1997
<b>Daphnia magna</b>	S, M	1.06	70	0.59	Yes.	Rodgers et al. 1997
<b>Hyalella azteca</b>	S, M	6.8	70	3.81	Yes.	Rodgers et al. 1997
<b>Chironomus tentans</b>	S, M	676	70	388.0	Yes.	Rodgers et al. 1997
<b>Pimephales promelas</b>	S, M	11.6	70	6.5	No. Other studies with same species used flow through design.	Rodgers et al. 1997
<b>Danio rerio</b>	R, M	15.18	141	2.565	Yes.	Alsop et al. 2011
<b>Lepomis macrochirus</b>		60	33	122.6	Yes.	Buccafusco 1987
<b>Pimephales promelas</b>	FT, M	6.7	44	8.35	Yes.	Holcombe et al. 1983
<b>Ictalurus punctatus</b>	FT, M	17.3	44	21.55	Yes.	Holcombe et al. 1983
<b>Aplexa hypnorum</b>	S, M	241	50	241	Yes.	Holcombe et al. 1983



Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Daphnia magna</b>	S, U	1.5	72	0.8	No. Other studies with same species measured chemical concentrations.	Leblanc 1980
<b>Pimephales promelas</b>	FT, M	10.7	45	12.83	Yes.	Lima 1982
<b>Jordanella floridae</b>	FT, M	9.2	45	11.03	Yes.	Lima 1982
<b>Gammarus pseudolimnaeus</b>	FT, M	4.5	45	5.39	Yes.	Lima 1982
<b>Tanytarsus dissimiliis</b>	FT, M	3160	45	3788	Yes.	Lima 1982
<b>Pimephales promelas</b>	FT, M	9	45	10.78	Yes.	Holcombe et al. 1987
<b>Oncorhynchus mykiss</b>	FT, M	6	45	7.19	Yes.	Holcombe et al. 1987
<b>Ictalurus punctatus</b>	FT, M	13	45	15.58	Yes.	Holcombe et al. 1987
<b>Pimephales promelas</b>	S, M	2.43	50	2.43	No. Other studies with same species used flow through design.	Forsythe 1996
<b>Pimephales promelas</b>	S, M	2.24	100	0.6799	No. Other studies with same species used flow through design.	Forsythe 1996
<b>Pimephales promelas</b>	S, M	2.79	200	0.2571	No. Other studies with same species used flow through design.	Forsythe 1996

Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Daphnia magna</b>	S, U	10	240	0.673	No. Other studies with same species measured chemical concentrations.	Khangarot 1987
<b>Pimephales promelas</b>	FT, M	5.1	53	4.614	Yes.	Brooke et al. 1993
<b>Hyalella azteca</b>	FT, M	2.1	48	2.253	Yes.	Brooke et al. 1993
<b>Ceriodaphnia dubia</b>	S, M	0.4	88	0.1513	Yes.	Brooke et al. 1993
<b>Oncorhynchus mykiss</b>	FT, M	7.6	120	1.686	Yes.	Galvez et al. 2002

\* Normalized to 50 mg/L hardness

Table 42. Freshwater acute studies not used from previous EPA criteria derivations.

Species	SMAV *(µg/L)	Reason	Reference
<b>Gammarus pseudolimnaeus</b>	4827	Repeat of Lima 1982 publication used in current derivation.	USEPA, 1980
<b>Tanytarsus dissimiliis</b>	3433	Repeat of Lima 1982 publication used in current derivation.	USEPA, 1980
<b>Daphnia magna</b>	1.733	LC50 10x higher than other studies using the same species.	USEPA, 1980

### Freshwater Chronic Silver Criterion

EPA has not developed a freshwater chronic silver criterion, and the silver criterion has not been updated since 1980. We applied 1985 EPA derivation methods to calculate a silver criterion. There was not adequate toxicity data to calculate a chronic silver criterion using the eight-family method, and therefore, we applied a FACR to the FAV to calculate a criterion. The calculated FACR for silver is 5.028 (Table 43). Table 44 shows the ACR studies that met test acceptability requirements but were not used. Calculation results are as follows:

$$\text{FAV} = 0.3686 \text{ (hardness of 50 mg/L)}$$

$$\text{FACR} = 5.028$$

$$\text{CCC} = 0.0733 \text{ (hardness of 50 mg/L)}$$

$$\text{CCC} = e^{(1.72 \times \ln(\text{hardness}) - 9.342)} \times \text{CF}$$

Where CF (conversion factor from total to dissolved fraction) = 0.85

Chronic criterion (total) = 0.2414 µg/L (hardness of 100 mg/L)

Chronic criterion (dissolved) = 0.21 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 43. Acute to chronic ratios (ACR) used in chronic criterion derivation.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Daphnia magna</b>	43	22	2		USEPA, 1980
<b>Daphnia magna</b>	0.81	0.45	1.8		Kolkmeier and Brooks, 2013
<b>Daphnia magna</b>	2.12	6.88	3.25	2.27	Bianchini, 2008
<b>Mysidopsis bahia</b>	250	18	14	14	USEPA, 1980
<b>Oncorhynchus mykiss</b>	6.5	1.624	4.00	4	Davies, 1978
<b>Geometric mean</b>				5.028	

\* Geometric mean of ACRs were calculated for similar species preceding the final acute chronic ratio calculation

Table 44. Studies with acute to chronic ratios (ACR) that met test acceptability requirements but were not used in the chronic criterion derivation.

Species	ACR	Reason	Reference
<b>Oncorhynchus mykiss</b>	54	ACR was 10X greater than other study using the same species.	USEPA, 1980
<b>Ceriodaphnia dubia</b>	158	ACR was 10x greater than the lowest ACR for a given species.	Bielmyer et al. 2002

### Saltwater Acute Silver Criterion

EPA recommends a saltwater acute silver criterion of 1.9 µg/L with an instantaneous duration (Table 39). EPA recommendations for the saltwater acute silver criterion is based on pre-1985 EPA methods for deriving aquatic life toxics criteria. We used the data from EPA’s 1980 document and any new science to recalculate the acute silver criterion using EPA’s 1985 guidance. An evaluation of the saltwater acute silver criteria was done to align freshwater and saltwater averaging periods as well as use the latest science to derive a saltwater chronic silver criteria using the newly established FACR. Using EPA’s 1985 methodology, we calculated a saltwater acute silver criterion of 2.2 µg/L using 17 GMAVs (Table 45). New studies since EPA last updated the saltwater acute silver criterion are found in Table 46. Calculation results are as follows:

FAV = 5.171

CMC = 2.586

**Where CF (conversion factor from total to dissolved fraction) = 0.85**

**Acute criterion (total) = 2.586 µg/L**

**Acute criterion (dissolved) = 2.2 µg/L (rounded to 2 significant digits)**

Table 45. Saltwater acute toxicity data used for criteria derivation reported as total recoverable silver.

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
<b>1</b>	4.7	Paralichthys dentatus	4.7
<b>2</b>	18.97	Strongylocentrotus purpuratus	15
		Strongylocentrotus droebachiensis	24
<b>3</b>	20	Crassostrea virginica	20
<b>4</b>	21	Mercenaria mercenaria	21
<b>5</b>	24	Tigriopus japonicus	24
<b>5</b>	33	Argopecten irradians	33
<b>6</b>	33	Dendraster excentricus	33
<b>7</b>	33	Cancer magister	33

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
8	36	Acartia tonsa	36
9	77.41	Brachionus plicatilis	77.41
10	210	Menidia menidia	210
11	210.8	Mysidopsis bahia	210.8
12	331	Oligocottus maculosus	331
13		Oncorhynchus mykiss	404.5
14	500	Pseudopieuronectes americanus	500
15	550	Apeltes quadracus	550
16	1400	Cyprinodon variegatus	1400
17	2250	Opsanus beta	2250

Table 46. New saltwater acute studies that met data acceptability requirements since EPA last updated silver criteria (S = static, R = static renewal, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L total silver)	Used in Derivation?	Reference
<b>Oncorhynchus mykiss</b>	S, U	404.5	Yes.	Ferguson and Hogstrand, 1998
<b>Strongylocentrotus droebachiensis</b>	S, M	24	Yes.	Dinnel et al. 1989
<b>Strongylocentrotus purpuratus</b>	S, M	15	Yes.	Dinnel et al. 1989
<b>Dendraster excentricus</b>	S, M	33	Yes.	Dinnel et al. 1989
<b>Cancer magister</b>	S, M	33	Yes.	Dinnel et al. 1989
<b>Brachionus plicatilis</b>	S, M	77.41	Yes.	Saunders, 2012
<b>Oligocottus maculosus</b>	R, M	331	Yes.	Shaw et al. 1998
<b>Mysidopsis bahia</b>	FT, M	305.9	Yes.	Ward and Kramer, 2002
<b>Opsanus beta</b>	R, M	2250	Yes.	Wood et al. 2004
<b>Mysidopsis bahia</b>	FT, M	141	Yes.	McKenney, 1982
<b>Mysidopsis bahia</b>	FT, M	300	Yes.	McKenney, 1982
<b>Mysidopsis bahia</b>	FT, M	300	Yes.	McKenney, 1982
<b>Mysidopsis bahia</b>	FT, M	64	Yes.	McKenney, 1982
<b>Mysidopsis bahia</b>	FT, M	298	Yes.	McKenney, 1982
<b>Tigriopus japonicus</b>	R, U	24	Yes.	Lee et al. 2008

## Saltwater Chronic Silver Criterion

EPA has not developed a saltwater chronic silver criterion. We applied 1985 EPA derivation methods to calculate a silver criterion. There was not adequate toxicity data to calculate a chronic silver criterion using the eight-family method, and therefore, we applied a FACR to the FAV to calculate a criterion. The calculated FACR for silver is 5.028 (Table 43). Calculation results are as follows:

$$\text{FAV} = 5.171$$

$$\text{FACR} = 5.028$$

$$\text{CCC} = \text{FAV} / \text{FACR} = 1.028$$

**Where CF (conversion factor from total to dissolved fraction) = 0.85**

Chronic criterion (total) = 1.028 µg/L

Chronic criterion (dissolved) = 0.87 µg/L (rounded to 2 significant digits)

## Zinc

### Summary of Criteria Recommendations and Changes

The proposed freshwater zinc criteria accounts for endangered species protection levels by incorporating new science available since EPA last updated the freshwater criteria in 1995. The proposed freshwater zinc criteria are more stringent than EPA recommendations (Table 47; USEPA, 1996). No changes were necessary for saltwater criteria because Washington's saltwater zinc criteria are identical to EPA recommendations and there are no endangered species protection issues highlighted in previous ESA consultations in other Region 10 states.

Table 47. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic zinc criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	114* <sup>^</sup> (1-hour)	105* <sup>^</sup> (4-day)	90 <sup>^</sup> (1-hour)	81 <sup>^</sup> (4-day)
<b>EPA</b>	120* <sup>^</sup> (1-hour)	120* <sup>^</sup> (4-day)	90 <sup>^</sup>	81 <sup>^</sup>
<b>Proposed</b>	57* <sup>^</sup> (1-hour)	39 <sup>^</sup> (4-day)	No change	No change

\* Hardness based criteria (numeric value shown based on 100 mg/L)

<sup>^</sup> Presented as the dissolved fraction

## Endangered Species Act Consultation

### Oregon

There were likely to adversely affect designations for the zinc freshwater acute (120 µg/L at 100 mg/L hardness) and chronic (120 µg/L at 100 mg/L hardness) criteria in Oregon for bull trout, a species that is also on Washington's endangered species list. There were no jeopardy calls. The Oregon BiOps specifically state (NMFS, 2012; USFWS, 2012):

“Bull trout exposure to zinc at the proposed acute criterion is likely to result in the mortality of up to 507 adult bull trout in surface waters along 820.6 miles of habitat within the action area over each 3-year period during the 25-year term of the proposed action.”

“Bull trout exposure to zinc at the proposed chronic criterion is likely to kill up to 266 adult bull trout, and injure (via reduced fitness) up to another 1,370 individual adult bull trout during each- 3 year period over the 25 year term of the proposed action in 820.6 miles of bull trout habitat within the action area.”

“The available evidence for zinc indicates that listed species exposed to waters equal to the acute or chronic criteria concentrations will suffer acute and chronic toxic effects including mortality (moderately-high-intensity), reduced growth (moderately-high-intensity), cellular trauma (moderate intensity), physiological trauma (moderate intensity), and reproductive failure (moderately-high-intensity).”

### Idaho

There were jeopardy calls for the zinc freshwater acute (120 µg/L at 100 mg/L hardness) and chronic (120 µg/L at 100 mg/L hardness) criteria in Idaho (NMFS, 2014; USFWS, 2015) for species (i.e., bull trout and white sturgeon) relevant to Washington. The Idaho BiOp specifically states:

“For that reason, zinc concentrations at the proposed acute and chronic criteria level are likely to impair the capability of bull trout habitat to provide for the normal reproduction, growth, and survival of bull trout. Given that the state of Idaho represents 44 percent of streams and 34 percent of lakes and reservoirs occupied by the bull trout within its range, the above effects are considered to be significant and are likely to impede (1) maintaining/increasing the current distribution of the bull trout, (2) maintaining/increasing the current abundance of the bull trout, and (3) achieving stable/increasing trends in bull trout populations within a significant portion of its range.”

“The proposed zinc criteria are likely to impair water quality (PCE 8) by allowing aquatic zinc concentrations to rise to levels that have been shown to be lethal to juvenile bull trout throughout the range of bull trout critical habitat in Idaho. For that reason, zinc concentrations at the proposed acute and chronic criteria level would impair the capability of the critical habitat to provide for the normal reproduction, growth, and survival of bull trout.”

“Given that existing data show adverse effects to multiple freshwater fish species, including potential prey species of the Kootenai River white sturgeon, at zinc concentrations below the proposed criteria, and given the likelihood that zinc concentrations will be even higher

in sediments, thus increasing adverse impacts to white sturgeon eggs and juveniles, we conclude the proposed criteria for zinc are likely to have significant adverse effects (in the form of reduced growth and survival) to the Kootenai River white sturgeon throughout its range in Idaho, which represents 39 percent of its range. Such impacts are likely to impede natural reproduction of the Kootenai River white sturgeon and the maintenance or increase of the wild population.”

“Because the proposed water quality criteria would be implemented statewide, all of the designated white sturgeon critical habitat would be subjected to aquatic zinc concentrations up to 117 µg/L (acute) and 118 µg/L (chronic) at a water hardness value of 100 mg/L, in addition to unknown and unregulated concentrations in sediment. Thus, the proposed acute and chronic zinc criteria are likely to adversely affect sediment and water quality in 100 percent of the critical habitat within the distinct population segment and is reasonably certain to impair the ability of critical habitat to provide for the normal behavior, reproduction, and survival of white sturgeon.”

### Swinomish Tribe Biological Evaluation

EPA’s biological evaluation concluded likely to adversely affect (LAA) determinations for the freshwater zinc acute and chronic criteria to ESA listed species in Washington (USEPA, 2022a).

## Criteria Calculations

### Freshwater Acute Zinc Criterion

The data used to derive the freshwater acute zinc criterion is presented in Table 48. New studies that met data acceptability requirements are presented in Table 49. Studies used in previous EPA derivations but not used in this derivation are found in Table 50. The proposed freshwater acute criterion for zinc was derived using 64 GMAVs. Calculation results are as follows:

$$FAV = 64.34 \text{ (hardness of 50 mg/L)}$$

$$CMC = 32.17 \text{ µg/L (hardness of 50 mg/L)}$$

$$CMC = e^{(0.8473 \times \ln(\text{hardness} + 0.1564))} \times CF$$

Where CF (conversion factor from total to dissolved fraction) = 0.978

Acute criterion (total) = 58 µg/L (hardness of 100 mg/L)

Acute criterion (dissolved) = 57 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 48. Freshwater acute toxicity data used for criteria derivation reported as total recoverable zinc.

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
1	40.24	Neocloeon triangulifer	40.24
2	51.96	Hyalella azteca	51.96
3	61.38	Euchlanis dilatata	61.38
4	72.10	Ceriodaphnia dubia	102.5



Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
		<i>Ceriodaphnia reticulata</i>	50.7
5	76.13	<i>Leptoxis ampla</i>	76.13
6	102.3	<i>Limnodrilus hoffmeisteri</i>	102.3
7	102.5	<i>Acipenser transmontanus</i>	102.5
8	119.4	<i>Morone saxatilis</i>	119.4
9	175.7	<i>Cottus bairdi</i>	175.7
10	176.5	<i>Lampsilis rafinesqueana</i>	171.6
		<i>Lampsilis siliquoidea</i>	181.7
11	227.8	<i>Agosia chrysogaster</i>	227.8
12	255.4	<i>Pomacea paludosa</i>	255.4
13	303.1	<i>Daphnia magna</i>	232.5
		<i>Daphnia pulex</i>	252.9
		<i>Daphnia carinata</i>	188.9
		<i>Daphnia prolata</i>	759.7
14	344.6	<i>Bryocamptus zschokkei</i>	344.6
15	373.8	<i>Somatogyrus</i> sp.	373.8
16	474.3	<i>Prosopium williamsoni</i>	474.3
17	750.1	<i>Oncorhynchus mykiss</i>	623.7
		<i>Oncorhynchus kisutch</i>	1628
		<i>Oncorhynchus nerka</i>	1502
		<i>Oncorhynchus tshawytscha</i>	446.4
		<i>Oncorhynchus clarkii</i>	348.8
18	772.3	<i>Anaxyrus boreas boreas</i>	772.3
19	856.0	<i>Villosa umbrans</i>	1479
		<i>Villosa nebulosa</i>	495.4
20	863.0	<i>Pimephales promelas</i>	863.0
21	1224	<i>Salvelinus fontinalis</i>	1224
22	>1257	<i>Limnodrilus hoffmeisteri</i>	>1257
23	1307	<i>Pectinatella magnifica</i>	1307
24	1353	<i>Physa gyrina</i>	1683
25	1088	<i>Physa heterostropha</i>	1088
26	1370	<i>Salmo salar</i>	2176
		<i>Salmo trutta</i>	862.9
27	1578	<i>Helisoma campanulatum</i>	1578
28	1607	<i>Plumatella emarginata</i>	1607
29	1672	<i>Jordanella floridae</i>	1672
30	1707	<i>Lophopodella carteri</i>	1707
31	1746	<i>Catostomus latipinnis</i>	583.4
		<i>Catostomus commersoni</i>	5228
32	1769	<i>Drunella grandis</i>	1769

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
33	1913	<i>Atyaephyra desmarestii</i>	1913
34	1946	<i>Rhinichthys cataractae</i>	1946
35	2136	<i>Xyrauchen texanus</i>	2136
36	2545	<i>Platygobio gracilis</i>	2545
37	2791	<i>Gila elegans</i>	2791
38	2836	<i>Ptychocheilus lucius</i>	1222
		<i>Ptychocheilus oregonesis</i>	6580
39	2933	<i>Hydra viridissima</i>	1719
		<i>Hydra vulgaris</i>	3537
		<i>Hydra oligactis</i>	4150
40	3265	<i>Lirceus alabamae</i>	3265
41	3506	<i>Chironomus riparius</i>	3506
42	4341	<i>Xiphophorus maculatus</i>	4341
43	4900	<i>Corbicula fluminea</i>	4900
44	5135	<i>Hyla chrysocelis</i>	5135
45	5588	<i>Tubifex tubifex</i>	5588
46	6000	<i>Notemigonus crysoleucas</i>	6000
47	6315	<i>Nais elinguis</i>	2167
		<i>Nais sp.</i>	18400
48	8100	<i>Gammarus sp.</i>	8100
49	8157	<i>Asellus bicrenate</i>	5731
		<i>Asellus communis</i>	11610
50	8483	<i>Lepomis gibbosus</i>	18790
		<i>Lepomis macrochirus</i>	3830
51	9712	<i>Lumbriculus variegatus</i>	9712
52	11305	<i>Rana pipiens</i>	11305
53	11899	<i>Baetis tricaudatus</i>	11899
54	13630	<i>Anguilla rostrata</i>	13630
55	16820	<i>Amnicola sp.</i>	16820
56	17940	<i>Fundulus diaphanous</i>	17940
57	19800	<i>Crangonyx pseudogracilis</i>	19800
58	21608	<i>Branchiura sowerbyi</i>	21608
59	21890	<i>Chironomus plumosus</i>	21890
60	>48500	<i>Lepidostoma sp.</i>	>48500
61	>67543	Chloroperlidae	>67543
62	>67543	Ephemerella sp.	>67543
63	69062	<i>Cinygmula sp.</i>	69062
64	88960	<i>Argia sp.</i>	88960

\* Normalized to 50 mg/L hardness

Table 49. New freshwater acute studies that met data acceptability requirements since EPA last updated zinc criteria (S = static, R = static renewal, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L total zinc)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Tubifex tubifex</b>	S, U	11150	113	5588	Yes.	Chatterjee et al. 2019
<b>Branchiura sowerbyi</b>	S, U	51097	120	24335	Yes. 24-hour LC50.	Dhara et al. 2020
<b>Pimephales promelas</b>	S, M	839	110	429.4	No. Other studies using the same species had a flow through design.	Lynch et al. 2016
<b>Daphnia magna</b>	S, M	696	90	423	Yes.	Meyer et al. 2015
<b>Daphnia magna</b>	S, M	330	90	200.6	Yes.	Santos-Medrano & Rico-Martinez 2015
<b>Daphnia prolata</b>	S, M	1250	90	759.7	Yes.	Santos-Medrano & Rico-Martinez 2015
<b>Lampsilis rafinesqueana</b>	S, U	163	44	181.7	Yes.	Wang et al. 2010
<b>Lampsilis siliquoidea</b>	S, U	145	41	171.6	Yes.	Wang et al. 2010
<b>Hyalella azteca</b>	S, U	101.2	107	53.13	Yes.	Wang et al. 2020
<b>Oncorhynchus mykiss</b>	FT, M	162	20	352.1	Yes	Alsop et al. 1999
<b>Oncorhynchus mykiss</b>	FT, M	869	120	413.9	Yes	Alsop et al. 1999
<b>Oncorhynchus mykiss</b>	FT, M	103	10	402.8	Yes	Alsop and Wood, 1999
<b>Oncorhynchus mykiss</b>	FT, M	2615	120	1245	Yes.	Alsop and Wood, 2000
<b>Daphnia magna</b>	S, M	121	46	129.9	Yes.	Barata et al. 1998
<b>Daphnia magna</b>	R, M	1425	150	561.9	No. Concentrations were not measured.	Bianchini et al. 2002
<b>Pimephales promelas</b>	R, M	483.8	44.8	531.0	No. Other studies using the same species had a flow through design.	Bringolf et al. 2006

Species	Method	LC50 (µg/L total zinc)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Pimephales promelas</b>	R, M	745.3	49.3	754.2	No. Other studies using the same species had a flow through design.	Bringolf et al. 2006
<b>Pimephales promelas</b>	R, M	876.1	61.4	736.2	No. Other studies using the same species had a flow through design.	Bringolf et al. 2006
<b>Cottus bairdi</b>	FT, U	439	154	169.2	Yes.	Brinkman & Woodling 2005
<b>Rhithrogena hageni</b>	FT, M	51636	45	56458	No. LC50 10x higher than other species within genus.	Brinkman & Johnston 2012
<b>Oncorhynchus clarkii</b>	FT, M	189.2	47.4	197.9	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Oncorhynchus clarkii</b>	FT, M	1452	144	592.0	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Oncorhynchus clarkii stomias</b>	FT, M	321.1	47.4	335.9	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Oncorhynchus clarkii stomias</b>	FT, M	1534	144	624.7	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Oncorhynchus clarkii virginalis</b>	FT, M	145.2	41.7	169.3	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Oncorhynchus clarkii virginalis</b>	FT, M	1063	144	432.5	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Prosopium williamsoni</b>	FT, M	365.0	43.2	413.2	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012

Species	Method	LC50 (µg/L total zinc)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Prosopium williamsoni</b>	FT, M	437.6	41.1	516.4	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Prosopium williamsoni</b>	FT, M	481.6	47.8	500	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
<b>Cottus bairdi</b>	FT, M	338.4	99.5	188.9	Yes.	Brinkman & Johnston 2012
<b>Rhinichthys cataractae</b>	FT, M	1943	49.9	1946	Yes.	Brinkman & Johnston 2012
<b>Platygobio gracilis</b>	FT, M	2648	52.4	2545	Yes.	Brinkman & Johnston 2012
<b>Anaxyrus boreas boreas</b>	FT, M	863.0	57	772.3	Yes.	Brinkman & Johnston 2012
<b>Baetis tricaudatus</b>	FT, M	10327	42.3	11899	Yes.	Brinkman & Johnston 2012
<b>Cinygmula sp.</b>	FT, M	70348	51.1	69062	Yes.	Brinkman & Johnston 2012
<b>Drunella doddsi</b>	FT, M	>64000	49.8	>63783	No. LC50 10x higher than other species within genus and definitive values exist for this species.	Brinkman & Johnston 2012
<b>Chloroperlidae</b>	FT, M	>68800	51.1	>67543	Yes.	Brinkman & Johnston 2012
<b>Ephemerella sp.</b>	FT, M	>68800	51.1	>67543	Yes.	Brinkman & Johnston 2012
<b>Lepidostoma sp.</b>	S, M	>48500	50	>48500	Yes.	Brinkman & Johnston 2012
<b>Bryocamptus zschokkei</b>	R, M	620	100	344.6	Yes.	Brown et al. 2005
<b>Ptychocheilus lucius</b>	S, U	3340	199	1036	Yes.	Buhl 1996
<b>Gila elegans</b>	S, U	5350	199	1660	Yes.	Buhl 1996
<b>Xyrauchen texanus</b>	S, U	2920	199	906	Yes.	Buhl 1996
<b>Acipenser transmontanus</b>	FT, M	150	100	83.37	Yes.	Calfee et al. 2014

Species	Method	LC50 (µg/L total zinc)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Oncorhynchus mykiss</b>	FT, M	233.0	100	129.5	Yes.	Calfee et al. 2014
<b>Salmo trutta</b>	FT, M	890.6	51.9	862.9	Yes.	Davies et al. 2000
<b>Salvelinus fontinalis</b>	FT, M	1109	84.2	713.4	Yes.	Davies et al. 2001
<b>Ceriodaphnia dubia</b>	R, M	119.3	80	80.13	Yes.	Diamond et al. 1997
<b>Ceriodaphnia dubia</b>	R, M	203.5	80	136.6	Yes.	Diamond et al. 1997
<b>Ceriodaphnia dubia</b>	R, M	186.7	80	125.4	Yes.	Diamond et al. 1997
<b>Ceriodaphnia dubia</b>	R, M	307.4	80	206.4	Yes.	Diamond et al. 1997
<b>Pimephales promelas</b>	R, M	387.0	80	259.9	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
<b>Pimephales promelas</b>	R, M	296.8	80	199.3	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
<b>Pimephales promelas</b>	R, M	100	80	67.15	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
<b>Pimephales promelas</b>	R, M	380	80	255.1	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
<b>Acipenser transmontanus</b>	R, M	153.4	76	107.6	Yes.	Vardy et al. 2014
<b>Oncorhynchus mykiss</b>	S, U	12800	250	3273	No. Other studies using the same species had a flow through design.	Gundogdu 2008
<b>Pomacea paludosa</b>	R, M	136.0	28	222.3	Yes.	Hoang & Tong 2015
<b>Pomacea paludosa</b>	R, M	371.2	97	211.7	Yes.	Hoang & Tong 2015

Species	Method	LC50 (µg/L total zinc)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Pomacea paludosa</b>	R, M	462.2	103	250.5	Yes.	Hoang & Tong 2015
<b>Pomacea paludosa</b>	R, M	587.9	108	306.2	Yes.	Hoang & Tong 2015
<b>Pomacea paludosa</b>	R, M	1098	230	301.4	Yes.	Hoang & Tong 2015
<b>Hydra vulgaris</b>	S, M	7400	204	2248	Yes.	Karntanut & Pascoe 2000
<b>Hydra vulgaris (Zurich)</b>	S, M	14000	210	4150	Yes.	Karntanut & Pascoe 2002
<b>Hydra vulgaris</b>	S, M	13000	210	3854	Yes.	Karntanut & Pascoe 2002
<b>Hydra oligactis</b>	S, M	14000	210	4150	Yes.	Karntanut & Pascoe 2002
<b>Hydra viridissima</b>	S, M	11000	210	3261	Yes.	Karntanut & Pascoe 2002
<b>Hydra viridissima</b>	S, M	2500	207	750.2	Yes.	Karntanut & Pascoe 2002
<b>Daphnia magna</b>	R, U	157.5	105	83.98	Yes.	Lazorchak et al. 2009
<b>Pimephales promelas</b>	S, M	839.5	110	430.4	No. Other studies using the same species had a flow through design.	Lynch et al. 2016
<b>Oncorhynchus mykiss</b>	R, M	130	24	242.1	No. Other studies using the same species had a flow through design.	Mebane et al. 2008
<b>Ceriodaphnia dubia</b>	R, M	119	181	40.01	Yes.	Naddy et al. 2015
<b>Oncorhynchus mykiss</b>	S, M	304	181	102.2	No. Other studies using the same species had a flow through design.	Naddy et al. 2015
<b>Atyaephyra desmarestii</b>	S, M	7810	263	1913	Yes.	Pestana et al. 2007
<b>Nais elinguis</b>	R, M	912	18	2167	Yes.	Shuhaimi et al. 2012
<b>Lepomis macrochirus</b>	FT, M	4500	214	1313	Yes.	Van der Schalie et al. 2004
<b>Cottus bairdi</b>	FT, M	159.5	48.6	163.4	Yes.	Woodling et al. 2002

Species	Method	LC50 (µg/L total zinc)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Drunella grandis</b>	FT, M	1352	36.4	1769	Yes.	Brinkman & Vieira 2008
<b>Daphnia magna</b>	S, M	173.5	100	96.44	Yes.	Cooper et al. 2009
<b>Daphnia carinata</b>	S, M	339.8	100	188.9	Yes.	Cooper et al. 2009
<b>Chironomus plumosus</b>	S, U	32600	80	21890	Yes.	Fargasova 2001
<b>Daphnia magna</b>	S, U	550	90	334.3	Yes.	Jellyman et al. 2011
<b>Ptychocheilus lucius</b>	S, U	1700	197	532.0	Yes.	Hamilton 1995
<b>Xyrauchen texanus</b>	S, U	8900	197	2785	Yes.	Hamilton 1995
<b>Gila elegans</b>	S, U	15000	197	4694	Yes.	Hamilton 1995
<b>Ptychocheilus lucius</b>	S, U	8400	150	3311	Yes.	Hamilton & Buhl 1997
<b>Xyrauchen texanus</b>	S, U	9800	150	3863	Yes.	Hamilton & Buhl 1997
<b>Catostomus latipinnis</b>	S, U	1480	150	583.4	Yes.	Hamilton & Buhl 1997
<b>Hydra vulgaris</b>	S, U	2300	19.5	5108	Yes.	Holdway et al. 2001
<b>Hydra viridissima</b>	S, U	935	19.5	2076	Yes.	Holdway et al. 2001
<b>Daphnia magna</b>	S, M	1319	150	520.0	Yes	Yim et al. 2006
<b>Daphnia magna</b>	S, M	306.7	44	341.8	Yes	Yim et al. 2006
<b>Hyla chrysocelis</b>	S, M	4696	45	5135	Yes.	Gottschalk 1995
<b>Rana pipiens</b>	S, M	10339	45	11305	Yes.	Gottschalk 1995
<b>Daphnia magna</b>	R, M	233	250	59.58	Yes.	Li et al. 2019
<b>Limnodrilus hoffmeisteri</b>	R, M	400	250	102.3	Yes.	Li et al. 2019
<b>Chironomus riparius</b>	R, M	13710	250	3506	Yes.	Li et al. 2019
<b>Neocloeon triangulifer</b>	S, M	70.55	97	40.24	Yes.	Besser et al. 2021



Species	Method	LC50 (µg/L total zinc)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Villosa umbrans</b>	R, U	1302	43	1479	Yes.	Gibson et al. 2018
<b>Villosa nebulosa</b>	R, U	436	43	495.4	Yes.	Gibson et al. 2018
<b>Leptoxis ampla</b>	R, U	67	43	76.13	Yes.	Gibson et al. 2018
<b>Somatogyrus sp.</b>	R, U	329	43	373.8	Yes.	Gibson et al. 2018
<b>Euchlanis dilatata</b>	S, M	101	90	61.38	Yes.	Hernandez-Flores et al. 2020

\* Normalized to hardness of 50 mg/L

Table 50. Freshwater acute studies not used from previous EPA criteria derivations.

Species	SMAV *(µg/L)	Reason	Reference
Mozambique tilapia	790	Non-North American species	USEPA, 1996
Poecilia reticulata	6053	Non-North American species	USEPA, 1996
Cyprinus carpio	7233	Non-North American species	USEPA, 1996
Carrasius auratus	10250	Non-North American species	USEPA, 1996
Xenopus laevis	19176	Non-North American species	USEPA, 1996

### Freshwater Chronic Zinc Criterion

There was inadequate freshwater chronic zinc data to calculate criteria using the eight-family method. The FACR of 2.00 was previously used to calculate the freshwater chronic zinc criterion as presented in 1995 updates to aquatic life (USEPA, 1996). Additional chronic zinc ACRs were available since EPA's last update. The newly calculated FACR used to derive the chronic zinc criterion is 2.950 (Table 51). Table 52 shows studies with ACR values that were not used in final calculations. Calculation results are as follows:

FAV = 64.34 (hardness of 50 mg/L)

FACR = 3.062

CCC = 21.81 µg/L (hardness of 50 mg/L)

CCC =  $e^{(0.8473 \times \ln(\text{hardness}) - 0.2323)} \times \text{CF}$

Where CF (conversion factor from total to dissolved fraction) = 0.986

Chronic criterion (total) = 39.24 µg/L (hardness of 100 mg/L)

Chronic criterion (dissolved) = 39 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 51. Acute to chronic ratios (ACR) used in chronic criterion derivation.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
Daphnia magna	334	135.8	2.459		USEPA, 1987b
Daphnia magna	525	47.29	11.10		USEPA, 1987b
Daphnia magna	655	46.73	14.02	7.260	USEPA, 1987b
Oncorhynchus mykiss	430	276.7	1.554		USEPA, 1987b
Oncorhynchus mykiss	267	169	1.58		Wang et al. 2014

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Oncorhynchus mykiss</b>	2140	196	10.92		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	1470	1500	0.9800		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	194	114.4	1.695		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	904	247.7	3.650		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	2280	1146	1.990		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	130	88.18	1.474		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	153	88.62	1.726		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	214	225.9	0.9473		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	283	236.2	1.198		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	483	242.4	1.993		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	1510	566.4	2.666		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	548	412.6	1.328		De Schamphelaere et al. 2005
<b>Oncorhynchus mykiss</b>	610	200.5	3.042	1.936	De Schamphelaere et al. 2005
<b>Salvelinus fontinalis</b>	1996	854.7	2.335		USEPA, 1987b
<b>Salvelinus fontinalis</b>	1085	417	2.602	2.465	Davies et al. 2001
<b>Pimephales promelas</b>	600	106.3	5.644	5.644	USEPA, 1987b
<b>Mysidopsis bahia</b>	499	166.5	2.997	2.997	USEPA, 1987b

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Cottus bairdi</b>	439	255.3	1.719	1.719	Brinkman & Woodling 2005
<b>Cottus bairdi</b>	156	37.83	4.124	4.124	Davies et al. 2001
<b>Prosopium williamsoni</b>	471	269	1.590	1.590	Brinkman & Johnston 2012
<b>Bryocamptus zschokkei</b>	620	379.5	1.634	1.634	Brown et al. 2005
<b>Salmo trutta</b>	871	303	2.875	2.875	Davies et al. 2000
<b>Ceriodaphnia dubia</b>	173.5	18.06	9.605	9.605	Cooper et al. 2009
<b>Hyalella azteca</b>	99	33.94	2.917	2.917	Wang et al. 2020
<b>Lampsilis siliquoidea</b>	163	68.23	2.389	2.389	Wang et al. 2010
<b>Geometric mean</b>				3.062	

\* Geometric mean of ACRs were calculated for similar species preceding the final acute chronic ratio calculation

Table 52. Studies not used in chronic zinc acute to chronic ratio calculations.

Species	ACR (µg/L)	Reason	Reference
<b>Oncorhynchus nerka</b>	<6.074	“Less than value” is not a definitive value.	USEPA, 1987b
<b>Oncorhynchus tshawytscha</b>	0.2614-1.889	Acute values presented as a range and juvenile fish were used.	USEPA, 1987b
<b>Jordanella floridae</b>	41.20	ACR is 10X greater than other values for zinc	USEPA, 1987b
<b>Daphnia magna</b>	1.742	IC25 was representative of the acute value	Lazorchak et al. 2009
<b>Oncorhynchus mykiss</b>	1.051	NOEC was a “less than value” making the acute value inaccurate	Mebane et al. 2008

### Saltwater Zinc Criteria

No changes are proposed to the saltwater acute and chronic zinc criteria. Washington’s current saltwater zinc criteria are identical to EPA recommendations, and to our knowledge there are no endangered species protection concerns.

## Other Chemicals

The criteria in this section are for other chemicals besides metals listed in alphanumeric order. Toxics with an acute criteria duration of 1-hour are not to be exceeded more than once every three years on average. Toxics with an acute criteria duration of instantaneous are not to be exceeded at any time. Toxics with a chronic criteria duration of 4-day average concentration are not to be exceeded more than once every three years on average. Toxics with a chronic criteria duration of 24-hours are not to be exceeded at any time. Exceptions to these rules are otherwise noted in table footnotes (i.e., PFOS and PFOA).

### 4,4'-DDT and metabolites

#### Summary of Criteria Recommendations and Changes

Washington's freshwater and saltwater 4,4'-DDT and metabolites criteria are identical to EPA recommendations (Table 53). We are not aware of endangered species protection issues with EPA recommended 4,4'-DDT and metabolites criteria in Region 10 states. We propose no changes to Washington's current 4,4'-DDT and metabolites criteria.

Table 53. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic 4,4'-DDT and metabolites criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	1.1 (instantaneous)	0.001 (24-hour)	0.13 (instantaneous)	0.001 (24-hour)
<b>EPA</b>	1.1 (instantaneous)	0.001 (24-hour)	0.13 (instantaneous)	0.001 (24-hour)
<b>Proposed</b>	No change	No change	No change	No change

### 6-PPD-quinone (N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone)

#### Summary of Criteria Recommendations and Changes

The proposed criterion for 6PPD-q (N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone) is presented in Table 54. The common EPA methodology for developing criteria primarily relies on toxicity data from eight taxonomic families. We currently have freshwater acute toxicity data for five out of eight families for 6PPD-q and very limited chronic data. The eight-family minimum data requirement is intended to ensure evaluation of the most sensitive organisms with different life histories. As an alternate to the common EPA derivation method, if a commercially, recreationally, or culturally important organism is particularly sensitive, EPA recommends criteria be based on a single organism if it results in a criterion lower than the eight-family derivation method (Stephan et al. 1985).

Another, newer, alternative derivation method EPA has recommended is to set benchmarks for chemicals that do not meet the eight-family requirements by estimating toxicity data from missing families using the Web-based Interspecies Correlation Estimation (WEB-ICE) model. EPA states that these benchmarks are available for states to adopt as water quality criterion. We decided to apply EPA methods for developing benchmarks by using the WEB-ICE model to estimate toxicity for the three missing families of toxicity data for 6PPD-q (Appendix C). We required the WEB-ICE model to have a  $R^2$  greater than 0.8 and that the surrogate be within the range of the model. As a result of that exercise, we found that the additional toxicity information estimated from the model combined with the five families of toxicity data from scientific literature resulted in a criterion value of 46 ng/L.

When we calculated a 6PPD-q criterion using EPA's single species alternative method (34 ng/L), it resulted in a more protective criterion than the eight-family method with the use of WEB-ICE (i.e., 46 ng/L). Coho salmon are significantly more sensitive to 6PPD-q than all other aquatic life and have cultural, recreational, and commercial significance. There are three median lethal concentration (LC50) values available for coho salmon that have a relatively small standard deviation (Table 55). Using the geometric mean of the three LC50 values for coho salmon and a safety factor of two results in a single species derived criterion of 34 ng/L. The single species method is more protective than the eight-family derivation method with the use of WEB-ICE. However, there are several concerns regarding protection of coho salmon at 34 ng/L.

The lowest LC50 reported for coho salmon is 41 ng/L, indicating that a criterion of 34 ng/L will likely result in significant toxicity to coho salmon. Furthermore, the toxicity tests available for coho salmon are 24 hours in duration. The standard toxicity test for vertebrates is 96 hours and is what is typically used for criteria derivations. A longer duration toxicity test is anticipated to result in additional toxicity, suggesting that 24-hour LC50s are a conservative estimate of coho salmon toxicity in terms of data used for criteria derivations. Brinkman et al. (2022) compared toxicity of the rainbow trout after 24 hours to 96 hours and reported an almost 2-fold increase in toxicity between 24 and 96 hours. These uncertainties suggest that 34 ng/L will not be adequately protective of coho salmon. Therefore, we explored additional methods to derive a protective freshwater acute 6PPD-q criterion.

The eight-family derivation method combines toxicity information from individual species within a genus. This method averages out individual species toxicity information. For example, the genus *Oncorhynchus* would require combining toxicity data for rainbow trout, chinook salmon, and coho salmon when using standard EPA derivation methods. The high sensitivity of coho salmon is therefore discounted using this method. To account for individual species toxicity, we developed a species sensitivity distribution rather than a genus sensitivity distribution. We used [EPA's species sensitivity distribution calculator](https://www.epa.gov/chemical-research/species-sensitivity-distribution-ssd-toolbox)<sup>7</sup> to derive a 5<sup>th</sup> percentile of the toxicity data distribution for individual species. This method accounts for each individual species and derives a more protective criterion. The only available data with definitive toxicity values included five fish species. While toxicity studies have been conducted for invertebrates and other fish, LC50s were not determined and reported as greater than the highest test

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<sup>7</sup> <https://www.epa.gov/chemical-research/species-sensitivity-distribution-ssd-toolbox>

concentration or greater than 6PPD-q solubility, indicating that aquatic invertebrates are not sensitive to 6PPD-q.

The 5<sup>th</sup> percentile of the species sensitivity distribution resulted in a value of 0.008 µg/L or 8 ng/L. We support that 8 ng/L will be protective of coho salmon and other aquatic life for the following reasons:

- 8 ng/L is approximately 5-fold lower than the lowest 24-hour LC50 for coho salmon of 41 ng/L (Lo et al. 2023)
- Greer et al. (2023) reported a coho salmon LC5 of 20.7 ng/L and a LC10 of 29.2 ng/L
- Lo et al. (2023) reported a coho salmon LC5 of 16.6 ng/L and a LC10 of 20.8 ng/L
- The most sensitive individuals in the three coho salmon toxicity tests experienced mortality between 10-20 ng/L
- The species sensitivity distribution method is more protective than other options explored, including EPA single species method, genus species sensitivity distribution, and extrapolating 24-hour coho salmon LC50s to 96 hours and applying the single species method

The information presented above indicates that coho salmon (the most sensitive aquatic species known to 6PPD-q) will be adequately protected using a FW acute criterion of 8 ng/L.

Table 54. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic 6PPD-quinone criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	-	-	-
<b>Proposed</b>	0.008 (1-hour)	-	-	-

## Endangered Species Act Consultation

Since no state has adopted a water quality criterion for 6PPD-q, no ESA consultations have been completed on 6PPD-q water quality criteria.

## Criteria Calculations

### Freshwater Acute 6PPD-q Criterion

The data used to calculate the species sensitivity distribution is presented in Table 55. The species sensitivity distribution is presented in Figure 7.

Table 55. Acute toxicity data considered for criteria development for 6PPD-q.

Species	LC50 (µg/L)	Used for Derivation?	Reference
<b>Oncorhynchus kisutch</b>	0.0950	Yes.	Tian et al. 2022
<b>Oncorhynchus kisutch</b>	0.0410	Yes.	Lo et al. 2023
<b>Oncorhynchus kisutch</b>	0.0804	Yes.	Greer et al. 2023
<b>Oncorhynchus mykiss</b>	1.00	Yes.	Brinkman et al. 2022
<b>Oncorhynchus mykiss</b>	1.66	Yes.	Di et al. 2022
<b>Salvelinus fontinalis</b>	0.590	Yes.	Brinkman et al. 2022
<b>Salvelinus leucomaenis Pluvius</b>	0.510	Yes.	Hiki et al. 2022
<b>Danio rerio</b>	139	Yes.	Varshney et al. 2022
<b>Salvelinus alpinus</b>	>14.2	No. LC50 is not definitive.	Brinkman et al. 2022
<b>Acipenser transmontanus</b>	>14.2	No. LC50 is not definitive.	Brinkman et al. 2022
<b>Oryzias latipes</b>	34	No. Non-north American test species.	Hiki et al. 2021
<b>Hyalella azteca</b>	>43	No. LC50 is not definitive.	Hiki et al. 2021
<b>Daphnia magna</b>	>46	No. LC50 is not definitive	Hiki et al. 2021
<b>Danio rerio</b>	>54	No. LC50 is not definitive.	Hiki et al. 2021
<b>Gobiocypris rarus</b>	>500	No. LC50 is not definitive.	Di et al. 2022
<b>Oncorhynchus tshawytscha</b>	>67.3	No. LC50 is not definitive.	Lo et al. 2023
<b>Oncorhynchus tshawytscha</b>	>80	No. LC50 is not definitive.	Greer et al. 2023
<b>Oncorhynchus nerka</b>	>50	No. LC50 is not definitive.	Greer et al. 2023



Species	LC50 (µg/L)	Used for Derivation?	Reference
<b>Salmo salar</b>	>12.2	No. LC50 is not definitive.	Foldvik et al. 2022
<b>Salmo trutta</b>	>12.2	No. LC50 is not definitive.	Foldvik et al. 2022
<b>Pimephales promelas</b>	>39.27	No. LC50 is not definitive.	Anderson-Bain et al. 2023

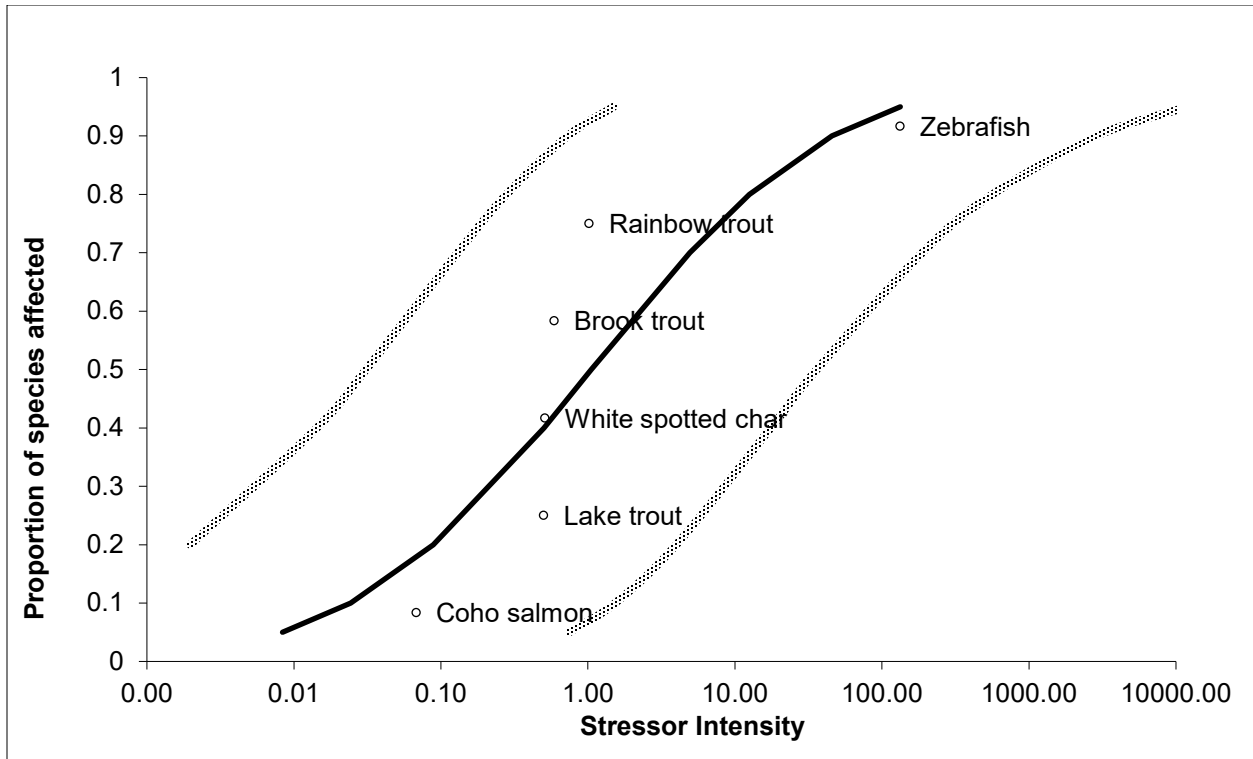


Figure 7. Species sensitivity distribution for fish species LC50 values for 6PPD-q.

## Acrolein

### Summary of Criteria Recommendations and Changes

Washington does not currently have acrolein criteria in the water quality standards. EPA recommended freshwater acute and chronic acrolein criteria in 2009 using 1985 EPA derivation methods. We propose that Washington adopt EPA recommendations for freshwater and acute acrolein criteria (Table 56). EPA does not have saltwater recommendations for acrolein. We are not aware of endangered species protection issues for Washington endangered species in regards to EPA’s recommended acrolein criteria.

Table 56. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic acrolein criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	3 (1-hour)	3 (4-day)	-	-
<b>Proposed</b>	3 (1-hour)	3 (4-day)	-	-

# Aldrin

## Summary of Criteria Recommendations and Changes

Washington’s freshwater and saltwater acute aldrin criteria are less than EPA recommendations (Table 57). We propose to adopt EPA recommendations for freshwater and saltwater acute aldrin criteria. We propose to retain Washington’s current freshwater and saltwater aldrin chronic criteria to ensure existing protections are not removed for aquatic life. We are not aware of endangered species protection issues with EPA recommended aldrin criteria in Region 10 states.

Table 57. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic aldrin criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	2.5 (instantaneous)	0.0019 (24-hour)	0.71 (instantaneous)	0.0019 (24-hour)
<b>EPA</b>	3 (instantaneous)	-	1.3 (instantaneous)	-
<b>Proposed</b>	3 (instantaneous)	No change	1.3 (instantaneous)	No change

# Carbaryl

## Summary of Criteria Recommendations and Changes

Washington does not currently have carbaryl criteria in the water quality standards. EPA recommended freshwater acute, freshwater chronic, and saltwater acute carbaryl criteria in 2012 using 1985 EPA derivation methods. We propose that Washington adopt EPA recommendations for carbaryl in freshwater and saltwater (Table 58). We are not aware of endangered species protection issues with EPA recommended carbaryl criteria in Region 10 states. There are no saltwater chronic recommendations for carbaryl.

Table 58. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic carbaryl criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	2.1 (1-hour)	2.1 (4-day)	1.6 (1-hour)	-
<b>Proposed</b>	2.1 (1-hour)	2.1 (4-day)	1.6 (1-hour)	-

# Chlordane

## Summary of Criteria Recommendations and Changes

Washington’s freshwater and saltwater chlordane criteria are identical to EPA recommendations (Table 59). We are not aware of endangered species protection issues with EPA recommended carbaryl criteria in Region 10 states. We propose no changes to Washington’s current chlordane criteria.

Table 59. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic chlordane criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	2.4 (instantaneous)	0.0043 (24-hour)	0.09 (instantaneous)	0.004 (24-hour)
<b>EPA</b>	2.4 (instantaneous)	0.0043 (24-hour)	0.09 (instantaneous)	0.004 (24-hour)
<b>Proposed</b>	No change	No change	No change	No change

# Chloride

## Summary of Criteria Recommendations and Changes

Washington’s freshwater chloride criteria are identical to EPA recommendations (Table 60). EPA does not have saltwater recommendations for chloride. We are not aware of endangered species protection issues with EPA recommended chloride criteria in Region 10 states. We propose no changes to Washington’s current chloride criteria.

Table 60. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic chloride criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	860000 (1-hour)	230000 (4-day)	-	-
<b>EPA</b>	860000 (1-hour)	230000 (4-day)	-	-
<b>Proposed</b>	No change	No change	-	-

# Chlorine

## Summary of Criteria Recommendations and Changes

Washington’s freshwater and saltwater acute and chronic chlorine criteria are identical to EPA recommendations (Table 61). We are not aware of endangered species protection issues with EPA recommended chlorine criteria in Region 10 states. The Swinomish Tribe BE suggested that the SW acute value may cause adverse effects to ESA species (USEPA, 2022a). However, the effects assessment concentration EPA developed of 12.56 µg/L rounded to two significant digits is 13 µg/L and equal to the saltwater acute chlorine criterion. We found the potential effects on ESA species negligible after considering rounding. Furthermore, the Swinomish Tribe BE has not been evaluated by NOAA/USFWS and do not represent official ESA consultation. We propose no changes to Washington’s current chlorine criteria.

Table 61. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic chlorine criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	19 (1-hour)	11 (4-day)	13 (1-hour)	7.5 (4-day)
<b>EPA</b>	19 (1-hour)	11 (4-day)	13 (1-hour)	7.5 (4-day)
<b>Proposed</b>	No change	No change	No change	No change

# Chlorpyrifos

## Summary of Criteria Recommendations and Changes

Washington’s freshwater and saltwater acute and chronic chlorpyrifos criteria are identical to EPA recommendations (Table 62). We are not aware of endangered species protection issues with EPA recommended chlorpyrifos criteria in Region 10 states. We propose no changes to Washington’s current chlorpyrifos criteria.

Table 62. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic chlorpyrifos criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	0.083 (1-hour)	0.041 (4-day)	0.011 (1-hour)	0.0056 (4-day)
<b>EPA</b>	0.083 (1-hour)	0.041 (4-day)	0.011 (1-hour)	0.0056 (4-day)
<b>Proposed</b>	No change	No change	No change	No change

# Cyanide

## Summary of Criteria Recommendations and Changes

The proposed freshwater acute and chronic cyanide criteria are more stringent than EPA recommendations (Table 63). The freshwater criteria are based on any new science since EPA last updated the cyanide criteria in 1995 (USEPA, 1996) and used the 1<sup>st</sup> percentile of the toxicity data distribution to ensure protection of Washington’s endangered species. The proposed cyanide saltwater criteria are identical to EPA recommendations.

Table 63. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic cyanide criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	22 (1-hour)	5.2 (4-day)	1 (1-hour)	1 (4-day)
<b>EPA</b>	22 (1-hour)	5.2 (4-day)	1 (1-hour)	1 (4-day)
<b>Proposed</b>	12 (1-hour)	2.7 (4-day)	No change	No change

## Endangered Species Act Consultation

### Idaho

There were jeopardy calls for freshwater acute (22 µg/L) and chronic (5.2 µg/L) cyanide criteria in Idaho (NMFS, 2014; USFWS, 2015). The jeopardy calls were for bull trout, a species relevant to Washington. The Idaho BiOps specifically state:

“The proposed acute and chronic criteria can expose listed salmonids to harmful cyanide concentrations under specific situations. The acute criterion cannot be considered to be reliably protective when water temperatures drop to about 6°C or lower. Further, Leduc (1984) found that cyanide concentrations at the chronic criterion in water colder than 6°C may be associated with chronic toxicity effects. Temperatures in streams within the action area routinely drop below 6°C.”

“The proposed acute criterion for cyanide (22 µg/L) is likely to cause mortality of exposed bull trout; an only slightly higher concentration of cyanide at 27 µg/L killed 50 percent of exposed brook trout. In separate reviews, USFWS (2010) and NMFS (2010b) evaluated the same cyanide criteria from a national perspective. Both described scenarios in which impaired reproduction from diverse species was extrapolated to effects on listed anadromous salmonids, through the use of interspecies correlation estimates of acute toxicity. Under these scenarios, adverse effects were considered by USFWS and NMFS as likely to jeopardize the continued existence of a variety of species, including Snake River salmon and steelhead.”

“Data on the long-term exposure effects of cyanide on the brook trout and the rainbow trout show reduced egg production for the brook trout, and reduced growth and swimming performance for rainbow trout at cyanide concentrations at or below the proposed chronic criterion.”

“The proposed criteria for cyanide are likely to create habitat conditions that impair or preclude the capability of the critical habitat to provide for the normal reproduction, growth, movement, and survival of the bull trout within approximately 44 percent of the streams and 35 percent of the lakes and reservoirs designated range-wide as critical habitat. On that basis, implementation of the proposed criteria for cyanide are likely to appreciably impair or preclude the recovery support function (persistent core area populations of the bull trout) of critical habitat within a major portion of the designated area.”

“Implementation of the proposed criteria for cyanide is likely to cause mortality, reduced swimming performance, reduced growth, and reduced egg production of exposed individuals within 39 percent of the sturgeon’s range. Similar effects are expected to exposed individuals of fish species that sturgeon prey on. These impacts are likely to reduce reproduction and numbers of the Kootenai River white sturgeon within 39 percent of its range. Given the scale and magnitude of anticipated effects, implementation of the proposed criteria for cyanide are likely to impede natural reproduction and achievement of a stable or increasing sturgeon population within a major portion of its range.”

“Implementation of the proposed criteria for cyanide is likely to create habitat conditions within the entire area of designated critical habitat for the Kootenai River white sturgeon that cause mortality, reduced swimming performance, reduced growth, and reduced egg production of exposed individuals of the sturgeon. Similar effects are expected to exposed individuals of fish species that sturgeon prey on. The impacts of these altered habitat conditions are likely to reduce the reproduction and numbers of the Kootenai River white sturgeon within the critical habitat.”

## Criteria Calculations

### Freshwater Acute Cyanide Criterion

The data used to derive the freshwater acute cyanide criterion is presented in Table 64. New studies that met data acceptability requirements are presented in Table 65. Studies used in previous EPA derivations but not used in this derivation are found in Table 66. The proposed freshwater acute criterion for cyanide was derived using 14 GMAVs and the 1<sup>st</sup> percentile of the toxicity data distribution. Calculation results are as follows:

FAV = 23.07

CMC = 11.53 µg/L

**Acute criterion = 12 µg/L (rounded to two significant digits)**

Table 64. Freshwater acute toxicity data used for criteria derivation.

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
1	42.61	Daphnia magna	19
		Daphnia pulex	95.55
2	44.73	Oncorhynchus mykiss	44.73
3	73	Salmo salar	73
4	85.8	Salvelinus fontinalis	85.8
5	92.64	Perca flavescens	92.64
6	100.3	Lepomis macrochirus	99.28
7	102	Pomoxis nigromaculatus	102
7	102	Micropterus salmoides	102
9	125.1	Pimephales promelas	125.1
10	167	Gammarus pseudolimnaeus	167
11	426	Pternoarcys dorsata	426
12	432	Physa heterostropha	432
13	500	Gambusia affinis	500
14	2326	Asellus communis	2326

Table 65. New freshwater acute studies that met data acceptability requirements since EPA last updated cyanide criteria (S = static, R = static renewal, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L)	Used in Derivation?	Reference
Salmo salar	R, M	90	No. Other study used flow through design with measured concentrations.	Tryland & Grande 1983
Salmo salar	FT, M	73	Yes.	Alabaster 1983
Daphnia magna	FT, U	19	Yes.	Jaafarzadeh et al. 2013
Lepomis macrochirus	FT, M	110	Yes.	Van der Schalie et al. 2004

Table 66. Freshwater acute studies not used from previous EPA criteria derivations.

Species	SMAV (µg/L)	Reason	Reference
Poecilia reticulata	147	Non-North American species	USEPA, 1996
Carassius auratus	318	Non-North American species	USEPA, 1996



## Freshwater Chronic Cyanide Criterion

There was not adequate toxicity data available to calculate a chronic cyanide criterion using the eight-family method, and therefore, an ACR was used. We did not find any new ACRs available since EPA last updated the freshwater cyanide criteria in 1995 aquatic life updates. We decided to use the FACR developed in EPA's 1995 cyanide derivation document of 8.57 (USEPA, 1996). We used the FAV derived from the proposed acute criterion using the 1<sup>st</sup> percentile to calculate the chronic criterion. Calculations results were as follows:

FACR = 8.57

FAV = 23.07

CCC = 2.6920

**Chronic criterion = 2.7 µg/L (rounded to two significant digits)**

## Saltwater Acute and Chronic Cyanide Criteria

No changes are proposed to the saltwater acute and chronic cyanide criteria. Washington's current saltwater cyanide criteria are identical to EPA recommendations and to our knowledge there are no endangered species protection concerns in Washington.

## Demeton

### Summary of Criteria Recommendations and Changes

Washington does not currently have demeton criteria in the water quality standards. EPA has recommended freshwater chronic and saltwater chronic demeton criteria since 1985. We propose that Washington adopt EPA recommendations for freshwater and saltwater chronic demeton criteria (Table 67). We are not aware of endangered species protection issues with the EPA recommended demeton criteria in Region 10 states.

Table 67. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic demeton criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	0.1 (-)	-	0.1 (-)
<b>Proposed</b>	-	0.1 (4-day)	-	0.1 (4-day)

## Diazinon

### Summary of Criteria Recommendations and Changes

Washington does not currently have diazinon criteria in the water quality standards. EPA has recommendations for freshwater acute, freshwater chronic, saltwater acute, and saltwater chronic diazinon criteria. We propose that Washington adopt EPA recommendations for diazinon in freshwater and saltwater (Table 68). We are not aware of endangered species protection issues with EPA recommended diazinon criteria in Region 10 states.

Table 68. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic diazinon criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	0.17 (1-hour)	0.17 (4-day)	0.82 (1-hour)	0.82 (4-day)
<b>Proposed</b>	0.17 (1-hour)	0.17 (4-day)	0.82 (1-hour)	0.82 (4-day)

## Dieldrin

### Summary of Criteria Recommendations and Changes

The freshwater dieldrin criteria were updated by EPA in 1995 (USEPA, 1996). We propose to adopt EPA recommendations for freshwater dieldrin criteria (Table 69). The saltwater dieldrin criteria were not updated in 1995 and uses pre-1985 EPA methods. Washington's current saltwater dieldrin criteria matches EPA recommendations, and therefore, no changes were necessary.

Table 69. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic dieldrin criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	2.5 (instantaneous)	0.0019 (24-hour)	0.71 (instantaneous)	0.0019 (24-hour)
<b>EPA</b>	0.24 (1-hour)	0.056 (4-day)	0.71 (instantaneous)	0.0019 (24-hour)
<b>Proposed</b>	0.24 (1-hour)	0.056 (4-day)	No change	No change

## Endosulfan (alpha)

### Summary of Criteria Recommendations and Changes

Washington has freshwater and saltwater acute and chronic endosulfan criteria that are identical to EPA recommendations (Table 70). We are not aware of endangered species protection issues with EPA recommendations in Region 10 states. Washington's endosulfan criteria do not specify stereochemistry (i.e., alpha and beta isomers). We intend to clarify that Washington's criteria include both alpha and beta configurations, but we propose no changes to the freshwater and saltwater numeric criteria.

Table 70. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic endosulfan (alpha) criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
<b>EPA</b>	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
<b>Proposed</b>	No change	No change	No change	No change

## Endosulfan (beta)

### Summary of Criteria Recommendations and Changes

Washington has freshwater and saltwater acute and chronic endosulfan criteria that are identical to EPA recommendations (Table 71). We are not aware of endangered species protection issues with EPA recommendations in Region 10 states. Washington's endosulfan criteria do not specify stereochemistry (i.e., alpha and beta isomers). We intend to clarify that Washington's criteria include both alpha and beta configurations, but we propose no changes to the freshwater and saltwater numeric criteria.

Table 71. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic endosulfan (beta) criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
<b>EPA</b>	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
<b>Proposed</b>	No change	No change	No change	No change

## Endrin

### Summary of Criteria Recommendations and Changes

The freshwater endrin criteria were updated by EPA in 1995 (USEPA, 1996). We propose to adopt EPA recommendations for freshwater endrin criteria (Table 72). The saltwater endrin criteria were not updated in 1995 and uses pre-1985 EPA methods. Washington's current saltwater endrin criteria matches EPA recommendation, and therefore, no changes were necessary.

Table 72. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic endrin criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	0.18 (instantaneous)	0.0023 (24-hour)	0.037 (instantaneous)	0.0023 (24-hour)
<b>EPA</b>	0.086 (1-hour)	0.036 (4-day)	0.037 (instantaneous)	0.0023 (24-hour)
<b>Proposed</b>	0.086 (1-hour)	0.036 (4-day)	No change	No change

## gamma-BHC (Lindane)

### Summary of Criteria Recommendations and Changes

We propose to adopt EPA recommendations for freshwater acute gamma-BHC (lindane; Table 73). EPA removed the freshwater chronic gamma-BHC criterion because EPA disqualified some of the data used to derive the chronic criterion in their 1995 update (Table 73; USEPA, 1996). However, we have not changed the FW chronic lindane criteria because of existing protections the criteria provides for aquatic life. EPA did not update the saltwater gamma-BHC criterion in 1995, and their current recommendations use pre-1985 EPA methods. Washington's current saltwater gamma-BHC criteria matches EPA recommendations, and therefore, no changes were necessary.

Table 73. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic gamma-BHC criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	2 (instantaneous)	0.08 (24-hour)	0.16 (instantaneous)	-
<b>EPA</b>	0.95 (1-hour)	-	0.16 (instantaneous)	-
<b>Proposed</b>	0.95 (1-hour)	No change	No change	-

## Guthion

### Summary of Criteria Recommendations and Changes

Washington does not currently have guthion criteria in the water quality standards. EPA recommended freshwater and saltwater chronic guthion criteria. We propose that Washington adopt EPA recommendations for freshwater and saltwater chronic guthion criteria (Table 74). We are not aware of endangered species protection issues with EPA recommended guthion criteria in Region 10 states.

Table 74. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic guthion criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	0.01 (-)	-	0.01 (-)
<b>Proposed</b>	-	0.01 (4-day)	-	0.01 (4-day)

## Heptachlor

### Summary of Criteria Recommendations and Changes

Washington’s freshwater and saltwater acute and chronic heptachlor criteria are identical to EPA recommendations. We are not aware of endangered species protection issues with EPA recommended heptachlor criteria in Region 10 states. We propose no changes to Washington’s current heptachlor criteria (Table 75).

Table 75. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic heptachlor criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	0.52 (instantaneous)	0.0038 (24-hour)	0.053 (instantaneous)	0.0036 (24-hour)
<b>EPA</b>	0.52 (instantaneous)	0.0038 (24-hour)	0.053 (instantaneous)	0.0036 (24-hour)
<b>Proposed</b>	No change	No change	No change	No change

## Heptachlor epoxide

### Summary of Criteria Recommendations and Changes

Washington does not currently have heptachlor epoxide criteria in the water quality standards. EPA has recommended freshwater acute and chronic and saltwater acute and chronic heptachlor criteria. EPA recommendations for heptachlor epoxide are based on toxicity studies for heptachlor. Heptachlor is the parent component of the metabolite heptachlor epoxide. Metabolites or degrades of parent compounds do not have the same chemical structure and can result in toxicity greater or less than a parent compound. There is uncertainty regarding aquatic life species sensitivity to heptachlor epoxide. We propose not to adopt EPA recommendations and to apply Washington’s narrative toxics criteria when needed (Table 76). EPA recommendations for heptachlor epoxide does not use EPA 1985 standard methods for deriving toxics and are based on limited toxicity studies.

Table 76. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic heptachlor epoxide criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	0.52 (instantaneous)	0.0038 (24-hour)	0.053 (instantaneous)	0.0036 (24-hour)
<b>Proposed</b>	-	-	-	-

## Malathion

### Summary of Criteria Recommendations and Changes

Washington does not currently have malathion criteria in the water quality standards. EPA has recommendations for freshwater and saltwater chronic malathion criteria. We propose that Washington adopt EPA recommendations for malathion in freshwater and saltwater (Table 77). We are not aware of endangered species protection issues with EPA recommended malathion criteria in Region 10 states.

Table 77. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic malathion criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	0.1 (-)	-	0.1 (-)
<b>Proposed</b>	-	0.1 (4-day)	-	0.1 (4-day)

## Methoxychlor

### Summary of Criteria Recommendations and Changes

Washington does not currently have methoxychlor criteria in the water quality standards. EPA has recommendations for freshwater and saltwater chronic methoxychlor criteria. We propose that Washington adopt EPA recommendations for methoxychlor in freshwater and saltwater (Table 78). We are not aware of endangered species protection issues with EPA recommended methoxychlor criteria in Region 10 states.

Table 78. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic methoxychlor criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	0.03 (-)	-	0.03 (-)
<b>Proposed</b>	-	0.03 (4-day)	-	0.03 (4-day)

## Mirex

### Summary of Criteria Recommendations and Changes

Washington does not currently have methoxychlor criteria in the water quality standards. EPA has recommendations for freshwater and saltwater chronic methoxychlor criteria. We propose that Washington adopt EPA recommendations for methoxychlor in freshwater and saltwater (Table 79). We are not aware of endangered species protection issues with EPA recommended methoxychlor criteria in Region 10 states.

Table 79. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic mirex criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	0.001 (-)	-	0.001 (-)
<b>Proposed</b>	-	0.001 (4-day)	-	0.001 (4-day)

## Nonylphenol

### Summary of Criteria Recommendations and Changes

Washington does not currently have nonylphenol criteria. EPA has recommendations for freshwater and saltwater nonylphenol criteria (USEPA, 2005; Table 80). The Swinomish Tribe BE suggests there could be a LAA but there are no completed BiOps in other Region 10 states. We examined the new science since EPA last updated nonylphenol criteria in 2005 and it resulted in a higher criterion value. We propose to match EPA recommendations for nonylphenol because there is not an existing BiOp with a LAA and EPA recommendations are intended to be protective of aquatic species (Table 80).

Table 80. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic nonylphenol criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	28 (1-hour)	6.6 (4-day)	7 (1-hour)	1.7 (4-day)
<b>Proposed</b>	28 (1-hour)	6.6 (4-day)	7 (1-hour)	1.7 (4-day)

### Endangered Species Act Consultation

We are not aware of any completed nonylphenol ESA consultations in EPA Region 10 states that are relevant to this rulemaking. EPA’s biological evaluation for the Swinomish Tribe suggested a likely to adversely affect determination but a BiOp has not been completed.

### Swinomish Tribe Biological Evaluation

Below is an explanation of potential effects of the nonylphenol criteria in the Swinomish Tribe BE (USEPA, 2022a):



“The acute toxicity of nonylphenol in freshwaters was evaluated in fish only. The PCLTV for fish was 13.5 µg/L for mortality to *Lepomis macrochirus* of two tested fish species. As the lowest PCLTV of 13.5 µg/L was lower than the criterion of 28.0 µg/L, the criterion may not be protective of prey species relevant to listed species. Therefore, EPA calculated the percent of species with toxicity values less than the criterion and found that because 2 of 2 (100%; >20% threshold) species toxicity values were greater than the criterion, exposure at the level of the acute freshwater criterion is **likely to result in reductions** in the community of prey species.”

“The nonylphenol marine acute criterion LAA call was not based on effects to any of the ESA listed fish species within the action area. Instead it was based on the 5th percentile of a SSD of eight 96 hour LC50 values for marine fish, five of which were found in a review of the literature published since the EPA (USEPA, 2005a) nonylphenol criteria document was issued. The 5th percentile of the fitted SSD (12.18 µg/L) divided by 2.27 resulted in a calculated acute toxicity threshold value of 5.37 µg/L, lower than the marine acute nonylphenol criterion of 7 µg/L. The same considerations apply to the chronic criterion, which was derived from the acute criterion. The nonylphenol chronic effects assessment concentration (0.6614 µg/L) is lower than the marine chronic nonylphenol criterion (1.0 µg/L). Our conclusion is that exposure at the level of the marine chronic nonylphenol criterion is likely to adversely affect rainbow trout (steelhead), Chinook salmon, chum salmon, bull trout, bocaccio and yelloweye rockfish.”

## Parathion

### Summary of Criteria Recommendations and Changes

Washington’s freshwater acute and chronic parathion criteria are identical to EPA recommendations. EPA does not have parathion saltwater criteria recommendations. We are not aware of endangered species protection issues with EPA recommended parathion criteria in Region 10 states. We propose no changes to Washington’s current parathion criteria (Table 81).

Table 81. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic parathion criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	0.065 (1-hour)	0.013 (4-day)	-	-
<b>EPA</b>	0.065 (1-hour)	0.013 (4-day)	-	-
<b>Proposed</b>	No change	No change	-	-

# Pentachlorophenol

## Summary of Criteria Recommendations and Changes

The proposed freshwater pentachlorophenol criteria accounts for endangered species protection levels by incorporating the new science available since EPA last updated the criteria in 1995 (USEPA, 1996). The proposed freshwater pentachlorophenol criteria are more stringent than EPA recommendations (Table 82). The saltwater pentachlorophenol criteria are more stringent than EPA recommendations to account for endangered species protection levels. The pentachlorophenol saltwater criteria were calculated using new science available since EPA last updated the criteria in 1986.

Table 82. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic pentachlorophenol criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	20* (1-hour)	13* (4-day)	13 (1-hour)	7.9 (4-day)
<b>EPA</b>	19* (1-hour)	15* (4-day)	13 (1-hour)	7.9 (4-day)
<b>Proposed</b>	9.4* (1-hour)	4.7* (4-day)	No change	6.7 (4-day)

\* pH dependent criteria (numeric values based on pH of 7.8)

## Endangered Species Act Consultation

### Oregon

The Oregon NMFS BiOp reported likely to adversely affect determinations for salmonids for EPA’s freshwater acute (19 µg/L) and chronic (15 µg/L) criteria and saltwater chronic (7.9 µg/L) criterion (NMFS, 2012). The Oregon BiOp stated:

“The available evidence for pentachlorophenol indicates that listed species exposed to waters equal to the acute or chronic criteria concentrations will suffer acute and chronic toxic effects including mortality (moderately-high-intensity) and reduced growth (moderate intensity).”

“In summary, the available evidence for saltwater PCP indicates that listed species exposed to waters equal to the chronic criterion concentrations will suffer chronic toxic effects including sublethal effects (moderately-high-intensity).”

“Based on the direct mortality population modeling results, juvenile salmon and steelhead exposed to aluminum, ammonia, arsenic, lindane, cadmium, chromium (III), chromium (VI), copper, dieldrin, endosulfan-alpha, endosulfan-beta, endrin, heptachlor epoxide, lead, nickel, pentachlorophenol, selenium, silver, tributyltin, and zinc is predicted to result in mortality at the population level—relative to the baseline population model.”

## Swinomish Tribe Biological Evaluation

The 2022 Swinomish BE indicated “likely to adversely affect” determinations for the saltwater acute pentachlorophenol criterion (USEPA, 2022a). More specifically it states:

“Dividing the Pacific herring 25.3 µg/L SMAV by 2.27 to convert this LC50 to the lowest LCLOW or minimum acute effect concentration for any marine fish species yields a threshold acute effect concentration of 11.1 µg/L. This concentration is lower than the pentachlorophenol marine acute criterion of 13 µg/L. Assuming that this threshold acute effect concentration is the same as that for all ESA listed fish species in the marine portions of the action area, exposure at the level of the marine pentachlorophenol acute criterion of 13 µg/L is likely to adversely affect rainbow trout (steelhead), Chinook salmon, chum salmon, bull trout, bocaccio and yelloweye rockfish.”

## Criteria Calculations

### Freshwater Acute Pentachlorophenol Criterion

The data used to derive the freshwater acute pentachlorophenol criterion are presented in Table 83. New studies that met data acceptability requirements are presented in Table 84. Studies used in previous EPA derivations but not used in this derivation are found in Table 85. The proposed freshwater acute criterion for pentachlorophenol was derived using 66 GMAVs. Calculation results are as follows:

FAV = 5.107 (pH of 6.5)

CMC = 2.554 µg/L (pH of 6.5)

**CMC =  $e^{[1.005(\text{pH}) - 5.595]}$**

**Acute criterion = 9.4 µg/L (at pH = 7.8; rounded to two significant digits)**

Table 83. Freshwater acute toxicity data (normalized to pH of 6.5) used for criteria derivation.

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
1	1.208	Plationus platulus	1.208
2	2.745	Keratella cochlearis	2.745
3	3.660	Lecane quadridentata	3.660
4	7.321	Triphysaria pusilla	7.321
5	7.840	Acipenser brevirostrum	10.371
		Acipenser oxyrinchus	<5.926
6	8.803	Hyalella azteca	8.803
7	12.55	Entosphenus tridentatus	12.55
8	21.96	Elliptio dilatate	21.96
9	22.93	Lithobates sphenoccephalus	22.93
10	26.54	Ictalurus punctatus	26.54
11	28.69	Oncorhynchus mykiss	33.63
		Oncorhynchus kisutch	31.82

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
		Oncorhynchus nerka	32.85
		Oncorhynchus tshawytscha	25.85
		Oncorhynchus apache	19.93
		Oncorhynchus clarkii	30.79
12	33.91	Rana catesbeiana	33.91
13	34.13	Salvelinus fontinalis	34.13
14	42.40	Lepomis macrochirus	42.40
15	51.56	Simocephalus vetulus	51.56
16	58.18	Chaetocorophium lucasi	58.18
17	58.47	Varichaeta pacifica	58.47
18	60.43	Aplexa hypnorum	60.43
19	60.5	Gambusia affinis	60.5
20	60.61	Anaxyrus boreas boreas	60.61
21	65.80	Pimephales promelas	65.80
22	76.74	Ceriodaphnia dubia	87.73
		Ceriodaphnia reticulata	67.13
23	91.48	Gammarus pseudolimnaeus	91.48
24	95.17	Asplanchna girodi	95.17
25	105.0	Micropterus salmoides	105.0
26	105.1	Leptodea fragilis	105.1
27	109.8	Philodina acuticornis	109.8
28	120.0	Brachionus calyciflorus	120.0
29	122.1	Daphnia pulex	90.83
		Daphnia magna	78.51
		Daphnia carinata	255.1
30	128.4	Deleatidium sp.	128.4
31	132.1	Physa gyrina	132.1
32	146.7	Utterbackia imbecillis	146.7
33	151.3	Corbicula fluminea	151.3
34	155.8	Ligumia subrostrate	155.8
35	155.9	Branchiura sowerbyi	155.9
36	161.2	Megalonaias nervosa	161.2
37	172.1	Crangonyx pseudogracilis	172.1
38	182.5	Limnodrilus hoffmeisteri	182.5
39	212.3	Heteropneustes fossilis	212.3
40	224.2	Tubifex tubifex	224.2
41	234.3	Clarias batrachus	234.3
42	246.3	Lampsilis cardium	240.9
		Lampsilis siliquoidea	251.8
43	281.9	Channa punctatus	281.9

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
44	306.7	Jordanella floridae	306.7
45	308.8	Lumbriculus variegatus	308.8
46	317.5	Quistradrilus multisetosus	317.5
47	361.6	Spirosperma ferox	239.5
		Spirosperma nikoiskyl	545.8
48	403.2	Gillia altilis	403.2
49	408.2	Stylodrilus heringianus	408.2
50	417.7	Rhyacodrilus montana	417.7
51	484.3	Prionchulus punctatus	484.3
52	492.3	Sphaerium novaezelandiae	492.3
53	805.6	Tanais standfordi	805.6
54	1145	Tobrilus gracilis	1145
55	1585	Dorylaimus stagnalis	1585
56	1672	Aporcelaimellus obtusicaudatus	1672
57	2818	Tylenchus elegans	2818
58	3881	Chironomus riparius	3881
59	8408	Plectus acuminatus	8408
60	10610	Sepedon fuscipennis	10610
61	11621	Diplogasteritus species	11621
62	11260	Tanytarsus dissimilis	11260
63	11914	Caenorhabditis elegans	11914
64	>14968	Rhabditis species	>14968
65	>14968	Cephalobus persegnis	>14968
66	35872	Culex pipiens fatigans	35872

\* Normalized to pH of 6.5

Table 84. New freshwater acute studies that met data acceptability requirements since EPA last updated pentachlorophenol criteria (S = static, R = static renewal, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L)	pH	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Entosphenus tridentatus</b>	FT, M	31	7.4	12.55	Yes.	Anderson et al. 2010
<b>Corbicula fluminea</b>	R, M	250	7	151.3	Yes.	Basack et al. 1997
<b>Lithobates sphenoccephalus</b>	S, M	140	8.3	22.93	Yes.	Bridges et al. 2002
<b>Anaxyrus boreas boreas</b>	S, M	370	8.3	60.61	Yes.	Bridges et al. 2002
<b>Lepomis macrochirus</b>	S, M	192	8.3	31.45	Yes.	Bridges et al. 2002
<b>Oncorhynchus mykiss</b>	S, M	160	8.2	28.98	Yes.	Dwyer et al. 2000
<b>Pimephales promelas</b>	S, M	250	8.3	40.95	Yes.	Dwyer et al. 2000
<b>Oncorhynchus apache</b>	S, M	110	8.2	19.93	Yes.	Dwyer et al. 2000
<b>Oncorhynchus clarkii</b>	S, M	>10	8.2	>1.811	No. LC50 10x more sensitive than other studies using the same species and LC50 is a "greater than value."	Dwyer et al. 2000
<b>Oncorhynchus clarkii</b>	S, M	170	8.2	30.79	Yes.	Dwyer et al. 2000
<b>Gila elegans</b>	S, M	230	8.3	37.68	Yes.	Dwyer et al. 2000
<b>Ptychocheilus lucius</b>	S, M	240	8.3	39.32	Yes.	Dwyer et al. 2000
<b>Xyrauchen texanus</b>	S, M	280	8.3	45.87	Yes.	Dwyer et al. 2000
<b>Acipenser brevirostrum</b>	S, M	70	8.4	10.37	Yes.	Dwyer et al. 2000
<b>Acipenser oxyrinchus</b>	S, M	<40	8.4	<5.926	Yes.	Dwyer et al. 2000

Species	Method	LC50 (µg/L)	pH	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Hyalella azteca</b>	R, U	4	8.0	0.8859	Yes.	McNulty et al. 1999
<b>Leptodea fragilis</b>	S, M	580	8.2	105.1	Yes.	Milam et al. 2005
<b>Lampsilis cardium</b>	S, M	1330	8.2	240.9	Yes.	Milam et al. 2005
<b>Lampsilis siliquoidea</b>	S, M	1390	8.2	251.8	Yes.	Milam et al. 2005
<b>Megaloniais nervosa</b>	S, M	890	8.2	161.2	Yes.	Milam et al. 2005
<b>Ligumia subrostrate</b>	S, M	860	8.2	155.8	Yes.	Milam et al. 2005
<b>Utterbackia imbecillis</b>	S, M	810	8.2	146.7	Yes.	Milam et al. 2005
<b>Ceriodaphnia dubia</b>	S, M	470	8.2	85.13	Yes.	Milam et al. 2005
<b>Daphnia magna</b>	S, M	680	8.2	123.2	Yes.	Milam et al. 2005
<b>Chironomus riparius</b>	R, U	1421	6.8	1051	Yes.	Morales et al. 2014
<b>Daphnia magna</b>	S, U	150	7.3	67.13	Yes.	Oda et al. 2006
<b>Brachionus calyciflorus</b>	S, U	262	7.5	95.90	Yes.	Preston et al. 2001
<b>Brachionus calyciflorus</b>	S, U	1310	7.5	479.5	Yes.	Radix et al. 2000
<b>Daphnia carinata</b>	S, U	570	7.3	255.1	Yes.	Willis 1999
<b>Ceriodaphnia dubia</b>	S, U	202	7.3	90.40	Yes.	Willis 1999
<b>Ceriodaphnia pulchella</b>	S, U	1790	7.3	801.1	Yes.	Willis 1999
<b>Simocephalus vetulus</b>	S, U	140	7.3	62.65	Yes.	Willis 1999
<b>Daphnia magna</b>	S, U	187	7.3	83.69	Yes.	Willis 1999
<b>Deleatidium sp.</b>	S, U	287	7.3	128.4	Yes.	Willis 1999
<b>Chaetocorophium lucasi</b>	S, U	130	7.3	58.18	Yes.	Willis 1999
<b>Sphaerium novaezelandiae</b>	S, U	1100	7.3	492.3	Yes.	Willis 1999

Species	Method	LC50 (µg/L)	pH	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Lumbriculus variegatus</b>	S, U	690	7.3	308.8	Yes.	Willis 1999
<b>Tanais standfordi</b>	S, U	1800	7.3	805.6	Yes.	Willis 1999
<b>Simocephalus vetulus</b>	S, M	140	7.8	37.91	Yes.	Willis et al. 1995
<b>Pimephales promelas</b>	FT, M	564	7.8	152.7	Yes. Combined with other LC50 values from Broderius et al. 1995.	Broderius et al. 1995
<b>Pimephales promelas</b>	FT, M	449	7.8	121.6	Yes. Combined with other LC50 values from Broderius et al. 1995.	Broderius et al. 1995
<b>Pimephales promelas</b>	FT, M	350	7.8	94.77	Yes. Combined with other LC50 values from Broderius et al. 1995.	Broderius et al. 1995
<b>Heteropneustes fossilis</b>	FT, M	580	7.5	212.3	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
<b>Clarias batrachus</b>	FT, M	640	7.5	234.3	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
<b>Channa punctatus</b>	FT, M	770	7.5	281.9	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
<b>Culex pipiens</b>	FT, M	98000	7.5	35872	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
<b>Prionchulus punctatus</b>	S, M	293	6.0	484.3	Yes.	Kammenga et al. 1994
<b>Dorylaimus stagnalis</b>	S, M	958.8	6.0	1585	Yes.	Kammenga et al. 1994
<b>Aporcelaimellus obtusicaudatus</b>	S, M	1012	6.0	1672	Yes.	Kammenga et al. 1994
<b>Tobrilus gracilis</b>	S, M	692.5	6.0	1145	Yes.	Kammenga et al. 1994
<b>Plectus acuminatus</b>	S, M	5087	6.0	8408	Yes.	Kammenga et al. 1994
<b>Cephalobus persegnis</b>	S, M	9056	6.0	>14968	Yes.	Kammenga et al. 1994



Species	Method	LC50 (µg/L)	pH	Normalized LC50* (µg/L)	Used in Derivation?	Reference
<b>Rhabditis sp.</b>	S, M	9056	6.0	>14968	Yes.	Kammenga et al. 1994
<b>Diplogasteritus sp.</b>	S, M	7031	6.0	11621	Yes.	Kammenga et al. 1994
<b>Tylenchus elegans</b>	S, M	1705	6.0	2818	Yes.	Kammenga et al. 1994
<b>Philodina acuticornis</b>	S, U	300	7.5	109.8	Yes.	McDaniel & Snell 1999
<b>Asplanchna girodi</b>	S, U	260	7.5	95.17	Yes.	McDaniel & Snell 1999
<b>Asplanchna girodi</b>	S, U	160	7.5	58.57	Yes.	McDaniel & Snell 1999
<b>Elliptio dilatate</b>	S, U	60	7.5	21.96	Yes.	McDaniel & Snell 1999
<b>Triphysaria pusilla</b>	S, U	20	7.5	7.321	Yes.	McDaniel & Snell 1999
<b>Lecane quadrientata</b>	S, U	10	7.5	3.660	Yes.	McDaniel & Snell 1999
<b>Keratella cochelaris</b>	S, U	7.5	7.5	2.745	Yes.	McDaniel & Snell 1999
<b>Plationus patulus</b>	S, U	3.3	7.5	1.208	Yes.	McDaniel & Snell 1999
<b>Brachionus calyciflorus</b>	S, U	210	7.5	76.87	Yes.	Preston et al. 1999
<b>Caenorhabditis elegans</b>	S, M	44000	7.8	11914	Yes.	Cressman & Williams 1997

\* Normalized to pH of 6.5

Table 85. Freshwater acute studies not used from previous EPA derivations.

Species	SMAV (µg/L)	Reason	Reference
<b>Cyprinus carpio</b>	4.355	Non-North American species	USEPA, 1996
<b>Carassius auratus</b>	65.53	Non-North American species	USEPA, 1996
<b>Poecilia reticulata</b>	195.4	Non-North American species	USEPA, 1996
<b>Orconectes immunis</b>	>43920	Non-North American species	USEPA, 1996

### Freshwater Chronic Pentachlorophenol Criterion

There was inadequate freshwater chronic pentachlorophenol data to calculate a chronic criterion using the eight-family method. The FACR of 2.608 was previously used to calculate the freshwater chronic pentachlorophenol criterion as presented in 1995 updates to aquatic life (USEPA, 1996). Additional chronic pentachlorophenol ACRs were available since EPA’s last update. The newly calculated FACR used to derive the chronic pentachlorophenol criterion is 4.044 (Table 86). Calculation results are as follows:

$$FAV = 5.107 \text{ (pH of 6.5)}$$

$$FACR = 4.044$$

$$CCC = FAV / FACR$$

$$CCC = 1.263 \text{ ug/L (pH of 6.5)}$$

$$CCC = e^{1.005(pH) - 6.299}$$

**Chronic criterion = 4.7 µg/L (at pH = 7.8; rounded to two significant digits)**

Table 86. Acute to chronic ratios (ACR) used in chronic criterion derivation.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Daphnia magna</b>	600	240	2.5	2.5	USEPA, 1986b
<b>Simocephalus vetulus</b>	160	177.2	0.9029		USEPA, 1986b
<b>Simocephalus vetulus</b>	196	221.2	0.8861	0.8944	USEPA, 1986b

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
<b>Oncorhynchus mykiss</b>	66	14.46	4.564	4.564	USEPA, 1986b
<b>Pimephales promelas</b>	224.9	57.25	3.928		USEPA, 1986b
<b>Pimephales promelas</b>	95	23.89	3.977		USEPA, 1986b
<b>Pimephales promelas</b>	218	40.08	5.439		USEPA, 1986b
<b>Pimephales promelas</b>	261	48.99	5.328		USEPA, 1986b
<b>Pimephales promelas</b>	378	89.23	4.236	4.701	USEPA, 1986b
<b>Cyprinodon variegatus</b>	442	64.31	6.873	6.873	USEPA, 1986b
<b>Lymnaea stagnalis</b>	170	27.91	6.091	6.091	Besser et al. 2009
<b>Pyrgulopsis idahoensis</b>	143	16.25	8.801	8.801	Besser et al. 2009
<b>Geometric mean</b>				4.044	

\* Geometric mean of ACRs were calculated for similar species preceding the final acute chronic ratio calculation

### Saltwater Acute Pentachlorophenol Criterion

The data used to derive the saltwater acute nonylphenol criterion are presented in Table 87. New studies that met data acceptability requirements are presented in Table 88. The proposed saltwater acute criterion for pentachlorophenol was derived using 20 GMAVs. Calculation results are as follows:

FAV = 26.87

CMC = 13.43

**Acute criterion = 13 µg/L (rounded to two significant digits)**

Table 87. Saltwater acute toxicity data used for criteria derivation.

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
1	25.29	<i>Clupea pallasii</i>	25.29
2	40.83	<i>Crassostrea gigas</i>	40.83
3	53.2	<i>Lagodon rhomboides</i>	53.2
4	62.81	<i>Pseudodiaptomus coronatus</i>	62.81
5	96	<i>Eurytemora affinis</i>	96
6	112.1	<i>Mugil cephalus</i>	112.1
7	170	<i>Temora longicornis</i>	170
8	188.0	<i>Cyprinodon variegatus</i>	442
		<i>Cyprinodon bovinus</i>	80
9	>306	<i>Fundulus similis</i>	>306
10	328.8	<i>Mytilus edulis</i>	328.8
11	397.2	<i>Limnodriloides verrucosus</i>	397.2
12	423.4	<i>Tubificoides gabriellae</i>	423.4
13	435	<i>Nereis arenaceodontata</i>	435
14	450	<i>Solea solea</i>	450
15	491.3	<i>Palaemonetes pugio</i>	491.3
16	598.2	<i>Monopylephorus cuticulatus</i>	598.2
17	862.6	<i>Ophryotrocha diadema</i>	862.6
18	>1045	<i>Penaeus aztecus</i>	>195
		<i>Penaeus duorarum</i>	5600
19	980	<i>Acartia bifilosa</i>	980
20	1200	<i>Crepidula fornicata</i>	1200

Table 88. New saltwater acute studies that met data acceptability requirements since EPA last updated pentachlorophenol criteria (S = static, R = static renewal, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	LC50 (µg/L)	Used in Derivation?	Reference
<b>Cyprinodon variegatus</b>	S, U	50	No. Other studies with the same species used a flow through design and measured test concentrations.	Sappington et al. 2001
<b>Cyprinodon bovinus</b>	S, U	80	Yes.	Sappington et al. 2001
<b>Eurytemora affinis</b>	S, M	96	Yes.	Lindley 1999
<b>Acartia bifilosa</b>	S, M	980	Yes.	Lindley 1999

## Saltwater Chronic Pentachlorophenol Criterion

There was inadequate saltwater chronic pentachlorophenol data to calculate criteria using the eight-family method. The FACR of 2.608 was previously used to calculate the saltwater chronic pentachlorophenol criterion as presented in 1995 updates to aquatic life (USEPA, 1996).

Additional chronic pentachlorophenol ACRs were available since EPA's last update. The newly calculated FACR used to derive the chronic pentachlorophenol criterion is 4.044 (Table 89).

Calculation results are as follows:

$$\text{FAV} = 26.87$$

$$\text{FACR} = 4.044$$

$$\text{CCC} = \text{FAV} / \text{FACR} = 6.652$$

**Chronic criterion = 6.7 µg/L (rounded to two significant digits)**

Table 89. Acute to chronic ratios (ACR) used in chronic criterion derivation.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR <sup>1</sup>	Species Mean ACR	Reference
<b>Daphnia magna</b>	600	240	2.5	2.5	USEPA, 1986b
<b>Simocephalus vetulus</b>	160	177.2	0.9029		USEPA, 1986b
<b>Simocephalus vetulus</b>	196	221.2	0.8861	0.8944	USEPA, 1986b
<b>Oncorhynchus mykiss</b>	66	14.46	4.564	4.564	USEPA, 1986b
<b>Pimephales promelas</b>	224.9	57.25	3.928		USEPA, 1986b
<b>Pimephales promelas</b>	95	23.89	3.977		USEPA, 1986b
<b>Pimephales promelas</b>	218	40.08	5.439		USEPA, 1986b
<b>Pimephales promelas</b>	261	48.99	5.328		USEPA, 1986b
<b>Pimephales promelas</b>	378	89.23	4.236	4.701	USEPA, 1986b
<b>Cyprinodon variegatus</b>	442	64.31	6.873	6.873	USEPA, 1986b

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR <sup>1</sup>	Species Mean ACR	Reference
<b>Lymnaea stagnalis</b>	170	27.91	6.091	6.091	Besser et al. 2009
<b>Pyrgulopsis idahoensis</b>	143	16.25	8.801	8.801	Besser et al. 2009
<b>Geometric mean</b>				4.044	

## Perfluorooctane sulfonic acid (PFOS)

### Summary of Criteria Recommendations and Changes

Washington does not currently have PFOS criteria in the water quality standards. EPA has draft recommendations for freshwater acute and chronic PFOS criteria and a saltwater acute benchmark (USEPA, 2022c). In EPA’s development of saltwater acute criteria, they found that there was inadequate toxicity data to meet the minimum data requirements for criteria development as outlined in EPA 1985 derivation guidelines. Thus, EPA filled data gaps with a WEB-ICE model and are recommending a benchmark value that is available for states to adopt rather than a 304(a) criteria recommendation. Washington proposes to adopt EPA draft recommendations for PFOS in freshwater and saltwater (Table 90). We intend to adopt EPA final recommendations if they are released during this rulemaking. If EPA’s recommendations are not finalized during the proposal phase, we do not intend to adopt the draft recommendations. We are not aware of endangered species protection issues with EPA recommended PFOS criteria in Region 10 states.

Table 90. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic PFOS criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	3000 (1-hour)	Water: 8.4 µg/L <sup>1,2</sup> Tissue: 6.75 mg/kg fish whole body <sup>1,3,4</sup> Tissue: 2.91 mg/kg fish muscle <sup>1,3,4</sup> Tissue: 0.937 mg/kg invertebrate whole body <sup>1,3,4</sup>	550 (1-hour)	-
<b>Proposed</b>	3000 (1-hour)	Water: 8.4 µg/L <sup>1,2</sup> Tissue: 6.75 mg/kg fish whole body <sup>1,3,4</sup> Tissue: 2.91 mg/kg fish muscle <sup>1,3,4</sup>	550 (1-hour)	-

		Tissue: 0.937 mg/kg invertebrate whole body <sup>1,3,4</sup>		
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<sup>1</sup> All water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy.

<sup>2</sup> Water column criteria are based on a 4-day average concentration not to be exceeded more than once every three years on average.

<sup>3</sup> Tissue criteria derived from the chronic water column concentration with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.

<sup>4</sup> Tissue data is an instantaneous point measurement that reflect integrative accumulation of PFOS over time and space. Criteria are not to be exceeded more than once every 10 years on average.

## Perfluorooctanoic acid (PFOA)

### Summary of Criteria Recommendations and Changes

Washington does not currently have PFOA criteria in the water quality standards. EPA has draft recommendations for freshwater acute and chronic PFOA criteria and a saltwater acute benchmark (USEPA, 2022d). In EPA’s development of saltwater acute criteria, they found that there was inadequate toxicity data to meet the minimum data requirements for criteria development as outlined in EPA 1985 derivation guidelines. Thus, EPA filled data gaps with a WEB-ICE model and are recommending a benchmark value that is available for states to adopt rather than a 304(a) criteria recommendation. We intend to adopt EPA final recommendations if they are released during this rulemaking. If EPA’s recommendations are not finalized during the proposal phase, we do not intend to adopt the draft recommendations. We are not aware of endangered species protection issues with EPA recommended PFOA criteria in Region 10 states.

Table 91. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic PFOA criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	49000 (1-hour)	Water: 94 µg/L Tissue: 6.10 mg/kg fish whole body Tissue: 0.125 mg/kg fish muscle Tissue: 1.11 mg/kg invertebrate whole body	7000 (1-hour)	-
<b>Proposed</b>	49000 (1-hour)	Water: 94 µg/L <sup>1,2</sup> Tissue: 6.10 mg/kg fish whole body <sup>1,3,4</sup> Tissue: 0.125 mg/kg fish muscle <sup>1,3,4</sup> Tissue: 1.11 mg/kg invertebrate whole body <sup>1,3,4</sup>	7000 (1-hour)	-

<sup>1</sup> All water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy.

<sup>2</sup> Water column criteria are based on a 4-day average concentration not to be exceeded more than once every three years on average.

<sup>3</sup> Tissue criteria derived from the chronic water column concentration with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.

<sup>4</sup> Tissue data is an instantaneous point measurement that reflect integrative accumulation of PFOS over time and space. Criteria are not to be exceeded more than once every 10 years on average.

## Polychlorinated biphenyls (PCBs)

### Summary of Criteria Recommendations and Changes

We are recommending no changes to Washington’s freshwater and saltwater PCB criteria (Table 92). EPA has recommendations for freshwater and saltwater chronic criteria but do not have recommendations for freshwater or saltwater acute criteria. Washington currently has freshwater and saltwater acute criteria based on protective values described in EPA’s 1986 Gold Book. We do not intend to modify our freshwater and saltwater acute PCB criteria because of existing protections the criteria provides for aquatic life. We are not aware of endangered species protection issues with EPA’s PCB recommendations in Region 10 states.

Table 92. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic PCBs criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	2 (24-hour)	0.014 (24-hour)	10 (24-hour)	0.03 (24-hour)
<b>EPA</b>	-	0.014 (24-hour)	-	0.03 (24-hour)
<b>Proposed</b>	No change	No change	No change	No change

## Sulfide-Hydrogen Sulfide

### Summary of Criteria Recommendations and Changes

We propose to not adopt EPA recommendations for sulfide-hydrogen sulfide (Table 93). EPA recommendations are based on very limited toxicity data. We evaluated the new science and found that only three out of eight families have toxicity data and there is less information on chronic toxicity. We recommend using Washington’s toxics narrative criteria to address any issues related to sulfide-hydrogen sulfide.



Table 93. Comparison of Washington current freshwater (FW) and saltwater (SW) acute and chronic hydrogen sulfide criteria, EPA recommendations, and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	-	2 (24-hour)	-	2 (24-hour)
<b>Proposed</b>	-	-	-	-

## Toxaphene

### Summary of Criteria Recommendations and Changes

Washington’s freshwater and saltwater toxaphene criteria are identical to EPA recommendations. We are not aware of endangered species protection issues with EPA recommended toxaphene criteria in Region 10 states. We propose no changes to Washington’s current toxaphene criteria (Table 94).

Table 94. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic toxaphene criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	0.73 (1-hour)	0.0002 (4-day)	0.21 (1-hour)	0.0002 (4-day)
<b>EPA</b>	0.73 (1-hour)	0.0002 (4-day)	0.21 (1-hour)	0.0002 (4-day)
<b>Proposed</b>	No change	No change	No change	No change

## Tributyltin

### Summary of Criteria Recommendations and Changes

Washington does not currently have tributyltin criteria in the water quality standards. EPA has recommendations for freshwater and saltwater acute and chronic tributyltin criteria. We propose that Washington adopt EPA recommendations for tributyltin in freshwater and saltwater (Table 95). We are not aware of endangered species protection issues with EPA recommended tributyltin criteria in Region 10 states.

Table 95. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic tributyltin criteria (duration in parentheses) with EPA recommendations and the newly proposed criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
<b>Washington</b>	-	-	-	-
<b>EPA</b>	0.46 (1-hour)	0.072 (4-day)	0.42 (1-hour)	0.0074 (4-day)
<b>Proposed</b>	0.46 (1-hour)	0.072 (4-day)	0.42 (1-hour)	0.0074 (4-day)

## Conclusions

The work presented in this document represent the updates needed to aquatic life toxics criteria to be consistent with Clean Water Act recommendations as well as protection levels needed for aquatic life toxics in Washington.

Additional analyses not covered in the body of this document regarding methods used to describe permit impacts and analysis (Appendix D) and water quality assessment considerations (Appendix E) are provided in the Appendix.

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## Appendix A. ECOTOX Database Results and References

The Environmental Protection Agency (EPA) Ecotoxicology Knowledgebase (ECOTOX) database was a primary source of new science to update aquatic life toxics criteria. Below are the results for each toxic that was updated using the ECOTOX database, including each citation that was evaluated for data acceptability (Tables A1-A28). A notes column was added to each table that provides an explanation on why the article was not used for criteria derivation. If the notes box is left blank for a corresponding citation, then that article was used in updating and deriving new toxic criteria. At the end of each section we added open literature studies that were evaluated but did not meet acceptability requirements.

### Arsenic

#### Freshwater Acute

Table A1. List of citations from EPA ECOTOX database reviewed for arsenic freshwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Broderius,S.J., M.D. Kahl, and M.D. Hoglund. Use of Joint Toxic Response to Define the Primary Mode of Toxic Action for Diverse Industrial Organic Chemicals. Environ. Toxicol. Chem.14(9): 1591-1605, 1995. Ecoref #15031	Did not find relevant arsenic data
Brodeur,J.C., C.M. Asorey, A. Sztrum, and J. Herkovits. Acute and Subchronic Toxicity of Arsenite and Zinc to Tadpoles of Rhinella arenarum both Alone and in Combination. J. Toxicol. Environ. Health Part A72(14): 884-890, 2009. Ecoref #117667	Non-north american test species
Buhl,K.J.. The Relative Toxicity of Waterborne Inorganic Contaminants to the Rio Grande Silvery Minnow ( <i>Hybognathus amarus</i> ) and Fathead Minnow ( <i>Pimephales promelas</i> ) in a Water Quality Simulating that in the Rio Grande, New Mexico. Final Rep.to U.S.Fish and Wildl.Serv., Study No.2F33-9620003, U.S.Geol.Surv., Columbia Environ.Res.Ctr., Yankton Field Res.Stn., Yankton, SD:75 p., 2002. Ecoref #77828	Arsenate based study; EPA arsenic derivation based on arsenite
Buhl,K.J., and S.J. Hamilton. Comparative Toxicity of Inorganic Contaminants Released by Placer Mining to Early Life Stages of Salmonids. Ecotoxicol. Environ. Saf.20(3): 325-342, 1990. Ecoref #334	Arsenate based study; EPA arsenic derivation based on arsenite
Buhl,K.J., and S.J. Hamilton. Relative Sensitivity of Early Life Stages of Arctic Grayling, Coho Salmon, and Rainbow Trout to Nine Inorganics. Ecotoxicol. Environ. Saf.22:184-197, 1991. Ecoref #3956	

Citation	Notes
Burton,G.A.,Jr., J.M. Lazorchak, W.T. Waller, and G.R. Lanza. Arsenic Toxicity Changes in the Presence of Sediment. Bull. Environ. Contam. Toxicol.38(3): 491-499, 1987. ECODEF #12154	Study included sediment
Dyer,S.D., G.L. Brooks, K.L. Dickson, B.M. Sanders, and E.G. Zimmerman. Synthesis and Accumulation of Stress Proteins in Tissues of Arsenite-Exposed Fathead Minnows ( <i>Pimephales promelas</i> ). Environ. Toxicol. Chem.12:913-924, 1993. ECODEF #7266	Very little information on methods; 3-5 fish per replicate
Dyer,S.D., K.L. Dickson, and E.G. Zimmerman. A Laboratory Evaluation of the Use of Stress Proteins in Fish to Detect Changes in Water Quality. ASTM Spec. Tech. Publ.:247-261, 1993. ECODEF #45073	Repeated information
Fargasova,A.. Ecotoxicology of Metals Related to Freshwater Benthos. Gen. Physiol. Biophys.18(Focus Issue): 48-53, 1999. ECODEF #61824	Arsenate based study; EPA arsenic derivation based on arsenite
Ghosh,A.R., and P. Chakrabarti. Toxicity of Arsenic and Cadmium to a Freshwater Fish <i>Notopterus notopterus</i> . Environ. Ecol.8(2): 576-579, 1990. ECODEF #3440	Non-north american test species
Gupta,A.K., and P. Chakrabarti. Toxicity of Arsenic to Freshwater Fishes <i>Mystus vittatus</i> (Bloch) and <i>Puntius javanicus</i> (Blkr.). Environ. Ecol.11(4): 808-811, 1993. ECODEF #4456	Non-north american test species
Hamilton,S.J., and K.J. Buhl. Safety Assessment of Selected Inorganic Elements to Fry of Chinook Salmon ( <i>Oncorhynchus tshawytscha</i> ). Ecotoxicol. Environ. Saf.20(3): 307-324, 1990. ECODEF #3526	
Hamilton,S.J., and K.J. Buhl. Hazard Evaluation of Inorganics, Singly and in Mixtures, to Flannelmouth Sucker <i>Catostomus latipinnis</i> in the San Juan River, New Mexico. Ecotoxicol. Environ. Saf.38(3): 296-308, 1997. ECODEF #18979	Arsenate based study; EPA arsenic derivation based on arsenite
Hamilton,S.J., and K.J. Buhl. Hazard Assessment of Inorganics, Individually and in Mixtures, to Two Endangered Fish in the San Juan River, New Mexico. Environ. Toxicol. Water Qual.12:195-209, 1997. ECODEF #20368	Arsenate based study; EPA arsenic derivation based on arsenite
Hartwell,S.I., J.H. Jin, D.S. Cherry, and J.,Jr. Cairns. Toxicity Versus Avoidance Response of Golden Shiner, <i>Notemigonus crysoleucas</i> , to Five Metals. J. Fish Biol.35(3): 447-456, 1989. ECODEF #3286	Pulsed exposure to toxicant; did not follow standard methods
Hockett,J.R., and D.R. Mount. Use of Metal Chelating Agents to Differentiate Among Sources of Acute Aquatic Toxicity. Environ. Toxicol. Chem.15(10): 1687-1693, 1996. ECODEF #45021	
Hu,J., D. Wang, B.E. Forthaus, and J. Wang. Quantifying the Effect of Nanoparticles on As(V) Ecotoxicity Exemplified by Nano-Fe <sub>2</sub> O <sub>3</sub> (Magnetic) and Nano-Al <sub>2</sub> O <sub>3</sub> . Environ. Toxicol. Chem.31(12): 2870-2876, 2012. ECODEF #165681	Nanoparticle study

Citation	Notes
Jeyasingham,K., and N. Ling. Acute Toxicity of Arsenic to Three Species of New Zealand Chironomids: Chironomus zealandicus, Chironomus sp. a and Polypedilum pavidus (Diptera, Chironomidae). Bull. Environ. Contam. Toxicol.64(5): 708-715, 2000. Ecoref #50648	Non-north american test species
Khangarot,B.S., A. Sehgal, and M.K. Bhasin. "Man and Biosphere" - Studies on the Sikkim Himalayas. Part 5: Acute Toxicity of Selected Heavy Metals on the Tadpoles of Rana hexadactyla. Acta Hydrochim. Hydrobiol.13(2): 259-263, 1985. Ecoref #11438	Non-north american test species
Klauda,R.J.. Acute and Chronic Effects of Waterborne Arsenic and Selenium on the Early Life Stages of Striped Bass (Morone saxatilis). Rep.No.JHU/APL PPRP-98, Rep.to Maryland Power Plant Siting Program, John Hopkins University, Laurel, MD:209 p., 1986. Ecoref #18109	Unable to retrieve article
Liber,K., L.E. Doig, and S.L. White-Sobey. Toxicity of Uranium, Molybdenum, Nickel, and Arsenic to Hyalella azteca and Chironomus dilutus in Water-Only and Spiked-Sediment Toxicity Tests. Ecotoxicol. Environ. Saf.74(5): 1171-1179, 2011. Ecoref #175087	
Lima,A.R., C. Curtis, D.E. Hammermeister, T.P. Markee, C.E. Northcott, and L.T. Brooke. Acute and Chronic Toxicities of Arsenic(III) to Fathead Minnows, Flagfish, Daphnids, and an Amphipod. Arch. Environ. Contam. Toxicol.13(5): 595-601, 1984. Ecoref #10695	Study used in previous EPA derivation
Liu,F., A. Gentles, and C.W. Theodorakis. Arsenate and Perchlorate Toxicity, Growth Effects, and Thyroid Histopathology in Hypothyroid Zebrafish Danio rerio. Chemosphere71(7): 1369-1376, 2008. Ecoref #111072	Arsenate based study; EPA arsenic derivation based on arsenite
Mayer,F.L.,Jr., and M.R. Eilersieck. Manual of Acute Toxicity: Interpretation and Data Base for 410 Chemicals and 66 Species of Freshwater Animals. USDI Fish and Wildlife Service, Publication No.160, Washington, DC:505 p., 1986. Ecoref #6797	This reference is a database; ecotox likely incorporated similar studies
Mount,D.I., and T.J. Norberg. A Seven-Day Life-Cycle Cladoceran Toxicity Test. Environ. Toxicol. Chem.3(3): 425-434, 1984. Ecoref #11181	Study used in previous EPA derivation
Palawski,D., J.B. Hunn, and F.J. Dwyer. Sensitivity of Young Striped Bass to Organic and Inorganic Contaminants in Fresh and Saline Waters. Trans. Am. Fish. Soc.114(5): 748-753, 1985. Ecoref #11334	Arsenate based study; EPA arsenic derivation based on arsenite
Rankin,M.G., and D.G. Dixon. Acute and Chronic Toxicity of Waterborne Arsenite to Rainbow Trout (Oncorhynchus mykiss). Can. J. Fish. Aquat. Sci.51(2): 372-380, 1994. Ecoref #14077	
Richie,J.P.,Jr., B.J. Mills, and C.A. Lang. The Verification of a Mammalian Toxicant Classification Using a Mosquito Screening Method. Fundam. Appl. Toxicol.4(6): 1029-1035, 1984. Ecoref #173907	Arsenate based study; EPA arsenic derivation based on arsenite
Shaw,J.R., K. Gabor, E. Hand, A. Lankowski, L. Durant, R. Thibodeau, C.R. Stanton, R. Barnaby, B. Coutermarsh, K.H. Kar. Role of Glucocorticoid Receptor in Acclimation of Killifish (Fundulus	Saltwater based study

Citation	Notes
heteroclitus) to Seawater and Effects of Arsenic. Am. J. Physiol., Regul. Integr. Comp. Physiol.292(2): R1052 - R1060, 2007. Ecoref #101073	
Shaw,J.R., S.P. Glaholt, N.S. Greenberg, R. Sierra-Alvarez, and C.L. Folt. Acute Toxicity of Arsenic to Daphnia pulex: Influence of Organic Functional Groups and Oxidation State. Environ. Toxicol. Chem.26(7): 1532-1537, 2007. Ecoref #100641	
Shukla,J.P., K.N. Shukla, and U.N. Dwivedi. Survivality and Impaired Growth in Arsenic Treated Fingerlings of Channa punctatus, a Fresh Water Murrel. Acta Hydrochim. Hydrobiol.15(3): 307-311, 1987. Ecoref #12594	Non-north american test species
Shukla,J.P., and K. Pandey. Toxicity and Long-Term Effect of Arsenic on the Gonadal Protein Metabolism in a Tropical Freshwater Fish, Colisa fasciatus (Bl. & Sch.). Acta Hydrochim. Hydrobiol.13(1): 127-131, 1985. Ecoref #11412	Non-north american test species
Spehar,R.L., and J.T. Fiandt. Acute and Chronic Effects of Water Quality Criteria-Based Metal Mixtures on Three Aquatic Species. Environ. Toxicol. Chem.5(10): 917-931, 1986. Ecoref #12093	Study used in EPA 1995 derivation
Tisler,T., and J. Zagorc-Koncan. Acute and Chronic Toxicity of Arsenic to Some Aquatic Organisms. Bull. Environ. Contam. Toxicol.69(3): 421-429, 2002. Ecoref #78709	Doesn't specify arsenic species
U.S. Environmental Protection Agency. Pesticide Ecotoxicity Database (Formerly: Environmental Effects Database (EEDB)). Environmental Fate and Effects Division, U.S.EPA, Washington, D.C., 1992. Ecoref #344	This reference is to a database
Wang,D., J. Hu, B.E. Forthaus, and J. Wang. Synergistic Toxic Effect of Nano-Al2O3 and As(V) on Ceriodaphnia dubia. Environ. Pollut.159(10): 3003-3008, 2011. Ecoref #165959	Arsenate based study; EPA arsenic derivation based on arsenite

## Open Literature

Table A2. List of open literature citations from EPA ECOTOX database reviewed for arsenic criteria derivation but did not meet acceptability requirements.

Citation	Notes
Gardner, S., Cline, G., Mwebi, N. and Rayburn, J., 2017. Developmental and interactive effects of arsenic and chromium to developing Ambystoma maculatum embryos: Toxicity, teratogenicity, and whole-body concentrations. Journal of Toxicology and Environmental Health, Part A, 80(2), pp.91-104.	12-day LC50

## Freshwater Chronic

Table A3. List of citations from EPA ECOTOX database reviewed for arsenic freshwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Chen,T.H., J.A. Gross, and W.H. Karasov. Chronic Exposure to Pentavalent Arsenic of Larval Leopard Frogs ( <i>Rana pipiens</i> ): Bioaccumulation and Reduced Swimming Performance. <i>Ecotoxicology</i> 18(5): 587-593, 2009. Ecoref #119404	Study used arsenate; EPA used arsenite to derive arsenic criteria
Cockell,K.A., and W.J. Bettger. Investigations of the Gallbladder Pathology Associated with Dietary Exposure to Disodium Arsenate Heptahydrate in Juvenile Rainbow Trout ( <i>Oncorhynchus mykiss</i> ). <i>Toxicology</i> 77(3): 233-248, 1993. Ecoref #7192	Study used arsenate; EPA used arsenite to derive arsenic criteria
Erickson,R.J., D.R. Mount, T.L. Highland, J.R. Hockett, E.N. Leonard, V.R. Mattson, T.D. Dawson, and K.G. Lott. Effects of Copper, Cadmium, Lead, and Arsenic in a Live Diet on Juvenile Fish Growth . <i>Can. J. Fish. Aquat. Sci.</i> 67:1816-1826, 2010. Ecoref #156202	Study used arsenate; EPA used arsenite to derive arsenic criteria
Hoang,T.C., and S.J. Klaine. Influence of Organism Age on Metal Toxicity to <i>Daphnia magna</i> . <i>Environ. Toxicol. Chem.</i> 26(6): 1198-1204, 2007. Ecoref #101846	Study limited to 1 test concentrations
Liber,K., L.E. Doig, and S.L. White-Sobey. Toxicity of Uranium, Molybdenum, Nickel, and Arsenic to <i>Hyalella azteca</i> and <i>Chironomus dilutus</i> in Water-Only and Spiked-Sediment Toxicity Tests. <i>Ecotoxicol. Environ. Saf.</i> 74(5): 1171-1179, 2011. Ecoref #175087	Chronic toxicity value borrowed from another study
Tisler,T., and J. Zagorc-Koncan. Acute and Chronic Toxicity of Arsenic to Some Aquatic Organisms. <i>Bull. Environ. Contam. Toxicol.</i> 69(3): 421-429, 2002. Ecoref #78709	Study used arsenate; EPA used arsenite to derive arsenic criteria
Vellinger,C., E. Gismondj, V. Felten, P. Rousselle, K. Mehennaoui, M. Parant, and P. Usseglio-Polatera. Single and Combined Effects of Cadmium and Arsenate in <i>Gammarus pulex</i> (Crustacea, Amphipoda): Understanding the Links Between Physiological and Behavioural Responses. <i>Aquat. Toxicol.</i> 140/141:106-116, 2013. Ecoref #164550	Study used arsenate; EPA used arsenite to derive arsenic criteria
Okamoto, A., Masunaga, S. and Tatarazako, N., 2021. Chronic toxicity of 50 metals to <i>Ceriodaphnia dubia</i> . <i>Journal of Applied Toxicology</i> , 41(3), pp.375-386.	10x threshold for ACR value and no MATC value reported; did not use flow through design
Irving, E.C., Lowell, R.B., Culp, J.M., Liber, K., Xie, Q. and Kerrich, R., 2008. Effects of arsenic speciation and low dissolved oxygen condition on the toxicity of arsenic to a lotic mayfly. <i>Environmental Toxicology and Chemistry: An International Journal</i> , 27(3), pp.583-590.	12-day LC50 not relevant to ACR development
Gardner, S., Cline, G., Mwebi, N. and Rayburn, J., 2017. Developmental and interactive effects of arsenic and chromium to developing <i>Ambystoma maculatum</i> embryos: Toxicity, teratogenicity,	Study used arsenate; EPA used arsenite to derive arsenic criteria

Citation	Notes
and whole-body concentrations. <i>Journal of Toxicology and Environmental Health, Part A</i> , 80(2), pp.91-104.	

## Saltwater Acute

Table A4. List of citations from EPA ECOTOX database reviewed for arsenic saltwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Gaion,A., A. Scuderi, D. Pellegrini, and D. Sartori. The Influence of Solid Matrices on Arsenic Toxicity to <i>Corophium orientale</i> . <i>Chem. Ecol.</i> 29(7): 653-659, 2013. Ecoref #166137	Non-north american test species; sediment study
Hwang,D.S., K.W. Lee, J. Han, H.G. Park, J. Lee, Y.M. Lee, and J.S. Lee. Molecular Characterization and Expression of Vitellogenin (Vg) Genes from the Cyclopoid Copepod, <i>Paracyclops nana</i> Exposed to Heavy Metals. <i>Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.</i> 151(3): 360-368, 2010. Ecoref #153073	Not relevant endpoints
Lee,K.W., S. Raisuddin, D.S. Hwang, H.G. Park, H.U. Dahms, I.Y. Ahn, and J.S. Lee. Two-Generation Toxicity Study on the Copepod Model Species <i>Tigriopus japonicus</i> . <i>Chemosphere</i> 72:1359-1365, 2008. Ecoref #104287	Non-north american test species
Lee,K.W., S. Raisuddin, J.S. Rhee, D.S. Hwang, I.T. Yu, Y.M. Lee, H.G. Park, and J.S. Lee. Expression of Glutathione S-Transferase (GST) Genes in the Marine Copepod <i>Tigriopus japonicus</i> Exposed to Trace Metals. <i>Aquat. Toxicol.</i> 89(3): 158-166, 2008. Ecoref #107127	Non-north american test species
Liu,F., R.J. Kendall, and C.W. Theodorakis. Joint Toxicity of Sodium Arsenate and Sodium Perchlorate to Zebrafish <i>Danio rerio</i> Larvae. <i>Environ. Toxicol. Chem.</i> 24(6): 1505-1507, 2005. Ecoref #110484	Arsenate used; EPA used arsenite to derive criteria
Shaw,J.R., K. Gabor, E. Hand, A. Lankowski, L. Durant, R. Thibodeau, C.R. Stanton, R. Barnaby, B. Coutermarsh, K.H. Kar. Role of Glucocorticoid Receptor in Acclimation of Killifish ( <i>Fundulus heteroclitus</i> ) to Seawater and Effects of Arsenic. <i>Am. J. Physiol., Regul. Integr. Comp. Physiol.</i> 292(2): R1052 - R1060, 2007. Ecoref #101073	



## Saltwater Chronic

Table A5. List of citations from EPA ECOTOX database reviewed for arsenic saltwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Lee, K.W., S. Raisuddin, D.S. Hwang, H.G. Park, H.U. Dahms, I.Y. Ahn, and J.S. Lee. Two-Generation Toxicity Study on the Copepod Model Species <i>Tigriopus japonicus</i> . <i>Chemosphere</i> 72:1359-1365, 2008. Ecoref #104287	Non-north american test species
Liu, F.J., J.S. Wang, and C.W. Theodorakis. Thyrotoxicity of Sodium Arsenate, Sodium Perchlorate, and Their Mixture in Zebrafish <i>Danio rerio</i> . <i>Environ. Sci. Technol.</i> 40(10): 3429-3436, 2006. Ecoref #151957	Arsenate study; EPA derived arsenic criteria based on arsenite

## Chromium VI

### Freshwater Acute

Table A6. List of citations from EPA ECOTOX database reviewed for chromium vi freshwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Al-Akel, A.S.. Chromium Toxicity and Its Impact on Behavioural Responses in Freshwater Carp, <i>Cyprinus carpio</i> from Saudi Arabia. <i>Pak. J. Zool.</i> 28(4): 361-363, 1996. Ecoref #46875	Non-north american species used
Al-Akel, A.S., and M.J.K. Shamsi. Hexavalent Chromium: Toxicity and Impact on Carbohydrate Metabolism and Haematological Parameters of Carp ( <i>Cyprinus carpio</i> L.) from Saudi Arabia. <i>Aquat. Sci.</i> 58(1): 24-30, 1996. Ecoref #19485	Non-north american species used
Anusuya, D., and I. Christy. Effects of Chromium Toxicity on Hatching and Development of Tadpoles of <i>Bufo melanostictus</i> . <i>J. Environ. Biol.</i> 20(4): 321-323, 1999. Ecoref #47043	Non-north american species used
Arkhipchuk, V.V., C. Blaise, and M.V. Malinovskaya. Use of Hydra for Chronic Toxicity Assessment of Waters Intended for Human Consumption. <i>Environ. Pollut.</i> 142(2): 200-211, 2006. Ecoref #90306	Ambient water subchronic study
Baral, A., R. Engelken, W. Stephens, J. Farris, and R. Hannigan. Evaluation of Aquatic Toxicities of Chromium and Chromium-Containing Effluents in Reference to Chromium Electroplating Industries. <i>Arch. Environ. Contam. Toxicol.</i> 50(4): 496-502, 2006. Ecoref #119599	

Citation	Notes
Begum,G., J.V. Rao, and K. Srikanth. Oxidative Stress and Changes in Locomotor Behavior and Gill Morphology of Gambusia affinis Exposed to Chromium. Toxicol. Environ. Chem.88(2): 355-365, 2006. ECODEF #119520	
Bichara,D., N.B. Calcaterra, S. Arranz, P. Armas, and S.H. Simonetta. Set-up of an Infrared Fast Behavioral Assay Using Zebrafish (Danio rerio) Larvae, and Its Application in Compound Biototoxicity Screening. J. Appl. Toxicol.34:214-219, 2014. ECODEF #169111	Examined swimming behavior as endpoint
Buhl,K.J.. Relative Sensitivity of Three Endangered Fishes, Colorado Squawfish, Bonytail, and Razorback Sucker, to Selected Metal Pollutants. Ecotoxicol. Environ. Saf.37:186-192, 1997. ECODEF #18325	
Bulus Rossini,G.D., and A.E. Ronco. Sensitivity of Cichlasoma facetum (Cichlidae, Pisces) to Metals. Bull. Environ. Contam. Toxicol.72(4): 763-768, 2004. ECODEF #74230	Non-north american species used
Centeno,M.D.F., G. Persoone, and M.P. Goyvaerts. Cyst-Based Toxicity Tests. IX. The Potential of Thamnocephalus platyurus as Test Species in Comparison with Streptocephalus proboscideus (Crustacea: Branchiopoda: Anostraca). Environ. Toxicol. Water Qual.10(4): 275-282, 1995. ECODEF #14017	
Chu,K.W., and K.L. Chow. Synergistic Toxicity of Multiple Heavy Metals is Revealed by a Biological Assay Using a Nematode and Its Transgenic Derivative. Aquat. Toxicol.61(1/2): 53-64, 2002. ECODEF #65728	Transgenic nematode used in testing
Da Silva Kraus,L.A., A.C.T. Bonecker, N. De Almeida, and A. Vital. Acute Toxicity of Potassium Dichromate, Sodium Dodecyl Sulfate, Copper and Zinc to Poecilia vivipara (Osteichthyes, Cyprinodontiformes). Fresenius Environ. Bull.7(11/12): 654-658, 1998. ECODEF #60132	Non-north american species used
De Souza,J.P., L.S. Medeiros, E.U. Winkaler, and J.G. Machado-Neto. Acute Toxicity and Environmental Risk of Diflubenzuron to Daphnia magna, Poecilia reticulata and Lemna minor in the Absence and Presence of Sediment. Pesticidas21:1-12, 2011. ECODEF #174961	Non-north american species used
Di Marzio,W.D., D. Castaldo, C. Pantani, A. Di Cioccio, T. Di Lorenzo, M.E. Saenz, and D.M.P. Galassi. Relative Sensitivity of Hyporheic Copepods to Chemicals. Bull. Environ. Contam. Toxicol.82(4): 488-491, 2009. ECODEF #114244	
Diao,J., P. Xu, P. Wang, D. Lu, Y. Lu, and Z. Zhou. Enantioselective Degradation in Sediment and Aquatic Toxicity to Daphnia magna of the Herbicide Lactofen Enantiomers. J. Agric. Food Chem.58(4): 2439-2445, 2010. ECODEF #152904	Herbicide used in testing; sediment study
Elumalai,M., C. Antunes, and L. Guilhermino. Effects of Single Metals and Their Mixtures on Selected Enzymes of Carcinus maenas. Water Air Soil Pollut.141(1-4): 273-280, 2002. ECODEF #72944	Ambient estuary water used in testing

Citation	Notes
Fargasova,A.. Ecotoxicology of Metals Related to Freshwater Benthos. Gen. Physiol. Biophys.18(Focus Issue): 48-53, 1999. ECOREF #61824	
Gutierrez,M.F., A.M. Gagneten, and J.C. Paggi. Copper and Chromium Alter Life Cycle Variables and the Equiproportional Development of the Freshwater Copepod Notodiaptomus conifer (Sars.). Water Air Soil Pollut.213:275-286, 2010. ECOREF #169526	
Hockett,J.R., and D.R. Mount. Use of Metal Chelating Agents to Differentiate Among Sources of Acute Aquatic Toxicity. Environ. Toxicol. Chem.15(10): 1687-1693, 1996. ECOREF #45021	Unclear if resulting LC50 mixed with chelating agents
Joshi,S.N., and H.S. Patil. Differential Toxicity of Four Chromium Salts to Male Skipper Frog Rana cyanophlyctis. Environ. Ecol.12(1): 36-38, 1994. ECOREF #17526	Non-north american test species used
Kazlauskienė,N., A. Burba, and G. Svecevičius. Acute Toxicity of Five Galvanic Heavy Metals to Hydrobionts. Ekologija1:33-36, 1994. ECOREF #17573	
Kungolos,A., S. Hadjispyrou, P. Samaras, M. Petala, V. Tsiridis, K. Aravossis, and G.P. Sakellaropoulos. Assessment of Toxicity and Bioaccumulation of Organotin Compounds. In: Proceedings of the 7th International Conference on Environmental Science and Technology, Syros, Greece:499-505, 2001. ECOREF #68179	Hexavalent chromium not used in study
Li,Y., F. Dong, X. Liu, J. Xu, Y. Han, and Y. Zheng. Chiral Fungicide Triadimefon and Triadimenol: Stereoselective Transformation in Greenhouse Crops and Soil, and Toxicity to Daphnia magna. J. Hazard. Mater.265:115-123, 2014. ECOREF #170571	Fungicide based study
Li,Y., F. Dong, X. Liu, J. Xu, Y. Han, and Y. Zheng. Enantioselectivity in Tebuconazole and Myclobutanil Non-Target Toxicity and Degradation in Soils. Chemosphere122:145-153, 2015. ECOREF #178194	Fungicide based study
Lin,K., S. Zhou, C. Xu, and W. Liu. Enantiomeric Resolution and Biototoxicity of Methamidophos. J. Agric. Food Chem.54(21): 8134-8138, 2006. ECOREF #99572	Pesticide based study
Madoni,P., D. Davoli, G. Gorbi, and L. Vescovi. Toxic Effect of Heavy Metals on the Activated Sludge Protozoan Community. Water Res.30(1): 135-141, 1996. ECOREF #16363	Test organisms from sludge
Madoni,P., D. Davoli, and G. Gorbi. Acute Toxicity of Lead, Chromium, and Other Heavy Metals to Ciliates from Activated Sludge Plants. Bull. Environ. Contam. Toxicol.53(3): 420-425, 1994. ECOREF #13671	Test organisms from sludge
Madoni,P., and M.G. Romeo. Acute Toxicity of Heavy Metals Towards Freshwater Ciliated Protists. Environ. Pollut.141(1): 1-7, 2006. ECOREF #95678	Single celled organism; inappropriate test organism
Maestre,Z., M. Martinez-Madrid, and P. Rodriguez. Monitoring the Sensitivity of the Oligochaete Tubifex tubifex in Laboratory Cultures Using Three Toxicants. Ecotoxicol. Environ. Saf.72:2083-2089, 2009. ECOREF #118134	

Citation	Notes
Mohammed,A.. Comparative Sensitivities of the Tropical Cladoceran, Ceriodaphnia rigaudii and the Temperate Species Daphnia magna to Seven Toxicants. Toxicol. Environ. Chem.89(2): 347-352, 2007. Ecoref #102662	Tests conducted in 24 well plates and the test chamber volume to organism ratio was too low. Possible organism density related effects.
Mohammed,A., and J.B.R. Agard. Comparative Sensitivity of Three Tropical Cladoceran Species (Diaphanosoma brachyurum, Ceriodaphnia rigaudii and Moinodaphnia macleayi) to Six Chemicals. J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control41(12): 2713-2720, 2006. Ecoref #101029	Tests conducted in 24 well plates and the test chamber volume to organism ratio was too low. Possible organism density related effects.
Nalecz-Jawecki,G., and J. Sawicki. Toxicity of Inorganic Compounds in the Spirotox Test: A Miniaturized Version of the Spirostomum ambiguum Test. Arch. Environ. Contam. Toxicol.34(1): 1-5, 1998. Ecoref #18997	Not relevant
Natale,G.S., L.L. Ammassari, N.G. Basso, and A.E. Ronco. Acute and Chronic Effects of Cr(VI) on Hypsiboas pulchellus Embryos and Tadpoles. Dis. Aquat. Org.72(3): 261-267, 2006. Ecoref #101072	Non-north american test species used
Oliveira-Filho,E.C., and F.J.R. Paumgarten. Comparative Study on the Acute Toxicities of alpha, beta, gamma, and delta Isomers of Hexachlorocyclohexane to Freshwater Fishes. Bull. Environ. Contam. Toxicol.59(6): 984-988, 1997. Ecoref #18622	Study does not involve chromium
Perez-Legaspi,I.A., and R. Rico-Martinez. Acute Toxicity Tests on Three Species of the Genus Lecane (Rotifera: Monogononta). Hydrobiologia446-447:375-381, 2001. Ecoref #65813	
Rathore,R.S., and B.S. Khangarot. Effects of Temperature on the Sensitivity of Sludge Worm Tubifex tubifex Muller to Selected Heavy Metals. Ecotoxicol. Environ. Saf.53(1): 27-36, 2002. Ecoref #69566	
Safadi,R.S.. The Use of Freshwater Planarians in Acute Toxicity Tests with Heavy Metals. Verh. Int. Ver. Theor. Angew. Limnol.26(5): 2391-2392, 1998. Ecoref #83191	Lacks detailed methods such as controls, methods, purity, etc.
Sivakami,R., G. Premkishore, and M.R. Chandran. Effect of Chromium on the Metabolism and Biochemical Composition of Selected Tissues in the Freshwater Catfish Mystus vittatus. Environ. Ecol.12(2): 259-266, 1994. Ecoref #12676	Non-north american test species used
Sivakumar,S., R. Karuppasamy, and S. Subathra. Acute Toxicity and Behavioural Changes in Freshwater Fish Mystus vittatus (Bloch) Exposed to Chromium (VI) Oxide. Nat. Environ. Pollut. Technol.5(3): 381-388, 2006. Ecoref #119339	Non-north american test species used
Sorensen,M.A., P.D. Jensen, W.E. Walton, and J.T. Trumble. Acute and Chronic Activity of Perchlorate and Hexavalent Chromium Contamination on the Survival and Development of Culex quinquefasciatus Say (Diptera: Culicidae). Environ. Pollut.144(3): 759-764, 2006. Ecoref #96296	

Citation	Notes
Sornaraj,R., P. Baskaran, and S. Thanalakshmi. Effects of Heavy Metals on Some Physiological Responses of Air-Breathing Fish <i>Channa punctatus</i> (Bloch). <i>Environ. Ecol.</i> 13(1): 202-207, 1995. ECOREF #17380	Non-north american test species used
Sotero-Santos,R.B., O. Rocha, and J. Povinelli. Toxicity of Ferric Chloride Sludge to Aquatic Organisms. <i>Chemosphere</i> 68(4): 628-636, 2007. ECOREF #118678	Sludge used in testing
Tsui,M.T.K., W.X. Wang, and L.M. Chu. Influence of Glyphosate and Its Formulation (Roundup) on the Toxicity and Bioavailability of Metals to <i>Ceriodaphnia dubia</i> . <i>Environ. Pollut.</i> 138(1): 59-68, 2005. ECOREF #87704	Pesticide mixture study; LC50 not provided
Twagilimana,L., J. Bohatier, CA Groliere, F. Bonnemoy, and D. Sargos. A New Low-Cost Microbiotest with the Protozoan <i>Spirostomum teres</i> : Culture Conditions and Assessment of Sensitivity of the Ciliate to 14 Pure Chemicals. <i>Ecotoxicol. Environ. Saf.</i> 41(3): 231-244, 1998. ECOREF #20057	Microbiotest not relevant
Vedamanikam,V.J., and N.A.M. Shazilli. The Effect of Multi-Generational Exposure to Metals and Resultant Change in Median Lethal Toxicity Tests Values over Subsequent Generations. <i>Bull. Environ. Contam. Toxicol.</i> 80(1): 63-67, 2008. ECOREF #111291	
Wong,C.K., and A.P. Pak. Acute and Subchronic Toxicity of the Heavy Metals Copper, Chromium, Nickel, and Zinc, Individually and in Mixture, to the Freshwater Copepod <i>Mesocyclops pehpeiensis</i> . <i>Bull. Environ. Contam. Toxicol.</i> 73(1): 190-196, 2004. ECOREF #80006	Non-north american test species
Yang,H.B., Z. Ya-Zhou, Y. Tang, G. Hui-Qin, F. Guo, S. Wei-Hua, L. Shu-Shen, H. Tan, and F. Chen. Antioxidant Defence System is Responsible for the Toxicological Interactions of Mixtures: A Case Study on PFOS and PFOA in <i>Daphnia magna</i> . <i>Sci. Total Environ.</i> 667:435-443, 2019. ECOREF #182580	Test did not use chromium
Zhang,Q., and C. Wang. Toxicity of Binary Mixtures of Enantiomers in Chiral Organophosphorus Insecticides: The Significance of Joint Effects Between Enantiomers. <i>Chirality</i> 25(11): 787-792, 2013. ECOREF #165491	Pesticide study; did not use chromium

## Open Literature

Table A7. List of open literature citations from EPA ECOTOX database reviewed for chromium vi criteria derivation but did not meet acceptability requirements.

Citation	Notes
Gardner, S., Cline, G., Mwebi, N. and Rayburn, J., 2017. Developmental and interactive effects of arsenic and chromium to developing <i>Ambystoma maculatum</i> embryos: Toxicity, teratogenicity, and whole-body concentrations. <i>Journal of Toxicology and Environmental Health, Part A</i> , 80(2), pp.91-104.	12-day LC50
Hernández-Ruiz, E., Alvarado-Flores, J., Rubio-Franchini, I., Ventura-Juárez, J. and Rico-Martínez, R., 2016. Adverse effects and bioconcentration of chromium in two freshwater rotifer species. <i>Chemosphere</i> , 158, pp.107-115.	Low organism to volume ratio
Hose, G.C., Symington, K., Lott, M.J. and Lategan, M.J., 2016. The toxicity of arsenic (III), chromium (VI) and zinc to groundwater copepods. <i>Environmental Science and Pollution Research</i> , 23, pp.18704-18713.	Groundwater test organisms; non-north American test species; field collected organisms with no exposure information
Okamoto, A., Masunaga, S. and Tatarazako, N., 2021. Chronic toxicity of 50 metals to <i>Ceriodaphnia dubia</i> . <i>Journal of Applied Toxicology</i> , 41(3), pp.375-386.	Inhibition concentrations reported; very little details on test methods, ACR based on two different organisms; did not use flow through design

## Freshwater Chronic

Table A8. List of citations from EPA ECOTOX database reviewed for chromium vi freshwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Baral,A., R. Engelken, W. Stephens, J. Farris, and R. Hannigan. Evaluation of Aquatic Toxicities of Chromium and Chromium-Containing Effluents in Reference to Chromium Electroplating Industries. <i>Arch. Environ. Contam. Toxicol.</i> 50(4): 496-502, 2006. Ecoref #119599	
Carrquiriborde,P., and A.E. Ronco. Distinctive Accumulation Patterns of Cd(II), Cu(II), and Cr(VI) in Tissue of the South American Teleost, Pejerrey ( <i>Odontesthes bonariensis</i> ). <i>Aquat. Toxicol.</i> 86(2): 313-322, 2008. Ecoref #117068	Acceptable but ACR cannot be calculated
Diamantino,T.C., L. Guilhermino, E. Almeida, and A.M.V.M. Soares. Toxicity of Sodium Molybdate and Sodium Dichromate to <i>Daphnia magna</i> Straus Evaluated in Acute, Chronic, and	

Citation	Notes
Acetylcholinesterase Inhibition Tests. <i>Ecotoxicol. Environ. Saf.</i> 45(3): 253-259, 2000. Ecoref #48695	
Gutierrez,M.F., A.M. Gagneten, and J.C. Paggi. Copper and Chromium Alter Life Cycle Variables and the Equiproportional Development of the Freshwater Copepod <i>Notodiaptomus conifer</i> (Sars.). <i>Water Air Soil Pollut.</i> 213:275-286, 2010. Ecoref #169526	
Mishra,A.K., and B. Mohanty. Chronic Exposure to Sublethal Hexavalent Chromium Affects Organ Histopathology and Serum Cortisol Profile of a Teleost, <i>Channa punctatus</i> (Bloch). <i>Sci. Total Environ.</i> 407(18): 5031-5038, 2009. Ecoref #119189	Non-north american test species used
Natale,G.S., L.L. Ammassari, N.G. Basso, and A.E. Ronco. Acute and Chronic Effects of Cr(VI) on <i>Hypsiboas pulchellus</i> Embryos and Tadpoles. <i>Dis. Aquat. Org.</i> 72(3): 261-267, 2006. Ecoref #101072	
Nguyen,L.T.H., and C.R. Janssen. Comparative Sensitivity of Embryo-Larval Toxicity Assays with African Catfish ( <i>Clarias gariepinus</i> ) and Zebra Fish ( <i>Danio rerio</i> ). <i>Environ. Toxicol.</i> 16(6): 566-571, 2001. Ecoref #68928	Acceptable but ACR cannot be calculated
Oner,M., G. Atli, and M. Canli. Effects of Metal (Ag, Cd, Cr, Cu, Zn) Exposures on Some Enzymatic and Non-Enzymatic Indicators in the Liver of <i>Oreochromis niloticus</i> . <i>Bull. Environ. Contam. Toxicol.</i> 82(3): 317-321, 2009. Ecoref #112714	Non-north american test species used
Pickering,Q.H., and J.M. Lazorchak. Evaluation of the Robustness of the Fathead Minnow, <i>Pimephales promelas</i> , Larval Survival and Growth Test, U.S. EPA Method 1000.0. <i>Environ. Toxicol. Chem.</i> 14(4): 653-659, 1995. Ecoref #45200	Acceptable but ACR cannot be calculated
Sofyan,A.. Toxicity of Metals to Green Algae and <i>Ceriodaphnia dubia</i> : The Importance of Water Column and Dietary Exposures. Ph.D.Thesis, University of Kentucky, Lexington, KY:161 p., 2004. Ecoref #78692	Chromium III study

## Saltwater Acute

Table A9. List of citations from EPA ECOTOX database reviewed for chromium vi saltwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Andersen,H.R., L. Wollenberger, B. Halling-Sorensen, and K.O. Kusk. Development of Copepod Nauplii to Copepodites - a Parameter for Chronic Toxicity Including Endocrine Disruption. <i>Environ. Toxicol. Chem.</i> 20(12): 2821-2829, 2001. Ecoref #66691	

Citation	Notes
Bookhout,C.G., R.J. Monroe, R.B.,Jr. Forward, and J.D.,Jr. Costlow. Effects of Hexavalent Chromium on Development of Crabs, Rhithropanopeus harrisi and Callinectes sapidus. Water Air Soil Pollut.21(1-4): 199-216, 1984. ECOREF #7013	Used in previous 1984 derivation
Bryant,V., D.S. McLusky, K. Roddie, and D.M. Newbery. Effect of Temperature and Salinity on the Toxicity of Chromium to Three Estuarine Invertebrates (Corophium volutator, Macoma balthica, Nereis diversicolor). Mar. Ecol. Prog. Ser.20(1-2): 137-149, 1984. ECOREF #11873	Threshold reported as LT50 (time based)
Cardin,J.A.. Results of Acute Toxicity Tests Conducted with Chromium at ERL, Narragansett. U.S.EPA, Narragansett, RI:2 p., 1985. ECOREF #3754	Unable to locate
D'Asaro,C.N.. Effects Assessment of Selected Chemicals on Estuarine and Marine Organisms. EPA-600/X-85/056, Environmental Research Laboratory, U.S. Environmental Protection Agency, Gulf Breeze,FL:77 p., 1985. ECOREF #82668	
Dave,G., E. Nilsson, and A.S. Wernersson. Sediment and Water Phase Toxicity and UV-Activation of Six Chemicals Used in Military Explosives. Aquat. Ecosyst. Health Manag.3(3): 291-299, 2000. ECOREF #157913	Study not relevant to Cr6 thresholds
Dorn,P.B., J.H.,Jr. Rodgers, K.M. Jop, J.C. Raia, and K.L. Dickson. Hexavalent Chromium as a Reference Toxicant in Effluent Toxicity Tests. Environ. Toxicol. Chem.6(6): 435-444, 1987. ECOREF #12660	
Ek,H., E. Nilsson, G. Birgersson, and G. Dave. TNT Leakage Through Sediment to Water and Toxicity to Nitocra spinipes. Ecotoxicol. Environ. Saf.67(3): 341-348, 2007. ECOREF #97664	Study not relevant to Cr6 thresholds
Espiritu,E.Q., C.R. Janssen, and G. Persoone. Cyst-Based Toxicity Tests. VII. Evaluation of the 1-h Enzymatic Inhibition Test (Fluotox) with Artemia nauplii. Environ. Toxicol. Water Qual.10:25-34, 1995. ECOREF #16031	1985 EPA guidance suggests not using Artemia data
Gao,S., and D. Zou. Acute Toxicity of Copper, Mercury and Chromium to Larvae of Penaeus penicillatus Alcock. Mar. Sci. Bull. (Haiyang-Tongbao Shuangyuekan)13(2): 28-32, 1994. ECOREF #16613	Non-north american tests species
Garcia,K., J.B.R. Agard, and A. Mohammed. Comparative Sensitivity of a Tropical Mysid Metamysidopsis insularis and the Temperate Species Americamysis bahia to Six Toxicants. Toxicol. Environ. Chem.90(4): 779-785, 2008. ECOREF #117932	
Hori,H., M. Tateishi, K. Takayanagi, and H. Yamada. Applicability of Artificial Seawater as a Rearing Seawater for Toxicity Tests of Hazardous Chemicals by Marine Fish Species. Nippon Suisan Gakkaishi(4): 614-622, 1996. ECOREF #16999	Wrong language



Citation	Notes
Hutchinson,T.H., T.D. Williams, and G.J. Eales. Toxicity of Cadmium, Hexavalent Chromium and Copper to Marine Fish Larvae ( <i>Cypinodon variegatus</i> ) and Copepods ( <i>Tisbe battagliai</i> ). <i>Mar. Environ. Res.</i> 38(4): 275-290, 1994. Ecoref #14137	
Jop,K.M.. Acute and Rapid-Chronic Toxicity of Hexavalent Chromium to Five Marine Species. <i>ASTM Spec. Tech. Publ.</i> 12:251-260, 1989. Ecoref #198	
Jop,K.M., J.H.,Jr. Rodgers, P.B. Dorn, and K.L. Dickson. Use of Hexavalent Chromium as a Reference Toxicant in Aquatic Toxicity Tests. <i>ASTM Spec. Tech. Publ.</i> 9:390-403, 1986. Ecoref #7772	
Kidwai,S., and M. Ahmed. Heavy Metal Bioassays on Selected Fauna from the Karachi Coast (Northwest Arabian Sea). <i>Pak. J. Zool.</i> 30(2): 147-157, 1999. Ecoref #62226	Non-north american test species
Kissa,E., M. Moraitou-Apostolopoulou, and V. Kiortsis. Effects of Four Heavy Metals on Survival and Hatching Rate of <i>Artemia salina</i> (L.). <i>Arch. Hydrobiol.</i> 102(2): 255-264, 1984. Ecoref #11259	1985 EPA guidance suggests not using <i>Artemia</i> data
Krishnani,K.K., I.S. Azad, M. Kailasam, A.R. Thirunavukkarasu, B.P. Gupta, K.O. Joseph, M. Muralidhar, and M. Abraham. Acute Toxicity of Some Heavy Metals to Lates calcarifer Fry with a Note on Its Histopathological Manifestations. <i>J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control</i> 38(4): 645-655, 2003. Ecoref #78035	Non-north american test species
Lussier,S.M., J.H. Gentile, and J. Walker. Acute and Chronic Effects of Heavy Metals and Cyanide on <i>Mysidopsis bahia</i> (Crustacea: Mysidacea). <i>Aquat. Toxicol.</i> 7(1/2): 25-35, 1985. Ecoref #11331	
Marino-Balsa,J.C., E. Poza, E. Vazquez, and R. Beiras. Comparative Toxicity of Dissolved Metals to Early Larval Stages of <i>Palaemon serratus</i> , <i>Maja squinado</i> , and <i>Homarus gammarus</i> (Crustacea: Decapoda). <i>Arch. Environ. Contam. Toxicol.</i> 39(3): 345-351, 2000. Ecoref #56995	Doesn't specify what type of chromium
McLusky,D.S., and L. Hagerman. The Toxicity of Chromium, Nickel and Zinc: Effects of Salinity and Temperature, and the Osmoregulatory Consequences in the Mysid <i>Praunus flexuosus</i> . <i>Aquat. Toxicol.</i> 10:225-238, 1987. Ecoref #6039	Non-north american test species
Miliou,H., G. Verriopoulos, D. Maroulis, D. Bouloukos, and M. Moraitou-Apostolopoulou. Influence of Life-History Adaptations on the Fidelity of Laboratory Bioassays for the Impact of Heavy Metals (Co <sup>2+</sup> and Cr <sup>6+</sup> ) on Tolerance and Population Dynamics of <i>Tisbe holothuria</i> . <i>Mar. Pollut. Bull.</i> 40(4): 352-359, 2000. Ecoref #52250	Non-north american test species
Mortimer,M.R., and G.J. Miller. Susceptibility of Larval and Juvenile Instars of the Sand Crab, <i>Portunus pelagicus</i> (L.), to Sea Water Contaminated by Chromium, Nickel or Copper. <i>Aust. J. Mar. Freshw. Res.</i> 45(7): 1107-1121, 1994. Ecoref #16331	Non-north american test species

Citation	Notes
Parametrix Inc.. Acute Toxicity of Sodium Cyanide to Marine Copepods ( <i>Acartia tonsa</i> ). Report 3555, Parametrix Environmental Research Laboratory, Albany, OR:158 p., 2006. Ecoref #167149	Not relevant; study used cyanide
Parker,J.G.. The Effects of Selected Chemicals and Water Quality on the Marine Polychaete <i>Ophryotrocha diadema</i> . <i>Water Res.</i> 18(7): 865-868, 1984. Ecoref #10890	Not relevant; multi-generational study with tolerant species
Ramirez,P., G. Barrera, and C. Rosas. Effects of Chromium and Cadmium upon Respiration and Survival of <i>Callinectes similis</i> . <i>Bull. Environ. Contam. Toxicol.</i> 43(6): 850-857, 1989. Ecoref #2549	Field collect organisms; only 4 test concentrations
Rao,K.R., and D.G. Doughtie. Histopathological Changes in Grass Shrimp Exposed to Chromium, Pentachlorophenol and Dithiocarbamates. <i>Mar. Environ. Res.</i> 14:371-395, 1984. Ecoref #13291	Not relevant
Rao,K.R., and P.J. Conklin. Molt-Related Susceptibility and Regenerative Limb Growth as Sensitive Indicators of Aquatic Pollutant Toxicity to Crustaceans. In: M.F.Thompson, R.Sarojini, and R.Nagabhushanam (Eds.), <i>Biology of Benthic Marine Organisms: Techniques and Methods as Applied to the Indian Ocean</i> , A.A.Balkema, Rotterdam, Netherlands:523-534, 1986. Ecoref #14267	Endpoints were not relevant to criteria development
Reish,D.J., and J.A. Lemay. Toxicity and Bioconcentration of Metals and Organic Compounds by Polychaeta. <i>Ophelia</i> 5(suppl.): 653-660, 1991. Ecoref #3785	
Savant,K.B., and G.V. Nilkanth. On Comparative Studies of Acute Toxicity of Hexavalent Chromium and Selenium to <i>Scylla serrata</i> (Forsk.). <i>Pollut. Res.</i> 10(4): 239-243, 1991. Ecoref #81814	Non-north american test species
Taylor,D., B.G. Maddock, and G. Mance. The Acute Toxicity of Nine "Grey List" Metals (Arsenic, Boron, Chromium, Copper, Lead, Nickel, Tin, Vanadium and Zinc) to Two Marine Fish Species. <i>Aquat. Toxicol.</i> 7(3): 135-144, 1985. Ecoref #11451	
U.S. Environmental Protection Agency. Pesticide Ecotoxicity Database (Formerly: Environmental Effects Database (EEDB)). Environmental Fate and Effects Division, U.S.EPA, Washington, D.C.:, 1992. Ecoref #344	Database reference
Van der Meer,C., C. Teunissen, and T.F.M. Boog. Toxicity of Sodium Chromate and 3,4-Dichloroaniline to Crustaceans. <i>Bull. Environ. Contam. Toxicol.</i> 40(2): 204-211, 1988. Ecoref #2419	Lacking informaton on methods such as test concentrations and replicates
Verriopoulos,G., A.V. Catsiki, A. Pantelidou, and M. Moraitou-Apostolopoulo. Studies on the Impact of Chromium to the Marine Gastropod <i>Monodonta turbinata</i> (Toxicity, Bioaccumulation, Acclimation). <i>Rev. Int. Oceanogr. Med.</i> 93:103-118, 1990. Ecoref #18853	

Citation	Notes
Verriopoulos,G., M. Moraitou-Apostolopoulou, and E. Milliou. Combined Toxicity of Four Toxicants (Cu, Cr, Oil, Oil Dispersant) to <i>Artemia salina</i> . <i>Bull. Environ. Contam. Toxicol.</i> 38(3): 483-490, 1987. Ecoref #9336	
Vranken,G., R. Vanderhaeghen, and C. Heip. Effects of Pollutants on Life-History Parameters of the Marine Nematode <i>Monhystera disjuncta</i> . <i>ICES J. Mar. Sci.</i> 48:325-334, 1991. Ecoref #7215	Non-north american test species
Wong,C.K., K.H. Chu, K.W. Tang, T.W. Tam, and L.J. Wong. Effects of Chromium, Copper and Nickel on Survival and Feeding Behaviour of <i>Metapenaeus ensis</i> Larvae and Postlarvae (Decapoda: Penaeidae). <i>Mar. Environ. Res.</i> 36(2): 63-78, 1993. Ecoref #4127	Non-north american test species

## Saltwater Chronic

Table A10. List of citations from EPA ECOTOX database reviewed for chromium vi saltwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Ahsanullah,M., and A.R. Williams. Sublethal Effects and Bioaccumulation of Cadmium, Chromium, Copper, and Zinc in the Marine Amphipod <i>Allorchestes compressa</i> . <i>Mar. Biol.</i> 108:59-65, 1991. Ecoref #331	LC50 reported as greater than value
Andersen,H.R., L. Wollenberger, B. Halling-Sorensen, and K.O. Kusk. Development of Copepod Nauplii to Copepodites - a Parameter for Chronic Toxicity Including Endocrine Disruption. <i>Environ. Toxicol. Chem.</i> 20(12): 2821-2829, 2001. Ecoref #66691	
Goodfellow,W.L.,Jr., and W.J. Rue. Evaluation of a Chronic Estimation Toxicity Test Using <i>Mysidopsis bahia</i> . <i>ASTM Spec. Tech. Publ.</i> 12:333-344, 1989. Ecoref #2048	
Hutchinson,T.H., T.D. Williams, and G.J. Eales. Toxicity of Cadmium, Hexavalent Chromium and Copper to Marine Fish Larvae ( <i>Cypinodon variegatus</i> ) and Copepods ( <i>Tisbe battagliai</i> ). <i>Mar. Environ. Res.</i> 38(4): 275-290, 1994. Ecoref #14137	
Jop,K.M.. Acute and Rapid-Chronic Toxicity of Hexavalent Chromium to Five Marine Species. <i>ASTM Spec. Tech. Publ.</i> 12:251-260, 1989. Ecoref #198	
Lussier,S.M., J.H. Gentile, and J. Walker. Acute and Chronic Effects of Heavy Metals and Cyanide on <i>Mysidopsis bahia</i> (Crustacea: Mysidacea). <i>Aquat. Toxicol.</i> 7(1/2): 25-35, 1985. Ecoref #11331	
McCulloch,W.L., and W.J. Rue. Evaluation of Seven-Day Chronic Toxicity Estimation Test Using <i>Cyprinodon variegatus</i> . <i>ASTM Spec. Tech. Publ.</i> 12:355-364, 1989. Ecoref #13864	

Citation	Notes
Mortimer, M.R., and G.J. Miller. Susceptibility of Larval and Juvenile Instars of the Sand Crab, <i>Portunus pelagicus</i> (L.), to Sea Water Contaminated by Chromium, Nickel or Copper. <i>Aust. J. Mar. Freshw. Res.</i> 45(7): 1107-1121, 1994. ECODEF #16331	
Van der Meer, C., C. Teunissen, and T.F.M. Boog. Toxicity of Sodium Chromate and 3,4-Dichloroaniline to Crustaceans. <i>Bull. Environ. Contam. Toxicol.</i> 40(2): 204-211, 1988. ECODEF #2419	Methods lacking information such as test concentrations and replicates

## Cyanide

### Freshwater Acute

Table A11. List of citations from EPA ECOTOX database reviewed for cyanide freshwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Alabaster, J.S., D.G. Shurben, and M.J. Mallett. The Acute Lethal Toxicity of Mixtures of Cyanide and Ammonia to Smolts of Salmon, <i>Salmo salar</i> L. at Low Concentrations of Dissolved Oxygen. <i>J. Fish Biol.</i> 22(2): 215-222, 1983. ECODEF #10252	
Bailey, H.C., D.H.W. Liu, and H.A. Javitz. Time/Toxicity Relationships in Short-Term Static, Dynamic, and Plug-Flow Bioassays. <i>ASTM Spec. Tech. Publ.</i> :193-212, 1985. ECODEF #7398	Study explains a testing method and not test results
Beleau, M.H., and J.A. Bartosz. Colorado River Fisheries Project Acute Toxicity of Selected Chemicals: Data Base. In: <i>Rep.No.6, Dep.of Fish.Resour., Univ.of Idaho, Moscow, ID:243-254</i> , 1982. ECODEF #86404	Database reference
Broderius, S., and M. Kahl. Acute Toxicity of Organic Chemical Mixtures to the Fathead Minnow. <i>Aquat. Toxicol.</i> 6:307-322, 1985. ECODEF #14128	Sand and gravel as media in testing
Brooke, L.T., D.J. Call, D.L. Geiger, and C.E. Northcott. Acute Toxicities of Organic Chemicals to Fathead Minnows ( <i>Pimephales promelas</i> ), Vol. 1. Center for Lake Superior Environmental Studies, University of Wisconsin-Superior, Superior, WI:414 p., 1984. ECODEF #12448	Repeat of data
Buccafusco, R.J., S.J. Ells, and G.A. LeBlanc. Acute Toxicity of Priority Pollutants to Bluegill ( <i>Lepomis macrochirus</i> ). <i>Bull. Environ. Contam. Toxicol.</i> 26(4): 446-452, 1981. ECODEF #5590	No cyanide info available
Call, D.J., L.T. Brooke, D.H. Hammermeister, C.E. Northcott, and A.D. Hoffman. Variation of Acute Toxicity with Water Source. Center for Lake Superior Environmental Studies, Report No. LSRI0273:58 p., 1983. ECODEF #152135	EPA used in 1984 cyanide derivation

Citation	Notes
Call,D.J., L.T. Brooke, N. Ahmad, and J.E. Richter. Toxicity and Metabolism Studies with EPA (Environmental Protection Agency) Priority Pollutants and Related Chemicals in Freshwater Organisms. EPA 600/3-83-095, U.S.EPA, Duluth, MN:120 p., 1983. Ecoref #10579	EPA used in 1984 cyanide derivation
Call,D.J., and L.T. Brooke. Report on Stonefly Toxicity Tests with Priority Pollutants. Ctr.for Lake Superior Environ.Stud., Univ.of Wisconsin-Superior, Superior, WI (Memo to R.E.Siefert, U.S.EPA, Duluth, MN):2 p., 1982. Ecoref #9498	EPA used in 1984 cyanide derivation
Calleja,M.C., G. Persoone, and P. Geladi. Comparative Acute Toxicity of the First 50 Multicentre Evaluation of In Vitro Cytotoxicity Chemicals to Aquatic Non-vertebrates. Arch. Environ. Contam. Toxicol.26(1): 69-78, 1994. Ecoref #13669	Not relevant; cytotoxicity study
Collins,S.. Toxicity of Deicing Salt Components to Early Amphibian Life Stages. M.S. Thesis, Saint Mary's University, Canada:109 p., 2010. Ecoref #157604	Not relevant; test compound is ferrocyanide
David,M., H. Ramesh, S.P. Deshpande, S.G. Chebbi, and G. Krishnamurthy. Respiratory Distress and Behavioral Changes Induced by Sodium Cyanide in the Fresh Water Teleost, Cyprinus carpio (Linnaeus). J. Basic Clin. Physiol. Pharmacol.18(2): 55-65, 2007. Ecoref #118154	Non-north american test species
Dube,P.N., and B.B. Hosetti. Modulation in the Protein Metabolism by Subacute Sodium Cyanide Intoxication in the Freshwater Fish, Labeo rohita (Hamilton). Drug Chem. Toxicol.35(1): 25-31, 2012. Ecoref #160876	Non-north american test species
Dube,P.N., and B.B. Hosetti. Inhibition of ATPase Activity in the Freshwater Fish Labeo rohita (Hamilton) Exposed to Sodium Cyanide. Toxicol. Mech. Methods21(8): 591-595, 2011. Ecoref #164481	Non-north american test species
ENSR Corporation. Acute Toxicity of Cyanide to the Frog, Rana pipiens, in Horsetooth Reservoir Water Under Flow-Through Test Conditions. Report 8503-124-020-075, ENSR Corporation, Fort Collins, CO:45 p., 2005. Ecoref #166858	Unable to locate article
ENSR Corporation. Acute Toxicity of Cyanide to the Frog, Rana berlandieri, in Horsetooth Reservoir Water Under Flow-Through Test Conditions. Report 8503-124-020-076, ENSR Corporation, Fort Collins, CO:38 p., 2005. Ecoref #166859	Unable to locate article
ENSR Corporation. Acute Toxicity of Cyanide to the Frog, Xenopus laevis, in Horsetooth Reservoir Water Under Flow-Through Test Conditions. Report 8503-124-020-074, ENSR Corporation, Fort Collins, CO:50 p., 2005. Ecoref #166860	Unable to locate article
Elaziz,M.A., M. Moustafa, and A.E. Eissa. Assessment of Acute and Chronic Toxicity of Sodium Cyanide on Some Egyptian Freshwater Fishes. Abbassa Int. J. Aquac.:113-127, 2009. Ecoref #165769	Non-north american test species

Citation	Notes
Ewell,W.S., J.W. Gorsuch, R.O. Kringle, K.A. Robillard, and R.C. Spiegel. Simultaneous Evaluation of the Acute Effects of Chemicals on Seven Aquatic Species. Environ. Toxicol. Chem.5(9): 831-840, 1986. Ecoref #11951	
Jin,H., X. Yang, H. Yu, and D. Yin. Identification of Ammonia and Volatile Phenols as Primary Toxicants in a Coal Gasification Effluent. Bull. Environ. Contam. Toxicol.63(3): 399-406, 1999. Ecoref #117105	Study objectives and methods don't align with criteria development
Kitamura,H.. Relation Between the Toxicity of Some Toxicants to the Aquatic Animals (Tanichthys albonubes and Neocaridina denticulata) and the Hardness of the Test Solution. Bull. Fac. Fish. Nagasaki Univ. (Chodai Sui Kempo)67:13-19, 1990. Ecoref #5459	Non-north american test species
Kovacs,T.G., and G. Leduc. Acute Toxicity of Cyanide to Rainbow Trout (Salmo gairdneri) Acclimated at Different Temperatures. Can. J. Fish. Aquat. Sci.39(10): 1426-1429, 1982. Ecoref #15601	EPA used in 1984 cyanide derivation
LeBlanc,G.A.. Acute Toxicity of Priority Pollutants to Water Flea (Daphnia magna). Bull. Environ. Contam. Toxicol.24(5): 684-691, 1980. Ecoref #5184	Did not find any cyanide toxicity data
LeBlanc,G.A., and D.C. Surprenant. The Chronic Toxicity of 8 of the 65 Priority Pollutants to the Water Flea (Daphnia magna). Draft Manuscript, EG&G Bionomics, Aquatic Toxicology Laboratory, Wareham, MA:36 p., 1980. Ecoref #121018	Chronic based study
Marking,L.L., T.D. Bills, and J.R. Crowther. Effects of Five Diets on Sensitivity of Rainbow Trout to Eleven Chemicals. Prog. Fish-Cult.46(1): 1-5, 1984. Ecoref #10656	Diet based study; not relevant to water exposure
McGeachy,S.M.. Acute and Sublethal Toxicity of Cyanide to Exercised and Non-Exercised Rainbow Trout (Salmo gairdneri) at Different Times of the Year. Ph.D.Thesis, Concordia Univ., Montreal, Quebec, Canada:71 p., 1984. Ecoref #118391	Repeat of other McGeachy study
McGeachy,S.M., and G. Leduc. The Influence of Season and Exercise on the Lethal Toxicity of Cyanide to Rainbow Trout (Salmo gairdneri). Arch. Environ. Contam. Toxicol.17(3): 313-318, 1988. Ecoref #2344	
Meyn,E.L., R.K. Zajdel, and R.V. Thurston. Acute Toxicity of Ferrocyanide and Ferricyanide to Rainbow Trout (Salmo gairdneri). Tech.Rep.No.84-1, Fish.Bioassay Lab., Montana State Univ., Bozeman, MT:19 p., 1984. Ecoref #12029	Ferrocyanide used (mixture of iron and cyanide)
Moore,S.B., R.A. Diehl, J.M. Barnhardt, and G.B. Avery. Aquatic Toxicities of Textile Surfactants. Text. Chem. Color.19(5): 29-32, 1987. Ecoref #12754	Did not find cyanide data
Mowbray,D.L.. Assessment of the Biological Impact of OK Tedi Mine Tailings, Cyanide and Heavy Metals. In: J.C.Pernetta (Ed.), Reg.Seas Rep.Stud.No.99, Potential Impacts of Mining on the Fly River, UNEP, Athens, Greece:45-74, 1988. Ecoref #17356	Not relevant; site-specific assessment

Citation	Notes
Nalecz-Jawecki,G., and J. Sawicki. Toxicity of Inorganic Compounds in the Spirotox Test: A Miniaturized Version of the Spirostomum ambiguum Test. Arch. Environ. Contam. Toxicol.34(1): 1-5, 1998. Ecoref #18997	Bacteria based test; can't use single celled orgs
Parametrix Inc.. 96-h Acute Toxicity of Cyanide to Gasterosteus aculeatus Under Flow-Through Conditions. Report 3539-15, Parametrix Environmental Research Laboratory, Albany, OR:10 p., 2005. Ecoref #167153	Unable to locate article
Prashanth,M.S.. Acute Toxicity, Behavioral and Nitrogen Metabolism Changes of Sodium Cyanide Affected on Tissues of Tilapia mossambica (Peters). Drug Chem. Toxicol.35(2): 178-183, 2012. Ecoref #160874	Non-north american test species
Prashanth,M.S., H.A. Sayeswara, and H.S.R. Patil. Impact of Copper Cyanide on Behavioral Changes and Oxygen Consumption in Indian Major Carp Catla catla (Hamilton). J. Environ. Agric. Food Chem.9(9): 1433-1442, 2010. Ecoref #158813	Non-north american test species
Qureshi,A.A., K.W. Flood, S.R. Thompson, S.M. Janhurst, C.S. Inniss, and D.A. Rokosh. Comparison of a Luminescent Bacterial Test with Other Bioassays for Determining Toxicity of Pure Compounds and Complex Effluents. ASTM Spec. Tech. Publ.:179-195, 1982. Ecoref #15923	Bacteria based test; can't use single celled orgs
Richie,J.P.,Jr., B.J. Mills, and C.A. Lang. The Verification of a Mammalian Toxicant Classification Using a Mosquito Screening Method. Fundam. Appl. Toxicol.4(6): 1029-1035, 1984. Ecoref #173907	Not relevant; details a testing method
Sabourin,T.D.. Methods for Aquatic Toxicity Tests Conducted with Acrolein and DEHP as well as the Methods and Results for Acrylonitrile Tests. September 18 Memo to D.Call, University of Wisconsin, Superior, WI:16 p., 1987. Ecoref #17132	Not relevant; no cyanide data available
Sangli,A.B., and V.V. Kanabur. Lethal Toxicity of Cyanide and Formalin to a Freshwater Fish Gambusia affinis. Environ. Ecol.18(2): 362-364, 2000. Ecoref #74408	
Sanoli,A.B., and V.V. Kanabur. Acute Toxicity of Cyanide and Formalin to a Freshwater Fish Lepidocephalichthys guntea (Catfish). Indian J. Fish.48(1): 99-101, 2001. Ecoref #118101	Non-north american test species
Sarkar,S.K.. Toxicity Evaluation of Sodium Cyanide to Fish and Aquatic Organisms: Effects of Temperature. Sci. Cult.56(4): 165-168, 1990. Ecoref #8886	
Schimmel,S.C.. Results of Toxicity Tests Conducted with Cyanide at ERL, Narragansett. U.S.EPA, Narragansett, RI, (Memo to John H.Gentile, U.S.EPA, Narragansett, RI):2 p., 1981. Ecoref #103809	Unable to locate article

Citation	Notes
Skibba,W.D.. The Trout Test with <i>Salmo gairdneri</i> Rich. for Determining the Acute Toxicity of Aggressive Substances as Well as Measurement Results for. <i>Acta Hydrochim. Hydrobiol.</i> 9(1): 3-15, 1981. ECODEF #5639	EPA used in 1984 derivation
Slabbert,J.L., and E.A. Venter. Biological Assays for Aquatic Toxicity Testing. <i>Water Sci. Technol.</i> 39(10/11): 367-373, 1999. ECODEF #61447	Non-north american test species
Solbe,J.F.D., V.A. Cooper, C.A. Willis, and M.J. Mallett. Effects of Pollutants in Fresh Waters on European Non-Salmonid Fish I: Non-Metals. <i>J. Fish Biol.</i> 27(suppl.A): 197-207, 1985. ECODEF #11655	Non-north american test species
Thurston,R.V., and T.A. Heming. Acute Toxicity of Iron Cyanides and Thiocyanate to Trout. In: EPA-600/9-86/024, R.C.Ryans (Ed.), <i>Proc.of USA-USSR Symp.</i> , Jul.30-Aug.1, 1984, Borok, Jaroslavl Oblast, U.S.EPA, Athens, GA:55-71, 1984. ECODEF #67837	Unable to locate article
Tong,Z., Z. Huailan, and J. Hongjun. Chronic Toxicity of Acrylonitrile and Acetonitrile to <i>Daphnia magna</i> in 14-d and 21-d Toxicity Tests. <i>Bull. Environ. Contam. Toxicol.</i> 57(4): 655-659, 1996. ECODEF #13070	Chronic study
Tonogai,Y., S. Ogawa, Y. Ito, and M. Iwaida. Actual Survey on TLM (Median Tolerance Limit) Values of Environmental Pollutants, Especially on Amines, Nitriles, Aromatic Nitrogen Compounds. <i>J. Toxicol. Sci.</i> 7(3): 193-203, 1982. ECODEF #10132	Study not relevant; cyanide data not available
Tryland,O., and M. Grande. Removal of Cyanide from Scrubber Effluents and Its Effect on Toxicity to Fish. <i>Vatten</i> 39:168-174, 1983. ECODEF #20723	Study not relevant ; examined wastewater
Tscheu-Schluter,M.. On the Toxicity of Simple and Complex Cyanides to Aquatic Organisms (Zur Toxizitat Einfacher und Komplexer Cyanide Gegenuber Wasserorganismen). <i>Acta Hydrochim. Hydrobiol.</i> 11(2): 169-179, 1983. ECODEF #12314	Non-north american test species
U.S. Environmental Protection Agency. Pesticide Ecotoxicity Database (Formerly: Environmental Effects Database (EEDB)). Environmental Fate and Effects Division, U.S.EPA, Washington, D.C., 1992. ECODEF #344	Reference to a database
Van der Schalie,W.H., T.R. Shedd, M.W. Widder, and L.M. Brennan. Response Characteristics of an Aquatic Biomonitor Used for Rapid Toxicity Detection. <i>J. Appl. Toxicol.</i> 24(5): 387-394, 2004. ECODEF #77525	
Wellens,H.. Comparison of the Sensitivity of <i>Brachydanio rerio</i> and <i>Leuciscus idus</i> by Testing the Fish Toxicity of Chemicals and Wastewaters. <i>Z. Wasser-Abwasser-Forsch.</i> 51(2): 49-52, 1982. ECODEF #11037	Wrong language
Zhang,T., H. Jin, and H. Zhu. Quality Criteria of Acrylonitrile for the Protection of Aquatic Life in China. <i>Chemosphere</i> 32(10): 2083-2093, 1996. ECODEF #16884	Non-north american test species



## Freshwater Chronic

Table A12. List of citations from EPA ECOTOX database reviewed for cyanide freshwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Authman,M.M.N., W.T. Abbas, I.M.K. Abumourad, and A.M. Kenawy. Effects of Illegal Cyanide Fishing on Vitellogenin in the Freshwater African Catfish, <i>Clarias gariepinus</i> (Burchell, 1822). <i>Ecotoxicol. Environ. Saf.</i> 91(0): 61-70, 2013. Ecoref #164180	Non-north american test species
LeBlanc,G.A., and D.C. Surprenant. The Chronic Toxicity of 8 of the 65 Priority Pollutants to the Water Flea ( <i>Daphnia magna</i> ). Draft Manuscript, EG&G Bionomics, Aquatic Toxicology Laboratory, Wareham, MA:36 p., 1980. Ecoref #121018	No cyanide data
Moore,S.B., R.A. Diehl, J.M. Barnhardt, and G.B. Avery. Aquatic Toxicities of Textile Surfactants. <i>Text. Chem. Color.</i> 19(5): 29-32, 1987. Ecoref #12754	No cyanide data
Rippon,G.D., C.A. Le Gras, R.V. Hyne, and P.J. Cusbert. Toxic Effects of Cyanide on Aquatic Animals of the Alligator Rivers Region. Tech.Memorandum No.39, Commonwealth of Australia, Supervising Scientist for the Alligator Rivers Region, N.S.W.2022, Australia:10 p., 1992. Ecoref #6598	Non-north american test species
Szabo,A., S.M. Ruby, F. Rogan, and Z. Amit. Changes in Brain Dopamine Levels, Oocyte Growth and Spermatogenesis in Rainbow Trout, <i>Oncorhynchus mykiss</i> , Following Sublethal Cyanide Exposure. <i>Arch. Environ. Contam. Toxicol.</i> 21(1): 152-157, 1991. Ecoref #117809	Endpoints not relevant
Tong,Z., Z. Huailan, and J. Hongjun. Chronic Toxicity of Acrylonitrile and Acetonitrile to <i>Daphnia magna</i> in 14-d and 21-d Toxicity Tests. <i>Bull. Environ. Contam. Toxicol.</i> 57(4): 655-659, 1996. Ecoref #13070	No cyanide data
Zhang,T., H. Jin, and H. Zhu. Quality Criteria of Acrylonitrile for the Protection of Aquatic Life in China. <i>Chemosphere</i> 32(10): 2083-2093, 1996. Ecoref #16884	Non-north american test species

## Nickel

### Freshwater Acute

Table A13. List of citations from EPA ECOTOX database reviewed for nickel freshwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Alam,M.K., and O.E. Maughan. Acute Toxicity of Heavy Metals to Common Carp (Cyprinus carpio). J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control30(8): 1807-1816, 1995. Ecoref #45566	Non-north american test species used; no hardness
Alkalem,H.F.. The Toxicity of Nickel and the Effects of Sublethal Levels on Haematological Parameters and Behaviour of the Fish, Oreochromis niloticus. J. Univ. Kuwait Sci.21(2): 243-251, 1994. Ecoref #16861	Non-north american test species used
Alkalem,H.F.. Effects of Nickel on Carbohydrate Metabolism of Oreochromis niloticus. Dirasat Ser. B Pure Appl. Sci.22(1): 83-88, 1995. Ecoref #20533	Non-north american test species used
Alsop,D., and C.M. Wood. Metal Uptake and Acute Toxicity in Zebrafish: Common Mechanisms Across Multiple Metals. Aquat. Toxicol.105(3/4): 385-393, 2011. Ecoref #158223	
Alsop,D., and C.M. Wood. Metal and Pharmaceutical Mixtures: Is Ion Loss the Mechanism Underlying Acute Toxicity and Widespread Additive Toxicity in Zebrafish?. Aquat. Toxicol.140/141:257-267, 2013. Ecoref #166490	
Bechard,K.M., P.L. Gillis, and C.M. Wood. Acute Toxicity of Waterborne Cd, Cu, Pb, Ni, and Zn to First-Instar Chironomus riparius Larvae. Arch. Environ. Contam. Toxicol.54(3): 454-459, 2008. Ecoref #108924	24-hr LC50; control mortality after 24 hr
Borgmann,U., Y. Couillard, P. Doyle, and D.G. Dixon. Toxicity of Sixty-Three Metals and Metalloids to Hyalella azteca at Two Levels of Water Hardness. Environ. Toxicol. Chem.24(3): 641-652, 2005. Ecoref #80935	
Brix,K.V., J. Keithly, D.K. DeForest, and J. Laughlin. Acute and Chronic Toxicity of Nickel to Rainbow Trout (Oncorhynchus mykiss). Environ. Toxicol. Chem.23(9): 2221-2228, 2004. Ecoref #80785	
Chu,K.W., and K.L. Chow. Synergistic Toxicity of Multiple Heavy Metals is Revealed by a Biological Assay Using a Nematode and Its Transgenic Derivative. Aquat. Toxicol.61(1/2): 53-64, 2002. Ecoref #65728	No hardness data
Fargasova,A.. Ecotoxicology of Metals Related to Freshwater Benthos. Gen. Physiol. Biophys.18(Focus Issue): 48-53, 1999. Ecoref #61824	

Citation	Notes
Griffitt,R.J., J. Luo, J. Gao, J.C. Bonzongo, and D.S. Barber. Effects of Particle Composition and Species on Toxicity of Metallic Nanomaterials in Aquatic Organisms. Environ. Toxicol. Chem.27(9): 1972-1978, 2008. Ecoref #104806	
Herkovits,J., C.S. Perez-Coll, and F.D. Herkovits. Evaluation of Nickel-Zinc Interactions by Means of Bioassays with Amphibian Embryos. Ecotoxicol. Environ. Saf.45(3): 266-273, 2000. Ecoref #50151	No hardness data
Herkovits,J., L. Corro, C. Perez-Coll, and O. Dominguez. Fluid Motion Effect on Metal Toxicity in Bufo arenarum Embryos. Bull. Environ. Contam. Toxicol.68(4): 549-554, 2002. Ecoref #65778	No hardness data
Hockett,J.R., and D.R. Mount. Use of Metal Chelating Agents to Differentiate Among Sources of Acute Aquatic Toxicity. Environ. Toxicol. Chem.15(10): 1687-1693, 1996. Ecoref #45021	
Kallanagoudar,Y.P., and H.S. Patil. Influence of Water Hardness on Copper, Zinc and Nickel Toxicity to Gambusia affinis (B&G). J. Environ. Biol.18(4): 409-413, 1997. Ecoref #19028	
Kazlauskiene,N., A. Burba, and G. Svecevicus. Acute Toxicity of Five Galvanic Heavy Metals to Hydrobionts. Ekologija1:33-36, 1994. Ecoref #17573	
Keithly,J., J.A. Brooker, D.K. DeForest, B.K. Wu, and K.V. Brix. Acute and Chronic Toxicity of Nickel to a Cladoceran (Ceriodaphnia dubia) and an Amphipod (Hyalella azteca). Environ. Toxicol. Chem.23(3): 691-696, 2004. Ecoref #106584	
Keller,A.E.. Personal Communication to U.S. EPA: Water Quality and Toxicity Data for Unpublished Unionid Mussel Tests. Memo to R.Pepin and C.Roberts,U.S.EPA Region 5,Chicago, IL:14 p., 2000. Ecoref #76251	Unpublished work; no access
Khan,S., and D. Nugegoda. Sensitivity of Juvenile Freshwater Crayfish Cherax destructor (Decapoda: Parastacidae) to Trace Metals. Ecotoxicol. Environ. Saf.68(3): 463-469, 2007. Ecoref #106705	Non-north american test species
Khunyakari,R.P., V. Tare, and R.N. Sharma. Effects of Some Trace Heavy Metals on Poecilia reticulata (Peters). J. Environ. Biol.22(2): 141-144, 2001. Ecoref #62227	Non-north american test species
Liber,K., L.E. Doig, and S.L. White-Sobey. Toxicity of Uranium, Molybdenum, Nickel, and Arsenic to Hyalella azteca and Chironomus dilutus in Water-Only and Spiked-Sediment Toxicity Tests. Ecotoxicol. Environ. Saf.74(5): 1171-1179, 2011. Ecoref #175087	
Madoni,P.. The Acute Toxicity of Nickel to Freshwater Ciliates. Environ. Pollut.109(1): 53-59, 2000. Ecoref #51792	Single celled test organism; not appropriate
Madoni,P., and M.G. Romeo. Acute Toxicity of Heavy Metals Towards Freshwater Ciliated Protists. Environ. Pollut.141(1): 1-7, 2006. Ecoref #95678	Single celled test organism; not appropriate

Citation	Notes
Nalecz-Jawecki,G., and J. Sawicki. Toxicity of Inorganic Compounds in the Spirotox Test: A Miniaturized Version of the Spirostomum ambiguum Test. Arch. Environ. Contam. Toxicol.34(1): 1-5, 1998. Ecoref #18997	Bacteria test; not appropriate
Nanda,P., B.N. Panda, and M.K. Behera. Nickel Induced Alterations in Protein Level of Some Tissues of Heteropneustes fossilis. J. Environ. Biol.21(2): 117-119, 2000. Ecoref #52565	Non-north american test species used
Phipps,G.L., V.R. Mattson, and G.T. Ankley. Relative Sensitivity of Three Freshwater Benthic Macroinvertebrates to Ten Contaminants. Arch. Environ. Contam. Toxicol.28(3): 281-286, 1995. Ecoref #14907	10-day LC50; not appropriate
Pourkhabbaz,A., T. Khazaei, S. Behraves, M. Ebrahimpour, and H. Pourkhabbaz. Effect of Water Hardness on the Toxicity of Cobalt and Nickel to a Freshwater Fish, Capoeta fusca. Biomed. Environ. Sci.24(6): 656-660, 2011. Ecoref #166472	Non-north american test species used
Puttaswamy,N., and K. Liber. Influence of Inorganic Anions on Metals Release from Oil Sands Coke and on Toxicity of Nickel and Vanadium to Ceriodaphnia dubia. Chemosphere86(5): 521-529, 2012. Ecoref #165122	Mixture study; inappropriate water quality test conditions
Sanchez-Moreno,S., J.A. Camargo, and A. Navas. Ecotoxicological Assessment of the Impact of Residual Heavy Metals on Soil Nematodes in the Guadiamar River Basin (Southern Spain). Environ. Monit. Assess.116(1-3): 245-262, 2006. Ecoref #101819	Soil nematodes used as test organism
Sharma,S., S. Sharma, P.K. Singh, R.C. Swami, and K.P. Sharma. Exploring Fish Bioassay of Textile Dye Wastewaters and Their Selected Constituents in Terms of Mortality and Erythrocyte Disorders. Bull. Environ. Contam. Toxicol.83(1): 29-34, 2009. Ecoref #158330	Test material isn't relevant
Shuhaimi-Othman,M., N. Yakub, N.A. Ramle, and A. Abas. Toxicity of Metals to a Freshwater Ostracod: Stenocypris major. J. Toxicol.2011:8 p., 2011. Ecoref #165793	Non-north american test species used
Shuhaimi-Othman,M., N. Yakub, N.S. Umirah, and A. Abas. Toxicity of Eight Metals to Malaysian Freshwater Midge Larvae Chironomus javanus (Diptera, Chironomidae). Toxicol. Ind. Health27(10): 879-886, 2011. Ecoref #163320	Non-north american test species used
Shuhaimi-Othman,M., R. Nur-Amalina, and Y. Nadzifah. Toxicity of Metals to a Freshwater Snail, Melanoides tuberculata. Sci. World J.:10 p., 2012. Ecoref #166664	Non-north american test species used
Shuhaimi-Othman,M., Y. Nadzifah, N.S. Umirah, and A.K. Ahmad. Toxicity of Metals to Tadpoles of the Common Sunda Toad, Duttaphrynus melanostictus. Toxicol. Environ. Chem.94(2): 364-376, 2012. Ecoref #159422	Non-north american test species used
Shuhaimi-Othman,M., Y. Nadzifah, N.S. Umirah, and A.K. Ahmad. Toxicity of Metals to an Aquatic Worm, Nais elinguis (Oligochaeta, Naididae). Res. J. Environ. Toxicol.6(4): 122-132, 2012. Ecoref #163848	Non-north american test species used

Citation	Notes
Sornaraj,R., P. Baskaran, and S. Thanalakshmi. Effects of Heavy Metals on Some Physiological Responses of Air-Breathing Fish <i>Channa punctatus</i> (Bloch). <i>Environ. Ecol.</i> 13(1): 202-207, 1995. ECOREF #17380	Non-north american test species used
Sztrum,A.A., J.L. D'Eramo, and J. Herkovits. Nickel Toxicity in Embryos and Larvae of the South American Toad: Effects on Cell Differentiation, Morphogenesis, and Oxygen Consumption. <i>Environ. Toxicol. Chem.</i> 30(5): 1146-1152, 2011. ECOREF #153688	Non-north american test species used
Tatara,C.P., M.C. Newman, J.T. McCloskey, and P.L. Williams. Predicting Relative Metal Toxicity with Ion Characteristics: <i>Caenorhabditis elegans</i> LC50. <i>Aquat. Toxicol.</i> 39(3-4): 279-290, 1997. ECOREF #18605	No hardness data
Tsui,M.T.K., W.X. Wang, and L.M. Chu. Influence of Glyphosate and Its Formulation (Roundup) on the Toxicity and Bioavailability of Metals to <i>Ceriodaphnia dubia</i> . <i>Environ. Pollut.</i> 138(1): 59-68, 2005. ECOREF #87704	Pesticide mixture study
Vedamanikam,V.J., and N.A.M. Shazili. The Chironomid Larval Tube, a Mechanism to Protect the Organism from Environmental Disturbances?. <i>Toxicol. Environ. Chem.</i> 91(1): 171-176, 2009. ECOREF #115860	No hardness data
Vedamanikam,V.J., and N.A.M. Shazilli. Comparative Toxicity of Nine Metals to Two Malaysian Aquatic Dipterian Larvae with Reference to Temperature Variation. <i>Bull. Environ. Contam. Toxicol.</i> 80(6): 516-520, 2008. ECOREF #107050	No hardness data
Vedamanikam,V.J., and N.A.M. Shazilli. The Effect of Multi-Generational Exposure to Metals and Resultant Change in Median Lethal Toxicity Tests Values over Subsequent Generations. <i>Bull. Environ. Contam. Toxicol.</i> 80(1): 63-67, 2008. ECOREF #111291	No hardness data
Virk,S., and R.C. Sharma. Effect of Nickel and Chromium on Various Life Stages of <i>Cyprinus carpio</i> Linn. <i>Indian J. Ecol.</i> 22(2): 77-81, 1995. ECOREF #18750	Non-north american test species used
Wong,C.K., and A.P. Pak. Acute and Subchronic Toxicity of the Heavy Metals Copper, Chromium, Nickel, and Zinc, Individually and in Mixture, to the Freshwater Copepod <i>Mesocyclops pehpeiensis</i> . <i>Bull. Environ. Contam. Toxicol.</i> 73(1): 190-196, 2004. ECOREF #80006	Non-north american test species used

## Open Literature

Table A14. List of open literature citations from EPA ECOTOX database reviewed for nickel criteria derivation but did not meet acceptability requirements.

Citation	Notes
Zidour, M., Boubechiche, Z., Pan, Y.J., Bialais, C., Cudennec, B., Grard, T., Drider, D., Flahaut, C., Ouddane, B. and Souissi, S., 2019. Population response of the estuarine copepod <i>Eurytemora affinis</i> to its bioaccumulation of trace metals. <i>Chemosphere</i> , 220, pp.505-513.	LC50s are sex specific (male and female); tests were 96 hr and not the standard 48-hr for invertebrates
Panneerselvam, K., Marigoudar, S.R. and Dhandapani, M., 2018. Toxicity of nickel on the selected species of marine diatoms and copepods. <i>Bulletin of environmental contamination and toxicology</i> , 100, pp.331-337.	Marine study
Okamoto, A., Masunaga, S. and Tatarazako, N., 2021. Chronic toxicity of 50 metals to <i>Ceriodaphnia dubia</i> . <i>Journal of Applied Toxicology</i> , 41(3), pp.375-386.	Very little study details; Effect level reported as inhibitory concentrations; did not use flow through design
Ghosh, A., Kaviraj, A. and Saha, S., 2018. Deposition, acute toxicity, and bioaccumulation of nickel in some freshwater organisms with best-fit functions modeling. <i>Environmental Science and Pollution Research</i> , 25, pp.3588-3595.	Non-north American test species;
Ansari, S., Ansari, B.A. and Ansari, B.A., 2015. Effects of heavy metals on the embryo and larvae of Zebrafish, <i>Danio rerio</i> (Cyprinidae). <i>Scholars Academic Journal of Biosciences</i> , 3(1b), pp.52-56.	No hardness data
Leung, J., Witt, J.D., Norwood, W. and Dixon, D.G., 2016. Implications of Cu and Ni toxicity in two members of the <i>Hyalella azteca</i> cryptic species complex: Mortality, growth, and bioaccumulation parameters. <i>Environmental toxicology and chemistry</i> , 35(11), pp.2817-2826.	No 48-hour LC50s calculated
McKinley, K., McLellan, I., Gagné, F. and Quinn, B., 2019. The toxicity of potentially toxic elements (Cu, Fe, Mn, Zn and Ni) to the cnidarian <i>Hydra attenuata</i> at environmentally relevant concentrations. <i>Science of the Total Environment</i> , 665, pp.848-854.	Multi-well plates test chambers; 48-hour LC50 not reported; fed during study

## Freshwater Chronic

Table A15. List of citations from EPA ECOTOX database reviewed for nickel freshwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Brix,K.V., J. Keithly, D.K. DeForest, and J. Laughlin. Acute and Chronic Toxicity of Nickel to Rainbow Trout ( <i>Oncorhynchus mykiss</i> ). <i>Environ. Toxicol. Chem.</i> 23(9): 2221-2228, 2004. Ecoref #80785	
Jaworska,M., A. Gorczyca, J. Sepiol, and P. Tomasik. Effect of Metal Ions on the Entomopathogenic Nematode <i>Heterorhabditis bacteriophora</i> Poinar (Nematode: Heterorhabditidae) Under Laboratory Conditions. <i>Water Air Soil Pollut.</i> 93:157-166, 1997. Ecoref #40155	Bacteria study
Keithly,J., J.A. Brooker, D.K. DeForest, B.K. Wu, and K.V. Brix. Acute and Chronic Toxicity of Nickel to a Cladoceran ( <i>Ceriodaphnia dubia</i> ) and an Amphipod ( <i>Hyalella azteca</i> ). <i>Environ. Toxicol. Chem.</i> 23(3): 691-696, 2004. Ecoref #106584	
Kienle,C., H.R. Kohler, and A. Gerhardt. Behavioural and Developmental Toxicity of Chlorpyrifos and Nickel Chloride to Zebrafish ( <i>Danio rerio</i> ) Embryos and Larvae. <i>Ecotoxicol. Environ. Saf.</i> 72(6): 1740-1747, 2009. Ecoref #119259	No hardness data
Ku,T.T., W. Yan, W.Y. Jia, Y. Yun, N. Zhu, G.K. Li, and N. Sang. Characterization of Synergistic Embryotoxicity of Nickel and Buprofezin in Zebrafish. <i>Environ. Sci. Technol.</i> 49(7): 4600-4608, 2015. Ecoref #173640	Toxicity test endpoints aren't relevant
Lahnsteiner,F., N. Mansour, and B. Berger. The Effect of Inorganic and Organic Pollutants on Sperm Motility of Some Freshwater Teleosts. <i>J. Fish Biol.</i> 65(5): 1283-1297, 2004. Ecoref #112446	Toxicity test endpoints aren't relevant
Langer-Jaesrich,M., H.R. Kohler, and A. Gerhardt. Can Mouth Part Deformities of <i>Chironomus riparius</i> Serve as Indicators for Water and Sediment Pollution? A Laboratory Approach. <i>J. Soils Sediments</i> 10(3): 414-422, 2010. Ecoref #121124	Toxicity test endpoints aren't relevant
Liber,K., L.E. Doig, and S.L. White-Sobey. Toxicity of Uranium, Molybdenum, Nickel, and Arsenic to <i>Hyalella azteca</i> and <i>Chironomus dilutus</i> in Water-Only and Spiked-Sediment Toxicity Tests. <i>Ecotoxicol. Environ. Saf.</i> 74(5): 1171-1179, 2011. Ecoref #175087	Water only test duration too short for chronic study
Mwangi,J.N., N. Wang, C.G. Ingersoll, D.K. Hardesty, E.L. Brunson, H. Li, and B. Deng. Toxicity of Carbon Nanotubes to Freshwater Aquatic Invertebrates. <i>Environ. Toxicol. Chem.</i> 31(8): 1823-1830, 2012. Ecoref #158582	Nanotube study

Citation	Notes
Ouellette, J.D., M.G. Dube, and S. Niyogi. A Single Metal, Metal Mixture, and Whole-Effluent Approach to Investigate Causes of Metal Mine Effluent Effects on Fathead Minnows ( <i>Pimephales promelas</i> ). <i>Water Air Soil Pollut.</i> 224(1462): 44 p., 2013. Ecoref #166026	Study mimicked effluent and didn't aim find threshold value
Pane, E.F., A. Haque, and C.M. Wood. Mechanistic Analysis of Acute, Ni-Induced Respiratory Toxicity in the Rainbow Trout ( <i>Oncorhynchus mykiss</i> ): An Exclusively Branchial Phenomenon. <i>Aquat. Toxicol.</i> 69(1): 11-24, 2004. Ecoref #89704	Test endpoints are not relevant to criteria development
Pavlaki, M.D., R. Pereira, S. Loureiro, and A.M.V.M. Soares. Effects of Binary Mixtures on the Life Traits of <i>Daphnia magna</i> . <i>Ecotoxicol. Environ. Saf.</i> 74(1): 99-110, 2011. Ecoref #166654	
Puttaswamy, N., and K. Liber. Influence of Inorganic Anions on Metals Release from Oil Sands Coke and on Toxicity of Nickel and Vanadium to <i>Ceriodaphnia dubia</i> . <i>Chemosphere</i> 86(5): 521-529, 2012. Ecoref #165122	Mixture study; inappropriate water quality test conditions
Zuiderveen, J.A., and W.J. Birge. The Relationship Between Chronic Values in Toxicity Tests with <i>Ceriodaphnia dubia</i> . <i>ASTM Spec. Tech. Publ.</i> 6:551-556, 1997. Ecoref #76252	Did not include analytical chemistry
Besser, J.M., C.D. Ivey, J.A. Steevens, D. Cleveland, D. Soucek, A. Dickinson, E.J. Van Genderen, A.C. Ryan, C.E. Schlek. Modeling the Bioavailability of Nickel and Zinc to <i>Ceriodaphnia dubia</i> and <i>Neocloeon triangulifer</i> in Toxicity Tests with Natural Waters. <i>Environ. Toxicol. Chem.</i> 40(11): 3049-3062, 2021. Ecoref #188814	
Cremazy, A., K.V. Brix, and C.M. Wood. Chronic Toxicity of Binary Mixtures of Six Metals (Ag, Cd, Cu, Ni, Pb and Zn) to the Great Pond Snail <i>Lymnaea stagnalis</i> . <i>Environ. Sci. Technol.</i> 52(10): 5979-5988, 2018. Ecoref #188091	EC20 useful; study duration too long for acute toxicity value
De Schamphelaere, K., L.V. Laer, N. Deleebeeck, B.T. Muysen, F. Degryse, E. Smolders, and C. Janssen. Nickel Speciation and Ecotoxicity in European Natural Surface Waters: Development, Refinement and Validation of Bioavailability Models. Ghent University Laboratory for Environmental Toxicology and Aquatic Ecology: 125 p., 2006. Ecoref #187751	Wrong language
Deleebeeck, N.M.E., K.A.C. De Schamphelaere, and C.R. Janssen. A Novel Method for Predicting Chronic Nickel Bioavailability and Toxicity to <i>Daphnia magna</i> in Artificial and Natural Waters. <i>Environ. Toxicol. Chem.</i> 27(10): 2097-2107, 2008. Ecoref #187752	EC20 useful; study duration too long for acute toxicity value
Keithly, J., J.A. Brooker, D.K. DeForest, B.K. Wu, and K.V. Brix. Acute and Chronic Toxicity of Nickel to a Cladoceran ( <i>Ceriodaphnia dubia</i> ) and an Amphipod ( <i>Hyalella azteca</i> ). <i>Environ. Toxicol. Chem.</i> 23(3): 691-696, 2004. Ecoref #106584	Repeat



## Open Literature

Table A16. List of open literature citations from EPA ECOTOX database reviewed for nickel criteria derivation but did not meet acceptability requirements.

Citation	Notes
Nys, C., Janssen, C.R., Van Sprang, P. and De Schamphelaere, K.A., 2016. The effect of pH on chronic aquatic nickel toxicity is dependent on the pH itself: Extending the chronic nickel bioavailability models. <i>Environmental toxicology and chemistry</i> , 35(5), pp.1097-1106.	Static-renewal test design; according to EPA 1985 guidance chronic studies should be flow-through
Nys, C., Van Regenmortel, T., Janssen, C.R., Blust, R., Smolders, E. and De Schamphelaere, K.A., 2017. Comparison of chronic mixture toxicity of nickel-zinc-copper and nickel-zinc-copper-cadmium mixtures between <i>Ceriodaphnia dubia</i> and <i>Pseudokirchneriella subcapitata</i> . <i>Environmental Toxicology and Chemistry</i> , 36(4), pp.1056-1066.	Static-renewal test design; according to EPA 1985 guidance chronic studies should be flow-through
Niyogi, S., Brix, K.V. and Grosell, M., 2014. Effects of chronic waterborne nickel exposure on growth, ion homeostasis, acid-base balance, and nickel uptake in the freshwater pulmonate snail, <i>Lymnaea stagnalis</i> . <i>Aquatic toxicology</i> , 150, pp.36-44.	Static-renewal test design; according to EPA 1985 guidance chronic studies should be flow-through
Klemish, J.L., Bogart, S.J., Luek, A., Lannoo, M.J. and Pyle, G.G., 2018. Nickel toxicity in wood frog tadpoles: Bioaccumulation and sublethal effects on body condition, food consumption, activity, and chemosensory function. <i>Environmental toxicology and chemistry</i> , 37(9), pp.2458-2466.	Static-renewal test design; according to EPA 1985 guidance chronic studies should be flow-through
Gissi, F., Wang, Z., Batley, G.E., Leung, K.M., Schlegel, C.E., Garman, E.R. and Stauber, J.L., 2020. Deriving a chronic guideline value for nickel in tropical and temperate marine waters. <i>Environmental Toxicology and Chemistry</i> , 39(12), pp.2540-2551.	Marine study
Deleebeeck, N.M., De Schamphelaere, K.A. and Janssen, C.R., 2007. A bioavailability model predicting the toxicity of nickel to rainbow trout ( <i>Oncorhynchus mykiss</i> ) and fathead minnow ( <i>Pimephales promelas</i> ) in synthetic and natural waters. <i>Ecotoxicology and Environmental Safety</i> , 67(1), pp.1-13.	Good study but ACRs not reported; data usable for 8 family method

## Pentachlorophenol

### Freshwater Acute

Table A17. List of citations from EPA ECOTOX database reviewed for pentachlorophenol freshwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Andersen,H.B., R.S. Caldwell, J. Toll, T. Do, and L. Saban. Sensitivity of Lamprey Ammocoetes to Six Chemicals. Arch. Environ. Contam. Toxicol.59(4): 622-631, 2010. Ecoref #153571	
Ashauer,R., A.B.A. Boxall, and C.D. Brown. New Ecotoxicological Model to Simulate Survival of Aquatic Invertebrates After Exposure to Fluctuating and Sequential Pulses of Pesticides. Environ. Sci. Technol.41(4): 1480-1486, 2007. Ecoref #115493	Modeling study; methods lack detail
Basack,S.B., M.L. Oneto, N.R. Verrengia Guerrero, and E.M. Kesten. Accumulation and Elimination of Pentachlorophenol in the Freshwater Bivalve Corbicula fluminea. Bull. Environ. Contam. Toxicol.58(3): 497-503, 1997. Ecoref #18004	
Bitton,G., K. Rhodes, B. Koopman, and M. Cornejo. Short-Term Toxicity Assay Based on Daphnid Feeding Behavior. Water Environ. Res.67(3): 290-293, 1995. Ecoref #19602	6-hour study; not standardized test
Bridges,C.M., F.J. Dwyer, D.K. Hardesty, and D.W. Whites. Comparative Contaminant Toxicity: Are Amphibian Larvae More Sensitive than Fish?. Bull. Environ. Contam. Toxicol.69(4): 562-569, 2002. Ecoref #72411	
Broderius,S.J., M.D. Kahl, and M.D. Hoglund. Use of Joint Toxic Response to Define the Primary Mode of Toxic Action for Diverse Industrial Organic Chemicals. Environ. Toxicol. Chem.14(9): 1591-1605, 1995. Ecoref #15031	
Centeno,M.D.F., G. Persoone, and M.P. Goyvaerts. Cyst-Based Toxicity Tests. IX. The Potential of Thamnocephalus platyurus as Test Species in Comparison with Streptocephalus proboscideus (Crustacea: Branchiopoda: Anostraca). Environ. Toxicol. Water Qual.10(4): 275-282, 1995. Ecoref #14017	Not relevant testing method; cyst based study
Cheng,Y., M. Ekker, and H.M. Chan. Relative Developmental Toxicities of Pentachloroanisole and Pentachlorophenol in a Zebrafish Model (Danio rerio). Ecotoxicol. Environ. Saf.112:7-14, 2015. Ecoref #170681	No details on bioassay. Does not use standard methods.
Cressman III,C.P., and P.L. Williams. Reference Toxicants for Toxicity Testing Using Caenorhabditis elegans in Aquatic Media. ASTM Spec. Tech. Publ.6:518-532, 1997. Ecoref #19999	

Citation	Notes
Donkin,S.G., and P.L. Williams. Influence of Developmental Stage, Salts and Food Presence on Various End Points Using <i>Caenorhabditis elegans</i> for Aquatic Toxicity Testing. <i>Environ. Toxicol. Chem.</i> 14(12): 2139-2147, 1995. Ecoref #16377	LC50 reported as range of values
Dwyer,F.J., D.K. Hardesty, C.E. Henke, C.G. Ingersoll, D.W. Whites, D.R. Mount, and C.M. Bridges. Assessing Contaminant Sensitivity of Endangered and Threatened Species: Toxicant Classes. EPA 600/R-99/098, U.S.EPA, Washington, D.C.:15 p., 1999. Ecoref #56161	Not accessible
Dwyer,F.J., D.K. Hardesty, C.G. Ingersoll, J.L. Kunz, and D.W. Whites. Assessing Contaminant Sensitivity of American Shad, Atlantic Sturgeon and Shortnose Strugeon, Final Report - February 2000. Final Rep., U.S.Geol.Surv., Columbia Environ.Res.Ctr., Columbia, MO:30 p., 2000. Ecoref #77827	
Dwyer,F.J., F.L. Mayer, L.C. Sappington, D.R. Buckler, C.M. Bridges, I.E. Greer, D.K. Hardesty, C.E. Henke, C.G. Ingers. Assessing Contaminant Sensitivity of Endangered and Threatened Aquatic Species: Part I. Acute Toxicity of Five Chemicals. <i>Arch. Environ. Contam. Toxicol.</i> 48(2): 143-154, 2005. Ecoref #81380	
Dwyer,F.J., L.C. Sappington, D.R. Buckler, and S.B. Jones. Use of Surrogate Species in Assessing Contaminant Risk to Endangered and Threatened Fishes. EPA/600/R-96/029, U.S.EPA, Washington, DC:78 p., 1995. Ecoref #73668	
Farah,M.A., B. Ateeq, M.N. Ali, R. Sabir, and W. Ahmad. Studies on Lethal Concentrations and Toxicity Stress of Some Xenobiotics on Aquatic Organisms. <i>Chemosphere</i> 55(2): 257-265, 2004. Ecoref #73350	
Fisher,S.W., H. Hwang, M. Atanasoff, and P.F. Landrum. Lethal Body Residues for Pentachlorophenol in Zebra Mussels ( <i>Dreissena polymorpha</i> ) Under Varying Conditions of Temperature and pH. <i>Ecotoxicol. Environ. Saf.</i> 43(3): 274-283, 1999. Ecoref #20453	Body residue study
Fort,D.J., E.L. Stover, and J.A. Bantle. Integrated Ecological Hazard Assessment of Waste Site Soil Extracts Using FETAX and Short-Term Fathead Minnow Teratogenesis Assay. <i>ASTM Spec. Tech. Publ.</i> 4:93-109, 1996. Ecoref #45211	FETAX assay of waste site
Fort,D.J., and E.L. Stover. Effect of Low-Level Copper and Pentachlorophenol Exposure on Various Early Life Stages of <i>Xenopus laevis</i> . <i>ASTM Spec. Tech. Publ.</i> :188-203, 1996. Ecoref #61813	FETAX assay with non-north american test species used
Janssen,C.R., G. Persoone, and T.W. Snell. Cyst-Based Toxicity Tests. VIII. Short-Chronic Toxicity Tests with the Freshwater Rotifer <i>Brachionus calyciflorus</i> . <i>Aquat. Toxicol.</i> 28(3/4): 243-258, 1994. Ecoref #16572	Cytotoxicity test

Citation	Notes
Jin,X., J. Zha, Y. Xu, J.P. Giesy, and Z. Wang. Toxicity of Pentachlorophenol to Native Aquatic Species in the Yangtze River. <i>Environ. Sci. Pollut. Res.</i> 19(3): 609-618, 2012. Ecoref #160738	Non-north american test species used
Jordao,R., B. Campos, M.F.L. Lemos, A.M.V.M. Soares, R. Tauler, and C. Barata. Induction of Multixenobiotic Defense Mechanisms in Resistant <i>Daphnia magna</i> Clones as a General Cellular Response to Stress. <i>Aquat. Toxicol.</i> 175:132-143, 2016. Ecoref #173580	Molecular study; endpoints not relevant
Kammenga,J.E., C.A.M. Van Gestel, and J. Bakker. Patterns of Sensitivity to Cadmium and Pentachlorophenol Among Nematode Species from Different Taxonomic and Ecological Groups. <i>Arch. Environ. Contam. Toxicol.</i> 27(1): 88-94, 1994. Ecoref #13656	
Keller,A.E.. Personal Communication to U.S. EPA: Water Quality and Toxicity Data for Unpublished Unionid Mussel Tests. Memo to R.Pepin and C.Roberts,U.S.EPA Region 5,Chicago, IL:14 p., 2000. Ecoref #76251	Not accessible
Kim,K.T., Y.G. Lee, and S.D. Kim. Combined Toxicity of Copper and Phenol Derivatives to <i>Daphnia magna</i> : Effect of Complexation Reaction. <i>Environ. Int.</i> 32(4): 487-492, 2006. Ecoref #87184	Mixture toxicity study
Kishino,T., and K. Kobayashi. Relation Between Toxicity and Accumulation of Chlorophenols at Various pH, and Their Absorption Mechanism in Fish. <i>Water Res.</i> 29(2): 431-442, 1995. Ecoref #13717	Non-north american test species used
Kishino,T., and K. Kobayashi. Acute Toxicity and Structure-Activity Relationships of Chlorophenols in Fish. <i>Water Res.</i> 30(2): 387-392, 1996. Ecoref #16366	Non-north american test species used
Kishino,T., and K. Kobayshi. Studies on the Mechanism of Toxicity of Chlorophenols Found in Fish Through Quantitative Structure-Activity Relationships. <i>Water Res.</i> 30(2): 393-399, 1996. Ecoref #16365	Non-north american test species used
Kurume Laboratory. Final Report. Bioconcentration Test of 2-Perfluoroalkyl (C=4-16) Ethanol [This Test was Performed Using 2-(Perfluorooctyl) Ethanol (Test Substance Number K-1518)] in Carp. Test Substance K-1518, Kurame Laboratory, Chemicals Evaluation and Research Institute, Japan:94 p., 2001. Ecoref #181458	Bioconcentration study
Lee,S.I., E.J. Na, Y.O. Cho, B. Koopman, and G. Bitton. Short-Term Toxicity Test Based on the Algal Uptake by <i>Ceriodaphnia dubia</i> . <i>Water Environ. Res.</i> 69:1207-1210, 1997. Ecoref #61914	Dietary exposure route; not relevant
Markle,P.J., J.R. Gully, R.B. Baird, K.M. Nakada, and J.P. Bottomley. Effects of Several Variables on Whole Effluent Toxicity Test Performance and Interpretation. <i>Environ. Toxicol. Chem.</i> 19(1): 123-132, 2000. Ecoref #51911	LC50s not provided

Citation	Notes
Martinez-Jeronimo,F., and G. Munoz-Mejia. Evaluation of the Sensitivity of Three Cladoceran Species Widely Distributed in Mexico to Three Reference Toxicants. J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control42(10): 1417-1424, 2007. Ecoref #119176	No pH reported
Mayer,F.L., D.R. Buckler, F.J. Dwyer, M.R. Ellersieck, L.C. Sappington, J.M. Besser, and C.M. Bridges. Endangered Aquatic Vertebrates: Comparative and Probabilistic-Based Toxicology. EPA/600/R-08/045, U.S.EPA, Washington, DC:43 p., 2008. Ecoref #153255	Repeat of Dwyer/other EPA studies
McDaniel,M., and T.W. Snell. Probability Distributions of Toxicant Sensitivity for Freshwater Rotifer Species. Environ. Toxicol.14(3): 361-366, 1999. Ecoref #76116	
McNulty,E.W., F.J. Dwyer, M.R. Ellersieck, E.I. Greer, C.G. Ingersoll, and C.F. Rabeni. Evaluation of Ability of Reference Toxicity Tests to Identify Stress in Laboratory Populations of the Amphipod Hyalella azteca. Environ. Toxicol. Chem.18(3): 544-548, 1999. Ecoref #52121	
Milam,C.D., J.L. Farris, F.J. Dwyer, and D.K. Hardesty. Acute Toxicity of Six Freshwater Mussel Species (Glochidia) to Six Chemicals: Implications for Daphnids and Utterbackia imbecillis as Surrogates for Protection of Freshwater Mussels (Unionidae). Arch. Environ. Contam. Toxicol.48(2): 166-173, 2005. Ecoref #81810	
Morales,M., P. Martinez-Paz, R. Martin, R. Planello, J. Urien, J.L. Martinez-Guitarte, and G. Morcillo. Transcriptional Changes Induced by In Vivo Exposure to Pentachlorophenol (PCP) in Chironomus riparius (Diptera) Aquatic Larvae. Aquat. Toxicol.157:1-9, 2014. Ecoref #170699	
Nikkila,A., A. Halme, and J.V.K. Kukkonen. Toxicokinetics, Toxicity and Lethal Body Residues of Two Chlorophenols in the Oligochaete Worm, Lumbriculus variegatus, in Different Sediments. Chemosphere51(1): 35-46, 2003. Ecoref #71410	Sediment based toxicity study
Oda,S., N. Tatarazako, H. Watanabe, M. Morita, and T. Iguchi. Genetic Differences in the Production of Male Neonates in Daphnia magna Exposed to Juvenile Hormone Analogs. Chemosphere63(9): 1477-1484, 2006. Ecoref #97744	
Powell,R.L., E.M. Moser, R.A. Kimerle, D.E. McKenzie, and M. McKee. Use of a Miniaturized Test System for Determining Acute Toxicity of Toxicity Identification Evaluation Fractions. Ecotoxicol. Environ. Saf.35(1): 1-6, 1996. Ecoref #109574	Test design modified from standard methods
Preston,B.L., T.W. Snell, D.M. Fields, and M.J. Weissburg. The Effects of Fluid Motion on Toxicant Sensitivity of the Rotifer Brachionus calyciflorus. Aquat. Toxicol.52(2): 117-131, 2001. Ecoref #60075	
Preston,B.L., T.W. Snell, and R. Kneisel. UV-B Exposure Increases Acute Toxicity of Pentachlorophenol and Mercury to the Rotifer Brachionus calyciflorus. Environ. Pollut.106(1): 23-31, 1999. Ecoref #20344	

Citation	Notes
Ra,J.S., S.Y. Oh, B.C. Lee, and S.D. Kim. The Effect of Suspended Particles Coated by Humic Acid on the Toxicity of Pharmaceuticals, Estrogens, and Phenolic Compounds. <i>Environ. Int.</i> 34(2): 184-192, 2008. ECOREF #155080	Sediment study
Radix,P., M. Leonard, C. Papantoniou, G. Roman, E. Saouter, S. Gallotti-Schmitt, H. Thiebaud, and P. Vasseur. Comparison of Four Chronic Toxicity Tests Using Algae, Bacteria, and Invertebrates Assessed with Sixteen Chemicals. <i>Ecotoxicol. Environ. Saf.</i> 47(2): 186-194, 2000. ECOREF #60083	
Saka,M.. Examination of an Amphibian-Based Assay Using the Larvae of <i>Xenopus laevis</i> and <i>Ambystoma mexicanum</i> . <i>Ecotoxicol. Environ. Saf.</i> 55(1): 38-45, 2003. ECOREF #69555	LC50s not reported in text; non-north american test species used
Sappington,L.C., F.L. Mayer, F.J. Dwyer, D.R. Buckler, J.R. Jones, and M.R. Eilersieck. Contaminant Sensitivity of Threatened and Endangered Fishes Compared to Standard Surrogate Species. <i>Environ. Toxicol. Chem.</i> 20(12): 2869-2876, 2001. ECOREF #65396	Repeat of dwyer info
Sawle,A.D., E. Wit, G. Whale, and A.R. Cossins. An Information-Rich Alternative, Chemicals Testing Strategy Using a High Definition Toxicogenomics and Zebrafish ( <i>Danio rerio</i> ) Embryos. <i>Toxicol. Sci.</i> 118(1): 128-139, 2010. ECOREF #158552	Genotoxic based study
Shedd,T.R., M.W. Widder, M.W. Toussaint, M.C. Sunkel, and E. Hull. Evaluation of the Annual Killifish <i>Nothobranchius guentheri</i> as a Tool for Rapid Acute Toxicity Screening. <i>Environ. Toxicol. Chem.</i> 18(10): 2258-2261, 1999. ECOREF #20487	Non-north american test species used
Trapido,M., Y. Veressinina, and R. Munter. A Study of the Toxicity of the Ozonation Products of Phenols and Chlorophenols by <i>Daphnia magna</i> Test. <i>Proc. Estonian Acad. Sci.</i> 46(3): 130-139, 1997. ECOREF #65394	Lacking study design details; pH is very high
Twagilimana,L., J. Bohatier, CA Groliere, F. Bonnemoy, and D. Sargos. A New Low-Cost Microbiotest with the Protozoan <i>Spirostomum teres</i> : Culture Conditions and Assessment of Sensitivity of the Ciliate to 14 Pure Chemicals. <i>Ecotoxicol. Environ. Saf.</i> 41(3): 231-244, 1998. ECOREF #20057	Single cell test; not relevant
Van der Schalie,W.H., T.R. Shedd, M.W. Widder, and L.M. Brennan. Response Characteristics of an Aquatic Biomonitor Used for Rapid Toxicity Detection. <i>J. Appl. Toxicol.</i> 24(5): 387-394, 2004. ECOREF #77525	Rapid toxicity test; deviates from standard methods
Willis,K.J.. Acute and Chronic Bioassays with New Zealand Freshwater Copepods Using Pentachlorophenol. <i>Environ. Toxicol. Chem.</i> 18(11): 2580-2586, 1999. ECOREF #20641	
Willis,K.J., N. Ling, and M.A. Chapman. Effects of Temperature and Chemical Formulation on the Acute Toxicity of Pentachlorophenol to <i>Simocephalus vetulus</i> (Schoedler, 1858) (Crustacea: Cladocera). <i>N. Z. J. Mar. Freshw. Res.</i> 29(2): 289-294, 1995. ECOREF #18919	

Citation	Notes
Xia,X., H. Chunxiu, S. Xue, B. Shi, G. Gui, D. Zhang, X. Wang, and L. Guo. Response of Selenium-Dependent Glutathione Peroxidase in the Freshwater Bivalve Anodonta woodiana Exposed to 2,4-Dichlorophenol, 2,4,6-Trichlorophenol and Pentachlorophenol. Fish Shellfish Immunol.55:499-509, 2016. Ecoref #188367	Molecular based study / endpoints
Yin,D., Y. Gu, Y. Li, X. Wang, and Q. Zhao. Pentachlorophenol Treatment In Vivo Elevates Point Mutation Rate in Zebrafish p53 Gene. Mutat. Res.609(1): 92-101, 2006. Ecoref #91629	Molecular based study / endpoints
Zhao,Y.. Application of Survival Analysis Methods to Pulsed Exposures: Exposure Duration, Latent Mortality, Recovery Time, and the Underlying Theory of Survival Distribution Models. Ph.D.Thesis, The College of William and Mary, Williamsburg, VA:127 p., 2006. Ecoref #169510	LC50 not reported in figure only
Zhao,Y., and M.C. Newman. Shortcomings of the Laboratory-Derived Median Lethal Concentration for Predicting Mortality in Field Populations: Exposure Duration and Latent Mortality. Environ. Toxicol. Chem.23(9): 2147-2153, 2004. Ecoref #77534	LC50 not reported in figure only

## Freshwater Chronic

Table A18. List of citations from EPA ECOTOX database reviewed for pentachlorophenol freshwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Arthur,A.D., and D.G. Dixon. Effects of Rearing Density on the Growth Response of Juvenile Fathead Minnow (Pimephales promelas) Under Toxicant-Induced Stress. Can. J. Fish. Aquat. Sci.51(2): 365-371, 1994. Ecoref #14078	
Besser,J.M., D.L. Hardesty, I.E. Greer, and C.G. Ingersoll. Sensitivity of Freshwater Snails to Aquatic Contaminants: Survival and Growth of Endangered Snail Species and Surrogates in 28-Day Exposures to Copper, Ammonia and Pentachlorophenol. Administrative Report CERC-8335-FY07-20-10, Columbia, MO:51 p., 2009. Ecoref #151380	
Besser,J.M., N. Wang, F.J. Dwyer, F.L.,Jr. Mayer, and C.G. Ingersoll. Assessing Contaminant Sensitivity of Endangered and Threatened Aquatic Species: Part II. Chronic Toxicity of Copper and Pentachlorophenol to Two Endangered Species and Two Surrogate Species. Arch. Environ. Contam. Toxicol.48(2): 155-165, 2005. Ecoref #91632	
Yu,L.Q., G.F. Zhao, M. Feng, W. Wen, K. Li, P.W. Zhang, X. Peng, W.J. Huo, and H.D. Zhou. Chronic Exposure to Pentachlorophenol Alters Thyroid Hormones and Thyroid Hormone Pathway mRNAs in Zebrafish. Environ. Toxicol. Chem.33(1): 170-176, 2014. Ecoref #170360	Endpoints are not relevant

## Saltwater Acute

Table A19. List of citations from EPA ECOTOX database reviewed for pentachlorophenol saltwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Espiritu,E.Q., C.R. Janssen, and G. Persoone. Cyst-Based Toxicity Tests. VII. Evaluation of the 1-h Enzymatic Inhibition Test (Fluotox) with <i>Artemia nauplii</i> . <i>Environ. Toxicol. Water Qual.</i> 10:25-34, 1995. Ecoref #16031	Cyst based study
Hori,H., M. Tateishi, K. Takayanagi, and H. Yamada. Applicability of Artificial Seawater as a Rearing Seawater for Toxicity Tests of Hazardous Chemicals by Marine Fish Species. <i>Nippon Suisan Gakkaishi</i> (4): 614-622, 1996. Ecoref #16999	Wrong language
Lawrence,A.J., and C. Poulter. Development of a Sub-lethal Pollution Bioassay Using the Estuarine Amphipod <i>Gammarus duebeni</i> . <i>Water Res.</i> 32(3): 569-578, 1998. Ecoref #18971	Non-north american test species; no evidence of its presence on the coast North America.
Lindley,J.A., P. Donkin, S.V. Evans, C.L. George, and K.F. Uil. Effects of Two Organochlorine Compounds on Hatching and Viability of Calanoid Copepod Eggs. <i>J. Exp. Mar. Biol. Ecol.</i> 242:59-74, 1999. Ecoref #59982	
Mayer,F.L., D.R. Buckler, F.J. Dwyer, M.R. Ellersieck, L.C. Sappington, J.M. Besser, and C.M. Bridges. <i>Endangered Aquatic Vertebrates: Comparative and Probabilistic-Based Toxicology</i> . EPA/600/R-08/045, U.S.EPA, Washington, DC:43 p., 2008. Ecoref #153255	No saltwater data
Palau-Casellas,A., and T.H. Hutchinson. Acute Toxicity of Chlorinated Organic Chemicals to the Embryos and Larvae of the Marine Worm <i>Platynereis dumerilii</i> (Polychaeta: Nereidae). <i>Environ. Toxicol. Water Qual.</i> 13(2): 149-155, 1998. Ecoref #60056	Non-north american test species; no evidence of its presence on the coast North America.
Perez,S., D. Rial, and R. Beiras. Acute Toxicity of Selected Organic Pollutants to Saltwater ( <i>Mysid Siriella armata</i> ) and Freshwater ( <i>Cladoceran Daphnia magna</i> ) Ecotoxicological Models. <i>Ecotoxicology</i> 24(6): 1229-1238, 2015. Ecoref #170705	Non-north american test species; no evidence of its presence on the coast North America.
Rinna,F., F. Del Prete, V. Vitiello, G. Sansone, and A.L. Langellotti. Toxicity Assessment of Copper, Pentachlorophenol and Phenanthrene by Lethal and Sublethal Endpoints on Nauplii of <i>Tigriopus fulvus</i> . <i>Chem. Ecol.</i> 27(S2): 77-85, 2011. Ecoref #166814	Non-north american test species; no evidence of its presence on the coast North America.
Sappington,L.C., F.L. Mayer, F.J. Dwyer, D.R. Buckler, J.R. Jones, and M.R. Ellersieck. Contaminant Sensitivity of Threatened and Endangered Fishes Compared to Standard Surrogate Species. <i>Environ. Toxicol. Chem.</i> 20(12): 2869-2876, 2001. Ecoref #65396	
Silva,J., L. Troncoso, E. Bay-Schmith, and A. Larrain. Utilization of <i>Odontesthes regia</i> (Atherinidae) from the South Eastern Pacific as a Test Organism for Bioassays: Study of Its	Non-north american test species; Lacks some method details



Citation	Notes
Sensitivity to Six Chemicals. Bull. Environ. Contam. Toxicol.66(5): 570-575, 2001. Ecoref #62074	
Smith,S., V.J. Furay, P.J. Layiwola, and J.A. Menezes-Filho. Evaluation of the Toxicity and Quantitative Structure-Activity Relationships (QSAR) of Chlorophenols to the Copepodid Stage of a Marine Copepod (Tisbe battagliai) and Two Species of Benthic Flatfish, the Flounder (Plati. Chemosphere28(4): 825-836, 1994. Ecoref #4071	Flatfish and flounder were collected in ambient waters that were not characterized

## Silver

### Freshwater Acute

Table A20. List of citations from EPA ECOTOX database reviewed for silver freshwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Alsop,D., and C.M. Wood. Metal Uptake and Acute Toxicity in Zebrafish: Common Mechanisms Across Multiple Metals. Aquat. Toxicol.105(3/4): 385-393, 2011. Ecoref #158223	
Bianchini,A., K.C. Bowles, C.J. Brauner, J.W. Gorsuch, J.R. Kramer, and C.M. Wood. Evaluation of the Effect of Reactive Sulfide on the Acute Toxicity of Silver (I) to Daphnia magna. Part 2: Toxicity Results. Environ. Toxicol. Chem.21(6): 1294-1300, 2002. Ecoref #66362	
Bianchini,A., M. Grosell, S.M. Gregory, and C.M. Wood. Acute Silver Toxicity in Aquatic Animals is a Function of Sodium Uptake Rate. Environ. Sci. Technol.36(8): 1763-1766, 2002. Ecoref #66367	Toxicity values not provided
Bianchini,A., and C.M. Wood. Does Sulfide or Water Hardness Protect Against Chronic Silver Toxicity in Daphnia magna? A Critical Assessment of the Acute-to-Chronic Toxicity Ratio for Silver. Ecotoxicol. Environ. Saf.71:32-40, 2008. Ecoref #104819	Organisms fed during study artificially raising LC50
Bielmyer,G.K., K.V. Brix, and M. Grosell. Is Cl- Protection Against Silver Toxicity Due to Chemical Speciation?. Aquat. Toxicol.87(2): 81-87, 2008. Ecoref #104888	Hardness too low - water quality not adequate
Bielmyer,G.K., R.A. Bell, and S.J. Klaine. Effects of Ligand-Bound Silver on Ceriodaphnia dubia. Environ. Toxicol. Chem.21(10): 2204-2208, 2002. Ecoref #68229	
Birge,W.J., J.A. Black, J.F. Hobson, A.G. Westerman, and T.M. Short. Toxicological Studies on Aquatic Contaminants Originating from Coal Production and Utilization: The Induction of Tolerance to Silver in Laboratory Populations of Fish and the Chronic Toxicity of Nickel to Fish	

Citation	Notes
Early Li. Proj.No.G-844-02, Water Resources Research Institute Research Rep.No.151, University of Kentucky, Lexington, KY:36 p., 1984. Ecoref #18858	
Brooke,L.T.. The Effects of Food and Test Solution Age on the Toxicity of Silver to Three Freshwater Organisms. Contract No.68-C1-0034, Work Assignment No.1-10, Environ.Health Lab, Univ.of Wisconsin-Superior, Superior, WI:19 p., 1993. Ecoref #77568	
Brooke,L.T., D.J. Call, C.A. Lindberg, T.P. Markee, S.H. Poirier, and D.J. McCauley. Acute Toxicity of Silver to Selected Freshwater Invertebrates. Report to: Battelle Memorial Research Institute, Collumbus, Ohio, Subcontract No.F-4114(8834)-411; Center for Lake Superior Environmental Studies, University of Wisconsin-Superior, Superior, WI:11 p., 1986. Ecoref #3658	
Buccafusco,R.J., S.J. Ells, and G.A. LeBlanc. Acute Toxicity of Priority Pollutants to Bluegill ( <i>Lepomis macrochirus</i> ). Bull. Environ. Contam. Toxicol.26(4): 446-452, 1981. Ecoref #5590	Test material had 80% purity; insufficient
Bury,N.R., F. Galvez, and C.M. Wood. Effects of Chloride, Calcium, and Dissolved Organic Carbon on Silver Toxicity: Comparison Between Rainbow Trout and Fathead Minnows. Environ. Toxicol. Chem.18(1): 56-62, 1999. Ecoref #19262	Mixture toxicity study
Bury,N.R., J. Shaw, C. Glover, and C. Hogstrand. Derivation of a Toxicity-Based Model to Predict how Water Chemistry Influences Silver Toxicity to Invertebrates. Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.133(1-2): 259-270, 2002. Ecoref #65742	Mixture toxicity study
Chapman,G.A., S. Ota, and F. Recht. Effects of Water Hardness on the Toxicity of Metals to <i>Daphnia magna</i> . U.S.EPA, Corvallis, OR:17 p., 1980. Ecoref #3621	Already incorporated into 1980 EPA criteria
De Medeiros,A.M.Z., L.U. Khan, G.H. Da Silva, C.A. Ospina, O.L. Alves, V.L. De Castro, and D.S.T. Martinez. Graphene Oxide-Silver Nanoparticle Hybrid Material: An Integrated Nanosafety Study in Zebrafish Embryos. Ecotoxicol. Environ. Saf.209:14 p., 2021. Ecoref #186027	Nanoparticle study
Diamond,J.M., D.E. Koplisch, J. McMahon III, and R. Rost. Evaluation of the Water-Effect Ratio Procedure for Metals in a Riverine System. Environ. Toxicol. Chem.16(3): 509-520, 1997. Ecoref #17591	
Diamond,J.M., D.G. Mackler, M. Collins, and D. Gruber. Derivation of a Freshwater Silver Criteria for the New River, Virginia, Using Representative Species. Environ. Toxicol. Chem.9(11): 1425-1434, 1990. Ecoref #3774	Test water contained silver; field collected orgs; hardness reported as range
Erickson,R.J., L.T. Brooke, M.D. Kahl, F.V. Venter, S.L. Harting, T.P. Markee, and R.L. Spehar. Effects of Laboratory Test Conditions on the Toxicity of Silver to Aquatic Organisms. Environ. Toxicol. Chem.17(4): 572-578, 1998. Ecoref #18938	
Forsythe II,B.L.. Silver in a Freshwater Ecosystem: Acute Toxicity and Trophic Transfer. Ph.D. Thesis, Clemson University, Clemson, SC:149 p., 1996. Ecoref #83754	

Citation	Notes
Galvez,F., and C.M. Wood. The Mechanisms and Costs of Physiological and Toxicological Acclimation to Waterborne Silver in Juvenile Rainbow Trout ( <i>Oncorhynchus mykiss</i> ). J. Comp. Physiol., B Biochem. Syst. Environ. Physiol.172(7): 587-597, 2002. Ecoref #76331	
Griffitt,R.J., J. Luo, J. Gao, J.C. Bonzongo, and D.S. Barber. Effects of Particle Composition and Species on Toxicity of Metallic Nanomaterials in Aquatic Organisms. Environ. Toxicol. Chem.27(9): 1972-1978, 2008. Ecoref #104806	Nanoparticle study
Grosell,M., C. Hogstrand, C.M. Wood, and H.J.M. Hansen. A Nose-to-Nose Comparison of the Physiological Effects of Exposure to Ionic Silver Versus Silver Chloride in the European Eel ( <i>Anguilla anguilla</i> ) and the Rainbow Trout ( <i>Oncorhynchus mykiss</i> ). Aquat. Toxicol.48(2-3): 327-342, 2000. Ecoref #49762	No hardness data
Hobson,J.F.. Acclimation-Induced Changes in Toxicity and Induction of Metallothionein-Like Proteins in the Fathead Minnow Following Sublethal Exposure to Cobalt, Silver, and Zinc. Ph.D.Thesis, University of Kentucky, Lexington, KY:145 p., 1986. Ecoref #150469	Zinc acclimation study
Hockett,J.R., and D.R. Mount. Use of Metal Chelating Agents to Differentiate Among Sources of Acute Aquatic Toxicity. Environ. Toxicol. Chem.15(10): 1687-1693, 1996. Ecoref #45021	Unclear if resulting LC50 mixed with chelating agents
Hogstrand,C., F. Galvez, and C.M. Wood. Toxicity, Silver Accumulation and Metallothionein Induction in Freshwater Rainbow Trout During Exposure to Different Silver Salts. Environ. Toxicol. Chem.15(7): 1102-1108, 1996. Ecoref #17253	No hardness data
Holcombe,G.W., G.L. Phipps, A.H. Sulaiman, and A.D. Hoffman. Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families. Arch. Environ. Contam. Toxicol.16:697-710, 1987. Ecoref #12665	
Holcombe,G.W., G.L. Phipps, and J.T. Fiandt. Toxicity of Selected Priority Pollutants to Various Aquatic Organisms. Ecotoxicol. Environ. Saf.7(4): 400-409, 1983. Ecoref #10417	
Hook,S.E., and N.S. Fisher. Sublethal Effects of Silver in Zooplankton: Importance of Exposure Pathways and Implications for Toxicity Testing. Environ. Toxicol. Chem.20(3): 568-574, 2001. Ecoref #59900	Could not relate LC50s to particular species
Karen,D.J., D.R. Ownby, B.L. Forsythe, T.P. Bills, T.W. LaPoint, G.B. Cobb, and S.J. Klaine. Influence of Water Quality on Silver Toxicity to Rainbow Trout ( <i>Oncorhynchus mykiss</i> ), Fathead Minnows ( <i>Pimephales promelas</i> ), and Water Fleas ( <i>Daphnia magna</i> ). Environ. Toxicol. Chem.18(1): 63-70, 1999. Ecoref #19218	
Keller,A.E.. Personal Communication to U.S. EPA: Water Quality and Toxicity Data for Unpublished Unionid Mussel Tests. Memo to R.Pepin and C.Roberts,U.S.EPA Region 5,Chicago, IL:14 p., 2000. Ecoref #76251	Could not find

Citation	Notes
Khangarot,B.S., A. Sehgal, and M.K. Bhasin. "Man and Biosphere" - Studies on the Sikkim Himalayas. Part 5: Acute Toxicity of Selected Heavy Metals on the Tadpoles of Rana hexadactyla. Acta Hydrochim. Hydrobiol.13(2): 259-263, 1985. Ecoref #11438	Non-north american test species used
Khangarot,B.S., P.K. Ray, and H. Chandra. Daphnia magna as a Model to Assess Heavy Metal Toxicity: Comparative Assessment with Mouse System. Acta Hydrochim. Hydrobiol.15(4): 427-432, 1987. Ecoref #12575	
Khangarot,B.S., and P.K. Ray. Sensitivity of Toad Tadpoles, Bufo melanostictus (Schneider), to Heavy Metals. Bull. Environ. Contam. Toxicol.38(3): 523-527, 1987. Ecoref #12339	Non-north american test species used
Khangarot,B.S., and P.K. Ray. Sensitivity of Freshwater Pulmonate Snails, Lymnaea luteola L., to Heavy Metals. Bull. Environ. Contam. Toxicol.41(2): 208-213, 1988. Ecoref #12943	Non-north american test species used
Khangarot,B.S., and P.K. Ray. The Acute Toxicity of Silver to Some Freshwater Fishes. Acta Hydrochim. Hydrobiol.16(5): 541-545, 1988. Ecoref #13149	Non-north american test species used
Kim,J., S. Kim, and S. Lee. Differentiation of the Toxicities of Silver Nanoparticles and Silver Ions to the Japanese Medaka (Oryzias latipes) and the Cladoceran Daphnia magna. Nanotoxicology5(2): 208-214, 2011. Ecoref #160065	Nanoparticle study
Klaine,S.J., T.W. La Point, G.P. Cobb, B.L. Forsythe II, T.P. Bills, M.D. Wenzholz, and R.D. Jeffers. Influence of Water Quality Parameters on Silver Toxicity: Preliminary Result. In: A.W.Andren and T.W.Bober (Eds.), Silver in the Environment: Transport, Fate and Effects, Washington, DC:65-77, 1996. Ecoref #20261	Preliminary results
LeBlanc,G.A.. Acute Toxicity of Priority Pollutants to Water Flea (Daphnia magna). Bull. Environ. Contam. Toxicol.24(5): 684-691, 1980. Ecoref #5184	
LeBlanc,G.A., J.D. Mastone, A.P. Paradise, and B.F. Wilson. The Influence of Speciation on the Toxicity of Silver to Fathead Minnow (Pimephales promelas). Environ. Toxicol. Chem.3(1): 37-46, 1984. Ecoref #10538	
Lemke,A.E.. Interlaboratory Comparison Acute Testing Set. EPA-600/3-81-005, U.S.EPA, Duluth, MN:29 p., 1981. Ecoref #9479	Already used in the 1980 criteria derivation
Lima,A.R., C. Curtis, D.E. Hammermeister, D.J. Call, and T.A. Felhaber. Acute Toxicity of Silver to Selected Fish and Invertebrates. Bull. Environ. Contam. Toxicol.29(2): 184-189, 1982. Ecoref #15327	
Mann,R.M., M.J. Ernste, R.A. Bell, J.R. Kramer, and C.M. Wood. Evaluation of the Protective Effects of Reactive Sulfide on the Acute Toxicity of Silver to Rainbow Trout (Oncorhynchus mykiss). Environ. Toxicol. Chem.23(5): 1204-1210, 2004. Ecoref #75078	

Citation	Notes
Morgan,T.P., and C.M. Wood. A Relationship Between Gill Silver Accumulation and Acute Silver Toxicity in the Freshwater Rainbow Trout: Support for the Acute Silver Biotic Ligand Model. Environ. Toxicol. Chem.23(5): 1261-1267, 2004. Ecoref #75070	
Mouneyrac,C., O. Mastain, J.C. Amiard, C. Amiard-Triquet, P. Beaunier, A.Y. Jeantet, B.D. Smith, and P.S. Rainbow. Trace-Metal Detoxification and Tolerance of the Estuarine Worm Hediste diversicolor Chronically Exposed in Their Environment. Mar. Biol.143(4): 731-744, 2003. Ecoref #75379	Lacks method details- controls/replicates; LC50 not reported
Mount,D.I., and T.J. Norberg. A Seven-Day Life-Cycle Cladoceran Toxicity Test. Environ. Toxicol. Chem.3(3): 425-434, 1984. Ecoref #11181	Organisms were fed
Nalecz-Jawecki,G., K. Demkowicz-Dobrzanski, and J. Sawicki. Protozoan Spirostomum ambiguum as a Highly Sensitive Bioindicator for Rapid and Easy Determination of Water Quality. Sci. Total Environ.Suppl(Pt.2):1227-1234, 1993. Ecoref #83577	Bacterial test; single cell organism not appropriate
Nalecz-Jawecki,G., and J. Sawicki. Toxicity of Inorganic Compounds in the Spirotox Test: A Miniaturized Version of the Spirostomum ambiguum Test. Arch. Environ. Contam. Toxicol.34(1): 1-5, 1998. Ecoref #18997	Bacterial test; single cell organism not appropriate
Nebeker,A.V., C.K. McAuliffe, R. Mshar, and D.G. Stevens. Toxicity of Silver to Steelhead and Rainbow Trout, Fathead Minnows and Daphnia magna. Environ. Toxicol. Chem.2:95-104, 1983. Ecoref #10525	Already used in 1980 criteria derivation
Norberg-King,T.J.. An Evaluation of the Fathead Minnow Seven-Day Subchronic Test for Estimating Chronic Toxicity. Environ. Toxicol. Chem.8(11): 1075-1089, 1989. Ecoref #5313	7-day study
Patil,H.S., and M.B. Kaliwal. Relative Sensitivity of a Freshwater Prawn Macrobrachium hendersodyanum to Heavy Metals. Environ. Ecol.4(2): 286-288, 1986. Ecoref #12787	Silver sulfate exposure; 1980 criteria used only silver nitrate
Rodgers,J.H.J., E. Deaver, B.C. Suedel, and P.L. Rogers. Comparative Aqueous Toxicity of Silver Compounds: Laboratory Studies with Freshwater Species. Bull. Environ. Contam. Toxicol.58:851-858, 1997. Ecoref #17981	
Shivaraj,K.M., and H.S. Patil. Toxicity of Silver Chloride to a Fresh Water Fish Lepidocephalichthyes guntea. Environ. Ecol.6(3): 713-716, 1988. Ecoref #806	Non north american test species used
Tsuji,S., Y. Tonogai, Y. Ito, and S. Kanoh. The Influence of Rearing Temperatures on the Toxicity of Various Environmental Pollutants for Killifish (Oryzias latipes). Jpn. J. Toxicol. Environ. Health32(1): 46-53, 1986. Ecoref #12497	Non north american test species used
U.S. Environmental Protection Agency. Pesticide Ecotoxicity Database (Formerly: Environmental Effects Database (EEDB)). Environmental Fate and Effects Division, U.S.EPA, Washington, D.C., 1992. Ecoref #344	Reference to a database

Citation	Notes
VanGenderen,E.J., A.C. Ryan, J.R. Tomasso, and S.J. Klaine. Influence of Dissolved Organic Matter Source on Silver Toxicity to Pimephales promelas. Environ. Toxicol. Chem.22(11): 2746-2751, 2003. Ecoref #71734	Test waters included DOC
Vedamanikam,V.J., and N.A.M. Shazili. The Chironomid Larval Tube, a Mechanism to Protect the Organism from Environmental Disturbances?. Toxicol. Environ. Chem.91(1): 171-176, 2009. Ecoref #115860	No hardness data
Vedamanikam,V.J., and N.A.M. Shazilli. Comparative Toxicity of Nine Metals to Two Malaysian Aquatic Dipterian Larvae with Reference to Temperature Variation. Bull. Environ. Contam. Toxicol.80(6): 516-520, 2008. Ecoref #107050	No hardness data
Vedamanikam,V.J., and N.A.M. Shazilli. The Effect of Multi-Generational Exposure to Metals and Resultant Change in Median Lethal Toxicity Tests Values over Subsequent Generations. Bull. Environ. Contam. Toxicol.80(1): 63-67, 2008. Ecoref #111291	No hardness data
Williams,P.L., and D.B. Dusenbery. Aquatic Toxicity Testing Using the Nematode, Caenorhabditis elegans. Environ. Toxicol. Chem.9(10): 1285-1290, 1990. Ecoref #3437	No hardness data
Wu,Y., Q. Zhou, H. Li, W. Liu, T. Wang, and G.Z. Jiang. Effects of Silver Nanoparticles on the Development and Histopathology Biomarkers of Japanese Medaka (Oryzias latipes) Using the Partial-Life Test. Aquat. Toxicol.100:160-167, 2010. Ecoref #151150	Non-north american test species used
Ziegenfuss,P.S., W.J. Renaudette, and W.J. Adams. Methodology for Assessing the Acute Toxicity of Chemicals Sorbed to Sediments: Testing the Equilibrium Partitioning Theory. ASTM Spec. Tech. Publ.9:479-493, 1986. Ecoref #7884	Sediment based study

## Open Literature

Table A21. List of open literature citations from EPA ECOTOX database reviewed for silver criteria derivation but did not meet acceptability requirements.

Citation	Notes
Hoheisel, S.M., Diamond, S. and Mount, D., 2012. Comparison of nanosilver and ionic silver toxicity in <i>Daphnia magna</i> and <i>Pimephales promelas</i> . <i>Environmental toxicology and chemistry</i> , 31(11), pp.2557-2563.	No hardness data

## Freshwater Chronic

Table A22. List of citations from EPA ECOTOX database reviewed for silver freshwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Bielmyer,G.K., R.A. Bell, and S.J. Klaine. Effects of Ligand-Bound Silver on <i>Ceriodaphnia dubia</i> . <i>Environ. Toxicol. Chem.</i> 21(10): 2204-2208, 2002. Ecoref #68229	
Call,D.J., C.N. Polkinghorne, T.P. Markee, L.T. Brooke, D.L. Geiger, J.W. Gorsuch, and K.A. Robillard. Silver Toxicity to <i>Chironomus tentans</i> in Two Freshwater Sediments. <i>Environ. Toxicol. Chem.</i> 18(1): 30-39, 1999. Ecoref #19468	Sediment study
Davies,P.H., J.P.,Jr. Goettl, and J.R. Sinley. Toxicity of Silver to Rainbow Trout ( <i>Salmo gairdneri</i> ). <i>Water Res.</i> 12(2): 113-117, 1978. Ecoref #2129	
Diamond,J.M., D.G. Mackler, M. Collins, and D. Gruber. Derivation of a Freshwater Silver Criteria for the New River, Virginia, Using Representative Species. <i>Environ. Toxicol. Chem.</i> 9(11): 1425-1434, 1990. Ecoref #3774	Field collected orgs and test water
Diamond,J.M., E.L. Winchester, D.G. Mackler, and D. Gruber. Use of the Mayfly <i>Stenonema modestum</i> (Heptageniidae) in Subacute Toxicity Assessments. <i>Environ. Toxicol. Chem.</i> 11(3): 415-425, 1992. Ecoref #16355	
Goettl,J.P.,Jr., J.R. Sinley, and P.H. Davies. Water Pollution Studies. Job Progress Report, Federal Aid Project F-33-R-8, DNR, Denver, CO:123 p., 1973. Ecoref #56144	Unable to locate
Goettl,J.P.,Jr., and P.H. Davies. Water Pollution Studies. Job Progress Report, Federal Aid Project F-33-R-11, DNR, Boulder, CO:58 p., 1976. Ecoref #10208	Unable to locate

Citation	Notes
Hobson, J.F.. Acclimation-Induced Changes in Toxicity and Induction of Metallothionein-Like Proteins in the Fathead Minnow Following Sublethal Exposure to Cobalt, Silver, and Zinc. Ph.D.Thesis, University of Kentucky, Lexington, KY:145 p., 1986. Ecoref #150469	Endpoints not relevant
Kolkmeier, M.A., and B.W. Brooks. Sublethal Silver and NaCl Toxicity in <i>Daphnia magna</i> : A Comparative Study of Standardized Chronic Endpoints and Progeny Phototaxis. <i>Ecotoxicology</i> 22(4): 693-706, 2013. Ecoref #163942	
LeBlanc, G.A., J.D. Mastone, A.P. Paradice, and B.F. Wilson. The Influence of Speciation on the Toxicity of Silver to Fathead Minnow ( <i>Pimephales promelas</i> ). <i>Environ. Toxicol. Chem.</i> 3(1): 37-46, 1984. Ecoref #10538	Lacking NOEC/LOEC data for silver nitrate
Morgan, T.P., C.M. Guadagnolo, M. Grosell, and C.M. Wood. Effects of Water Hardness on Toxicological Responses to Chronic Waterborne Silver Exposure in Early Life Stages of Rainbow Trout ( <i>Oncorhynchus mykiss</i> ). <i>Environ. Toxicol. Chem.</i> 24(7): 1642-1647, 2005. Ecoref #83081	Only 2 test concentrations
Naddy, R.B., A.B. Rehner, G.R. Mc Nerney, J.W. Gorsuch, J.R. Kramer, C.M. Wood, P.R. Paquin, and W.A. Stubblefield. Comparison of Short-Term Chronic and Chronic Silver Toxicity to Fathead Minnows in Unamended and Sodium Chloride-Amended Waters. <i>Environ. Toxicol. Chem.</i> 26(9): 1922-1930, 2007. Ecoref #104889	
Naddy, R.B., J.W. Gorsuch, A.B. Rehner, G.R. Mc Nerney, R.A. Bell, and J.R. Kramer. Chronic Toxicity of Silver Nitrate to <i>Ceriodaphnia dubia</i> and <i>Daphnia magna</i> , and Potential Mitigating Factors. <i>Aquat. Toxicol.</i> 84(1): 1-10, 2007. Ecoref #105683	
Nebeker, A.V., C.K. McAuliffe, R. Mshar, and D.G. Stevens. Toxicity of Silver to Steelhead and Rainbow Trout, Fathead Minnows and <i>Daphnia magna</i> . <i>Environ. Toxicol. Chem.</i> 2:95-104, 1983. Ecoref #10525	Data included in previous EPA derivation
Norberg-King, T.J.. An Evaluation of the Fathead Minnow Seven-Day Subchronic Test for Estimating Chronic Toxicity. <i>Environ. Toxicol. Chem.</i> 8(11): 1075-1089, 1989. Ecoref #5313	
Norberg-King, T.J.. An Evaluation of the Fathead Minnow Seven-Day Subchronic Test for Estimating Chronic Toxicity. M.S.Thesis, University of Wyoming, Laramie, WY:80 p., 1987. Ecoref #17878	Repeat of data from published Norberg-King, 1989
Cremazy, A., K.V. Brix, and C.M. Wood. Chronic Toxicity of Binary Mixtures of Six Metals (Ag, Cd, Cu, Ni, Pb and Zn) to the Great Pond Snail <i>Lymnaea stagnalis</i> . <i>Environ. Sci. Technol.</i> 52(10): 5979-5988, 2018. Ecoref #188091 Google Scholar	
Bianchini, A., and C.M. Wood. Does Sulfide or Water Hardness Protect Against Chronic Silver Toxicity in <i>Daphnia magna</i> ? A Critical Assessment of the Acute-to-Chronic Toxicity Ratio for Silver. <i>Ecotoxicol. Environ. Saf.</i> 71:32-40, 2008. Ecoref #104819	Repeat of other studies



## Open Literature

Table A23. List of open literature citations from EPA ECOTOX database reviewed for silver criteria derivation but did not meet acceptability requirements.

Citation	Notes
Okamoto, A., Masunaga, S. and Tatarazako, N., 2021. Chronic toxicity of 50 metals to <i>Ceriodaphnia dubia</i> . <i>Journal of Applied Toxicology</i> , 41(3), pp.375-386.	Very little study details; Effect level reported as inhibitory concentrations; did not use flow through design

## Saltwater Acute

Table A24. List of citations from EPA ECOTOX database reviewed for silver saltwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Cardin, J.A.. Unpublished Laboratory Data. U.S.EPA, Narragansett, RI:9 p., 1980. Ecoref #3751	Unpublished data; cannot find
Cardin, J.A.. Results of Acute Toxicity Tests Conducted with Silver at ERL, Narragansett. Memo to J.H.Gentile, U.S.EPA, Narragansett, RI:6 p., 1981. Ecoref #66501	Unpublished data; cannot find
Dinnel, P.A., J.M. Link, Q.J. Stober, M.W. Letourneau, and W.E. Roberts. Comparative Sensitivity of Sea Urchin Sperm Bioassays to Metals and Pesticides. <i>Arch. Environ. Contam. Toxicol.</i> 18(5): 748-755, 1989. Ecoref #2264	
Dinnel, P.A., Q.J. Stober, J.M. Link, M.W. Letourneau, W.E. Roberts, S.P. Felton, and R.E. Nakatani. Methodology and Validation of a Sperm Cell Toxicity Test for Testing Toxic Substances in Marine Waters. Final Rep.FRI-UW-8306, Fish.Res.Inst., Schl.of Fish., Univ.of Washington, Seattle, WA:208 p., 1983. Ecoref #3752	Not relevant; gamete study design
Ferguson, E.A., and C. Hogstrand. Acute Silver Toxicity to Seawater-Acclimated Rainbow Trout: Influence of Salinity on Toxicity and Silver Speciation. <i>Environ. Toxicol. Chem.</i> 17(4): 589-593, 1998. Ecoref #18940	
Heitmuller, P.T., T.A. Hollister, and P.R. Parrish. Acute Toxicity of 54 Industrial Chemicals to Sheepshead Minnows ( <i>Cyprinodon variegatus</i> ). <i>Bull. Environ. Contam. Toxicol.</i> 27(5): 596-604, 1981. Ecoref #10366	Uncertain data reported
Hook, S.E., and N.S. Fisher. Sublethal Effects of Silver in Zooplankton: Importance of Exposure Pathways and Implications for Toxicity Testing. <i>Environ. Toxicol. Chem.</i> 20(3): 568-574, 2001. Ecoref #59900	No specific information on copepod and cladocerans

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Lee,K.W., S. Raisuddin, J.S. Rhee, D.S. Hwang, I.T. Yu, Y.M. Lee, H.G. Park, and J.S. Lee. Expression of Glutathione S-Transferase (GST) Genes in the Marine Copepod Tigriopus japonicus Exposed to Trace Metals. <i>Aquat. Toxicol.</i> 89(3): 158-166, 2008. Ecoref #107127	
Lussier,S.M., J.H. Gentile, and J. Walker. Acute and Chronic Effects of Heavy Metals and Cyanide on <i>Mysidopsis bahia</i> (Crustacea: Mysidacea). <i>Aquat. Toxicol.</i> 7(1/2): 25-35, 1985. Ecoref #11331	Already used in EPA 1980 derivation
Lussier,S.M., and J.A. Cardin. Results of Acute Toxicity Tests Conducted with Silver at ERL, Narragansett. U.S.EPA, Narragansett, RI:14 p., 1985. Ecoref #3825	Repeat
Mathew,R., and N.R. Menon. Effects of Heavy Metals on Bysso-genesis in <i>Perna viridis</i> (Linn.). <i>Indian J. Mar. Sci.</i> 12(2): 125-127, 1983. Ecoref #11120	Non-north American test species
McKenney,C.L.,Jr., and S.H. Hong. Interlaboratory Comparison of Chronic Toxicity Testing Using the Estuarine Mysid ( <i>Mysidopsis bahia</i> ): A Final Report. U.S.EPA, Gulf Breeze, FL:35 p., 1982. Ecoref #3736	Chronic study
Menasria,R., and J.F. Pavillon. Toxic Effects of Two Trace Metals, Copper and Silver, on a Crustacean Harpacticoid Copepod <i>Tigriopus brevicornis</i> (Muller). Lethal and Sublethal Effects at Different Development Stages (Effets Biologiques de Deux Metaux . <i>J. Rech. Oceanogr.</i> 19(3-4): 157-165, 1994. Ecoref #18833	Non-north American test species
Nelson,D.A., J.E. Miller, and A. Calabrese. Effect of Heavy Metals on Bay Scallops, Surf Clams, and Blue Mussels in Acute and Long-Term Exposures. <i>Arch. Environ. Contam. Toxicol.</i> 17(5): 595-600, 1988. Ecoref #15056	Adult life stage used for blue mussel
Pavillon,J.F., C. Douez, R. Menasria, J. Forget, J.C. Amiard, and R. Cosson. Impact of Dissolved and Particulate Organic Carbon on the Bioavailability of the Trace Metals Silver and Mercury for the Harpacticoid Copepod <i>Tigriopus brevicornis</i> . <i>J. Rech. Oceanogr.</i> 27(1): 43-52, 2002. Ecoref #76315	Used particulate matter in test
Pesch,C.E., and G.L. Hoffman. Interlaboratory Comparison of a 28-Day Toxicity Test with the Polychaete <i>Neanthes arenaceodentata</i> . <i>ASTM Spec. Tech. Publ.</i> :482-493, 1983. Ecoref #10168	Chronic study
Saunders,C.E.. Effects of Dissolved Organic Matter and Salinity on the Toxicity of Individual and Metal Mixtures of Copper with Zinc and Silver to the Saltwater Rotifer, <i>Brachionus plicatilis</i> . M.S. Thesis, Stephen F. Austin State University, Nacogdoches, TX:189 p., 2012. Ecoref #167104	
Schimmel,S.C.. Results: Interlaboratory Comparison - Acute Toxicity Tests Using Estuarine Animals. Final Draft, EPA 600/4-81-003, U.S.EPA, Gulf Breeze, FL:13 p., 1981. Ecoref #3740	

Citation	Notes
Shaw,J.R., C. Hogstrand, M.D. Kercher, and W.J. Birge. The Acute and Chronic Toxicity of Silver to Marine Fish. In: A.W.Andren and T.W.Bober (Eds.), Silver in the Environment: Transport, Fate and Effects, Washington, DC:317-324, 1997. Ecoref #83117	Literature review
Shaw,J.R., C.M. Wood, W.J. Birge, and C. Hogstrand. Toxicity of Silver to the Marine Teleost (Oligocottus maculosus): Effects of Salinity and Ammonia. Environ. Toxicol. Chem.17(4): 594-600, 1998. Ecoref #18941	Repeat
Shaw,J.R., W.J. Birge, and C. Hostrand. Parameters that Influence Silver Toxicity: Ammonia and Salinity. In: 4th Int.Conf.Proc.: Transport, Fate and Effects of Silver in the Environment, Aug.25-28, 1996, Madison, WI:155-159, 1996. Ecoref #20142	Repeat
U.S. Environmental Protection Agency. Pesticide Ecotoxicity Database (Formerly: Environmental Effects Database (EEDB)). Environmental Fate and Effects Division, U.S.EPA, Washington, D.C., 1992. Ecoref #344	Database reference
Vijayavel,K., S. Gopalakrishnan, and M.P. Balasubramanian. Sublethal Effect of Silver and Chromium in the Green Mussel Perna viridis with Reference to Alterations in Oxygen Uptake, Filtration Rate and Membrane Bound ATPase System as Biomarkers. Chemosphere69(6): 979-986, 2007. Ecoref #105682	Non-north American test species
Ward,T.J., and J.R. Kramer. Silver Speciation During Chronic Toxicity Tests with the Mysid, Americamysis bahia. Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.133(1-2): 75-86, 2002. Ecoref #65743	
Wood,C.M., M.D. McDonald, P. Walker, M. Grosell, J.F. Barimo, R.C. Playle, and P.J. Walsh. Bioavailability of Silver and Its Relationship to Ionoregulation and Silver Speciation Across a Range of Salinities in the Gulf Toadfish (Opsanus beta). Aquat. Toxicol.70:137-157, 2004. Ecoref #75372	

## Zinc

### Freshwater Acute

Table A25. List of citations from EPA ECOTOX database reviewed for zinc freshwater acute criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Adebayo,O.A., D.P.N. Kio, and O.O. Emmanuel. Assessment of Potential Ecological Disruption Based on Heavy Metal Toxicity, Accumulation and Distribution in Media of the Lagos Lagoon. Afr. J. Ecol.45(4): 454-463, 2007. Ecoref #151240	Non-north american test species used
Agrawal,U.. Effect of Sublethal Concentration of Zinc on Some Hematological Parameters of Freshwater Indian Catfish, Heteropneustes fossilis. J. Adv. Zool.15(2): 86-89, 1994. Ecoref #82971	Non-north american test species used
Alam,M.K., and O.E. Maughan. Acute Toxicity of Heavy Metals to Common Carp (Cyprinus carpio). J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control30(8): 1807-1816, 1995. Ecoref #45566	Non-north american test species used
Ali,D., S. Alarifi, S. Kumar, M. Ahamed, and M.A. Siddiqui. Oxidative Stress and Genotoxic Effect of Zinc Oxide Nanoparticles in Freshwater Snail Lymnaea luteola L.. Aquat. Toxicol.124/125(0): 83-90, 2012. Ecoref #160562	Nanoparticle study
Alsop,D., and C.M. Wood. Metal Uptake and Acute Toxicity in Zebrafish: Common Mechanisms Across Multiple Metals. Aquat. Toxicol.105(3/4): 385-393, 2011. Ecoref #158223	Hardness <10 mg/L can't compute/unsuitable conditions
Alsop,D.H., J.C. McGeer, D.G. McDonald, and C.M. Wood. Costs of Chronic Waterborne Zinc Exposure and the Consequences of Zinc Acclimation on the Gill/Zinc Interactions of Rainbow Trout in Hard and Soft Water. Environ. Toxicol. Chem.18(5): 1014-1025, 1999. Ecoref #46946	
Alsop,D.H., and C.M. Wood. Influence of Waterborne Cations on Zinc Uptake and Toxicity in Rainbow Trout, Oncorhynchus mykiss. Can. J. Fish. Aquat. Sci.56(11): 2112-2119, 1999. Ecoref #46945	
Alsop,D.H., and C.M. Wood. Kinetic Analysis of Zinc Accumulation in the Gills of Juvenile Rainbow Trout: Effects of Zinc Acclimation and Implications for Biotic Ligand Modeling. Environ. Toxicol. Chem.19(7): 1911-1918, 2000. Ecoref #46947	Study design and endpoints not relevant
Aquatic Toxicology Group. Brenda Mines Sulphate and Molybdenum Toxicity Testing. Proj.Rep.No.2-11-825/826, Prepared for Noranda Mining and Exploration Inc., Brenda Mines Div., B.C.:222 p., 1998. Ecoref #116817	Not available

Citation	Notes
Arambasic, M.B., S. Bjelic, and G. Subakov. Acute Toxicity of Heavy Metals (Copper, Lead, Zinc), Phenol and Sodium on <i>Allium cepa</i> L., <i>Lepidium sativum</i> L. and <i>Daphnia magna</i> St.: Comparative Investigations and the Practical Applications. <i>Water Res.</i> 29(2): 497-503, 1995. Ecoref #13712	No hardness data
Barata, C., D.J. Baird, and S.J. Markich. Influence of Genetic and Environmental Factors on the Tolerance of <i>Daphnia magna</i> Straus to Essential and Non-Essential Metals. <i>Aquat. Toxicol.</i> 42(2): 115-137, 1998. Ecoref #19146	
Bechard, K.M., P.L. Gillis, and C.M. Wood. Acute Toxicity of Waterborne Cd, Cu, Pb, Ni, and Zn to First-Instar <i>Chironomus riparius</i> Larvae. <i>Arch. Environ. Contam. Toxicol.</i> 54(3): 454-459, 2008. Ecoref #108924	24-hr LC50; control mortality observed after 24 hours
Bianchini, A., K.C. Bowles, C.J. Brauner, J.W. Gorsuch, J.R. Kramer, and C.M. Wood. Evaluation of the Effect of Reactive Sulfide on the Acute Toxicity of Silver (I) to <i>Daphnia magna</i> . Part 2: Toxicity Results. <i>Environ. Toxicol. Chem.</i> 21(6): 1294-1300, 2002. Ecoref #66362	
Bianchini, A., and P. Carvalho de Castilho. Effects of Zinc Exposure on Oxygen Consumption and Gill Na <sup>+</sup> , K <sup>+</sup> -ATPase of the Estuarine Crab <i>Chasmagnathus granulata</i> Dana, 1851 (Decapoda - Grapsidae). <i>Bull. Environ. Contam. Toxicol.</i> 62(1): 63-69, 1999. Ecoref #47569	Non-north american test species used
Bringolf, R.B., B.A. Morris, C.J. Boese, R.C. Santore, H.E. Allen, and J.S. Meyer. Influence of Dissolved Organic Matter on Acute Toxicity of Zinc to Larval Fathead Minnows ( <i>Pimephales promelas</i> ). <i>Arch. Environ. Contam. Toxicol.</i> 51(3): 438-444, 2006. Ecoref #96586	
Brinkman, S., and J. Woodling. Zinc Toxicity to the Mottled Sculpin ( <i>Cottus bairdi</i> ) in High-Hardness Water. <i>Environ. Toxicol. Chem.</i> 24(6): 1515-1517, 2005. Ecoref #84053	
Brinkman, S., and N. Vieira. Water Pollution Studies. Federal Aid Project F-243-R15, Job Progress Report, Colorado Div. of Wildlife, Fort Collins, Co:38 p., 2008. Ecoref #117718	Could not find
Brinkman, S.F., and J.D. Woodling. Acclimation and Deacclimation of Brown Trout ( <i>Salmo trutta</i> ) to Zinc and Copper Singly and in Combination with Cadmium or Copper. <i>Arch. Environ. Contam. Toxicol.</i> 67(2): 214-223, 2014. Ecoref #169219	Acclimation chronic study
Brinkman, S.F., and W.D. Johnston. Acute Toxicity of Aqueous Copper, Cadmium, and Zinc to the Mayfly <i>Rhithrogena hageni</i> . <i>Arch. Environ. Contam. Toxicol.</i> 54(3): 466-472, 2008. Ecoref #101773	
Brinkman, S.F., and W.D. Johnston. Acute Toxicity of Zinc to Several Aquatic Species Native to the Rocky Mountains. <i>Arch. Environ. Contam. Toxicol.</i> 62(2): 272-281, 2012. Ecoref #161667	

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Brodeur, J.C., C.M. Asorey, A. Sztrum, and J. Herkovits. Acute and Subchronic Toxicity of Arsenite and Zinc to Tadpoles of <i>Rhinella arenarum</i> both Alone and in Combination. <i>J. Toxicol. Environ. Health Part A</i> 72(14): 884-890, 2009. Ecoref #117667	Non-north american test species used
Brooks, A., R.M. White, and D.C. Paton. Effects of Heavy Metals on the Survival of <i>Diacypris compacta</i> (Herbst) (Ostracoda) from the Coorong, South Australia. <i>Int. J. Salt Lake Res.</i> 4(2): 133-163, 1995. Ecoref #59762	Non-north american test species used
Brown, R.J., S.D. Rundle, T.H. Hutchinson, T.D. Williams, and M.B. Jones. A Microplate Freshwater Copepod Bioassay for Evaluating Acute and Chronic Effects of Chemicals. <i>Environ. Toxicol. Chem.</i> 24(6): 1528-1531, 2005. Ecoref #84071	
Buhl, K.J., and S.J. Hamilton. Toxicity of Inorganic Contaminants, Individually and in Environmental Mixtures, to Three Endangered Fishes (Colorado Squawfish, Bonytail, and Razorback Sucker). <i>Arch. Environ. Contam. Toxicol.</i> 30(1): 84-92, 1996. Ecoref #16423	
Bulus Rossini, G.D., and A.E. Ronco. Sensitivity of <i>Cichlasoma facetum</i> (Cichlidae, Pisces) to Metals. <i>Bull. Environ. Contam. Toxicol.</i> 72(4): 763-768, 2004. Ecoref #74230	Non-north american test species used
Calfee, R.D., E.E. Little, H.J. Puglis, E. Scott, W.G. Brumbaugh, and C.A. Mebane. Acute Sensitivity of White Sturgeon ( <i>Acipenser transmontanus</i> ) and Rainbow Trout ( <i>Oncorhynchus mykiss</i> ) to Copper, Cadmium, or Zinc in Water-Only Laboratory Exposures. <i>Environ. Toxicol. Chem.</i> 33(10): 2259-2272, 2014. Ecoref #188154	
Canli, M.. Dietary and Water-Borne Zn Exposures Affect Energy Reserves and Subsequent Zn Tolerance of <i>Daphnia magna</i> . <i>Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.</i> 141(1): 110-116, 2005. Ecoref #84070	Dietary exposure/preexposure
Centeno, M.D.F., G. Persoone, and M.P. Goyvaerts. Cyst-Based Toxicity Tests. IX. The Potential of <i>Thamnocephalus platyurus</i> as Test Species in Comparison with <i>Streptocephalus proboscideus</i> (Crustacea: Branchiopoda: Anostraca). <i>Environ. Toxicol. Water Qual.</i> 10(4): 275-282, 1995. Ecoref #14017	Non-north american test species used
Chan, K.M., L.L. Ku, P.C.Y. Chan, and W.K. Cheuk. Metallothionein Gene Expression in Zebrafish Embryo-Larvae and ZFL Cell-Line Exposed to Heavy Metal Ions. <i>Mar. Environ. Res.</i> 62(suppl.1): S83 - S87, 2006. Ecoref #94046	Molecular based endpoints; not relevant
Chen, H.C., and Y.K. Yuan. Acute Toxicity of Copper, Cadmium and Zinc to Freshwater Fish <i>Acrossocheilus paradoxus</i> . <i>Dongwu Xuekan</i> 5(2): 45-60, 1994. Ecoref #18913	Non-north american test species used
Chu, K.W., and K.L. Chow. Synergistic Toxicity of Multiple Heavy Metals is Revealed by a Biological Assay Using a Nematode and Its Transgenic Derivative. <i>Aquat. Toxicol.</i> 61(1/2): 53-64, 2002. Ecoref #65728	Transgenic test organism

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Ciji,P.P., and S.B. Nandan. Toxicity of Copper and Zinc to <i>Puntius parrah</i> (Day, 1865). <i>Mar. Environ. Res.</i> 93:38-46, 2014. ECOREF #166483	Non-north american test species used
Collyard,S.A., G.T. Ankley, R.A. Hoke, and T. Goldenstein. Influence of Age on the Relative Sensitivity of <i>Hyalella azteca</i> to Diazinon, Alkylphenol Ethoxylates, Copper, Cadmium, and Zinc. <i>Arch. Environ. Contam. Toxicol.</i> 26(1): 110-113, 1994. ECOREF #13554	LC50 values not found
Cooper,N.L., J.R. Bidwell, and A. Kumar. Toxicity of Copper, Lead, and Zinc Mixtures to <i>Ceriodaphnia dubia</i> and <i>Daphnia carinata</i> . <i>Ecotoxicol. Environ. Saf.</i> 72:1523-1528, 2009. ECOREF #115778	
Crane,M.. Effect of Zinc on Four Populations and Two Generations of <i>Gammarus pulex</i> (L.). <i>Freshw. Biol.</i> 33(1): 119-126, 1995. ECOREF #14884	LC50 values not reported; field caught organisms preexposed to zinc
Da Silva Kraus,L.A., A.C.T. Bonecker, N. De Almeida, and A. Vital. Acute Toxicity of Potassium Dichromate, Sodium Dodecyl Sulfate, Copper and Zinc to <i>Poecilia vivipara</i> (Osteichthyes, Cyprinodontiformes). <i>Fresenius Environ. Bull.</i> 7(11/12): 654-658, 1998. ECOREF #60132	Non-north american test species used
Dalal,R., and S. Bhattacharya. Effect of Cadmium, Mercury, and Zinc on the Hepatic Microsomal Enzymes of <i>Channa punctatus</i> . <i>Bull. Environ. Contam. Toxicol.</i> 52(6): 893-897, 1994. ECOREF #13692	Non-north american test species used
Davies,P.H., S. Brinkman, and D. Hansen. <i>Water Pollution Studies. Federal Aid Project F-243R-6, Colorado Division of Wildlife, Fort Collins, CO:47 p., 2000. ECOREF #161558</i>	
Davies,P.H., and S. Brinkman. <i>Water Pollution Studies. Fed.Aid Proj.#F-33, Colorado Div.of Wildl., Fish Res.Sect., Fort Collins, CO:138 p., 1994. ECOREF #90601</i>	Could not find
De Schamphelaere,K.A.C., and C.R. Janssen. Bioavailability and Chronic Toxicity of Zinc to Juvenile Rainbow Trout ( <i>Oncorhynchus mykiss</i> ): Comparison with Other Fish Species and Development of a Biotic Ligand Model. <i>Environ. Sci. Technol.</i> 38(23): 6201-6209, 2004. ECOREF #84051	Not standard dilution water; deionized
Dhawan,R., D.B. Dusenbery, and P.L. Williams. A Comparison of Metal-Induced Lethality and Behavioral Responses in the Nematode <i>Caenorhabditis elegans</i> . <i>Environ. Toxicol. Chem.</i> 19(12): 3061-3067, 2000. ECOREF #59817	No hardness data
Diamantino,T.C., E. Almeida, A.M.V.M. Soares, and L. Guilhermino. Lactate Dehydrogenase Activity as an Effect Criterion in Toxicity Tests with <i>Daphnia magna</i> Straus. <i>Chemosphere</i> 45(4/5): 553-560, 2001. ECOREF #61028	No hardness data
Diamond,J.M., D.E. Koplisch, J. McMahon III, and R. Rost. Evaluation of the Water-Effect Ratio Procedure for Metals in a Riverine System. <i>Environ. Toxicol. Chem.</i> 16(3): 509-520, 1997. ECOREF #17591	

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Du,J., S. Wang, H. You, R. Jiang, C. Zhuang, and X. Zhang. Developmental Toxicity and DNA Damage to Zebrafish Induced by Perfluorooctane Sulfonate in the Presence of ZnO Nanoparticles. <i>Environ. Toxicol.</i> 31(3): 360-371, 2016. Ecoref #177124	Nanoparticle study
Ebrahimpour,M., H. Alipour, and S. Rakhshah. Influence of Water Hardness on Acute Toxicity of Copper and Zinc on Fish. <i>Toxicol. Ind. Health</i> 26(6): 361-365, 2010. Ecoref #167433	Non-north american test species used
Entrix. Acute Water Exposures of Cadmium, Copper, and Zinc to Early Life-Stages of White Sturgeon ( <i>Acipenser transmontanus</i> ). Report to Teck American Incorporated, Saskatoon, SK, Canada:19 p., 2011. Ecoref #188257	
Erten-Unal,M., B.G. Wixson, N. Gale, and J.L. Pitt. Evaluation of Toxicity, Bioavailability and Speciation of Lead, Zinc and Cadmium in Mine/Mill Wastewaters. <i>Chem. Spec. Bioavail.</i> 10(2): 37-46, 1998. Ecoref #76100	No hardness data
Everitt,V., P.A. Scherman, and M.H. Villet. The Toxicity of Zinc to a Selected Macroinvertebrate, <i>Adenophlebia auriculata</i> (Ephemeroptera, Leptophlebiidae): Method Development. <i>Afr. J. Aquat. Sci.</i> 27(1): 31-38, 2002. Ecoref #84132	Non-north american test species used
Fargasova,A.. Winter Third- to Fourth-Instar Larvae of <i>Chironomus plumosus</i> as Bioassay Tools for Assessment of Acute Toxicity of Metals and Their Binary Combinations. <i>Ecotoxicol. Environ. Saf.</i> 48(1): 1-5, 2001. Ecoref #59843	
Fargasova,A.. Cd, Cu, Zn, Al and Their Binary Combinations Acute Toxicity for <i>Chironomus plumosus</i> Larvae. <i>Fresenius Environ. Bull.</i> 12(8): 830-834, 2003. Ecoref #168016	Same value as Fargasova 2001
Fort,D.J., E.L. Stover, and J.A. Bantle. Integrated Ecological Hazard Assessment of Waste Site Soil Extracts Using FETAX and Short-Term Fathead Minnow Teratogenesis Assay. <i>ASTM Spec. Tech. Publ.</i> 4:93-109, 1996. Ecoref #45211	Non-north american test species used
Fugare,S.H., M.P. Deshmukh, B.B. Waykar, and B.K. Pardeshi. Acute Toxicity of Chlorides of Zinc, Copper and Mercury to Fresh Water Bivalve, <i>Parreysia cylindrica</i> (Annandale and Prashad). <i>Nat. Environ. Pollut. Technol.</i> 3(2): 147-150, 2004. Ecoref #100007	Non-north american test species used
Gioda,C.R., L.A. Lissner, A. Pretto, J.B.T. Da Rocha, M.R.C. Schetinger, J.R. Neto, V.M. Morsch, and V.L. Loro. Exposure to Sublethal Concentrations of Zn(II) and Cu(II) Changes Biochemical Parameters in <i>Leporinus obtusidens</i> . <i>Chemosphere</i> 69(1): 170-175, 2007. Ecoref #100038	Non-north american test species used
Gomez,S., C. Villar, and C. Bonetto. Zinc Toxicity in the Fish <i>Cnesterodon decemmaculatus</i> in the Parana River and Rio de la Plata Estuary. <i>Environ. Pollut.</i> 99(2): 159-165, 1998. Ecoref #19136	Non-north american test species used
Gottschalk,J.A.. Copper and Zinc Toxicity to the Gray Treefrog ( <i>Hyla chrysocelis</i> ) and the Northern Leopard Frog ( <i>Rana pipiens</i> ). M.S. Thesis, Clemson University, Clemson, SC:68 p., 1995. Ecoref #169548	



Citation	Notes
Gray,H.M.. The Ecotoxicology of Zinc on a Freshwater Leech, <i>Nepheleopsis obscura</i> . M.S.Thesis, Univ.of Calgary, Canada:118 p., 1995. Ecoref #100816	No LC50 data
Gundogdu,A.. Acute Toxicity of Zinc and Copper for Rainbow Trout ( <i>Onchorhynchus mykiss</i> ). J. Fish. Sci.2(5): 711-721, 2008. Ecoref #115298	
Gupta,A.K., and S.K. Sharma. Bioaccumulation of Zinc in <i>Cirrhinus mrigala</i> (Hamilton) Fingerlings During Short-Term Static Bioassay. J. Environ. Biol.15(3): 231-237, 1994. Ecoref #12768	Non-north american test species used
Guy,C.P., A.E. Pinkney, and M.H. Taylor. Effects of Sediment-Bound Zinc Contamination on Early Life Stages of the Mummichog ( <i>Fundulus heteroclitus</i> L.) in the Christina Watershed, Delaware, USA. Environ. Toxicol. Chem.25(5): 1305-1311, 2006. Ecoref #101779	Sediment/field water
Guzman,F.T., F.J.A. Gonzalez, and R.R. Martinez. Implementing <i>Lecane quadridentata</i> Acute Toxicity Tests to Assess the Toxic Effects of Selected Metals (Al, Fe and Zn). Ecotoxicol. Environ. Saf.73(3): 287-295, 2010. Ecoref #162100	Conducted in 24 well plates in limited test volumes and used uncharacterized ambient waters
Hamilton,S.J.. Hazard Assessment of Inorganics to Three Endangered Fish in the Green River, Utah. Ecotoxicol. Environ. Saf.30(2): 134-142, 1995. Ecoref #15346	
Hamilton,S.J., and K.J. Buhl. Hazard Evaluation of Inorganics, Singly and in Mixtures, to Flannelmouth Sucker <i>Catostomus latipinnis</i> in the San Juan River, New Mexico. Ecotoxicol. Environ. Saf.38(3): 296-308, 1997. Ecoref #18979	
Hamilton,S.J., and K.J. Buhl. Hazard Assessment of Inorganics, Individually and in Mixtures, to Two Endangered Fish in the San Juan River, New Mexico. Environ. Toxicol. Water Qual.12:195-209, 1997. Ecoref #20368	
Hattink,J., G. De Boeck, and R. Blust. Toxicity, Accumulation, and Retention of Zinc by Carp Under Normoxic and Hypoxic Conditions. Environ. Toxicol. Chem.25(1): 87-96, 2006. Ecoref #100041	Non-north american test species used
Heinlaan,M., A. Ivask, I. Blinova, H.C. Dubourguier, and A. Kahru. Toxicity of Nanosized and Bulk ZnO, CuO and TiO2 to Bacteria <i>Vibrio fischeri</i> and Crustaceans <i>Daphnia magna</i> and <i>Thamnocephalus platyurus</i> . Chemosphere71(7): 1308-1316, 2008. Ecoref #110793	Nanoparticle study
Herkovits,J., L. Corro, C. Perez-Coll, and O. Dominguez. Fluid Motion Effect on Metal Toxicity in <i>Bufo arenarum</i> Embryos. Bull. Environ. Contam. Toxicol.68(4): 549-554, 2002. Ecoref #65778	Non-north american test species; study design not relevant
Hoang,T.C., and X. Tong. Influence of Water Quality on Zinc Toxicity to the Florida Apple Snail ( <i>Pomacea paludosa</i> ) and Sensitivity of Freshwater Snails to Zinc. Environ. Toxicol. Chem.34(3): 545-553, 2015. Ecoref #188086	
Hockett,J.R., and D.R. Mount. Use of Metal Chelating Agents to Differentiate Among Sources of Acute Aquatic Toxicity. Environ. Toxicol. Chem.15(10): 1687-1693, 1996. Ecoref #45021	Mixture study with chelating agents

Citation	Notes
Holdway,D.A., K. Lok, and M. Semaan. The Acute and Chronic Toxicity of Cadmium and Zinc to Two Hydra Species. <i>Environ. Toxicol.</i> 16:557-565, 2001. Ecoref #62146	
Ingersoll,C.G., R.D. Calfee, E. Beahan, W.G. Brumbaugh, R.A. Dorman, D.K. Hardesty, J.L. Kunz, E.E. Little, C.A. Mebane. Acute and Chronic Sensitivity of White Sturgeon ( <i>Acipenser transmontanus</i> ) and Rainbow Trout ( <i>Oncorhynchus mykiss</i> ) to Cadmium, Copper, Lead, or Zinc in Laboratory Water-Only Exposures. <i>Sci. Investig. Rep.</i> :120 p., 2014. Ecoref #169495	Repeat of Wang; older life stage used
Jellyman,P.G., S.J. Clearwater, J.S. Clayton, C. Kilroy, N. Blair, C.W. Hickey, and B.J.F. Biggs. Controlling the Invasive Diatom <i>Didymosphenia geminata</i> : An Ecotoxicity Assessment of Four Potential Biocides. <i>Arch. Environ. Contam. Toxicol.</i> 61(1): 115-127, 2011. Ecoref #158448	
Juarez-Franco,M.F., S.S.S. Sarma, and S. Nandini. Effect of Cadmium and Zinc on the Population Growth of <i>Brachionus havanaensis</i> (Rotifera: Brachionidae). <i>J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control</i> 42(10): 1489-1493, 2007. Ecoref #101880	No hardness data
Kallanagoudar,Y.P., and H.S. Patil. Influence of Water Hardness on Copper, Zinc and Nickel Toxicity to <i>Gambusia affinis</i> (B&G). <i>J. Environ. Biol.</i> 18(4): 409-413, 1997. Ecoref #19028	Non-north american test species used
Karntanut,W., and D. Pascoe. A Comparison of Methods for Measuring Acute Toxicity to <i>Hydra vulgaris</i> . <i>Chemosphere</i> 41:1543-1548, 2000. Ecoref #50836	
Karntanut,W., and D. Pascoe. The Toxicity of Copper, Cadmium and Zinc to Four Different Hydra (Cnidaria: Hydrozoa). <i>Chemosphere</i> 47(10): 1059-1064, 2002. Ecoref #65809	
Karntanut,W., and D. Pascoe. Effects of Removing Symbiotic Green Algae on the Response of <i>Hydra viridissima</i> (Pallas 1776) to Metals. <i>Ecotoxicol. Environ. Saf.</i> 60(3): 301-305, 2005. Ecoref #77767	
Kazlauskienė,N., A. Burba, and G. Svecevičius. Acute Toxicity of Five Galvanic Heavy Metals to Hydrobionts. <i>Ekologija</i> 1:33-36, 1994. Ecoref #17573	Wrong language
Keller,A.E.. Personal Communication to U.S. EPA: Water Quality and Toxicity Data for Unpublished Unionid Mussel Tests. Memo to R.Pepin and C.Roberts,U.S.EPA Region 5,Chicago, IL:14 p., 2000. Ecoref #76251	Not peer reviewed
Khunyakari,R.P., V. Tare, and R.N. Sharma. Effects of Some Trace Heavy Metals on <i>Poecilia reticulata</i> (Peters). <i>J. Environ. Biol.</i> 22(2): 141-144, 2001. Ecoref #62227	Non-north american test species used
Lam,K.L., P.W. Ko, J.K.Y. Wong, and K.M. Chan. Metal Toxicity and Metallothionein Gene Expression Studies in Common Carp and Tilapia. <i>Mar. Environ. Res.</i> 46(1-5): 563-566, 1998. Ecoref #67658	Non-north american test species used

Citation	Notes
Lazorchak,J.M., M.E. Smith, and H.J. Haring. Development and Validation of a Daphnia magna Four-Day Survival and Growth Test Method. Environ. Toxicol. Chem.28(5): 1028-1034, 2009. Ecoref #118322	
Lindhjem,P.A., and M.G. Bennet-Chambers. Bioaccumulation and Acute Toxicity of Zinc in Marron, Cherax tenuimanus (Smith) (Decapoda: Parastacidae). In: G.J.Whisson and B.Knott, Proc.13th Symp.of the Int.Assoc.of Astacology:424-430, 2002. Ecoref #81789	Non-north american test species used
Liu,J., R. Qu, L. Yan, L. Wang, and Z. Wang. Evaluation of Single and Joint Toxicity of Perfluorooctane Sulfonate and Zinc to Limnodrilus hoffmeisteri: Acute Toxicity, Bioaccumulation and Oxidative Stress. J. Hazard. Mater.301:342-349, 2016. Ecoref #177071	Study design flaw; 3 test concentrations
Lynch,N.R., T.C. Hoang, and T.E. O'Brien. Acute Toxicity of Binary-Metal Mixtures of Copper, Zinc, and Nickel to Pimephales promelas: Evidence of More-than-Additive Effect. Environ. Toxicol. Chem.35(2): 446-457, 2016. Ecoref #188130	
Madoni,P., D. Davoli, G. Gorbi, and L. Vescovi. Toxic Effect of Heavy Metals on the Activated Sludge Protozoan Community. Water Res.30(1): 135-141, 1996. Ecoref #16363	Protozoa test species not relevant; sludge study
Madoni,P., D. Davoli, and G. Gorbi. Acute Toxicity of Lead, Chromium, and Other Heavy Metals to Ciliates from Activated Sludge Plants. Bull. Environ. Contam. Toxicol.53(3): 420-425, 1994. Ecoref #13671	Protozoa test species not relevant; sludge study
Magliette,R.J., F.G. Doherty, D. McKinney, and E.S. Venkataramani. Need for Environmental Quality Guidelines Based on Ambient Freshwater Quality Criteria in Natural Waters--Case Study "Zinc". Bull. Environ. Contam. Toxicol.54(4): 626-632, 1995. Ecoref #14962	Literature review not relevant
Malik,D.S., K.V. Sastry, and D.P. Hamilton. Effects of Zinc Toxicity on Biochemical Composition of Muscle and Liver of Murrel (Channa punctatus). Environ. Int.24(4): 433-438, 1998. Ecoref #51832	Non-north american test species used
Mariager,L.P.. Effects of Environmental Endocrine Disruptors on a Freshwater and a Marine Crustacean. M.S. Thesis, Aarhus University, Institute of Biological Sciences, Aarhus, Denmark:143 p., 2001. Ecoref #172856	No information - not peer reviewed
Martini,F., J.V. Tarazona, and M.V. Pablos. Are Fish and Standardized FETAX Assays Protective Enough for Amphibians? A Case Study on Xenopus laevis Larvae Assay with Biologically Active Substances Present in Livestock Wastes. Sci. World J.2012:605804, 2012. Ecoref #174140	No hardness data
McLoughlin,N., D. Yin, L. Maltby, R.M. Wood, and H. Yu. Evaluation of Sensitivity and Specificity of Two Crustacean Biochemical Biomarkers. Environ. Toxicol. Chem.19(8): 2085-2092, 2000. Ecoref #56618	No hardness data

Citation	Notes
McWilliam,R.A., and D.J. Baird. Postexposure Feeding Depression: A new Toxicity Endpoint for Use in Laboratory Studies with <i>Daphnia magna</i> . <i>Environ. Toxicol. Chem.</i> 21(6): 1198-1205, 2002. Ecoref #66374	No hardness data
Mebane,C.A., D.P. Hennessy, and F.S. Dillon. Developing Acute-to-Chronic Toxicity Ratios for Lead, Cadmium, and Zinc Using Rainbow Trout, a Mayfly, and a Midge. <i>Water Air Soil Pollut.</i> :21 p., 2007. Ecoref #97672	
Mebane,C.A., D.P. Hennessy, and F.S. Dillon. Developing Acute-to-Chronic Toxicity Ratios for Lead, Cadmium, and Zinc Using Rainbow Trout, a Mayfly, and a Midge. <i>Water Air Soil Pollut.</i> 188(1-4): 41-66, 2008. Ecoref #111766	Repeat of other Mebane study
Mohammed,A.. Comparative Sensitivities of the Tropical Cladoceran, <i>Ceriodaphnia rigaudii</i> and the Temperate Species <i>Daphnia magna</i> to Seven Toxicants. <i>Toxicol. Environ. Chem.</i> 89(2): 347-352, 2007. Ecoref #102662	Conducted in 24 well plates and concern for test chamber volume to organism density related effects.
Mouneyrac,C., O. Mastain, J.C. Amiard, C. Amiard-Triquet, P. Beaunier, A.Y. Jeantet, B.D. Smith, and P.S. Rainbow. Trace-Metal Detoxification and Tolerance of the Estuarine Worm <i>Hediste diversicolor</i> Chronically Exposed in Their Environment. <i>Mar. Biol.</i> 143(4): 731-744, 2003. Ecoref #75379	Saltwater worm test species
Naddy,R.B., A.S. Cohen, and W.A. Stubblefield. The Interactive Toxicity of Cadmium, Copper, and Zinc to <i>Ceriodaphnia dubia</i> and Rainbow Trout ( <i>Oncorhynchus mykiss</i> ). <i>Environ. Toxicol. Chem.</i> 34(4): 809-815, 2015. Ecoref #188131	
Naddy,R.B., A.S. Cohen, and W.A. Stubblefield. The Interactive Toxicity of Cadmium, Copper, and Zinc to <i>Ceriodaphnia dubia</i> and Rainbow Trout ( <i>Oncorhynchus mykiss</i> ). <i>Environ. Toxicol. Chem.</i> 34(4): 809-815, 2015. Ecoref #188131	Bacteria test; single celled organism not relevant
Nandini,S., E.A. Picazo-Paez, and S.S.S. Sarma. The Combined Effects of Heavy Metals (Copper and Zinc), Temperature and Food ( <i>Chlorella vulgaris</i> ) Level on the Demographic Characters of <i>Moina macrocopa</i> (Crustacea: Cladocera). <i>J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control</i> 42(10): 1433-1442, 2007. Ecoref #101826	No hardness data
Nelson,S.M., and R.A. Roline. Evaluation of the Sensitivity of Rapid Toxicity Tests Relative to Daphnid Acute Lethality Tests. <i>Bull. Environ. Contam. Toxicol.</i> 60:292-299, 1998. Ecoref #18961	Not standardized test
Oronsaye,J.A.O., N.F. Okolo, and E.E. Obano. The Toxicity of Zinc and Cadmium to <i>Clarias submaginatus</i> . <i>J. Aquat. Sci.</i> 18(1): 65-69, 2003. Ecoref #100470	Non-north american test species used
Othman,M.S., and M.N. Azwa. Acute Toxicity and Bioaccumulation of Zinc and Lead in the Freshwater Prawn <i>Macrobrachium lanchesteri</i> . <i>Malays. J. Sci.</i> 23(2): 11-18, 2004. Ecoref #100582	Non-north american test species used

Citation	Notes
Pestana,J.L.T., A. Re, A.J.A. Nogueira, and A.M.V.M. Soares. Effects of Cadmium and Zinc on the Feeding Behaviour of Two Freshwater Crustaceans: <i>Atyaephyra desmarestii</i> (Decapoda) and <i>Echinogammarus meridionalis</i> (Amphipoda). <i>Chemosphere</i> 68(8): 1556-1562, 2007. Ecoref #100061	
Rajkumar,J.S.I., M.C.J. Milton, and T. Ambrose. Acute Toxicity of Water Borne Cd, Cu, Pb and Zn to <i>Mugil cephalus</i> Fingerlings. <i>Int. J. Chem. Sci.</i> 9(2): 477-480, 2011. Ecoref #166665	Saltwater species used for testing
Rawi,S.M., M. Al-Hazmi, and F.S. Al-Nassr. Comparative Study of the Molluscicidal Activity of Some Plant Extracts on the Snail Vector of <i>Schistosoma mansoni</i> , <i>Biomphalaria alexandrina</i> . <i>Int. J. Zool. Res.</i> 7(2): 169-189, 2011. Ecoref #168775	Test endpoints not relevant
Rico,D., A. Martin-Gonzalez, S. Diaz, P. De Lucas, and J.C. Gutierrez. Heavy Metals Generate Reactive Oxygen Species in Terrestrial and Aquatic Ciliated Protozoa. <i>Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.</i> 149(1): 90-96, 2009. Ecoref #116520	Single celled test organism not relevant
Safadi,R.S.. The Use of Freshwater Planarians in Acute Toxicity Tests with Heavy Metals. <i>Verh. Int. Ver. Theor. Angew. Limnol.</i> 26(5): 2391-2392, 1998. Ecoref #83191	Wrong language
Sakamoto,M., Y. Ogami, and Y. Tanaka. <i>Leptodora kindtii</i> : A Cladoceran Species Highly Sensitive to Toxic Chemicals. <i>Limnology</i> 11(2): 193-196, 2010. Ecoref #171510	No hardness data
Sanchez-Moreno,S., J.A. Camargo, and A. Navas. Ecotoxicological Assessment of the Impact of Residual Heavy Metals on Soil Nematodes in the Guadiamar River Basin (Southern Spain). <i>Environ. Monit. Assess.</i> 116(1-3): 245-262, 2006. Ecoref #101819	Soil based test organism
Sharma,S., S. Sharma, P.K. Singh, R.C. Swami, and K.P. Sharma. Exploring Fish Bioassay of Textile Dye Wastewaters and Their Selected Constituents in Terms of Mortality and Erythrocyte Disorders. <i>Bull. Environ. Contam. Toxicol.</i> 83(1): 29-34, 2009. Ecoref #158330	Test material not relevant; non-north american test species
Shaw,J.R., T.D. Dempsey, C.Y. Chen, J.W. Hamilton, and C.L. Folt. Comparative Toxicity of Cadmium, Zinc, and Mixtures of Cadmium and Zinc to <i>Daphnids</i> . <i>Environ. Toxicol. Chem.</i> 25(1): 182-189, 2006. Ecoref #83466	No hardness data
Shedd,T.R., M.W. Widder, M.W. Toussaint, M.C. Sunkel, and E. Hull. Evaluation of the Annual Killifish <i>Nothobranchius guentheri</i> as a Tool for Rapid Acute Toxicity Screening. <i>Environ. Toxicol. Chem.</i> 18(10): 2258-2261, 1999. Ecoref #20487	Non-north american test specise used
Shuhaimi-Othman,M., N. Yakub, N.A. Ramle, and A. Abas. Toxicity of Metals to a Freshwater Ostracod: <i>Stenocypris major</i> . <i>J. Toxicol.</i> 2011:8 p., 2011. Ecoref #165793	Non-north american test specise used
Shuhaimi-Othman,M., N. Yakub, N.A. Ramle, and A. Abas. Sensitivity of the Freshwater Prawn, <i>Macrobrachium lanchesteri</i> (Crustacea: Decapoda), to Heavy Metals. <i>Toxicol. Ind. Health</i> :8 p., 2011. Ecoref #166618	Non-north american test specise used

Citation	Notes
Shuhaimi-Othman,M., N. Yakub, N.S. Umirah, and A. Abas. Toxicity of Eight Metals to Malaysian Freshwater Midge Larvae <i>Chironomus javanus</i> (Diptera, Chironomidae). <i>Toxicol. Ind. Health</i> 27(10): 879-886, 2011. Ecoref #163320	Non-north american test specise used
Shuhaimi-Othman,M., R. Nur-Amalina, and Y. Nadzifah. Toxicity of Metals to a Freshwater Snail, <i>Melanoides tuberculata</i> . <i>Sci. World J.</i> :10 p., 2012. Ecoref #166664	Non-north american test specise used
Shuhaimi-Othman,M., Y. Nadzifah, N.S. Umirah, and A.K. Ahmad. Toxicity of Metals to Tadpoles of the Common Sunda Toad, <i>Duttaphrynus melanostictus</i> . <i>Toxicol. Environ. Chem.</i> 94(2): 364-376, 2012. Ecoref #159422	Non-north american test specise used
Shuhaimi-Othman,M., Y. Nadzifah, N.S. Umirah, and A.K. Ahmad. Toxicity of Metals to an Aquatic Worm, <i>Nais elinguis</i> (Oligochaeta, Naididae). <i>Res. J. Environ. Toxicol.</i> 6(4): 122-132, 2012. Ecoref #163848	
Shuhaimi-Othman,M., and D. Pascoe. Acute Toxicity of Copper, Zinc and Cadmium to the Freshwater Amphipod <i>Hyalella azteca</i> . <i>Malays. Appl. Biol.</i> 30:1-8, 2001. Ecoref #169735	Not adequate test design information
Shukla,V., M. Dhankhar, and K.V. Sastry. Heavy Metal Toxicity on <i>Labeo rohita</i> . <i>J. Ecotoxicol. Environ. Monit.</i> 16(3): 247-250, 2006. Ecoref #102559	Non-north american test species used
Sornaraj,R., P. Baskaran, and S. Thanalakshmi. Effects of Heavy Metals on Some Physiological Responses of Air-Breathing Fish <i>Channa punctatus</i> (Bloch). <i>Environ. Ecol.</i> 13(1): 202-207, 1995. Ecoref #17380	Non-north american test species used
Svecevicus,G.. Acute Toxicity of Zinc to Common Freshwater Fishes of Lithuania. <i>Acta Zool. Litu.</i> 9(2): 114-118, 1999. Ecoref #100435	Non-north american test species used
Taju,G., S.A. Majeed, K.S.N. Nambi, and A.S.S. Hameed. Development and Characterization of Cell Line from the Gill Tissue of <i>Catla catla</i> (Hamilton, 1822) for Toxicological Studies. <i>Chemosphere</i> 90(7): 2172-2180, 2013. Ecoref #168821	Non-north american test species used
Tatara,C.P., M.C. Newman, J.T. McCloskey, and P.L. Williams. Predicting Relative Metal Toxicity with Ion Characteristics: <i>Caenorhabditis elegans</i> LC50. <i>Aquat. Toxicol.</i> 39(3-4): 279-290, 1997. Ecoref #18605	Predictive model study; not relevant
Traudt,E.M., J.F. Ranville, S.A. Smith, and J.S. Meyer. A Test of the Additivity of Acute Toxicity of Binary-Metal Mixtures of Ni with Cd, Cu, and Zn to <i>Daphnia magna</i> , Using the Inflection Point of the Concentration-Response Curves. <i>Environ. Toxicol. Chem.</i> 35(7): 1843-1851, 2016. Ecoref #188201	No hardness data
Traudt,E.M., J.F. Ranville, and J.S. Meyer. Effect of Age on Acute Toxicity of Cadmium, Copper, Nickel, and Zinc in Individual-Metal Exposures to <i>Daphnia magna</i> Neonates. <i>Environ. Toxicol. Chem.</i> 36(1): 113-119, 2017. Ecoref #188152	No hardness data

Citation	Notes
Tsui,M.T.K., W.X. Wang, and L.M. Chu. Influence of Glyphosate and Its Formulation (Roundup) on the Toxicity and Bioavailability of Metals to Ceriodaphnia dubia. Environ. Pollut.138(1): 59-68, 2005. Ecoref #87704	LC50 only reported in figure possible request info
Twagilimana,L., J. Bohatier, CA Groliere, F. Bonnemoy, and D. Sargos. A New Low-Cost Microbiotest with the Protozoan Spirostomum teres: Culture Conditions and Assessment of Sensitivity of the Ciliate to 14 Pure Chemicals. Ecotoxicol. Environ. Saf.41(3): 231-244, 1998. Ecoref #20057	Protozoa test species not relevant
Van der Schalie,W.H., T.R. Shedd, M.W. Widder, and L.M. Brennan. Response Characteristics of an Aquatic Biomonitor Used for Rapid Toxicity Detection. J. Appl. Toxicol.24(5): 387-394, 2004. Ecoref #77525	
Vedamanikam,V.J., and N.A.M. Shazili. The Chironomid Larval Tube, a Mechanism to Protect the Organism from Environmental Disturbances?. Toxicol. Environ. Chem.91(1): 171-176, 2009. Ecoref #115860	No hardness data
Vedamanikam,V.J., and N.A.M. Shazilli. Comparative Toxicity of Nine Metals to Two Malaysian Aquatic Dipterian Larvae with Reference to Temperature Variation. Bull. Environ. Contam. Toxicol.80(6): 516-520, 2008. Ecoref #107050	No hardness data
Vedamanikam,V.J., and N.A.M. Shazilli. The Effect of Multi-Generational Exposure to Metals and Resultant Change in Median Lethal Toxicity Tests Values over Subsequent Generations. Bull. Environ. Contam. Toxicol.80(1): 63-67, 2008. Ecoref #111291	No hardness data
Viljoen,A., G.J. Steyn, J.H.J. Van Vuren, and P.W. Wade. Zinc Effects on the Embryos and Larvae of the Sharptooth Catfish, Clarias gariepinus (Burchell, 1822). Bull. Environ. Contam. Toxicol.70(5): 1022-1027, 2003. Ecoref #71916	Non-north american test species used
Vyskushenko,A.D.. Effects of Copper Sulfate and Zinc Chloride on Lymnaea stagnalis L.. Hydrobiol. J.42(1): 107-113, 2006. Ecoref #102012	Field collected organisms; lacks study details
Wang,H., R.L. Wick, and B. Xing. Toxicity of Nanoparticulate and Bulk ZnO, Al2O3 and TiO2 to the Nematode Caenorhabditis elegans. Environ. Pollut.157(4): 1171-1177, 2009. Ecoref #108200	Nanoparticle study
Wang,N., C.G. Ingersoll, R.A. Dorman, W.G. Brumbaugh, C.A. Mebane, J.L. Kunz, and D.K. Hardesty. Chronic Sensitivity of White Sturgeon (Acipenser transmontanus) and Rainbow Trout (Oncorhynchus mykiss) to Cadmium, Copper, Lead, or Zinc in Laboratory Water-Only Exposures. Environ. Toxicol. Chem.33(10): 2246-2258, 2014. Ecoref #188097	Chronic data

Citation	Notes
Widianarko,B., F.X.S. Kuntoro, C.A.M. Van Gestel, and N.M. Van Straalen. Toxicokinetics and Toxicity of Zinc Under Time-Varying Exposure in the Guppy ( <i>Poecilia reticulata</i> ). <i>Environ. Toxicol. Chem.</i> 20(4): 763-768, 2001. Ecoref #60205	72 hr toxicity studies, euryhaline species, salinity not reported; possibly invasive
Williams,N.D., and D.A. Holdway. The Effects of Pulse-Exposed Cadmium and Zinc on Embryo Hatchability, Larval Development, and Survival of Australian Crimson Spotted Rainbow Fish ( <i>Melanotaenia fluviatilis</i> ). <i>Environ. Toxicol.</i> 15(3): 165-173, 2000. Ecoref #76127	Non-north american test species used
Wong,C.K., and A.P. Pak. Acute and Subchronic Toxicity of the Heavy Metals Copper, Chromium, Nickel, and Zinc, Individually and in Mixture, to the Freshwater Copepod <i>Mesocyclops pehpeiensis</i> . <i>Bull. Environ. Contam. Toxicol.</i> 73(1): 190-196, 2004. Ecoref #80006	Non-north american test species used
Woodling,J., S. Brinkman, and S. Albeke. Acute and Chronic Toxicity of Zinc to the Mottled Sculpin <i>Cottus bairdi</i> . <i>Environ. Toxicol. Chem.</i> 21(9): 1922-1926, 2002. Ecoref #68304	
Yang,H.N., and H.C. Chen. The Influence of Temperature on the Acute Toxicity and Sublethal Effects of Copper, Cadmium and Zinc to Japanese Eel, <i>Anguilla japonica</i> . <i>Dongwu Xuekan</i> 7(1): 29-38, 1996. Ecoref #18914	Non-north american test species used
Yim,J.H., K.W. Kim, and S.D. Kim. Effect of Hardness on Acute Toxicity of Metal Mixtures Using <i>Daphnia magna</i> : Prediction of Acid Mine Drainage Toxicity. <i>J. Hazard. Mater.</i> B138(1): 16-21, 2006. Ecoref #112477	
Yu,L.P., T. Fang, D.W. Xiong, W.T. Zhu, and X.F. Sima. Comparative Toxicity of Nano-ZnO and Bulk ZnO Suspensions to Zebrafish and the Effects of Sedimentation, OH Production and Particle Dissolution in Distilled Water. <i>J. Environ. Monit.</i> 13(7): 1975-1982, 2011. Ecoref #158590	No hardness data
Zhu,X., L. Zhu, Y. Chen, and S. Tian. Acute Toxicities of Six Manufactured Nanomaterial Suspensions to <i>Daphnia magna</i> . <i>J. Nanopart. Res.</i> 11:67-75, 2009. Ecoref #153603	Nanoparticle study
Zou,E., and S. Bu. Acute Toxicity of Copper, Cadmium, and Zinc to the Water Flea, <i>Moina irrasa</i> (Cladocera). <i>Bull. Environ. Contam. Toxicol.</i> 52(5): 742-748, 1994. Ecoref #13762	Less than value for hardness; hardness too low



## Open Literature

Table A26. List of open literature citations from EPA ECOTOX database reviewed for zinc criteria derivation but did not meet acceptability requirements.

Citation	Notes
Moyson, S., Vissenberg, K., Fransen, E., Blust, R. and Husson, S.J., 2018. Mixture effects of copper, cadmium, and zinc on mortality and behavior of <i>Caenorhabditis elegans</i> . <i>Environmental toxicology and chemistry</i> , 37(1), pp.145-159.	No hardness data
Loro, V.L., Nogueira, L., Nadella, S.R. and Wood, C.M., 2014. Zinc bioaccumulation and ionoregulatory impacts in <i>Fundulus heteroclitus</i> exposed to sublethal waterborne zinc at different salinities. <i>Comparative Biochemistry and Physiology Part C: Toxicology &amp; Pharmacology</i> , 166, pp.96-104.	Saltwater study
Hose, G.C., Symington, K., Lott, M.J. and Lategan, M.J., 2016. The toxicity of arsenic (III), chromium (VI) and zinc to groundwater copepods. <i>Environmental Science and Pollution Research</i> , 23, pp.18704-18713.	Groundwater test organisms; non-north American test species; field collected organisms with no exposure information
Gawad, S.S.A., 2018. Acute toxicity of some heavy metals to the fresh water snail, <i>Theodoxus niloticus</i> (Reeve, 1856). <i>The Egyptian Journal of Aquatic Research</i> , 44(2), pp.83-87.	Non-north American test species

## Freshwater Chronic

Table A27. List of citations from EPA ECOTOX database reviewed for zinc freshwater chronic criteria derivation. If the citation was reviewed but not used for criteria derivation, we provided an explanation in the notes column.

Citation	Notes
Alsop, D.H., S.B. Brown, and G.J. Van der Kraak. Dietary Retinoic Acid Induces Hindlimb and Eye Deformities in <i>Xenopus laevis</i> . <i>Environ. Sci. Technol.</i> 38(23): 6290-6299, 2004. Ecoref #110332	Feeding/diet study; not water exposure
Araujo, G.S., C. Pinheiro, J.L.T. Pestana, A. Soares, D.M.S. Abessa, and S. Loureiro. Toxicity of Lead and Mancozeb Differs in Two Monophyletic <i>Daphnia</i> Species. <i>Ecotoxicol. Environ. Saf.</i> 178:230-238, 2019. Ecoref #182062	No zinc exposure
Asparch, Y., G. Svartz, and C.S. Perez Coll. Toxicity Characterization and Environmental Risk Assessment of Mancozeb on the South American Common Toad <i>Rhinella arenarum</i> . <i>Environ. Sci. Pollut. Res. Int.</i> 27(3): 3034-3042, 2020. Ecoref #182173	Non-north american test species used

Citation	Notes
Atli,G., and M. Canli. Responses of Metallothionein and Reduced Glutathione in a Freshwater Fish <i>Oreochromis niloticus</i> Following Metal Exposures. <i>Environ. Toxicol. Pharmacol.</i> 25(1): 33-38, 2008. Ecoref #117067	Non-north american test species used
Balch,G.C., R.D. Evans, P. Welbourn, and R. Prairie. Weight Loss and Net Abnormalities of <i>Hydropsyche betteni</i> (Caddisfly) Larvae Exposed to Aqueous Zinc. <i>Environ. Toxicol. Chem.</i> 19(12): 3036-3043, 2000. Ecoref #59272	No hardness data
Barry,M.J.. Effects of Copper, Zinc and Dragonfly Kairomone on Growth Rate and Induced Morphology of <i>Bufo arabicus</i> Tadpoles. <i>Ecotoxicol. Environ. Saf.</i> 74(4): 918-923, 2011. Ecoref #161496	Non-north american test species used
Bianchini,A., and C.M. Wood. Does Sulfide or Water Hardness Protect Against Chronic Silver Toxicity in <i>Daphnia magna</i> ? A Critical Assessment of the Acute-to-Chronic Toxicity Ratio for Silver. <i>Ecotoxicol. Environ. Saf.</i> 71:32-40, 2008. Ecoref #104819	Doesn't include zinc exposure
Bieniarz,K., P. Epler, and M. Sokolowska-Mikolajczyk. Goldfish ( <i>Carassius auratus gibelio</i> Bloch) Breeding in Different Concentrations of Zinc. <i>Pol. Arch. Hydrobiol.</i> 43(3): 365-371, 1996. Ecoref #84088	Wrong language
Borgmann,U., and W.P. Norwood. Toxicity and Accumulation of Zinc and Copper in <i>Hyalella azteca</i> Exposed to Metal-Spiked Sediments. <i>Can. J. Fish. Aquat. Sci.</i> 54:1046-1054, 1997. Ecoref #67044	Sediment study
Brinkman,S., and J. Woodling. Zinc Toxicity to the Mottled Sculpin ( <i>Cottus bairdi</i> ) in High-Hardness Water. <i>Environ. Toxicol. Chem.</i> 24(6): 1515-1517, 2005. Ecoref #84053	
Brinkman,S., and N. Vieira. Water Pollution Studies. Federal Aid Project F-243-R15, Job Progress Report, Colorado Div.of Wildlife, Fort Collins, Co:38 p., 2008. Ecoref #117718	
Brinkman,S.F., and J.D. Woodling. Acclimation and Deacclimation of Brown Trout ( <i>Salmo trutta</i> ) to Zinc and Copper Singly and in Combination with Cadmium or Copper. <i>Arch. Environ. Contam. Toxicol.</i> 67(2): 214-223, 2014. Ecoref #169219	Only 2 test concentrations
Brodeur,J.C., C.M. Asorey, A. Sztrum, and J. Herkovits. Acute and Subchronic Toxicity of Arsenite and Zinc to Tadpoles of <i>Rhinella arenarum</i> both Alone and in Combination. <i>J. Toxicol. Environ. Health Part A</i> 72(14): 884-890, 2009. Ecoref #117667	Non-north american test species used
Brown,J.M.. Net Effects of <i>Batrachochytrium dendrobatidis</i> (Bd) and Fungicides on Anurans Across Life Stages. M.S.Thesis, University of South Florida, Tampa, FL:48 p., 2013. Ecoref #175870	Fungicide study

Citation	Notes
Brown,R.J., S.D. Rundle, T.H. Hutchinson, T.D. Williams, and M.B. Jones. A Microplate Freshwater Copepod Bioassay for Evaluating Acute and Chronic Effects of Chemicals. Environ. Toxicol. Chem.24(6): 1528-1531, 2005. Ecoref #84071	
Ciereszko,A., I. Babiak, and K. Dabrowski. Efficacy of Animal Anti-Fertility Compounds Against Sea Lamprey (Petromyzon marinus) Spermatozoa. Theriogenology61(6): 1039-1050, 2004. Ecoref #79860	Study endpoints not relevant
Cooper,N.L., J.R. Bidwell, and A. Kumar. Toxicity of Copper, Lead, and Zinc Mixtures to Ceriodaphnia dubia and Daphnia carinata. Ecotoxicol. Environ. Saf.72:1523-1528, 2009. Ecoref #115778	
Davies,P.H., S. Brinkman, and D. Hansen. Water Pollution Studies. Federal Aid Project F-243R-6, Colorado Division of Wildlife, Fort Collins, CO:47 p., 2000. Ecoref #161558	
Davies,P.H., and S. Brinkman. Water Pollution Studies. Fed.Aid Proj.#F-33, Colorado Div.of Wildl., Fish Res.Sect., Fort Collins, CO:138 p., 1994. Ecoref #90601	
De Schamphelaere,K.A.C., S. Lofts, and C.R. Janssen. Bioavailability Models for Predicting Acute and Chronic Toxicity of Zinc to Algae, Daphnids, and Fish in Natural Surface Waters. Environ. Toxicol. Chem.24(5): 1190-1197, 2005. Ecoref #84052	
De Schamphelaere,K.A.C., and C.R. Janssen. Bioavailability and Chronic Toxicity of Zinc to Juvenile Rainbow Trout (Oncorhynchus mykiss): Comparison with Other Fish Species and Development of a Biotic Ligand Model. Environ. Sci. Technol.38(23): 6201-6209, 2004. Ecoref #84051	
Dorgelo,J., H. Meester, and C. Van Velzen. Effects of Diet and Heavy Metals on Growth Rate and Fertility in the Deposit-Feeding Snail Potamopyrgus jenkinsi (Smith) (Gastropoda: Hydrobiidae). Hydrobiologia316(3): 199-210, 1995. Ecoref #16506	Non-north American test species used
Du,J., J. Tang, S. Xu, J. Ge, Y. Dong, H. Li, and M. Jin. Parental Transfer of Perfluorooctane Sulfonate and ZnO Nanoparticles Chronic Co-Exposure and Inhibition of Growth in F1 Offspring. Regul. Toxicol. Pharmacol.98:41-49, 2018. Ecoref #179529	Nanoparticle study
Du,J., S. Wang, H. You, and Z. Liu. Effects of ZnO Nanoparticles on Perfluorooctane Sulfonate Induced Thyroid-Disrupting on Zebrafish Larvae. J. Environ. Sci.47:153-164, 2016. Ecoref #177092	Nanoparticle study
Fort,D.J., E.L. Stover, and J.A. Bantle. Integrated Ecological Hazard Assessment of Waste Site Soil Extracts Using FETAX and Short-Term Fathead Minnow Teratogenesis Assay. ASTM Spec. Tech. Publ.4:93-109, 1996. Ecoref #45211	Soil study

Citation	Notes
Guo,F., R. Tu, and W.X. Wang. Different Responses of Abalone <i>Haliotis discus hannai</i> to Waterborne and Dietary-Borne Copper and Zinc Exposure. <i>Ecotoxicol. Environ. Saf.</i> 91:10-17, 2013. ECODEF #166247	Study endpoints not relevant for criteria development
Heijerick,D.G., C.R. Janssen, and W.M. De Coen. The Combined Effects of Hardness, pH, and Dissolved Organic Carbon on the Chronic Toxicity of Zn to <i>D. magna</i> : Development of a Surface Response Model. <i>Arch. Environ. Contam. Toxicol.</i> 44(2): 210-217, 2003. ECODEF #71981	Modeling study; high DOC in testing
Heijerick,D.G., K.A.C. De Schamphelaere, P.A. Van Sprang, and C.R. Janssen. Development of a Chronic Zinc Biotic Ligand Model for <i>Daphnia magna</i> . <i>Ecotoxicol. Environ. Saf.</i> 62:1-10, 2005. ECODEF #188078	
Ingersoll,C.G., R.D. Calfee, E. Beahan, W.G. Brumbaugh, R.A. Dorman, D.K. Hardesty, J.L. Kunz, E.E. Little, C.A. Mebane. Acute and Chronic Sensitivity of White Sturgeon ( <i>Acipenser transmontanus</i> ) and Rainbow Trout ( <i>Oncorhynchus mykiss</i> ) to Cadmium, Copper, Lead, or Zinc in Laboratory Water-Only Exposures. <i>Sci. Investig. Rep.</i> :120 p., 2014. ECODEF #169495	Found in Wang et al. 2014
Lazorchak,J.M., M.E. Smith, and H.J. Haring. Development and Validation of a <i>Daphnia magna</i> Four-Day Survival and Growth Test Method. <i>Environ. Toxicol. Chem.</i> 28(5): 1028-1034, 2009. ECODEF #118322	
Lazorchak,J.M., and M.E. Smith. Rainbow Trout ( <i>Oncorhynchus mykiss</i> ) and Brook Trout ( <i>Salvelinus fontinalis</i> ) 7-Day Survival and Growth Test Method. <i>Arch. Environ. Contam. Toxicol.</i> 53(3): 397-405, 2007. ECODEF #100026	No hardness data
Magliette,R.J., F.G. Doherty, D. McKinney, and E.S. Venkataramani. Need for Environmental Quality Guidelines Based on Ambient Freshwater Quality Criteria in Natural Waters--Case Study "Zinc". <i>Bull. Environ. Contam. Toxicol.</i> 54(4): 626-632, 1995. ECODEF #14962	Case study; not relevant
Martin-Diaz,M.L., S.R. Tuberty, C.L.,Jr. McKenney, D. Sales, and T.A. Del Valls. Effects of Cadmium and Zinc on <i>Procambarus clarkii</i> : Simulation of the Aznalcollar Mining Spill. <i>Cienc. Mar.</i> 31(1B): 197-202, 2005. ECODEF #84097	Lacks study details; no hardness data
Mebane,C.A., D.P. Hennessy, and F.S. Dillon. Developing Acute-to-Chronic Toxicity Ratios for Lead, Cadmium, and Zinc Using Rainbow Trout, a Mayfly, and a Midge. <i>Water Air Soil Pollut.</i> :21 p., 2007. ECODEF #97672	
Mebane,C.A., D.P. Hennessy, and F.S. Dillon. Developing Acute-to-Chronic Toxicity Ratios for Lead, Cadmium, and Zinc Using Rainbow Trout, a Mayfly, and a Midge. <i>Water Air Soil Pollut.</i> 188(1-4): 41-66, 2008. ECODEF #111766	Repeat
Muysen,B.T.A., K.A.C. De Schamphelaere, and C.R. Janssen. Mechanisms of Chronic Waterborne Zn Toxicity in <i>Daphnia magna</i> . <i>Aquat. Toxicol.</i> 77(4): 393-401, 2006. ECODEF #97407	NOEC/LC50 not provided for ACR development

Citation	Notes
Muysen,B.T.A., and C.R. Janssen. Age and Exposure Duration as a Factor Influencing Cu and Zn Toxicity Toward Daphnia magna. Ecotoxicol. Environ. Saf.68(3): 436-442, 2007. Ecoref #101832	No hardness data
Nguyen,L.T.H., and C.R. Janssen. Comparative Sensitivity of Embryo-Larval Toxicity Assays with African Catfish (Clarias gariepinus) and Zebra Fish (Danio rerio). Environ. Toxicol.16(6): 566-571, 2001. Ecoref #68928	Non-north american test species used
Oner,M., G. Atli, and M. Canli. Effects of Metal (Ag, Cd, Cr, Cu, Zn) Exposures on Some Enzymatic and Non-Enzymatic Indicators in the Liver of Oreochromis niloticus. Bull. Environ. Contam. Toxicol.82(3): 317-321, 2009. Ecoref #112714	Non-north american test species used
Rohr,J.R., J. Brown, W.A. Battaglin, T.A. McMahon, and R.A. Relyea. A Pesticide Paradox: Fungicides Indirectly Increase Fungal Infections. Ecol. Appl.27(8): 2290-2302, 2017. Ecoref #175858	Fungicide study
Saxena,S., and H. Chaturvedi. Effect of Zinc on the Development of Toad, Bufo fergusonii. J. Ecotoxicol. Environ. Monit.10(4): 259-263, 2000. Ecoref #84089	Non-north american test species used
Shenoy,K., B.T. Cunningham, J.W. Renfroe, and P.H. Crowley. Growth and Survival of Northern Leopard Frog (Rana pipiens) Tadpoles Exposed to Two Common Pesticides. Environ. Toxicol. Chem.28(7): 1469-1474, 2009. Ecoref #118251	Pesticide based study
Vardy,D.W., A.R. Tompsett, J.L. Sigurdson, J.A. Doering, X. Zhang, J.P. Giesy, and M. Hecker. Effects of Subchronic Exposure of Early Life Stages of White Sturgeon (Acipenser transmontanus) to Copper, Cadmium, and Zinc. Environ. Toxicol. Chem.30(11): 2497-2505, 2011. Ecoref #156324	Endpoints not relevant for criteria derivation
Wang,N., C.G. Ingersoll, R.A. Dorman, W.G. Brumbaugh, C.A. Mebane, J.L. Kunz, and D.K. Hardesty. Chronic Sensitivity of White Sturgeon (Acipenser transmontanus) and Rainbow Trout (Oncorhynchus mykiss) to Cadmium, Copper, Lead, or Zinc in Laboratory Water-Only Exposures. Environ. Toxicol. Chem.33(10): 2246-2258, 2014. Ecoref #188097	
Waykar,B., and S.M. Shinde. Assessment of the Metal Bioaccumulation in Three Species of Freshwater Bivalves. Bull. Environ. Contam. Toxicol.87(3): 267-271, 2011. Ecoref #166615	Bioaccumulation study; no toxicity data

## Open Literature

Table A28. List of open literature citations from EPA ECOTOX database reviewed for zinc criteria derivation but did not meet acceptability requirements.

Citation	Notes
Okamoto, A., Masunaga, S. and Tatarazako, N., 2021. Chronic toxicity of 50 metals to <i>Ceriodaphnia dubia</i> . <i>Journal of Applied Toxicology</i> , 41(3), pp.375-386.	Study did not use flow through design; very little method details
Calfee, R.D. and Little, E.E., 2017. Toxicity of cadmium, copper, and zinc to the threatened Chiricahua leopard frog ( <i>Lithobates [Rana] chiricahuensis</i> ). <i>Bulletin of environmental contamination and toxicology</i> , 99, pp.679-683.	Questionable data due to unusual dose-response results

# Appendix B. Multiple Linear Regression Dataset and Decisions

## Database Qualifiers and Management Decisions

- Locations: irrigation ditches, proximity to salt water bodies, proximity to mining/rock quarry, outside state border
- Studies removed: targeting any kind of discharge event – storm, WWTP, construction, pesticide, fertilizer, CSO. Remediation/taxonomic studies at sites with known pollution and significant human disturbance
- Reviewed “field collection” & “Result” comments for key words like storm sample, discharge event, pesticide application, fertilizer application, QC failed, rain
- Units and outlier parameters – DOC with unit as %, pH above 14, pH with ppm units, TOC parameters labeled as dissolved and vice versa
- Result Data Qualifiers – Qualifiers U, UJ, REJ, E, EQP were removed \*While data with EST, J, FS, K, B, JK, JL, NJ, and T were included, the majority of final concurrent data used in the MLR and conversion factors had no qualifier. The J qualifier was the most frequent to remain.

U = analyte was detected at or above the reported results.

UJ = analyte was not detected at or above the reported estimate.

REJ = data was unusable for all purposes.

E = reported result is an estimate because it exceeds the calibration range.

EQP = inconsistent equipment performance.

EST = measurement value reported is estimated.

J = analyte was positively identified.

FS = stagnant water – no flow.

K = reported results with unknown bias.

B = analyte detected in sample and method blank.

JK = analyte was positively identified. Reported result is an estimate with unknown bias.

JL = analyte was positively identified. Value may be less than the reported estimate.

NJ = there is evidence that the analyte is present in the sample. Reported result is an estimate.

T = reported result below associated quantitation limit but above MDL.

- EIM QA level 1 was removed (data neither verified nor assessed for usability)
- Federal WQ Portal Result Status Identifier – Rejected
- Data only included fresh/surface waters – all groundwater, marine, springs, estuary, tidal waters, wetlands and canals/ditches were removed
- Data prior to 1/1/2000 was excluded

- Data from the federal WQ Portal that was found to be a duplicate from EIM was removed. The EIM version was retained in use of the MLR dataset
- Locations outside the boundaries of the state were removed. Locations on the Columbia River in the shared waters of Oregon and Washington remained in the dataset
- Duplicates were removed if the percent difference from one another was less than 10%
- Samples were averaged on a daily basis

## Database Data Counts

Results from Ecology’s Environmental Information Management (EIM) and the Federal Water Quality Portal (WQ Portal):

Data was downloaded on:

- EIM MLR (Including TOC) – March 2023
- Federal WQ Portal MLR (Including TOC) – March 2023
- EIM TOC-DOC Conversion – May 2023 (The practice download was in late Jan/early Feb)
- EIM SpCon-T.Hardness Conversion – August 2023
- Federal WQ Portal SpCon-T.Hardness MLR – August 2023

Count of total download:

- pH
  - EIM – 336,597
  - WQ Portal – 50,876
- DOC
  - EIM – 14,892
  - WQ Portal – 3,231
- Total Hardness
  - EIM – 8,904
  - WQ Portal – 2,314
- TOC (for MLR)
  - EIM – 17,985
  - WQ Portal – 5,361
- Specific Conductivity for MLR [WQ Portal] – 64,109
- DOC for *Conversion Factor* [EIM] – 15,802
- TOC for *Conversion Factor* [EIM] – 18,475
- Total Hardness for *Conversion Factor* [EIM] – 9,445
- Specific Conductivity for *Conversion Factor* [EIM] – 109,392



Total MLR Dataset – 3,337

- Unique locations - 646

Count of concurrent samples for tradition MLR

- EIM – 1,234
- WQ Portal - 1,088

Count of concurrent samples for TOC based MLR

- EIM - 71
- WQ Portal - 34

Count of concurrent samples for Conductivity based MLR - 910

Count of concurrent samples for TOC conversion factor – 6,317

Count of concurrent samples for Specific Conductivity conversion factor - 3,459

**The final MLR dataset produced 3,337 concurrent sampling events across 646 unique locations.**

## Appendix C. 6PPD-quinone WEB-ICE Results

Table C1. 6PPD-quinone WEB-ICE Results

Surrogate	Common Name	Species Name	Predicted LC50 (ug/L)	R <sup>2</sup>	Notes
Rainbow trout	Western toad		0.556	0.883	surrogate outside of model range
Rainbow trout	Midge	Chironomus tentans	0.297	0.819	surrogate outside of model range
Rainbow trout	Bullfrog	Lithobates catesbeianus	7.13	0.977	
Rainbow trout	Stonefly	Pteronarcys californica	1.33	0.64	
Rainbow trout	Daphnid	Daphnia magna	2.03	0.83	
Rainbow trout	Daphnid	Daphnia pulex	2.23	0.21	
Rainbow trout	Polychaete	Hydroides elegans	212.71	0.21	surrogate outside of model range
Rainbow trout	Southern leopard frog	Lithobates sphenoccephala	2.45	0.95	surrogate outside of model range
Rainbow trout	Stonefly	Claassenia sabulosa	0.41	0.55	
Rainbow trout	Stonefly	Pteronarcella badia	0.715	0.49	
Rainbow trout	Snipefly	Atherix variegata	6.91	0.91	
Rainbow trout	Eastern oyster	Crassostrea virginica	11.1	0.5	
Rainbow trout	Amphipod	Gammarus fasciatus	1.22	0.41	
Rainbow trout	Amphipod	Gammarus lacustris	0.951	0.26	
Rainbow trout	Amphipod	Gammarus pseudolimnaeus	0.258	0.67	
Rainbow trout	Amphipod	Hyalella azteca	0.252	0.57	
Rainbow trout	Beaver tail fairy shrimp	Thamnocephalus platyurus	1.16	0.61	surrogate outside of model range
Rainbow trout	Daphnid	Ceriodaphnia dubia	0.0376	0.64	
Rainbow trout	Daphnid	Simocephalus vetulus	2.08	0.99	surrogate outside of model range
Rainbow trout	Isopod	Caecidotea brevicauda	3.17	0.65	
Rainbow trout	Midge	Chironomus plumosus	2.47	0.5	
Rainbow trout	Midge	Paratanytarsus dissimilis	35.22	0.84	
Rainbow trout	Midge	Paratanytarsus parthenogeneticus	35.12	0.78	surrogate outside of model range
Rainbow trout	Mysid	Americamysis bahia	0.396	0.6	
Rainbow trout	Paper pondshell	Utterbackia imbecillis	12.29	0.6	surrogate outside of model range

Surrogate	Common Name	Species Name	Predicted LC50 (ug/L)	R <sup>2</sup>	Notes
Rainbow trout	Pink shirmp	Farfantepenaeus duorarum	0.0591	0.72	
Rainbow trout	Tadpole physa	Physa gyrina	0.671	0.75	surrogate outside of model range
Rainbow trout	Swamp lymnae	Lymnaea stagnalis	0.756	0.73	surrogate outside of model range
Rainbow trout	Versatile fairy shrimp	Branchinecta lindahli	3.94	0.99	surrogate outside of model range
Brook trout	Amphipod	Salvelinus fontinalis	1.03	0.58	
Brook trout	Eastern oyster	Crassostrea virginica	24.12	0.92	
Brook trout	Stonefly	Claassenia sabuolsa	0.21	0.67	
Brook trout	Stonefly	Pteronarcella badia	0.869	0.76	
Brook trout	Stonefly	Pteronarcys californica	1.91	0.41	
Brook trout	Amphipod	Gammarus lacustris	1.03	0.58	
Brook trout	Fowler's toad	Anaxyrus fowleri	106.35	0.94	
Coho salmon	Amphipod	Crangonyx pseudogracilis	4.49	0.8	surrogate outside of model range
Coho salmon	Amphipod	Gammarus fasciatus	0.203	0.41	surrogate outside of model range
Coho salmon	Amphipod	Thamnocephalus platyurus	0.012	0.83	surrogate outside of model range
Coho salmon	Amphipod	Lithobates catesbeianus	0.639	0.63	surrogate outside of model range
Coho salmon	Beaver tail fairy shrimp	Thamnocephalus platyurus	0.012	0.83	surrogate outside of model range
Coho salmon	Bullfrog	Lithobates catesbeianus	0.639	0.99	surrogate outside of model range
Coho salmon	Daphnid	Daphnia magna	0.324	0.35	surrogate outside of model range
Coho salmon	Isopod	Caecidotea brevicauda	0.274	0.63	surrogate outside of model range
Coho salmon	Rainbow mussel	Villosa iris	0.00204	0.99	surrogate outside of model range
Coho salmon	Snipefly	Atherix variegata	0.73	0.94	
Coho salmon	Southern leopard frog	Lithobates sphenoccephala	0.00201	0.99	surrogate outside of model range
Coho salmon	Stonefly	Pteronarcella badia	0.433	0.86	surrogate outside of model range
zebrafish	Flagfish	Jordanella floridae	61.09	0.99	
zebrafish	Medaka	Oryzias latipes	595.94	0.78	

## Appendix D. PARIS Query

### Identifying Future Changes to Permits (PARIS Query)

As part of this rulemaking, we conducted a permitting and reporting information system (PARIS) query to evaluate how permits may be impacted as a result of this rulemaking. We used discharge monitoring report (DMR) data and priority pollutant scan information to determine the potential for permitted effluent discharges to cause an exceedance of revised toxics criteria. This analysis is not definitive, and methods used do not account for all facets of developing effluent limits. However, this analysis provides an approximation of which permits may need closer review since they do have these chemicals in their effluent. The costs to permitting is evaluated in the [Preliminary Regulatory Analysis](#)<sup>9</sup>.

#### Methods

Ecology evaluates the need for water quality-based effluent limits in each individual permit based on effluent variability, sampling frequencies, dilution factors (if applicable), and the water quality criteria. Permittees report data on toxics in the effluent on their routine DMRs and priority pollutant scans, which is stored in PARIS. We selected the following parameters in PARIS for inclusion into the query spreadsheet: water quality name, permit number, permit type, permit status, feature name, city, county, monitoring point code, parameter, unit, fraction, statistical base, is report only, benchmark min, benchmark max, limit min, limit max, param impairment, parameter notes, feature latitude, and feature longitude. We searched for permits for toxic chemicals that are proposed to have lower criteria or are new to the water quality standards.

We searched PARIS for effluent data for the following toxic chemicals:

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<sup>9</sup> <https://apps.ecology.wa.gov/publications/summarypages/2410009.html>

- aluminum
- arsenic
- cadmium
- chromium III
- chromium VI
- copper
- nickel
- mercury
- selenium
- silver
- zinc
- 6PPD-quinone
- acrolein
- carbaryl
- cyanide
- demeton
- diazinon
- endrin
- gamma-BHC (lindane)
- guthion
- malathion
- methoxychlor
- mirex
- nonylphenol
- pentachlorophenol
- PFOS
- PFOA
- tributyltin

For hardness-based metals, we used a default hardness of 70.2 mg/L to calculate the criteria, which represents the statewide mean value based on data in the EIM database collected by Ecology's Environmental Assessment Program since 2000. We set the matrix for water, filtered out data for only river/streams, used Quality Assurance (QA) level 2 or higher, and removed samples during storm events.

For pH-based pentachlorophenol, we used a default pH of 7.8, which represents the statewide mean value based on data in EIM. The pH data used to calculate a statewide mean value used all pH data in the EIM database under the study type of RoutineMonitor, HabitatMonitoring, or GenEnvironmentalStudy Field Collection, collected on or after October 1, 2013, with a sample matrix of water and a sample source of fresh/surface water. We filtered the pH data to include QA level 2 or higher and data for rivers/streams.

For aluminum and copper, we used statewide values for pH, hardness, and DOC to calculate criteria using the multiple linear regression (MLR) as the representative criteria for comparison to effluent data. The statewide mean for concurrently sampled data was a pH of 7.58, hardness of 59.69 mg/L, and 2.71 mg/L DOC. The copper criteria are 9.3 ug/L for freshwater acute and 7.3 mg/L for freshwater chronic using statewide mean values for pH, hardness, and DOC. The aluminum criteria are 2100 ug/L for freshwater acute and 780 ug/L for freshwater chronic using statewide mean values for pH, hardness, and DOC. We reviewed the last 10 years for individual permits because permit renewal can be delayed and priority pollutant scan information from the last renewal is relevant to this analysis. We reviewed only the last two years for general permits because of corrective actions that are employed when a discharger is not meeting effluent limits. The most recent monitoring data are relevant because if there was an exceedance demonstrated during monitoring, actions should currently be underway to make a correction. Effluent exceedances prior to 2021 should have already been corrected; thus, only the most recent effluent data are relevant to evaluating permittees compliance with current and proposed aquatic life criteria for general permits.

For analysis of individual permits, we applied the acute and chronic dilution factors from each individual permit fact sheet to the proposed acute and chronic aquatic life criteria. The application of dilution factors to the newly proposed aquatic life criteria was representative of the potential effluent limit for each pollutant. We then compared the maximum reported effluent concentration from each permit's dataset to the respective calculated limit (aquatic life criterion divided by the dilution factor). Some permits do not have a dilution factor, for example if they discharge to a 303(d) listed water body. If the calculated limit was less than the maximum concentration reported in the monitoring data, then that discharge was deemed to have a reasonable potential to cause an exceedance of the proposed criterion, which could result in a new or revised effluent limits. This method for estimating permit limits is a conservative approach because it does not account for effluent variability, sampling frequencies, flow, and statistical based approaches typically used to calculate effluent limits that would likely drive effluent limits lower than the approach used in this analysis. We tallied all the individual NPDES permits for industrial and municipal entities that could potentially need changes to the effluent limits based on their effluent exceeding calculated limits using the methods described above. Individual permits were removed from consideration in this analysis when they did not have a reported pollutant concentration above the calculated limit.

For determining whether general permits could be affected by this rule, we compared maximum concentrations reported in DMRs or priority pollutant scans in PARIS to the applicable acute aquatic life toxics criteria. The acute toxics criteria are the more pertinent criteria to the general permits based on the short-term duration of general permit discharges such as stormwater runoff and time-limited discharges. If the maximum toxic concentration in effluent for a given permit exceeded the proposed aquatic life toxics acute criteria, the permit was listed as potentially of concern under the new criteria. Comparing the acute toxics criteria to the effluent data represents a conservative estimate of the number of permits potentially affected in this rulemaking. For example, the industrial stormwater general permit uses benchmark values rather than direct comparisons to the acute toxics criteria. The benchmark values are usually equal to or higher than the acute toxics criteria. Furthermore, the industrial stormwater permit allows for corrective actions in their stormwater pollution prevention plan (SWPPP) to meet benchmarks. An exceedance of the benchmark does mean there is a violation of permit requirements. For other general permits without numeric limits, a qualitative analysis was completed based on the permit description to determine where this rulemaking could potentially impact the permit.

## Results

The PARIS query found reported information for the following permits listed below based on the filtering methods described in the methodology section. Other permit types are not included here because they do not discharge into surface waters of the state, the permit may not require monitoring of toxics in the effluent, or their effluent data was below the revised criteria or calculated limits. The impacts of new toxics to the water quality standards are not captured here because they are not currently incorporated into existing permits. A reasonable potential analysis will need to be conducted on new toxics to determine if a given permit requires a permit condition or limit.

### Individual Permits

We identified 28 industrial and 18 municipal individual NPDES permits, for a total of 46 individual permits, that may require new or revised effluent limits based on the proposed criteria. The maximum reported discharge levels in DMR data from 46 different individual permits are anticipated to exceed potential limits based on the proposed criteria in this rulemaking. The parameters that have potential to affect permitted effluent limits are listed in Table D1.

Table D1. The number of individual permits that have potential to require new or revised limits based on the proposed criteria.

Toxic chemical	Industrial NPDES	Municipal NPDES
Acrolein	2	1
Aluminum	2	-
Arsenic	2	3
Cadmium	3	3

<b>Chromium VI</b>	4	2
<b>Copper</b>	15	7
<b>Cyanide</b>	2	4
<b>Mercury</b>	-	3
<b>Nickel</b>	6	3
<b>Pentachlorophenol</b>	4	-
<b>Selenium</b>	3	1
<b>Silver</b>	3	6
<b>Zinc</b>	18	8

### State Waste Discharge Permit: Individual Pretreatment Permit

There are 46 individual pretreatment permits that could be impacted by this rulemaking (based on direct comparison of the effluent pollutant levels to the calculated limits described above using dilution factors). However, pretreatment dischargers, industrial facilities discharging to publicly owned treatment works (POTWs), do not receive effluent limits calculated directly from water quality criteria. Instead, to protect operations and to ensure compliance with state and federal requirements, POTWs will design local limits based on site-specific criteria such as applicable water quality criteria.

Ecology delegates authority to municipalities for discharge permits for industries discharging to their POTW and also issues permits for industries discharging to non-delegated municipalities. This rulemaking may require delegated municipalities, POTWs, and Ecology to reevaluate local limits and/or modify discharge permits for industries if necessary for the POTW to comply with new limits in their NPDES permit and changing water quality criteria. We cannot definitively determine whether pretreatment permits will be impacted. Of the 50 individual pretreatment permits, potential impacts for specific parameters in permits include aluminum (6), arsenic (3), cadmium (23), copper (40), cyanide (18), lead (30), mercury (5), nickel (31), pentachlorophenol (1), selenium (11), silver (19), and zinc (39).

### Industrial Stormwater General Permit

We identified 540 industrial stormwater general permits that could be impacted by this rulemaking. The maximum reported discharge in DMRs from 634 different permits are anticipated to exceed limits based on the proposed criteria in this rulemaking. Potential exceedances by parameter in the 540 permits were as follows: arsenic (1), copper (371), mercury (2), and zinc (499). Industrial stormwater general permits are based on benchmarks, and an exceedance does not necessarily equate to violation of permit conditions. Industrial stormwater general permits have a SWPPP that allows for corrective actions to take place to maintain compliance.



## **Boatyard General Permit**

We identified eight boatyard permits that could be impacted by this rulemaking. The maximum reported discharge in DMRs from eight different boatyard permits are anticipated to exceed limits based on the proposed criteria in this rulemaking. Of the eight boatyard permits, copper was exceeded in all eight permits and zinc in five of the permits.

## **Construction Stormwater General Permit**

We identified five construction stormwater general permits that could be impacted by this rulemaking. The maximum reported discharge in DMRs from six different construction stormwater general permits are anticipated to exceed limits based on the proposed criteria in this rulemaking. Of the six construction stormwater general permits, the following toxics were of concern: cadmium (1), copper (3), mercury (1), and zinc (2).

## **Municipal Stormwater General Permit**

The municipal stormwater general permit does not require numeric effluent limits that permittees need to meet (except in some cases to meet TMDL-related requirements; e.g., total suspended solids). These permits are written to require stormwater management programs that establish narrative effluent limits, based on best management practices, to meet water quality standards. Thus, the proposed criteria in this rulemaking could result in an assessment of appropriate best management practices to ensure water quality standards will continue to be met.

## **Irrigation System Aquatic Weed Control General Permit**

The irrigation system aquatic weed control general permit contains limits for copper and acrolein, two toxics that are part of this rulemaking. The freshwater copper criteria are currently hardness-based, which requires hardness data. The copper criteria proposed are based on the MLR model and will now require hardness, pH, and dissolved organic carbon levels to calculate criteria. The proposed copper criteria will also include default copper criteria based on a 5<sup>th</sup> percentile of criteria calculated from concurrently monitored hardness, pH, and dissolved organic carbon collected throughout the state. If there is sufficient water quality data, a copper criterion will be calculated use site-specific data. If there is not water quality data available for a water body, Ecology may decide to use the 5<sup>th</sup> percentile default criteria in the irrigation general permit or require permittees to sample hardness, pH, and dissolved organic carbon in receiving waters or compliance points for this permit. Copper criteria may increase or decrease compared with current irrigation permit requirements based on the unique water quality of a site-specific location or water body.

Washington does not currently have acrolein criteria in the surface water quality standards. In this rulemaking, we are proposing to adopt EPA recommendations for acrolein. Future acrolein permits may include a lower limit given that current limits are based on outdated EPA criteria.

## **Aquatic Invasive Species Management General Permit**

The aquatic invasive species management (AISM) general permit includes the application of chelated copper to water bodies to control aquatic invasive species. This rulemaking is proposing a MLR-based copper criteria which may result in higher or lower copper criteria

based on the unique water quality characteristics of the water body. The AISM permit currently uses short-term modifications during the application of chelated copper that allows for a temporary zone of impact with recognition of the benefits of the application to the water body and full restoration following application. We anticipate that if the proposed copper aquatic life criteria are adopted, short-term modifications will continue to be used for chelated copper treatments in the AISM permit and that it will have minimal impact to this permit.

### **Aquatic Plant and Algae Management General Permit**

This rulemaking is proposing the addition of an aluminum criteria to Washington's surface water quality standards. The aquatic plant and algae management (APAM) general permit includes ALUM treatments to control aquatic plants. ALUM treatment consists of the application of high levels of aluminum to water bodies. We anticipate that ALUM treatments could result in short-term exceedances of the proposed aluminum aquatic life criteria. Currently, the APAM permit uses short-term modifications to apply ALUM treatments that allows for a temporary zone of impact with recognition of the benefits of the application to the water body and full restoration following application. We anticipate that if aluminum aquatic life criteria are adopted, short-term modifications will continue to be used for ALUM treatments in the APAM permit and that it will have minimal impact to this permit. Future monitoring of aluminum during ALUM applications may need to be considered for this permit.

## Appendix E. Water Quality Assessment Analysis

### Analysis of Water Concentrations Relative to Criteria

This analysis is not representative of the water quality assessment process but rather provides a rough estimate on how statewide water quality samples compare to the criteria. This analysis provides speculation around where the proposed criteria may result in a need to update 303(d) listings. We extracted all the data from January 2013 to January 2023 for toxics that are new or becoming more stringent in the proposed rulemaking from Ecology's EIM database. We evaluated the amount of data that exceeds the current criteria versus the proposed criteria to get an estimate of the percent increase in exceedances of the data available for statewide water quality assessments. When the criteria were less than the reporting limit for the analytical method, the U and UJ qualifiers (which signify non-detects) were removed from consideration because the reporting limit was greater than the criteria and would count toward an exceedance.

We also removed quality assurance and planning levels of one and two from this analysis to ensure the data we used in our analysis were of high quality. In our analysis, a single sampling event was considered the average daily concentration for a given location. We compared the average concentration to the current criteria and the proposed criteria to determine if the sample exceeded the respective criteria. For hardness-based metals criteria, we used a default hardness of 70.2 mg/L, which represents the statewide mean value based on data in EIM since 2000. We used mean statewide inputs for concurrently sampled pH (7.58), hardness (59.69 mg/L), and DOC (2.71 mg/L) to calculate the MLR based aluminum and copper criteria being proposed.

The results from this analysis in Table 5 demonstrated that revising some criteria may result in additional 303(d) listings. Of the highest concerns in this analysis are the following criteria (>3% percent increase in exceedance of all state data): 6PPD-quinone freshwater (FW) acute, cyanide FW acute, cyanide FW chronic, endrin FW acute, nickel FW chronic, pentachlorophenol FW acute, pentachlorophenol FW chronic, selenium FW chronic, and zinc FW chronic. This analysis does not mean there will be any new 303(d) listings because this analysis did not follow all steps of Policy 1-11, and exceedance data may be from one or multiple locations (e.g., if there are 10 exceedances, all samples may be from one stream, or they could be from 10 different streams).

Table E1. Evaluation of statewide data in comparison to the current and proposed criteria for new toxics or toxics becoming more stringent.

<b>Toxic Criteria</b>	<b>No. of Samples</b>	<b>Percent Exceedance Current Criteria</b>	<b>Percent Exceedance Proposed Criteria</b>	<b>Percent Increase in Exceedances</b>	<b>Notes</b>
<b>6PPD-quinone FW Acute</b>	4	N/A	75.0%	75.0%	
<b>Acrolein FW Acute</b>	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Acrolein FW Chronic</b>	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Aluminum FW Acute</b>	452	N/A	0.00%	N/A	Used statewide mean input values for concurrently sampled pH, hardness, and DOC for the aluminum MLR model.
<b>Aluminum FW Chronic</b>	452	N/A	1.55%	N/A	Used statewide mean input values for concurrently sampled pH, hardness, and DOC for the aluminum MLR model.
<b>Arsenic FW Acute</b>	799	0.13%	0.13%	0.00%	
<b>Arsenic FW Chronic</b>	799	1.00%	2.75%	1.75%	
<b>Arsenic SW Acute</b>	17	0.00%	0.00%	0.00%	
<b>Arsenic SW Chronic</b>	17	0.00%	0.00%	0.00%	

<b>Toxic Criteria</b>	<b>No. of Samples</b>	<b>Percent Exceedance Current Criteria</b>	<b>Percent Exceedance Proposed Criteria</b>	<b>Percent Increase in Exceedances</b>	<b>Notes</b>
<b>Cadmium FW Acute</b>	335	3.28%	4.48%	1.20%	
<b>Cadmium FW Chronic</b>	335	4.48%	7.16%	2.68%	
<b>Cadmium SW Acute</b>	14	0.00%	0.00%	0.00%	
<b>Cadmium SW Chronic</b>	14	0.00%	0.00%	0.00%	
<b>Carbaryl FW Acute</b>	532	N/A	20.68%	N/A	
<b>Carbaryl FW Chronic</b>	532	N/A	20.68%	N/A	
<b>Carbaryl SW Acute</b>	1	N/A	0.00%	N/A	
<b>Chromium III FW Chronic</b>	0	N/A	N/A	N/A	No chromium II samples.
<b>Chromium VI FW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Copper FW Acute</b>	868	0.57%	1.15%	0.58%	Used mean hardness of 70.2 mg/L for current copper hardness based criteria and statewide mean input values for concurrently sampled pH, hardness, and DOC for the copper MLR model.
<b>Copper FW Chronic</b>	868	1.38%	1.61%	0.23%	Used mean hardness of 70.2 mg/L for current copper hardness based criteria and statewide mean

Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Proposed Criteria	Percent Increase in Exceedances	Notes
					input values for concurrently sampled pH, hardness, and DOC for the copper MLR model.
<b>Cyanide FW Acute</b>	21	4.76%	9.52%	4.76%	
<b>Cyanide FW Chronic</b>	21	66.67%	100%	33.33%	
<b>Demeton FW Chronic</b>	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Demeton SW Chronic</b>	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Diazinon FW Acute</b>	551	N/A	0.73%		
<b>Diazinon FW Chronic</b>	551	N/A	0.73%		
<b>Diazinon SW Acute</b>	4	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Diazinon SW Chronic</b>	4	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Dieldrin FW Acute</b>	255	0.00%	0.39%	0.39%	
<b>Endrin FW Acute</b>	225	0.00%	8.44%	8.44%	

<b>Toxic Criteria</b>	<b>No. of Samples</b>	<b>Percent Exceedance Current Criteria</b>	<b>Percent Exceedance Proposed Criteria</b>	<b>Percent Increase in Exceedances</b>	<b>Notes</b>
<b>Gamma-BHC FW Acute</b>	225	0.00%	0.00%	0.00%	
<b>Guthion FW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Guthion SW Chronic</b>	0	N/A	N/A	N/A	No saltwater samples.
<b>Malathion FW Chronic</b>	535	N/A	1.12%	N/A	
<b>Malathion SW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Mercury FW Acute</b>	392	0.00%	0.00%	0.00%	
<b>Methoxychlor FW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Methoxychlor SW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Mirex FW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Mirex SW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit.

Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Proposed Criteria	Percent Increase in Exceedances	Notes
					Removed non-detects. No samples to evaluate.
<b>Nickel FW Acute</b>	410	0.00%	0.24%	0.24%	
<b>Nickel FW Chronic</b>	410	0.24%	3.41%	3.17%	
<b>Nonylphenol FW Acute</b>	3	N/A	0.00%	0.00%	
<b>Nonylphenol FW Chronic</b>	3	N/A	0.00%	0.00%	
<b>Nonylphenol SW Acute</b>	15	N/A	0.00%	0.00%	
<b>Nonylphenol SW Chronic</b>	15	N/A	0.00%	0.00%	
<b>Pentachlorophenol FW Acute</b>	596	0.00%	5.20%	5.20%	
<b>Pentachlorophenol FW Chronic</b>	596	0.00%	5.20%	5.20%	
<b>Pentachlorophenol SW Chronic</b>	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>PFOS FW Acute</b>	0	N/A	N/A	N/A	
<b>PFOS FW Chronic</b>	0	N/A	N/A	N/A	
<b>PFOS SW Acute</b>	0	N/A	N/A	N/A	
<b>PFOS SW Chronic</b>	0	N/A	N/A	N/A	
<b>PFOA FW Acute</b>	0	N/A	N/A	N/A	
<b>PFOA FW Chronic</b>	0	N/A	N/A	N/A	
<b>PFOA SW Acute</b>	0	N/A	N/A	N/A	
<b>PFOA SW Chronic</b>	0	N/A	N/A	N/A	
<b>Selenium FW Acute</b>	126	0.79%	N/A	N/A	Proposed criteria does not include acute criteria.
<b>Selenium FW Chronic</b>	126	0.79%	3.97%	3.18%	
<b>Silver FW Acute</b>	516	0.19%	1.37%	1.18%	Some Reporting Limits less than



Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Proposed Criteria	Percent Increase in Exceedances	Notes
					the criteria were removed.
<b>Silver FW Chronic</b>	409	N/A	3.91	N/A	Currently do not have chronic criteria. Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
<b>Silver SW Chronic</b>	8	0.00%	0.00%	0.00%	
<b>Tributyltin FW Acute</b>	0	N/A	N/A	N/A	
<b>Tributyltin FW Chronic</b>	0	N/A	N/A	N/A	
<b>Tributyltin SW Acute</b>	0	N/A	N/A	N/A	
<b>Tributyltin SW Chronic</b>	0	N/A	N/A	N/A	
<b>Zinc FW Acute</b>	6706	1.17%	2.94%	1.77%	
<b>Zinc FW Chronic</b>	6706	1.35%	4.88%	3.53%	