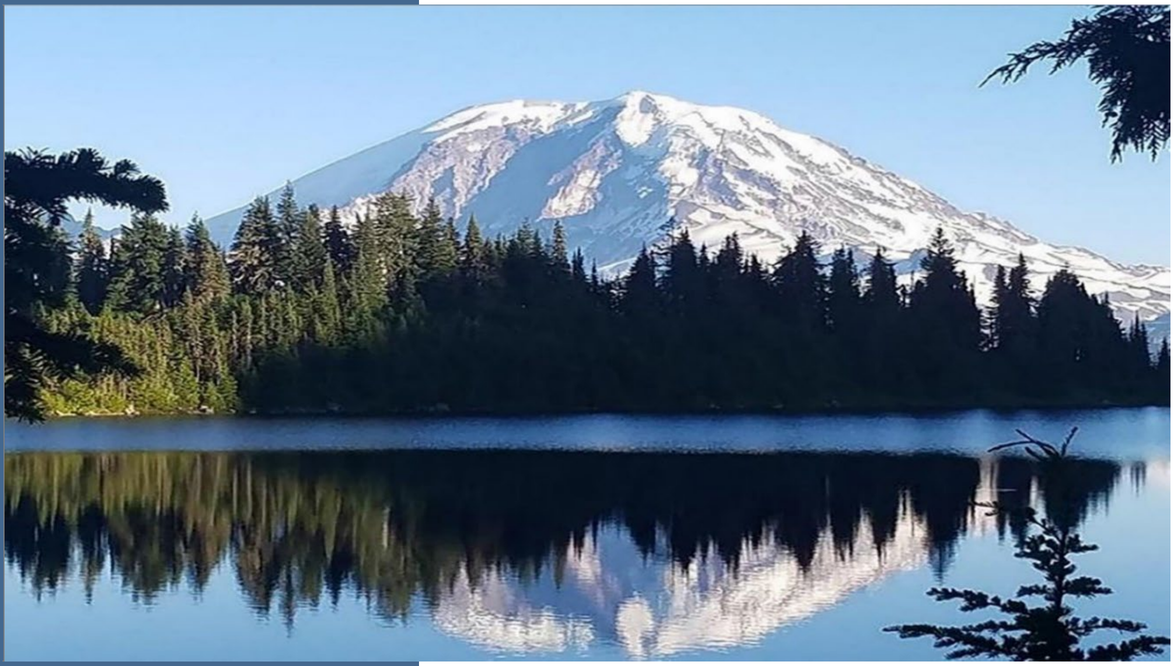

Adopted updates to Aquatic Life Toxics Criteria, WAC 173-201A-240

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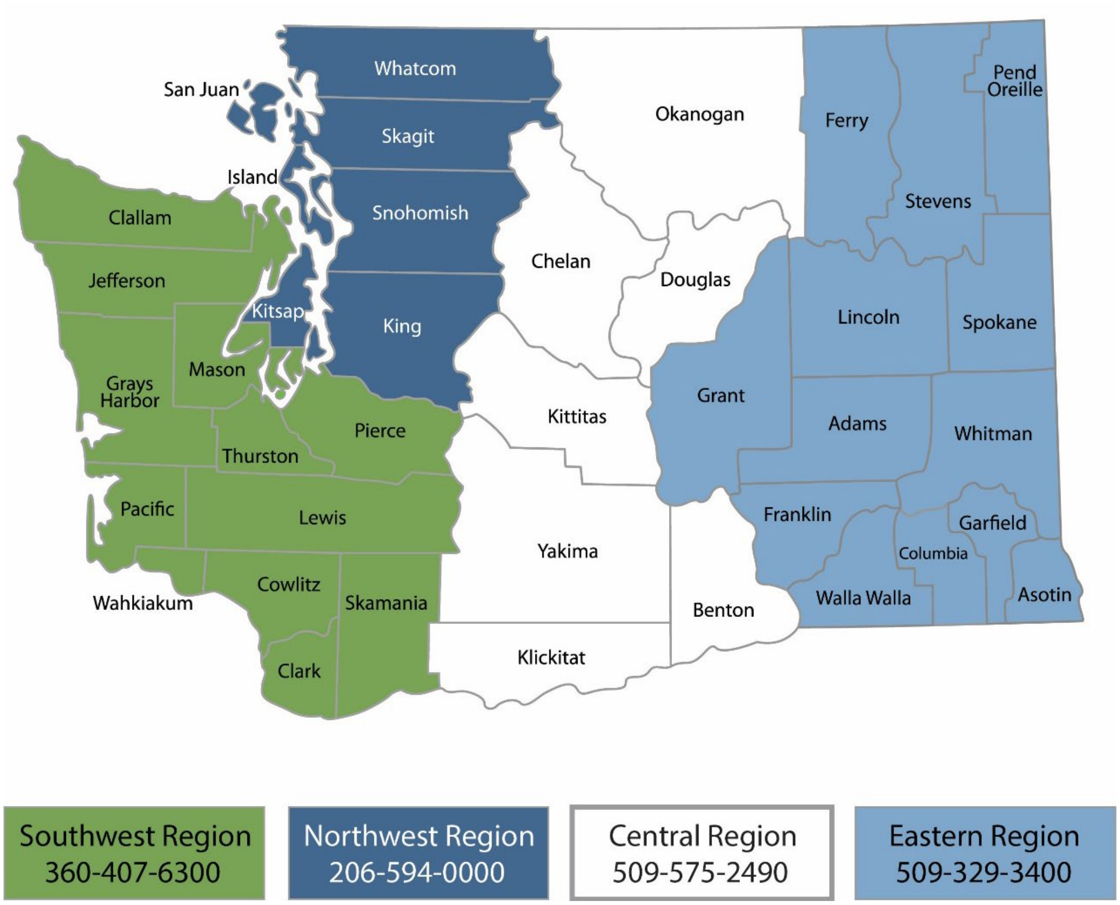

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Adopted revisions to Aquatic Life Toxics Criteria, WAC 173-201A-240

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Water Quality Program
Washington State Department of Ecology
Headquarters

Olympia, WA

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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
CaCO3	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 adopting amendments to chapter 173-201A Washington Administrative Code (WAC) Water Quality Standards for Surface Waters of the State of Washington. These adopted 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 adopted 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 5th percentile of the toxicity data distribution. We derived the 1st 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 scientific studies on toxic effects 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 scientific studies, and adopted 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[2] 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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[2] 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 (as presented in the BiOps used in this rulemaking):

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 consequences 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. The USFWS and NOAA recently updated Endangered Species Act rule language to clarify and improve how the agencies make listing, delisting, reclassification decisions, and critical habitat designations[3].

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.

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[3] Docket No. FWS-HQ-ES-2021-0107, FXES1111090FEDR-245-FF09E23000; Docket No. 240325-0088

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

* Criteria value represented at 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
Aluminum	LAA*	LAA*	N/A	N/A
Arsenic	NLAA	LAA	N/A	N/A
Cadmium	LAA*	LAA	NLAA	NLAA
Chromium III	LAA	LAA	N/A	N/A
Chromium VI	LAA	LAA	NLAA	NLAA
Copper	LAA*	LAA*	NLAA	NLAA
Lead	LAA	LAA	NLAA	NLAA
Nickel	LAA	LAA	NLAA	NLAA
Selenium	LAA	LAA	NLAA	LAA
Silver	LAA	N/A	NLAA	N/A
Zinc	LAA	LAA	NLAA	NLAA
Ammonia	LAA	LAA	N/A	N/A
Dieldrin	NLAA	NLAA	N/A	N/A
Endosulfan (alpha)	NLAA	NLAA	NLAA	NLAA
Endosulfan (beta)	NLAA	NLAA	NLAA	NLAA
Endrin	NLAA	NLAA	N/A	N/A
Heptachlor Epoxide	NLAA	NLAA	NLAA	NLAA
Lindane (gamma-BHC)	NLAA	NLAA	N/A	N/A
Pentachlorophenol	LAA	LAA	NLAA	NLAA
Tributyltin	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
Arsenic	360	340	190	150
Cadmium*	-	-	-	-
Copper	17	17	11	11
Cyanide	22	22	5.2	5.2
Lead	65	65	2.5	2.5
Mercury	2.1	2.1	0.012	0.012
Selenium	20	20	5	5
Zinc	114	120	105	120
Chromium III	550	570	180	74
Chromium VI	15	16	10	11
Nickel	1400	470	160	52
Silver	3.4	3.4	N/A	N/A
Endosulfan (alpha and beta)	0.22	2.0	0.056	89
Aldrin	3	0.00014	-	0.000050
Chlordane	2.4	0.00057	0.0043	0.00081
4,4-DDT	1.1	0.00059	0.001	0.00022
Dieldrin	2.5	0.00014	0.0019	0.000054
Endrin	0.18	0.81	0.0023	0.060
Heptachlor	0.52	0.00021	0.0038	0.000079
Lindane (gamma-BHC)	2	0.063	0.08	1.8
Polychlorinated biphenyls (PCBs)	N/A	0.014	N/A	0.014
Pentachlorophenol	20	6.2	13	3.0
Toxaphene	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 and are found in EPA's biological evaluation (USEPA, 2022a). 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 scientific studies.

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
Arsenic	NLAA	Not evaluated	NLAA	LAA
Chromium III	NLAA	NLAA	No criterion	No criterion
Chromium VI	NLAA	LAA	LAA	LAA
Copper	NLAA	NLAA	NLAA	NLAA
Iron	No criterion	LAA	No criterion	No criterion
Lead	NLAA	NLAA	NLAA	NLAA
Mercury	Not evaluated	Not evaluated	Not evaluated	Not evaluated
Nickel	LAA	NLAA	NLAA	NLAA
Selenium	NLAA	NLAA	NLAA	LAA
Silver	NLAA	No criterion	NLAA	No criterion
Zinc	LAA	LAA	NLAA	NLAA
Acrolein	NLAA	NLAA	No criterion	No criterion
Aldrin	NLAA	No criterion	NLAA	No criterion
Carbaryl	NLAA	NLAA	NLAA	No criterion
Chlordane	NLAA	NLAA	NLAA	NLAA
Chloride	Not evaluated	Not evaluated	No criterion	No criterion
Chlorine	NLAA	NLAA	LAA	NLAA
Chlorpyrifos	NLAA	NLAA	NLAA	NLAA
Cyanide	Not evaluated	Not evaluated	NLAA	NLAA
Demeton	No criterion	NLAA	No criterion	NLAA
Diazinon	NLAA	NLAA	NLAA	NLAA
Dieldrin	NLAA	NLAA	NLAA	NLAA
Endosulfan (alpha & beta)	NLAA	NLAA	NLAA	NLAA
gamma-BHC (Lindane)	NLAA	No criterion	NLAA	No criterion
Guthion	No criterion	NLAA	No criterion	NLAA
Heptachlor	NLAA	NLAA	NLAA	NLAA
Heptachlor epoxide	NLAA	NLAA	NLAA	NLAA
Hydrogen sulfide	No criterion	LAA	No criterion	LAA
Malathion	No criterion	NLAA	No criterion	NLAA
Methoxychlor	No criterion	NLAA	No criterion	NLAA
Mirex	No criterion	NLAA	No criterion	NLAA
Nonylphenol	LAA	NLAA	LAA	LAA
4,4-DDT	NLAA	NLAA	NLAA	NLAA
Parathion	NLAA	NLAA	No criterion	No criterion
Pentachlorophenol	NLAA	NLAA	LAA	NLAA

Chemical	Freshwater Acute	Freshwater Chronic	Saltwater Acute	Saltwater Chronic
Polychlorinated biphenyls	No criterion	NLAA	No criterion	NLAA
Toxaphene	NLAA	NLAA	NLAA	NLAA
Tributyltin	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 (Oncorhynchus tshawyscha) and critical habitat
- Sockeye salmon (Oncorhynchus nerka)
- Coho salmon (Oncorhynchus kisutch)
- Steelhead (Oncorhynchus mykiss)
- Chum salmon (Oncorhynchus keta)
- Bocaccio (Sebastes paucispinis) and critical habitat
- Yelloweye rockfish (Sebastes ruberrimus)

- Humpback whale (Megaptera novaeangliae)
- Southern resident killer whale (Orcinus orca) and critical habitat
- Bull trout (Salvelinus confluentus) and critical habitat
- Marbled murrelet (Brachyramphus marmoratus)
- Green sturgeon (Acipenser medirostris)
- Eulachon smelt (Thaleichthys pacificus)
- Oregon spotted frog (Rana pretiosa)

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 5th 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 5th 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. 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 affects 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., 1st 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. When a likely to adversely affect determination was designated, then we reviewed new scientific studies since EPA last updated the national aquatic life criteria recommendations. When incorporating new scientific studies and calculate the new criteria, we followed standard EPA methods (Stephan et al. 1985) and compared the newly calculated criteria to information in the Idaho and Oregon BiOps for similarly listed endangered species in Washington to determine if the new scientific studies provided adequate protection.

When new scientific studies did not provide adequate protection for endangered species and a jeopardy determination was made for a particular criterion, we applied a more conservative derivation process than EPA methods recommend in their 1985 guidance document for criteria development. EPA 1985 derivation guidelines state that if acceptable data are available for a large number of taxa from diverse groups, a reasonable level of protection will be provided. The 5th percentile used to calculate the final acute value does not imply that this percentage of adversely affected taxa should be used to decide in a field situation whether a criterion is too high or too low. The basis of EPA 1985 guidelines indicates that the 5th percentile should represent reasonable level of protection when there are large amounts of toxicity data for taxa. Given the endangered species protection concerns, limited toxicity datasets and taxa representation for the criteria based on the 1st percentile, we found it appropriate to derive criteria based on the 1st percentile. Furthermore, states have the option to develop more stringent criteria than EPA when justified. We support higher protection levels for endangered species and their populations in Washington.

We used the 1st percentile of the toxicity data distribution to derive a more conservative criterion value that will protect a greater proportion of species. Deriving the 1st 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. In a few instances, both the acute and chronic criteria were updated for a chemical because the chronic criterion was based on an acute to chronic ratio. The acute to chronic ratio is applied to the final acute value (FAV) in the acute criterion development to calculate the chronic criterion. To develop a protective chronic criterion and address the jeopardy call, we had to provide increased protection levels to both the acute and chronic criteria. Therefore, updating the acute criteria using the 1st percentile is the method used to lower the chronic criteria and provide protection for 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 scientific studies on toxic effects since EPA last updated national recommendations.
3. If new scientific studies on toxic effects 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 scientific studies on toxic effects did not provide adequate protection, then derive the 1st 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 scientific studies since EPA last updated the criteria ("New science").
6. We are proposing updated criteria for select toxics with ESA jeopardy calls that incorporate new scientific studies 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 scientific studies were 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
4,4'-DDT (and metabolites)	1988*	1980
Aldrin	1988*	1980
Ammonia	2003	2013
Arsenic	1992	1995
Cadmium	1997	2016
Chlordane	1988*	1980
Chloride (dissolved)	1992	1988
Chlorine (total)	1988	1986
Chlorpyrifos	1988*	1986
Chromium III	1992	1995
Chromium VI	1992	1995
Copper	1997	2007
Cyanide	2003*	1985
Dieldrin	1988*	1995
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 scientific studies in calculating state-specific criteria. We used the EPA ECOTOX database[4] to obtain new scientific articles for incorporation into criteria development. We restricted the ECOTOX database to look at new scientific studies 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”,

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[4] https://cfpub.epa.gov/ecotox/

“<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	June 2023
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 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 resident North American species with an established population
- 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 unless datasets are limited
- 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). In more recent criteria derivations, EPA accepts static-renewal test designs for invertebrates that are too small to be used in flow-through systems and could be lost or instances where degradation of the chemical tested is not anticipated.
- 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 studies were 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
Arsenic	1.000	1.000
Cadmium*	0.944	0.909
Chromium III	0.316	0.860
Chromium VI	0.982	0.962
Copper	0.960	0.960
Lead*	0.791	0.791
Mercury	0.85	-
Nickel	0.998	0.997
Silver	0.85	-
Zinc	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 ($CaCO_3$).

RESULTS

Summary Table of Proposal

Table 10 provides a summary of Washington’s freshwater acute, freshwater chronic, saltwater acute, and saltwater chronic aquatic life toxics criteria, including newly adopted criteria. For each criterion, we have also provided a comparison to EPA national recommended criteria when applicable.

Table 10. Acute and chronic aquatic life toxics criteria for freshwater (FW) and saltwater (SW) in Washington compared with 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
Aluminum	MLR Model$^{\$}$	MLR Model	MLR model$^{\$}$	MLR Model	-	-	-	-
Arsenic	300	340	130	150	69	69	36	36
Cadmium	1.3*	1.8*	0.41*	0.25*	33	33	7.9	7.9
Chromium III	470*	570*	61*	74*	-	-	-	-
Chromium VI	18	16	6.6	11	1100	1100	50	50
Copper	MLR model$^{\%}$	BLM model	MLR Model$^{\%}$	BLM Model	4.8	4.8	3.1	3.1
Iron	-	-	-	1000	-	-	-	-
Lead	65*	65*	2.5*	2.5*	210	210	8.1	8.1
Mercury	1.4	1.4	0.012	0.77	1.8	1.8	0.025	0.94
Nickel	58*	470*	11*	52*	74	74	8.2	8.2
Selenium	EPA’s tissue & water criteria	EPA’s tissue & water criteria	EPA’s tissue & water criteria	EPA’s tissue & water criteria	290	290	71	71
Silver	0.44*	3.2*	0.17	-	2.3	1.9	0.91	-
Zinc	67*	120*	24*	120*	90	90	81	81
4,4”-DDT (and metabolites)	1.1	1.1	0.001	0.001	0.13	0.13	0.001	0.001

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
6PPD-quinone **(N-(1,3-Dimethylbutyl)-N'-phenyl-p-phenylenediamine-quinone)**	0.012	-	-	-	-	-	-	-
Acrolein	3	3	3	3	-	-	-	-
Aldrin	3	3	0.0019	-	1.3	1.3	0.0019	-
Carbaryl	2.1	2.1	2.1	2.1	1.6	1.6	-	
Chlordane	2.4	2.4	0.0043	0.0043	0.09	0.09	0.004	0.004
Chloride	860000	860000	230000	23000	-	-	-	-
Chlorine	19	19	11	11	13	13	7.5	7.5
Chlorpyrifos	0.083	0.083	0.041	0.041	0.011	0.011	0.0056	0.0056
Cyanide	8.2	22	1.9	5.2	1	1	1	1
Demeton	-	-	0.1	0.1	-	-	0.1	0.1
Diazinon	0.17	0.17	0.17	0.17	0.82	0.82	0.82	0.82
Dieldrin	0.24	0.24	0.056	0.056	0.71	0.71	0.0019	0.0019
Endosulfan (alpha)	0.22	0.22	0.056	0.056	0.034	0.034	0.0087	0.0087
Endosulfan (beta)	0.22	0.22	0.056	0.056	0.034	0.034	0.0087	0.0087
Endrin	0.086	0.086	0.036	0.036	0.037	0.037	0.0023	0.0023
gamma-BHC	0.95	0.95	0.08	-	0.16	0.16	-	-
Guthion	-	-	0.01	0.01	-	-	0.01	0.01
Heptachlor	0.52	0.52	0.0038	0.0038	0.053	0.053	0.0036	0.0036
Heptachlor epoxide	-	0.52	-	0.0038	-	0.053	-	0.0036
Malathion	-	-	0.1	0.1	-	-	0.1	0.1
Methoxychlor	-	-	0.03	0.03	-	-	0.03	0.03
Mirex	-	-	0.001	0.001	-	-	0.001	0.001
Nonylphenol	28	28	6.6	6.6	7	7	1.7	1.7
Parathion	0.065	0.065	0.013	0.013	-	-	-	-
Pentachlorophenol	11^	19^	5.4^	15^	13	13	6.7	7.9

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
Polychlorinated biphenyls	2	-	0.014	0.014	10	-	0.03	0.03
PFOS	3000	3000	EPA's water & tissue criteria	EPA's water & tissue criteria	550	550	-	-
PFOA	49000	49000	EPA's water & tissue criteria	EPA's water & tissue criteria	7000	7000	-	-
Sulfide-hydrogen sulfide	-	-	-	2	-	-	-	2
Toxaphene	0.73	0.73	0.0002	0.0002	0.21	0.21	0.002	0.002
Tributyltin	0.46	0.46	0.072	0.072	0.42	0.42	0.0074	0.0074

[$] Acute defaults: Western Cordillera (6.2): 288; Marine West Coast Forest (7.1): 630; Cold Desert (10.1): 1400

[$] Chronic defaults: Western Cordillera (6.2): 180; Marine West Coast Forest (7.1): 302; Cold Desert (10.1): 720

[%] Acute defaults: Western Cordillera (6.2): 1.4; Marine West Coast Forest (7.1): 2.4; Cold Desert (10.1): 4.8

[%] Chronic defaults: Western Cordillera (6.2): 1.2; Marine West Coast Forest (7.1): 1.8; Cold Desert (10.1): 3.2

* Based on hardness of 100 mg/L

[#] 5th percentile default criteria from statewide dataset

^ Based on a pH of 7.8

Strategy for Aquatic Life Toxics Criteria

Table 11 provides a summary of strategies for Washington's freshwater acute, freshwater chronic, saltwater acute, and saltwater chronic 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)
Aluminum	EPA recommendation	EPA recommendation	-	-
Arsenic	New science & 1st percentile	New science & 1st percentile	No change	No change

Chemical	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Cadmium	EPA recommendation with state specific modification	1st percentile	EPA recommendation	EPA recommendation
Chromium III	New science	New science	-	-
Chromium VI	New science	New science	No change	No change
Copper	State-specific criteria	State-specific criteria	No change	No change
Iron	-	Do not adopt	-	-
Lead	No change	No change	No change	No change
Mercury	EPA recommendation	No change	No change	No change
Nickel	New science	New science	No change	No change
Selenium	EPA recommendation	EPA recommendation	No change	No change
Silver	New science	New state-specific criteria	New science	New state-specific criteria
Zinc	New science	New science	No change	No change
4,4’-DDT (and metabolites)	No change	No change	No change	No change
6PPD-quinone **(N-(1,3-Dimethylbutyl)-N’-phenyl-p-phenylenediamine-quinone)**	New state-specific criteria	-	-	-
Acrolein	EPA recommendation	EPA recommendation	-	-
Aldrin	EPA recommendation	No change	EPA recommendation	No change
Carbaryl	EPA recommendation	EPA recommendation	EPA recommendation	-
Chlordane	No change	No change	No change	No change
Chloride	No change	No change	-	-
Chlorine	No change	No change	No change	No change
Chlorpyrifos	No change	No change	No change	No change
Cyanide	New science & 1st percentile	New science & 1st percentile	No change	No change
Demeton	-	EPA recommendation	-	EPA recommendation
Diazinon	EPA recommendation	EPA recommendation	EPA recommendation	EPA recommendation

Chemical	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Dieldrin	EPA recommendation	EPA recommendation	No change	No change
Endosulfan (alpha & beta)	No change	No change	No change	No change
Endrin	EPA recommendation	EPA recommendation	No change	No change
gamma-BHC	EPA recommendation	No change	No change	-
Guthion	-	EPA recommendation	-	EPA recommendation
Heptachlor	No change	No change	No change	No change
Heptachlor epoxide	Do not adopt	Do not adopt	Do not adopt	Do not adopt
Malathion	-	EPA recommendation	-	EPA recommendation
Methoxychlor	-	EPA recommendation	-	EPA recommendation
Mirex	-	EPA recommendation	-	EPA recommendation
Nonylphenol	EPA recommendation	EPA recommendation	EPA recommendation	EPA recommendation
Parathion	No change	No change	-	-
Pentachlorophenol	New science	New science	New science	New science
Polychlorinated biphenyls	No change	No change	No change	No change
PFOA	EPA recommendation	EPA recommendation	EPA recommendation	-
PFOS	EPA recommendation	EPA recommendation	EPA recommendation	-
Sulfide-hydrogen sulfide	-	Do not adopt	-	Do not adopt
Toxaphene	No change	No change	No change	No change
Tributyltin	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[5]. We are presenting Washington's current criteria and the adopted 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 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 for EPA level II ecoregions in Washington using state-specific data that can be used when site-specific water chemistry data are not available. The default freshwater acute criterion is 288 µg/L for the Western Cordillera (6.2), 630 µg/L for the Marine West Coast Forest (7.1), and 1400 µg/L for the Cold Desert (10.1) ecoregion. The freshwater chronic default criterion is 180 µg/L for the Western Cordillera (6.2), 302 µg/L for the Marine West Coast Forest (7.1), and 720 µg/L for the Cold Desert (10.1) ecoregion. 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. Aluminum is reported as total recoverable concentration.

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[5] 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 adopted criteria.

	FW Acute (µg/L)*	FW Chronic (µg/L)*	SW Acute (µg/L)	SW Chronic (µg/L)
WA	-	-	-	-
EPA	Multiple Linear Regression Model	Multiple Linear Regression Model	-	-
Adopted	Western Cordillera (6.2): 288# Marine West Coast Forest (7.1): 630# Cold Desert (10.1): 1400# (Multiple Linear Regression Model; 1-hour)	Western Cordillera (6.2): 180# Marine West Coast Forest (7.1): 302# Cold Desert (10.1): 720# (Multiple Linear Regression Model; 4-day)	-	-

* Criteria are reported in total recoverable concentration

\# Numeric values shown represent the 5th percentile default criteria; specific water body data for pH, hardness, and dissolved organic carbon supersede the default criteria, regardless of whether the default criteria are higher or lower

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 from 2000 to 2023. 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 5th percentile of those 3,337 different criteria to be representative of the default criteria. The 5th 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 east/west and EPA level III ecoregional default values. When we reviewed the available data, we observed that the Cascade and Olympic mountain ranges had a strong influence on the default criteria values and that there was good justification for isolating this region. We had limited geospatial representation in some EPA level III ecoregions and did not find it appropriate to develop default criteria at this scale with the current dataset. The EPA level II ecoregions were used to represent regional default values in Washington (Figure 2). The three regions at EPA level II ecoregions represent the west coast forest, mountain ranges in central Washington and the Olympic peninsula, and cold desert in the east (Figure 2). When evaluating the number of concurrent samples of pH, hardness, and DOC in each ecoregion, we found that there were 617 samples in the Western Cordillera (6.2), 2085 samples in the Marine West Coast Forest (7.1), and 635 samples in the Cold Desert (10.1) ecoregion.

A 5th 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 10th 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 10th percentile default ecoregional aluminum criterion yielded <90% protection for some ecoregions and that the 5th 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 EPA level III ecoregional default values whereas Washington developed EPA level II ecoregional default values due to limited dispersion of concurrent sampling sites throughout the state. Thus, a higher level of protection at the 5th 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 5th 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 5th percentile default criteria. If site-specific criteria are less than the 5th percentile default criteria, permittees will need to use the site-specific information to determine effluent limits.

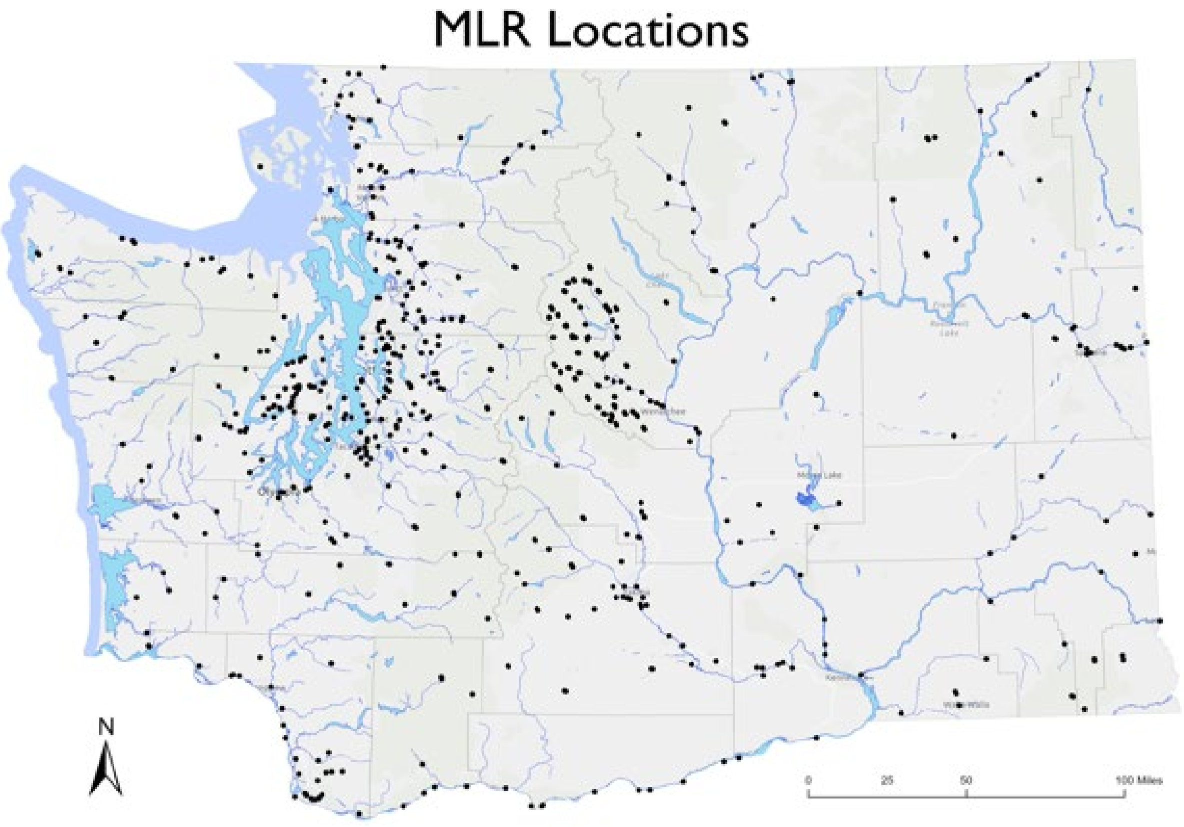

Figure 1. Locations in Washington with concurrently sampled pH, hardness, and dissolved organic carbon. Some hardness samples were calculated from conductivity and some dissolved organic carbon samples were calculated from total organic carbon.

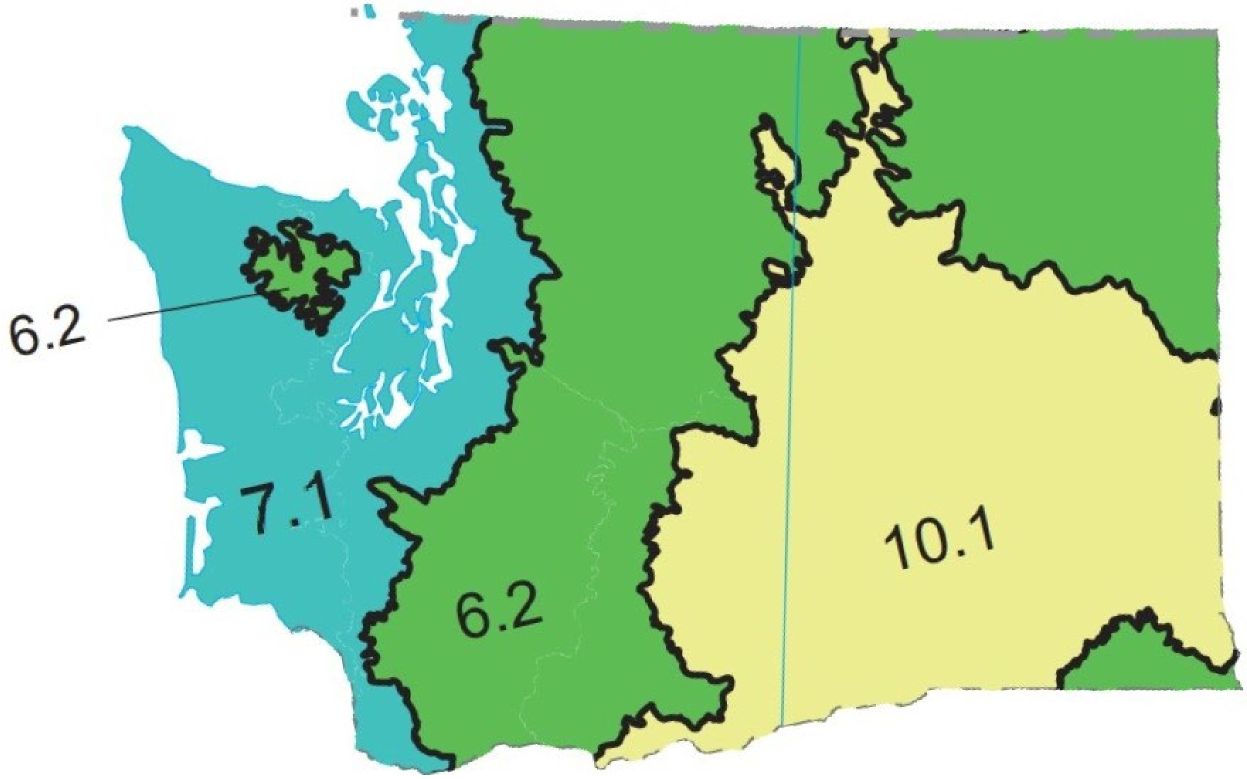

Figure 2. EPA level II ecoregions in Washington.

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 10th percentile of all the different ratios for statewide data. We used a conservative value (i.e., 10th 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. While we acknowledge using the slope of the regression between TOC and DOC to establish a conversion factor is preferred, this requires a dataset that is more representative and collected for the purpose of developing a conversion factor. The dataset used for the TOC:DOC conversion may contain biases such as more data on the west side, data collected for multiple purposes, and more data collected in the dry season. Given the potential biases, the choice to use a 10th percentile of the dataset is more appropriate. Furthermore, the slope of the regression would have resulted in a negligible change to the MLR default criteria because TOC to DOC conversions only added 105 sampling events to our dataset.

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 10th 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:

LN(Hardness) = 1.0108*LN(conductivity) - 0.9233

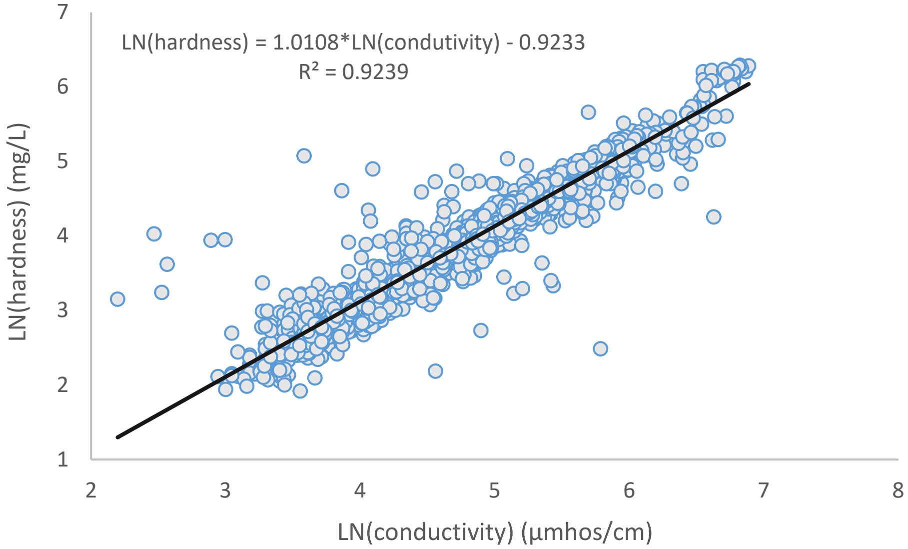

Figure 3. Relationship between hardness and conductivity (in micromhos per centimeter (µmhos/cm) for concurrent sampling throughout Washington.

Freshwater Acute and Chronic Criteria

The default freshwater acute aluminum criterion is 288 µg/L for the Western Cordillera (6.2), 630 µg/L for the Marine West Coast Forest (7.1), and 1400 µg/L for the Cold Desert (10.1) ecoregion. The default freshwater chronic aluminum criterion is 180 µg/L for the Western Cordillera (6.2), 302 µg/L for the Marine West Coast Forest (7.1), and 720 µg/L for the Cold Desert (10.1) ecoregion and 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 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 scientific studies since EPA last updated the arsenic freshwater criteria in 1995 (USEPA, 1996) and the saltwater criteria in 1984 (USEPA, 1985) were incorporated into the criteria. Additionally, the 1st percentile of the toxicity data distribution was used to calculate the freshwater 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; Iriving 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.

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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	360^ (1-hour)	190^ (4-day)	69^ (1-hour)	36^ (4-day)
EPA	340^ (1-hour)	150^ (4-day)	69^ (1-hour)	36^ (4-day)
Adopted	300^ (1-hour)	130^ (4-day)	No change	No change

^ 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 contaminant 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 ug/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). More recently, Erickson et al. (2019) exposed worms to arsenic in water, then exposed those worms to rainbow trout. No effects were observed to survival or growth at arsenic III levels in the water treatment at 2.4 mg/L resulting in a mean body burden of 32.6 µg/g dry weight in worms and 4.2 µg/g dry weight in rainbow trout. Similarly, no effects were observed for arsenic V at water treatments of 6 mg/L, 37.9 µg/g dry weight in worms, and 4.2 µg/g dry weight in rainbow trout.

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. We advise that the BCF be reevaluated for future ESA consultation purposes.

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. The freshwater acute criterion for arsenic was derived using 17 GMAVs and the 1st 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 x 1.00 = 300 µg/L (rounded to two significant digits)

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

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
1	874	Gammarus pseudolimnaeus	874
2	1175	Simocephalus vetulus	1700
		Simocephalus serrulatus	812
3	1600	Hyalella azteca	1600
4	1634	Ceriodaphnia reticulata	1511
		Ceriodaphnia dubia	1768
5	2533	Daphnia magna	3841
		Daphnia pulex	1670
6	7100	Chironomus dilutus	7100
7	13700	Thymallus arcticus	13700
8	14065	Pimephales promelas	14065
9	14960	Salvelinus fontinalis	14960
10	18100	Ictalurus punctatus	18100
11	18513	Oncorhynchus mykiss	16026
		Oncorhynchus kisutch	18500
		Oncorhynchus tshawytscha	21400
12	20130	Jordanella floridae	20130
13	22040	Plecoptera	22040
14	24500	Aplexa hypnorum	24500
15	26040	Carassius auratus	26040
16	41760	Lepomis macrochirus	41760
17	97000	Tanytarsus dissimilis	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
Oncorhynchus mykiss	S, U	16000	Yes.	Buhl 1991
Oncorhynchus mykiss	S, M	15300	Yes.	Tisler & Zagorc-Koncan 2002
Oncorhynchus tshawytscha	S, U	21400	Yes.	Hamilton & Buhl 1990
Oncorhynchus kisutch	S, U	18500	Yes.	Buhl 1991
Chironomus dilutis	S, M	7100	Yes.	Liber et al. 2011
Thymallus arcticus	S, U	13700	Yes.	Buhl 1991
Daphnia pulex	S, M	2566	Yes.	Shaw et al. 2007
Ceriodaphnia dubia	S, U	1768	Yes.	Hocket & Mount 1996
Daphnia magna	S, U	2500	Yes.	Tisler & Zagorc-Koncan 2002
Hyalella azteca	S, M	1600	Yes.	Liber et al. 2011
Oncorhynchus mykiss	FT, M	20200	Yes.	Rankin & Dixon 1994

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 and Chronic Arsenic Criteria

No changes are proposed to the saltwater acute and chronic arsenic criteria. Washington's current saltwater arsenic criteria are identical to EPA recommendations, and there are no known ESA consultation issues in other Region 10 states. The Swinomish BE suggests possible effects at EPA's saltwater arsenic criteria; however, formal ESA consultation was not completed and updated information should be used in evaluating saltwater arsenic effects.

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 (*communication with EPA*). 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.

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.

Cadmium

Summary of Criteria Recommendations and Changes

The freshwater acute and chronic cadmium criteria are more stringent than EPA recommendations (Table 16). The freshwater cadmium criteria are intended to provide additional protection to endangered species (specifically bull trout). The current saltwater cadmium criteria do not match EPA recommendations. Recent litigation has vacated EPA's freshwater chronic cadmium criterion of 0.72 µg/L and remanded the freshwater acute cadmium criterion of 1.8 µg/L (Center for Biological Diversity v. United States Environmental Protection Administration et al, No. 4:2022cv00138 - Document 39 (D. Ariz. 2023). The newly applicable freshwater chronic cadmium criterion is 0.25 µg/L based on the 2001 dataset. We considered new data since 2001 when calculating our freshwater chronic cadmium criterion.

Table 16. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic cadmium criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	3.7*^ (1-hour)	1.0*^ (4-day)	42^ (1-hour)	9.3^ (4-day)
EPA	1.8*^ (1-hour)	0.25 (4-day)	33^ (1-hour)	7.9^ (4-day)
Adopted	1.3*^ (1-hour)	0.41*^ (4-day)	33^ (1-hour)	7.9^ (4-day)

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

^ 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 ug/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 CaCO3) 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 CaCO3) 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 CaCO3)] 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 CaCO3)] 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 (recently vacated) has not undergone ESA consultation in other Pacific Northwest states.

Swinomish Tribe Biological Evaluation

The Swinomish BE concluded a not likely to adversely affect determination on 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 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 5th 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 20th percentile of available acute toxicity data for rainbow trout to add increased protection for endangered species. We sought to align the 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 in 2016 that would lower the GMAV. The decision to use a 20th percentile or lower of the SMAV is supported by USGS (Mebane, 2022):

> "In the present dataset, there are 47 acceptable hardness normalized acute values for rainbow trout with cadmium EC50 values ranging from 0.96 µg/L to 10.0 µg/L, with a

> median value of 3.71 µg/L. Although the math (geometric mean versus median) and datasets differ, this median is effectively the same concentration as the species mean acute value derived in USEPA (2016), 3.727 µg/L cadmium. Instead of using a central value of the rainbow trout dataset distribution such as the geometric mean or median to define the SMAV (which for cadmium is set equal to the FAV), a lower statistic such as the 20th percentile or the 10th percentile could be used in the calculation. The effect of doing so would reduce the acute CMC criterion from 1.86 µg/L in the 2016 version to 1.40 µg/L for a FAV using the "species 20th percentile acute value" or 0.82 µg/L for a FAV using the "species 10th percentile acute value" (Table 4). The lowest value in the dataset or a lower percentile than the 20th percentile such as the "species 10th percentile acute value" would be a logical choice from a species protection perspective."

Alternatively, Washington could justify the acute cadmium criterion of 1.3 µg/L by using the cadmium criteria developed by Mebane (2006). Mebane (2006) used EPA's single species method but with different datasets than the EPA 2016 cadmium update. Notably, Mebane (2006) included *Oncorhynchus clarkii* SMAV of 1.50 µg/L (hardness of 50 mg/L) which serves as the basis for the calculated criteria. Mebane (2006) lowered the FAV to protect *Oncorhynchus clarkiii* resulting a CMC of 0.75 µg/L based on a hardness of 50 mg/L (1.50 µg/L / 2 = 0.75 µg/L) or a CMC of 1.3 µg/L based on a hardness of 100 mg/L. EPA (2016) did not include *Oncorhynchus clarkii* data in their update. We support the use of the Mebane (2006) dataset or using the 20th percentile of the rainbow trout SMAV in EPA's 2016 update. Either method results in the same acute cadmium criterion of 1.3 µg/L (dissolved; hardness of 100 mg/L).

Table 17 shows the calculated 20th percentile of 30 rainbow trout LC50 values from the acute toxicity dataset presented in EPA's 2016 cadmium recommendations (USEPA, 2016). The 20th percentile was used to align with Idaho and the Swinomish Tribe freshwater acute cadmium criteria that received a not likely to adversely affect determination suggesting the criterion is protective of endangered species. Calculation results are as follows:

CMC = 1.376 µg/L (hardness of 100 mg/L)

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 hardness) x (0.041838)]

FAV = 2.7518

CMC = FAV /2 = 2.7518 / 2 = 1.376 ug/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 17. 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
20th percentile of Normalized Acute Values	**2.752 (FAV)**	
Acute criterion	**1.376 (CMC)**	

* Normalized to hardness of 100 mg/L

Freshwater Chronic Cadmium Criterion

The freshwater chronic cadmium criterion was calculated from the 2016 EPA toxicity dataset and used the 1st 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 hardness) x (0.041838)]

Chronic criterion (total) = 0.45 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 current 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

The freshwater chromium III criteria accounts for endangered species protection levels by incorporating new scientific studies available since EPA last updated the freshwater criteria in 1995 (Table 18; USEPA, 1996). The freshwater chromium III criteria are more stringent than EPA recommendations. Although jeopardy calls were specific to the freshwater chronic criterion for species relevant to Washington, new scientific studies were 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 scientific studies for chromium III because of the new data that demonstrates there are more sensitive species than previously used in the 1995 derivation (USEPA, 1996). There are no saltwater criteria for chromium III.

Table 18. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	550*^ (1-hour)	180*^ (4-day)	-	-
EPA	570*^ (1-hour)	74*^ (4-day)	-	-
Adopted	470*^ (1-hour)	61*^ (4-day)	-	-

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

^ 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 for similarly listed species in Washington (USFWS, 2012; NMFS, 2012). However, there was a likely to adversely affect determination for bull trout (USFWS, 2012). The Swinomish BE indicated a not likely to adversely affect (NLAA) determination for freshwater acute and chronic chromium III EPA recommendations (USEPA, 2022a).

Criteria Calculations

Freshwater Acute Chromium III Criterion

The data used to derive the freshwater acute chromium III criterion is presented in Table 19. New studies that met data acceptability requirements are presented in Table 20. The freshwater acute criterion for chromium III was derived using 20 GMAVs. Calculation results are as follows:

FAV = 1686 (hardness of 50 mg/L)

CMC = 842.8 µg/L (hardness of 50 mg/L; total)

CMC = $e^{(0.8190 \times \ln(\text{hardness}) + 3.533)} \times \text{CF}$

Where CF (conversion factor from total to dissolved fraction) = 0.316

Acute criterion (total) = 1487 µg/L (hardness of 100 mg/L)

Acute criterion (dissolved) = 470 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 19. Freshwater acute toxicity data used for criteria derivation reported as total recoverable chromium III.

Rank	**GMAV* (µg/L)**	**Species**	**SMAV* (µg/L)**
1	2187	Ceriodaphnia dubia	2187
2	2221	Ephemereila subvaria	2221
3	3200	Gammarus sp.	3200
4	7053	Poecilia reticulata	7053
5	8684	Carassius auratus	8684
6	9300	Nais sp.	9300
7	9669	Oncorhynchus mykiss	9669
8	10210	Amnicola sp.	10210
9	10320	Pimephales promelas	10580
10	11000	Chironomus sp.	11000
11	12860	Anguilla rostrata	12860
12	13320	Cyprinus carpio	13320
13	14770	Morone americana Morone saxatilis	13320 16370
14	15370	Lepomis gibbosus Lepomis macrochirus	15720 15020
15	15630	Fundulus diaphanous	15630
16	16010	Daphnia magna	16010
17	43100	Unidentified sp. (damselfly)	43100
18	50000	Unidentified sp. (caddisfly)	50000
19	71060	Hydropsyche betteni	71060
20	291000	Crangonyx psuedogracilis	291000

* Normalized to hardness of 50 mg/L

Table 20. 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
Ceriodaphnia dubia	S, M	3711	95	2187	Yes	Baral et al. 2006
Pimephales promelas	S, M	19793	95	11664	No. Other studies with the same species used flow-through design.	Baral et al. 2006

* Normalized to a hardness of 50 mg/L

FW Chronic Chromium III Criterion

There was inadequate freshwater chronic chromium III data to calculate criteria using the eight-family method. The FACR (final acute to chronic ratio) of 41.84 was used to calculate the freshwater chronic chromium III 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 = 1686

FACR = 41.84

CCC = 40.29 µg/L (total)

CCC = $e^{(0.8190 \times \ln(\text{hardness}) + 0.4921)} \times CF$

Conversion factor (total to dissolved fraction) = 0.860

Chronic criterion (total) = 71.07 µg/L (rounded to two significant digits)

Chronic criterion (dissolved) = 71.07 x 0.86 = 61 µg/L (rounded to two significant digits)

Chromium VI

Summary of Criteria Recommendations and Changes

The freshwater chromium VI criteria accounts for endangered species protection levels for species in Washington by incorporating the new scientific studies available since EPA last updated the freshwater criteria in 1995 (Table 21; USEPA, 1996).

There were likely to adversely affect determinations in Idaho or Oregon for similarly listed species in Washington, indicating a review of new scientific studies is needed to further protect aquatic life in Washington.. We used new scientific studies available 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 21. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	15^ (1-hour)	10^ (4-day)	1100^ (1-hour)	50^ (4-day)
EPA	16^ (1-hour)	11^ (4-day)	1100^ (1-hour)	50^ (4-day)
Adopted	18^ (1-hour)	6.6^ (4-day)	No change	No change

^ 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 22. New studies that met data acceptability requirements are presented in Table 23. The freshwater acute criterion for chromium VI was derived using 44 GMAVs. Calculation results are as follows:

FAV = 36.57

CMC = 18.29

Acute criterion (total) = 18.29 µg/L

Conversion factor (total to dissolved fraction) = 0.982

Acute criterion (dissolved) = 18.29 x 0.982 = 17.96 µg/L

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

Table 22. Freshwater acute toxicity data used for criteria derivation.

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
1	28.94	Daphnia magna Daphnia pulex	23.07 36.3
2	29	Pseudosida ramosa	29
3	36.35	Simocephalus serrulatus Simocephalus vetulus	40.9 32.3
4	67.1	Gammarus pseudolimnaeus	67.1
5	80.87	Ceriodaphnia reticulata Ceriodaphnia dubia	45.1 145
6	125	Thamnocephalus platyurus	125
7	170	Notodiaptomus conifer	170

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
8	177	Lecane papuana	177
9	456	Lampsilis siliquoidea	456
10	583	Crangonyx pseudogracilis	583
11	630	Hyalella azteca	630
12	650	Plumatella emarginata	650
13	919	Margaritifera falcata	919
14	1000	Culicoides furens	1000
15	1440	Pectinatella magnifica	1440
16	1560	Lophodella carteri	1560
17	2841	Bryocamptus zschokkei Bryocamptus pygmaeus Bryocamptus minutus	1850 3480 3560
18	3516	Tubifex tubifex	3516
19	3820	Attheyella crassa	3820
20	4000	Salmo salar	4000
21	19500	Carassius auratus	19500
22	23010	Physa heterostropha	23010
23	30000	Poecilia reticulata	30000
24	30450	Morone saxatilis	30450
25	32000	Xyrauchen texanus	32000
26	36300	Perca flavescens	36300
27	38000	Culex quinquefasciatus	38000
28	46000	Etheostoma nigrum	46000
29	47180	Pimephales notatus Pimephales promelas	54225 41050
30	49600	Ericymba buccata	49600
31	51250	Campostoma anomalum	51250
32	57300	Tanytarsus dissimilis	57300
33	59000	Salvelinus fontinalis	59000
34	61000	Chironomus tentans	61000
35	66000	Ptychocheilus Lucius	66000
36	67610	Notropis atherinoides Notropis chrysocephalus Notropis stramineus	48400 85600 74600
37	69000	Oncorhynchus mykiss	69000
38	72600	Promoxis annularis	72600
39	81000	Gila elegans	81000
40	123500	Lepomis cyanellus Lepomis macrochirus	114700 132900
41	140000	Enallagma aspersum	140000

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
42	151950	Gambusia affinis	151950
43	176000	Orconectes rusticus	176000
44	1870000	Neophasganophora capitata	1870000

Table 23. 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
Ceriodaphnia dubia	S, M	145	Yes.	Baral et al. 2006
Ceriodaphnia dubia	S, U	81.11	No. Other studies using the same species measured test concentrations.	Hockett 1996
Pimephales promelas	S, M	22464	No. FT, M available.	Baral et al. 2006
Gambusia affinis	R, U	151950	Yes.	Begum et al. 2006
Tubifex tubifex	S, U	2910	Yes.	Fargasova 1999
Notodiaptomus conifer	S, U	170	Yes.	Gutierrez et al. 2010
Lecane hamata	S, U	4410	No. LC50 10x higher than other species within genus.	Perez-Legaspi & Rico-Martinez 2001
Lecane luna	S, U	3260	No. LC50 10x higher than other species within genus.	Perez-Legaspi & Rico-Martinez 2001
Lecane quadridentata	S, U	4500	No. LC50 10x higher than other species within genus.	Perez-Legaspi & Rico-Martinez 2001
Culex quinquefasciatus	S, U	38000	Yes.	Sorenson et al. 2006
Salmo salar	R, M	4000	Yes.	Grande 1983
Thamnocephalus platyurus	S, U	125	Yes.	Centeno et al. 1995
Culicoides furens	S, U	1000	Yes.	Vedamanikan & Shazilli 2008
Ptychocheilus lucius	S, U	66000	Yes.	Buhl 1997
Gila elegans	S, U	81000	Yes.	Buhl 1997
Xyrauchen texanus	S, U	32000	Yes.	Buhl 1997
Bryocamptus pygmaeus	R, U	3480	Yes.	Di Marzio et al. 2009
Bryocamptus minutus	R, U	3560	Yes.	Di Marzio et al. 2009

Species	Method	LC50 (µg/L)	Used in Derivation?	Reference
Bryocamptus zschokkei	R, U	1850	Yes.	Di Marzio et al. 2009
Attheyella crassa	R, U	3820	Yes.	Di Marzio et al. 2009
Tubifex tubifex	S, U	5490	Yes.	Maestre et al. 2009
Oncorhynchus mykiss	R, U	12300	No. Other studies used flow-through design using the same species.	Kazlauskiene 1994
Tubifex tubifex	S, U	2720	Yes.	Rathore et al. 2002
Pseudosida ramosa	S, U	29	Yes.	Freitas & Rocha 2013
Lecane papuana	S, M	177	Yes.	Garza-Leon et al. 2021
Lampsilis siliquoidea	R, M	456	Yes.	Wang et al. 2017
Margaritifera falcata	R, M	919	Yes.	Wang et al. 2017
Mesocyclops pehpeiensis	S, U	510	Yes.	Wong and Pak, 2004

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 24). The newly calculated ACR used to derive the chronic chromium VI criteria is 5.349. Calculation results are as follows:

FAV = 36.57

FACR = 5.349

CCC = 6.837 µg/L

Chronic criterion (total) = 6.837 µg/L

Conversion factor (total to dissolved fraction) = 0.962

Chronic criterion (dissolved) = 6.837 x 0.962 = 6.6 µg/L (rounded to two significant digits)

Table 24. 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 pulex			5.92	5.92	1996 EPA doc
Simocephalus vetulus			5.267	5.267	1996 EPA doc
Simocephalus serrulatus			2.055	2.055	1996 EPA doc
Ceriodaphnia reticulata			1.13	1.13	1996 EPA doc
Pimephales promelas			18.55[A]	18.55[A]	1996 EPA doc
Lampsilis siliquoidea	456	26.15	17.44	17.44	Wang et al. 2017
Geometric mean				5.349	

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

[A] 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 25). 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. A copper MLR model has been published in the scientific literature (Brix et al. 2021). 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 a copper MLR model for which we have adequate water quality information to develop default values. We propose a default freshwater copper acute criterion of 1.4 µg/L for the Western Cordillera (6.2), 2.4 µg/L for the Marine West Coast Forest (7.1), and 4.8 µg/L for the Cold Desert (10.1) ecoregion. The freshwater default chronic copper criterion is 1.2 µg/L for the Western Cordillera (6.2), 1.8 µg/L for the Marine West Coast Forest (7.1), and 3.2 µg/L for the Cold Desert (10.1) ecoregion. These default criteria are based on the 5th percentile of the MLR criteria for the respective EPA level II ecoregions (Table 25). 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 25. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic copper criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	Hardness-based (1-hour)	Hardness-based (4-day)	4.8 (1-hour)	3.1 (4-day)
EPA	Biotic Ligand Model (1-hour)	Biotic Ligand Model (4-day)	4.8 (1-hour)	3.1 (4-day)
Adopted	Western Cordillera (6.2): 1.4# Marine West Coast Forest (7.1): 2.4# Cold Desert (10.1): 4.8# (Multiple Linear Regression Model; 1-hour)	Western Cordillera (6.2): 1.2# Marine West Coast Forest (7.1): 1.8# Cold Desert (10.1): 3.2# (Multiple Linear Regression Model; 4-day)	No change	No change

Represent 5th percentile default criteria values;

Copper MLR vs Copper BLM Models

A 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."

A MLR model for copper 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[6]). 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. While statistical analysis to test for species-specific slopes and intercepts revealed that some species slopes differed from the mean slope, the pooled model was still able to explain variability in copper toxicity for individual species at a comparable level to that explained by individual species models (Brix et al. 2017).

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 compiled chronic criteria dataset and concluded the Brix et al. (2021) copper MLR model generated criteria protective of the 95th 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 from 2000 to 2023. 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

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[6] https://www.epa.gov/wqc/metals-crada-phase-1-report

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 5th percentile of those 3,337 different criteria to be representative of the default criteria. The 5th 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 east/west and EPA level III ecoregional default values. When we reviewed the data, we observed that the Cascade and Olympic mountain ranges had a strong influence on the default criteria values and that there was good justification for isolating this region. We had limited geospatial representation in some EPA level III ecoregions and did not find it appropriate to develop default criteria with the current dataset. The EPA level II ecoregions were used to represent regional default values in Washington (Figure 2). The three regions at EPA level II ecoregions represent the west coast forest, mountain ranges in central Washington and the Olympic peninsula, and cold desert in the east. When evaluating the number of concurrent samples of pH, hardness, and DOC in each ecoregion, we found that there were 617 samples in the Western Cordillera (6.2), 2085 samples in the Marine West Coast Forest (7.1), and 635 samples in the Cold Desert (10.1) ecoregion.

A 5th percentile default criteria was used to provide protection of all aquatic species. Washington developed EPA level II ecoregion default values due to limited dispersion of concurrent sampling sites throughout the state that precluded the ability to develop EPA level III ecoregion or watershed specific default criteria values. A 5th percentile default criteria is appropriate because the EPA level III ecoregions and watershed water chemistry are not accounted for using the higher scale EPA level II ecoregions . The 5th percentile default value is also more protective of waters with higher bioavailability of copper.

The default acute copper criteria of 1.4 µg/L for the Western Cordillera (6.2), 2.4 µg/L for the Marine West Coast Forest (7.1), and 4.8 µg/L for the Cold Desert (10.1) ecoregion are similar to the calculated CMC (i.e., acute criterion) of 2.3 ug/L presented in EPA's 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, SO4 =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 5th percentile default value of 1.2 µg/L for the Western Cordillera (6.2), 1.8 µg/L for the Marine West Coast Forest (7.1), and 3.2 µg/L for the Cold Desert (10.1) ecoregion. 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 5th percentile default criteria. If site-specific criteria are less than the 5th 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 10th percentile of all ratios for statewide data. We used a conservative value (i.e., 10th 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. While we acknowledge using the slope of the regression between TOC and DOC to establish a conversion factor is preferred, this requires a dataset that is more representative and collected for the purpose of developing a conversion factor. The dataset used for the TOC:DOC conversion may contain biases such as more data on the west side, data collected for multiple purposes, and more data collected in the dry season. Given the potential biases, the choice to use a 10th percentile of the dataset is more appropriate. Furthermore, the slope of the regression would have resulted in a negligible change to the MLR default criteria because TOC to DOC conversions only added 105 sampling events to our dataset.

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 10th 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:

$\mathrm{LN(Hardness)} = 1.0108 \times \mathrm{LN(conductivity)} - 0.9233$

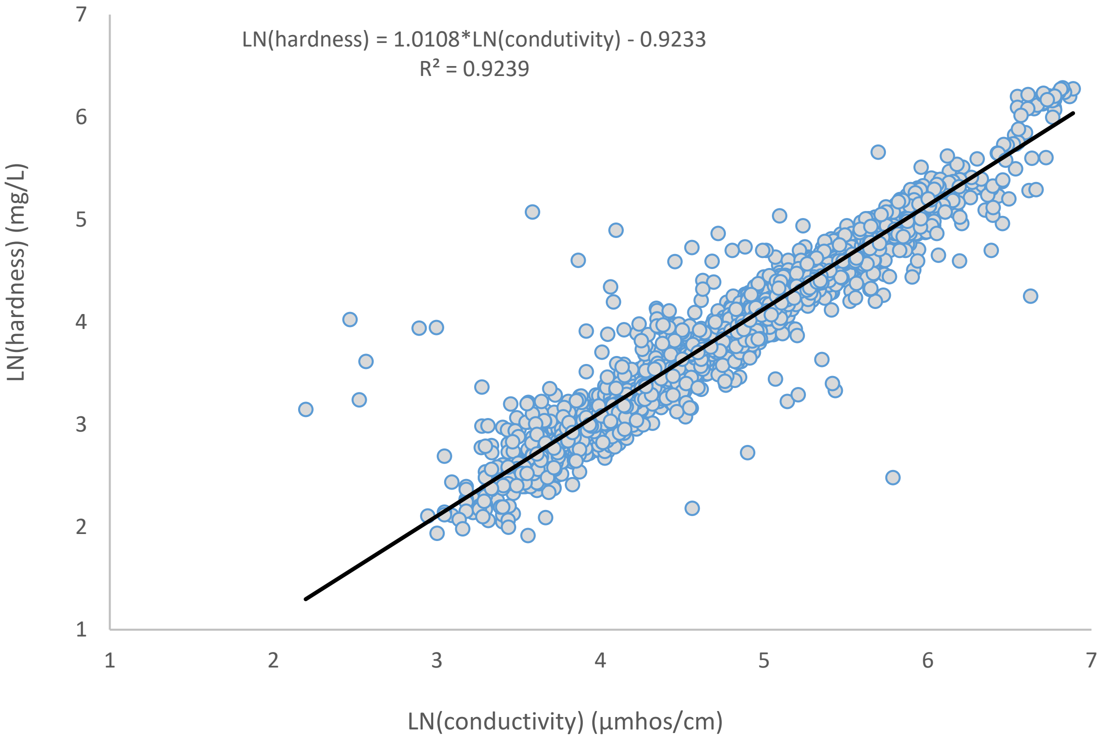

Figure 4. Relationship between hardness and conductivity (in micromhos per centimeter (µmhos/cm) for concurrent sampling throughout Washington.

Default Criteria

The default freshwater acute copper criterion is 1.4 µg/L for the Western Cordillera (6.2), 2.4 µg/L for the Marine West Coast Forest (7.1), and 4.8 µg/L for the Cold Desert (10.1) ecoregion. The default chronic copper criterion is 1.2 µg/L for the Western Cordillera (6.2), 1.8 µg/L for the Marine West Coast Forest (7.1), and 3.2 µg/L for the Cold Desert (10.1) ecoregion. 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) = $e^{(0.700 \times \ln(\mathrm{DOC}) + 0.579 \times \ln(\mathrm{hardness}) + 0.778 \times \mathrm{pH} - 6.738)}$, and

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

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 to derive the FAV followed by division by two to be consistent with 1985 USEPA methods for CMC calculations. The ACR used for copper can be found in Table 26 and ACRs not used are in Table 27.

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 and prioritizes using the more accurate empirical model. This concept is discussed in an upcoming publication (Brix et al. in prep). Some example scenarios where the acute copper criterion is calculated based on the higher value of the two equations is presented in Appendix B.

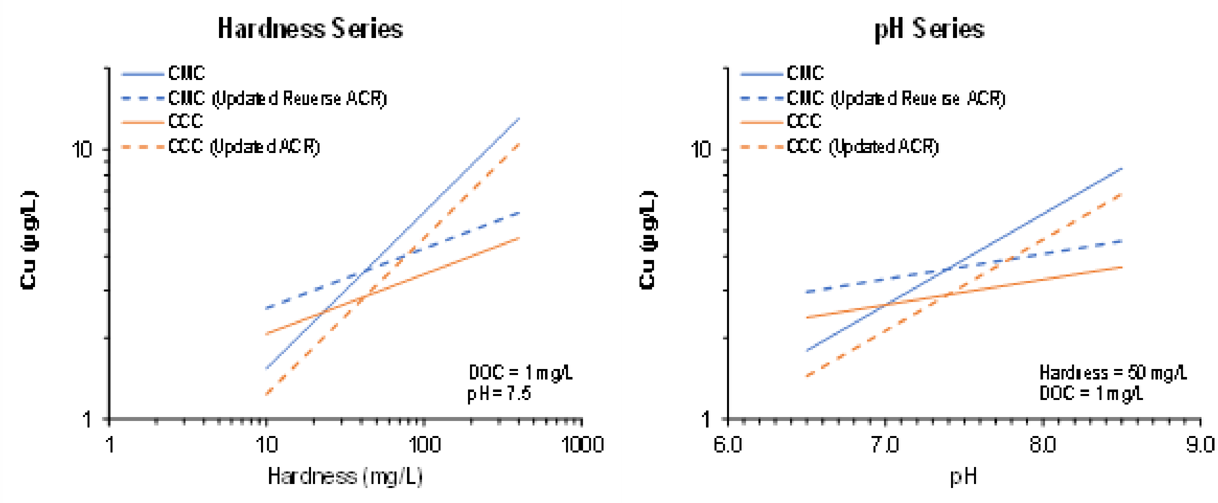

Figure 5. Demonstration of how the empirical based models (CMC and CCC), updated ACR, and the reverse ACR models function at different pH, hardness, and dissolved organic carbon levels.

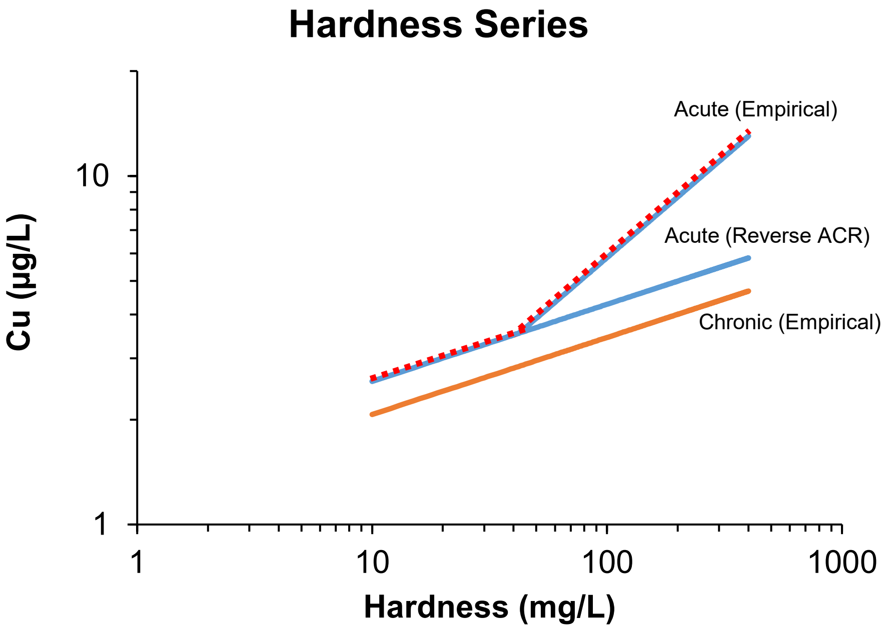

Figure 6. Depiction of how the acute MLR models functions in relation to the chronic MLR model. The acute copper criterion states two separate equations, whichever is greater. Equation 1 represents the empirical acute based MLR model, while equation 2 represents the reverse ACR based model. The red dotted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

Table 26. 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
Ceriodaphnia dubia	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
Cottus bairdii	83	29.35	2.8	2.80	Besser et al. 2007
Daphnia magna	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
Daphnia pulex	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
Oncorhynchus mykiss	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
	10.3	10	1.0		Cremazy et al. 2017
	19.7	5	3.9		Cremazy et al. 2017

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
	5.9	5.5	1.1		Cremazy et al. 2017
	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
	230.67	170	1.4	1.58	Cremazy et al. 2017
Oncorhynchus tshawytscha	33.1	5.92	5.59	5.59	Chapman 1975, 1982
Salvelinus fontinalis	198.7	141.0	1.4	1.40	Hansen et al. 2000, 2002
Villosa iris	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
Cyprinodon variegatus	368	249	1.48	1.48	Hughes et al. 1989
Geometric mean				2.49	

Table 27. Acute to chronic ratios not used for copper.

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Reason not used	Reference
Ceriodaphnia dubia	18	12	15	ACR is approximately 5 times greater than other ACRs for this species	Besser et al. 2007
Daphnia magna	8.8	9.2	0.96	ACR is <1	Villavicencio et al. 2011
Daphnia magna	3.6	8.5	0.42	ACR is <1	Villavicencio et al. 2011
Daphnia magna	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
Lymnaea stagnalis	20	1.8	11.1	ACR species mean is approximately 10x greater than lowest species mean ACR	Brix et al. 2011
Oncorhynchus mykiss	29	31	0.94	ACR is <1	Cremazy et al. 2017
Oncorhynchus mykiss	46	49	0.94	ACR is <1	Cremazy et al. 2017
Oncorhynchus mykiss	12.7	16	0.79	ACR is <1	Cremazy et al. 2017
Oncorhynchus mykiss	6.7	18	0.37	ACR is <1	Cremazy et al. 2017
Pimephales promelas	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:

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

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 28). 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 28. 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)
Washington	-	-	-	-
EPA	-	1000	-	-
Adopted	-	-	-	-

Lead

Summary of Criteria Recommendations and Changes

Washington's freshwater and saltwater lead criteria are identical to EPA's recommendations (Table 29). There were LAA determinations for freshwater acute and chronic lead criteria in Oregon for bull trout but there were no jeopardy calls. The new scientific studies resulted in higher freshwater criteria values than EPA recommendations. Therefore, we propose no changes to Washington's freshwater and saltwater lead criteria.

Table 29. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic lead criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

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

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

^ Presented as the dissolved fraction

Mercury

Summary of Criteria Recommendations and Changes

The only action for mercury criteria is the adoption of the mercury freshwater acute criterion recommended by EPA (Table 30). 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 30. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic mercury criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	2.1* (1-hour)	0.012^ (4-day)	1.8* (1-hour)	0.025^ (4-day)
EPA	1.4* (1-hour)	0.77* (4-day)	1.8* (1-hour)	0.94* (4-day)
Adopted	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 freshwater nickel criteria accounts for endangered species protection levels by incorporating new scientific studies available since EPA last updated the freshwater criteria in

1995 (Table 31; USEPA, 1996). The 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 scientific studies were 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 scientific studies 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 31. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic nickel criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	1415*^ (1-hour)	157*^ (4-day)	74^ (1-hour)	8.2^ (4-day)
EPA	470*^ (1-hour)	52*^ (4-day)	74^ (1-hour)	8.2^ (4-day)
Adopted	58*^ (1-hour)	11*^ (4-day)	No change	No change

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

^ 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 32. New studies that met data acceptability requirements are presented in Table 33. The freshwater acute criterion for nickel was derived using 46 GMAVs. Calculation results are as follows:

FAV = 64.67 (hardness of 50 mg/L)

CMC = 32.34 µg/L (hardness of 50 mg/L)

CMC = $e^{(0.846 \times \ln(\text{hardness}) + 0.1667)} \times CF$

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

Acute criterion (total) = 58.13 µg/L (hardness of 100 mg/L)

Acute criterion (dissolved) = 58 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 32. Freshwater acute toxicity data used for criteria derivation reported as total recoverable nickel.

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
1	37.49	Leptoxis ampla	37.49
2	59.87	Ceriodaphnia dubia	59.87
3	81.94	Neocloeon triangulifer	81.94
4	96.44	Megalonaias nervosa	96.44
5	130.4	Amblema plicata	130.4
6	150.0	Margaritifera falcata	150.0
7	236.6	Euchlanis dilata	236.6
8	287.2	Lymnaea stagnalis	287.2
9	302.7	Anodonta imbecillis	302.7
10	342.0	Somatogyrus sp.	342.0
11	355.6	Hamiota perovalis	355.6
12	360.8	Tubifex tubifex	360.8
13	376.8	Utterbackia imbecillis	376.8
14	385.5	Lampsilis siliquoidea Lampsilis cardium Lampsilis abrupta	239.0 466.1 514.2
15	418.2	Hyalella azteca	418.2
16	436.6	Physa gyrina	436.6
17	579.4	Villosa nebulosa	579.4

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
18	1207	Daphnia pulex Daphnia magna Daphnia pulicaria	526.1 1636 2042
19	1445	Bosmina coregoni	1445
20	2148	Diaptomus forbesi	2148
21	4312	Ambloplites rupestris	4312
22	4636	Ephemerella subvaria	4636
23	2315	Simocephalus vetulus Simocephalus serrulatus	1447 3704
24	5164	Nais elinguis Nais sp.	1891 14100
25	5520	Lumbriculus variegatus	5520
26	6103	Chydorus ovalis	6103
27	6707	Pimephales promelas	6707
28	7789	Acipenser fulvescens	7789
29	7805	Branchiura sowerbyi	7805
30	8257	Cyprinus carpio	8257
31	8697	Morone saxatilis Morone americana	5914 12790
32	9661	Poecilia reticulata	9661
33	12180	Anguilla rostrata	12180
34	12760	Lepomis gibbosus	12756
35	12770	Amnicola sp.	12770
36	13000	Gammarus sp.	13000
37	13210	Oncorhynchus mykiss	13210
38	19440	Melanoides tuberculate	19440
39	21200	Unidentified sp. (damselfly)	21200
40	21320	Carassius auratus	21320
41	28940	Chironomus riparius Chironomus dilutes	14700 56980
42	30200	Unidentified sp. (mayfly)	30200
43	40460	Acroneuria lycorias	40460
44	43250	Fundulus diaphanous	43250
45	58280	Gambusia affinis	58280
46	66100	Crangonyx pseudogracilis	66100

* Normalized to hardness of 50 mg/L

Table 33. 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
Pimephales promelas	R, M	3928	106	2080	No. Other studies with the same species used flow-through design.	Lynch et al. 2016
Neocloeon triangulifer	S, M	147	100	81.94	Yes.	Soucek et al. 2020
Hyalella azteca	S, M	917.8	100	510.6	Yes.	Wang et al. 2020
Hyalella azteca	S, M	75.15	18	178.4	Yes.	Borgman et al. 2005
Hyalella azteca	S, M	133.3	124	61.80	Yes.	Borgman et al. 2005
Oncorhynchus mykiss	FT, M	20842	91	12558	Yes.	Brix et al. 2004
Tubifex tubifex	S, U	537	80	360.8	Yes.	Fargasova 1999
Ceriodaphnia dubia	S, M	81.16	50	81.16	Yes.	Keithly et al. 2004
Ceriodaphnia dubia	S, M	148.3	113	74.40	Yes.	Keithly et al. 2004
Ceriodaphnia dubia	S, M	261.5	161	97.24	Yes.	Keithly et al. 2004
Ceriodaphnia dubia	S, M	400.8	253	101.7	Yes.	Keithly et al. 2004
Hyalella azteca	S, M	3051	98	1727	Yes.	Keithly et al. 2004
Ceriodaphnia dubia	S, U	29.3	80	19.69	Yes.	Hockett et al. 1996
Hyalella azteca	S, M	2000	120	953.6	Yes.	Liber et al. 2011

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Chironomus dilutus	S, M	119500	120	56978	Yes.	Liber et al. 2011
Chironomus riparius	S, M	79500	367.8	14696	Yes.	Powlesland 1986
Gambusia affinis	S, U	68000	60	58280	Yes.	Kallangoudar & Patil 1997
Oncorhynchus mykiss	R, U	1280	250	328.0	No. Other studies with same species used flow through design and measured concentrations.	Kazlausk et al. 1994
Daphnia pulex	R, M	1480	142	612	No. Adult life stage used for testing	Griffitt 2008
Ceriodaphnia dubia	R, M	19640	142		No. LC50 10x higher than other studies using the same species.	Griffitt 2008
Daphnia magna	S, M	1503	92.5	893.2	Yes.	Lari et al. 2017
Hamiota perovalis	R, U	313	43	355.6	Yes.	Gibson et al. 2018
Villosa nebulosa	R, U	510	43	579.4	Yes.	Gibson et al. 2018
Leptoxis ampla	R, U	33	43	37.49	Yes.	Gibson et al. 2018
Somatogyrus sp.	R, U	301	43	342.0	Yes.	Gibson et al. 2018
Ceriodaphnia dubia	R, M	133.3	100	74.14	Yes.	Ivey et al. 2017
Daphnia magna	R, M	3827	100	2129	Yes.	Ivey et al. 2017
Hyalella azteca	R, M	2158	100	1201	Yes.	Ivey et al. 2017
Physa gyrina	R, M	670.3	100	372.9	Yes.	Ivey et al. 2017

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Physa gyrina	R, M	918.8	100	511.2	Yes.	Ivey et al. 2017
Lymnaea stagnalis	R, M	737.5	100	410.3	Yes.	Ivey et al. 2017
Daphnia magna	S, U	3850	50.9	3792	No. Other studies measured test concentrations for the same species.	Kim et al. 2017
Daphnia pulex	R, M	440.9	50.9	434.3	Yes.	Leonard et al. 2013
Lumbriculus variegatus	R, M	4805	50.9	4733	Yes.	Leonard et al. 2013
Chironomus riparius	R, M	>646900	50.9	>637200	No. Greater than value when other more definitive data exists.	Leonard et al. 2013
Lymnaea stagnalis	R, M	482.3	140.7	201.0	Yes.	Leonard et al. 2013
Daphnia pulex	R, M	1529	140.7	637.2	Yes.	Leonard et al. 2013
Lumbriculus variegatus	R, M	14514	140.7	6049	Yes.	Leonard et al. 2013
Chironomus riparius	R, M	>64884	140.7	>27040	Yes.	Leonard et al. 2013
Anodonta imbecilis	S, M	240	38	302.7	Yes.	Keller 1991
Oncorhynchus mykiss	R, M	15330	140	6416	Yes.	Pane et al. 2003
Pimephales promelas	R, M	450	20	976.9	No. Other studies with the same species used a flow-through design.	Pyle et al. 2002

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Pimephales promelas	R, M	2270	140	950.0	No. Other studies with the same species used a flow-through design.	Pyle et al. 2002
Pimephales promelas	R, M	500	40	603.9	No. Other studies with the same species used a flow-through design.	Pyle et al. 2002
Cottus bairdi	R, M	2400	100	1335	Yes.	Besser et al. 2019
Pimephales promelas	R, M	15000	100	8345	Yes.	Besser et al. 2019
Acipenser fulvescens	R, M	14000	100	7789	Yes.	Besser et al. 2019
Euchlanis dilatata	S, M	389	90	236.6	Yes.	Hernandez-Flores et al. 2020
Ceriodaphnia quadrangular	S, M	518.0	43.4	583.9	Yes.	Deleebeck et al. 2007
Ceriodaphnia pulchella	S, M	983.0	43.4	1108	Yes.	Deleebeck et al. 2007
Chydorus ovalis	S, M	4265	43.4	4807	Yes.	Deleebeck et al. 2007
Simocephalus vetulus	S, M	1488	43.4	1677.3	Yes.	Deleebeck et al. 2007
Ceriodaphnia quadrangular	S, M	401.4	16.3	1036	Yes.	Deleebeck et al. 2007
Ceriodaphnia pulchella	S, M	843.4	16.3	2177	Yes.	Deleebeck et al. 2007
Chydorus ovalis	S, M	3002	16.3	7749	Yes.	Deleebeck et al. 2007

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Simocephalus vetulus	S, M	483.7	16.3	1248	Yes.	Deleebeck et al. 2007
Ceriodaphnia quadrangular	S, M	140.9	16.3	363.6	Yes.	Deleebeck et al. 2007
Simocephalus serrulatus	S, M	1435	16.3	3704	Yes.	Deleebeck et al. 2007
Bosmina coregoni	S, M	559.7	16.3	1445	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	1824	46.2	1950	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	2084	69.8	1572	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	2535	110	1301	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3417	154	1320	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3567	199	1109	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	4499	242	1185	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	5511	280	1283	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3407	382	609.9	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	2285	474	340.7	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	2265	47.6	2361	Yes.	Deleebeck et al. 2007

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Daphnia magna	S, M	2615	70.5	1956	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	2966	116	1455	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3246	159	1220	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3547	193	1131	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3778	237	1013	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	4068	292	914	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3637	367	673.6	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3517	475	523.6	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3176	45.9	3415	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3497	45.8	3766	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3196	45.8	3443	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3327	45.8	3583	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3617	43.6	4062	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3647	43.6	4095	Yes.	Deleebeck et al. 2007

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Daphnia magna	S, M	3406	43.7	3818	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3236	42.5	3714	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3557	43.3	4018	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	2816	43.4	3174	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	2615	43.7	2931	Yes.	Deleebeck et al. 2007
Daphnia magna	S, M	3076	43.3	3474	Yes.	Deleebeck et al. 2007
Diaptomus forbesi	S, M	5441	150	2148	Yes.	Ghosh et al. 2018
Branchiura sowerbyi	S, M	19770	150	7805	Yes.	Ghosh et al. 2018
Cyprinus carpio	S, M	14730	150	5815	Yes.	Ghosh et al. 2018
Daphnia magna	S, M	1070	45	1170	Yes.	Pane et al. 2003
Lampsilis abrupta	R, M	1376	160	514.2	Yes.	Popp et al. 2018
Lampsilis cardium	R, M	1247	160	466.1	Yes.	Popp et al. 2018
Utterbackia imbecillis	R, M	1500	160	>560.7	No. Greater than value when other more definitive data exists.	Popp et al. 2018
Amblema plicata	R, M	234.5	100	130.4	Yes.	Wang et al. 2017
Utterbackia imbecillis	R, M	677.4	100	376.8	Yes.	Wang et al. 2017

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Lampsilis siliquoidea	R, M	507.0	100	282.1	Yes.	Wang et al. 2017
Lampsilis siliquoidea	R, M	350.7	100	195.1	Yes.	Wang et al. 2017
Lampsilis siliquoidea	R, M	445.9	100	248.1	Yes.	Wang et al. 2017
Megalonaias nervosa	R, M	173.3	100	96.44	Yes.	Wang et al. 2017
Margaritifera falcata	R, M	269.5	100	150.0	Yes.	Wang et al. 2017
Daphnia magna	S, M	4155	240	1102	Yes.	Xie et al. 2009
Melanoides tuberculata	R, M	8460	18.7	19440	Yes.	Shuhaimi-Othman et al. 2012
Nais elinguis	R, M	793	17.9	1891	Yes.	Shuhaimi-Othman et al. 2012
Ceriodaphnia dubia	S, M	140	290	31.64	Yes.	Schubauer-Berigan et al. 1993
Hyalella azteca	S, M	890	290	201.2	Yes.	Shcubauer-Berigan et al. 1993
Pimephales promelas	S, M	3100	290	700.7	No. Other studies with the same species used a flow-through design.	Schubauer-Berigan et al. 1993
Lumbriculus variegatus	S, M	26000	290	5876	Yes.	Schubauer-Berigan et al. 1993

Species	Method	LC50 (µg/L total nickel)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Cyprinus carpio	S, U	6900	305	1494	No. Other studies with the same species had measured test concentrations.	Virk et al. 1995
Poecilia reticulata	S, U	12,650	18	30060	No. Other studies using the same test species have measured test concentrations.	Khunyakari et al. 2001

* Normalized to a hardness of 50 mg/L

Freshwater Chronic Nickel Criterion

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). We found adequate data to meet the eight family minimum data requirements for the chronic nickel criterion. The data used to derive the freshwater chronic nickel criterion are presented in Table 34. New studies that met data acceptability requirements are presented in Table 35. The freshwater chronic criterion for nickel was derived using 15 GMCVs. Calculation results are as follows:

FCV = 6.316 (hardness of 50 mg/L)

CCC = $e^{(0.846 \times \ln(\text{hardness}) - 1.466)} \times CF$

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

Chronic criterion (total) = 11.36 ug/L (hardness of 100 mg/L)

Chronic criterion (dissolved) = 11 ug/L (hardness of 100 mg/L; rounded to two significant digits)

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

Rank	GMCV* (µg/L)	Species	SMCV* (µg/L)
1	6.702	Ceriodaphnia dubia	6.702
2	7.728	Hyalella azteca	7.728
3	9.257	Neocloeon triangulifer	9.257
4	10.26	Lampsilis siliquoidea	10.26
5	10.68	Lymnaea stagnalis	10.68
6	22.78	Daphnia magna	22.78
7	82.99	Acipenser fulvescens	82.99
8	83.67	Xenopus laevis	83.67
9	120.0	Pimephales promelas	120.0
10	120.3	Clistoronia magnifica	120.3
11	146.8	Oncorhynchus mykiss	146.8
12	379.4	Gastrophryne carolinesis	379.4
13	429.7	Bufo terrestris	429.7
14	474.8	Cottus bairdi	474.8
15	893.2	Lithobates sylvaticus	893.2

Table 35. Freshwater chronic studies that met data acceptability requirements for nickel criteria development (S = static, R = static renewal, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Ceriodaphnia dubia	R, M	7.2	7.2	113	3.623	Yes.	Keithly et al. 2004
Ceriodaphnia dubia	R, M	4.2	4.2	161	1.566	Yes.	Keithly et al. 2004
Ceriodaphnia dubia	R, M	7.5	7.5	253	1.908	Yes.	Keithly et al. 2004
Hyalella azteca	R, M	41.01	41.14	91	24.79	Yes.	Keithly et al. 2004
Neocloeon triangulifer	R, M	23	23.07	97	13.17	Yes.	Besser et al. 2021
Ceriodaphnia dubia	R, M	12	12.04	24	22.40	Yes.	Besser et al. 2021
Ceriodaphnia dubia	R, M	8.5	8.5	292	1.916	Yes.	Besser et al. 2021
Lymnaea stagnalis	R, M	147	147	116.1	72.29	Yes.	Cremazy et al. 2018
Neocloeon triangulifer	R, M	11.66	11.70	100	6.507	Yes.	Soucek et al. 2020
Hyalella azteca	FT, M	4.5	4.5	105	2.409	Yes.	Wang et al. 2020
Lampsilis siliquoidea	FT, M	19	19	104	10.26	Yes.	Wang et al. 2020
Daphnia magna	R, M	191	192	175.2	66.32	Yes.	Nys et al. 2016a
Lymnaea stagnalis	R, M	32	32	175.2	11.11	Yes.	Nys et al. 2016a
Ceriodaphnia dubia	R, M	33	31	98	18.73	Yes.	Nys et al. 2016b

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Ceriodaphnia dubia	R, M	31	33	103	16.87	Yes.	Nys et al. 2016b
Ceriodaphnia dubia	R, M	33	33	84	21.34	Yes.	Nys et al. 2017
Ceriodaphnia dubia	R, M	14	14	88	8.704	Yes.	Nys et al. 2017
Bufo terrestris	R, M	770	772	100	429.7	Yes.	Fort et al. 2006
Gastrophryne carolinensis	R, M	680	682	100	379.4	Yes.	Fort et al. 2006
Xenopus laevis	R, M	150	150	100	83.45	Yes.	Fort et al. 2006
Daphnia magna	R, M	12.7	12.7	41.7	14.85	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	21.7	21.8	59.7	18.73	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	27	27	97.1	15.45	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	20.4	20.5	132	9.000	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	45	45	169	16.11	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	42.4	42.5	243	11.16	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	20.9	21.0	42.8	23.91	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	29	29	68.2	22.37	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	47.7	47.8	117	23.31	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	58.3	58.5	165	21.30	Yes.	Deleebeeck et al. 2008

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Daphnia magna	R, M	73.2	73.4	315	15.47	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	33.2	33.3	53.4	31.50	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	34.2	34.3	53.4	32.45	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	40.6	40.7	53.5	38.46	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	37.3	37.4	53.9	35.11	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	29.7	29.8	54	27.91	Yes.	Deleebeeck et al. 2008
Daphnia magna	R, M	25.8	25.9	52.4	24.87	Yes.	Deleebeeck et al. 2008
Lithobates sylvaticus	R, M	2440	2447	164	893.2	Yes.	Klemish et al. 2018
Daphnia magna	R, M	14.77	14.81	51	14.52	Yes.	Chapman et al. 1980
Daphnia magna	R, M	123.1	123.5	105	65.71	Yes.	Chapman et al. 1980
Daphnia magna	R, M	356.6	357.7	205	108.1	Yes.	Chapman et al. 1980
Clistoronia magnifica	FT, M	128.4	128.8	54	120.3	Yes.	Nebaker et al. 1984
Oncorhynchus mykiss	FT, M	91.15	91.42	52	88.18	Yes.	Nebaker et al. 1985
Oncorhynchus mykiss	FT, M	240.3	241.0	49	244.4	Yes.	Nebaker et al. 1985
Pimephales promelas	FT, M	526.7	528.3	210	156.4	Yes.	Pickering 1974

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Pimephales promelas	FT, M	217.3	218.0	44.5	239.8	Yes.	Lind et al. manuscript
Lymnaea stagnalis	R, M	1.766	1.772	60.1	1.512	Yes.	Niyogi et al. 2014
Daphnia magna	R, M	34.3	34.4	182	11.53	Yes.	Pereira et al. 2017
Daphnia magna	R, M	42.9	43.03	182	14.42	Yes.	Pereira et al. 2017
Daphnia magna	R, M	74.1	74.32	182	24.91	Yes.	Pereira et al. 2017
Cottus bairdi	R, M	741.6	743.9	85	474.8	Yes.	Besser et al. 2020
Acipenser fulvescens	R, M	129.6	130.0	85	82.99	Yes.	Besser et al. 2020
Pimephales promelas	FT, M	82.70	82.95	100	46.01	Yes.	Birge et al. 1984
Daphnia magna	R, M	29.70	29.79	45	32.56	Yes.	Pane et al. 2004

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 36; 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 Implementation Plan[7].

We propose to adopt EPA recommendations for freshwater selenium criteria and make no changes to Washington's saltwater acute and chronic selenium criteria (Table 36). 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.

Table 36. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic selenium criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute	FW Chronic	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	20 µg/L	5 µg/L	290	71
EPA	15.1 mg/kg dry weight (egg-ovary)[1,2] 8.5 mg/kg dry weight (whole-body)[1,3] 11.3 mg/kg dry weight (muscle)[1,3] 1.5 µg/L (lentic)[4] 3.1 µg/L (lotic)[4] $\mathrm{WQC}_{int} = \mathrm{WQC}_{30\text{-}day} - C_{bkgrnd}\,(1 - f_{int}) / f_{int}$ [4,5]		290	71
Adopted	15.1 mg/kg dry weight (egg-ovary)[1] 8.5 mg/kg dry weight (whole-body)[2] 11.3 mg/kg dry weight (muscle)[2] 1.5 µg/L (lentic)[3] 3.1 µg/L (lotic)[3] $\mathrm{WQC}_{int} = \mathrm{WQC} - C_{bkgrnd}\,(1 - f_{int}) / f_{int}$ [3,4]		No change	No change

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[7] https://fortress.wa.gov/ecy/publications/summarypages/2410031.html

[1] 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.

[2] 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.

[3] 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.

[4] 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_{bkgrnd} 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 ≥ 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 freshwater silver criteria accounts for endangered species protection levels by incorporating new scientific studies available since EPA last updated the criteria in 1980 (Table 37; USEPA, 1980). The 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 scientific studies, 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 37. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic silver criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	3.4*^ (1-hour)	-	1.9^ (instantaneous)	-
EPA	3.2*^ (instantaneous)	-	1.9^ (instantaneous)	-
Adopted	0.44*^ (1-hour)	0.17*^ (4-day)	2.3 (1-hour)	0.91 (4-day)

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

^ 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 38. New studies that met data acceptability requirements are presented in Table 39. Studies used in previous EPA derivations but not used in this derivation are found in Table 40. The freshwater acute criterion for silver was derived using 18 GMAVs. Calculation results are as follows:

FAV = 0.3111 (hardness of 50 mg/L)

CMC = 0.1555 µg/L (hardness of 50 mg/L)

CMC = $e^{(1.72 \times \ln(\text{hardness}) - 8.590)} \times CF$

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

Acute criterion (total) = 0.5122 µg/L (hardness of 100 mg/L)

Acute criterion (dissolved) = 0.44 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 38. Freshwater acute toxicity data used for criteria derivation reported as total recoverable silver.

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
1	0.3620	Ceriodaphnia dubia	0.3620
2	0.7346	Daphnia magna	0.7346

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
3	2.930	Hyalella azteca	2.930
4	3.222	Rhinichthys osculus	3.222
5	3.351	Cottus bairdi	3.351
6	4.992	Oncorhynchus mykiss	4.992
7	5.390	Gammarus pseudolimnaeus	5.390
8	7.421	Pimephales promelas	7.421
9	10.66	Jordanella floridae	10.66
10	10.84	Leptophlebia sp.	10.84
11	18.32	Ictalurus punctatus	18.32
12	29	Hydra sp.	29
13	63.29	Nephelopsis obscura	63.29
14	93.94	Lepomis macrochirus	93.94
15	241	Aplexa hypnorum	241
16	379.0	Chironomus tentans	379.0
17	3788	Tanytarsus dissimiliis	3788
18	4612	Philodina acuticornis	4612

* Normalized to 50 mg/L hardness

Table 39. 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
Daphnia magna	R, M	0.26	150	0.039	Yes.	Bianchini et al. 2002
Daphnia magna	R, M	0.18	115	0.043	Yes.	Bianchini et al. 2002
Ceriodaphnia dubia	R, M	0.5	90	0.18	Yes.	Bielmyer et al. 2002
Pimephales promelas	FT, M	30	103	8.66	Yes.	Birge et al. 1984
Pimephales promelas	R, M	7.8	48	8.37	No. Other studies with the same species used flow through design.	Erickson et al. 1998
Daphnia magna	S, M	0.58	49	0.60	Yes.	Erickson et al. 1998
Hydra sp.	S, M	29	50	29	Yes.	Brooke et al. 1986
Nephelopsis obscura	S, M	59	48	63.29	Yes.	Brooke et al. 1986
Leptophlebia sp.	S, M	8.7	44	10.84	Yes.	Brooke et al. 1986
Pimephales promelas	R, M	5.412	80	2.411	No. Other studies with the same species used flow through design.	Diamond et al. 1997
Pimephales promelas	R, M	8.471	80	3.774	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
Pimephales promelas	R, M	7.882	80	3.512	No. Other studies with the same species used flow through design.	Diamond et al. 1997
Pimephales promelas	R, M	5.294	80	2.359	No. Other studies with the same species used flow through design.	Diamond et al. 1997
Ceriodaphnia dubia	R, M	1.294	80	4.263	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
Ceriodaphnia dubia	R, M	1.294	80	4.263	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
Ceriodaphnia dubia	R, M	1.059	80	3.488	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
Ceriodaphnia dubia	R, M	0.8235	80	2.713	No. LC50 is 10x other studies with the same species.	Diamond et al. 1997
Pimephales promelas	S, M	2.43	50	2.43	No. Other studies with the same species used flow through design.	Karen et al. 1999
Pimephales promelas	S, M	2.24	100	0.68	No. Other studies with the same species used flow through design.	Karen et al. 1999
Pimephales promelas	S, M	2.79	200	0.26	No. Other studies with the same species used flow through design.	Karen et al. 1999
Daphnia magna	R, M	0.844	100	0.26	Yes.	Karen et al. 1999
Daphnia magna	R, M	1.009	200	0.09	Yes.	Karen et al. 1999
Pimephales promelas	FT, M	16	38	25.65	Yes.	LeBlanc et al. 1984

Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Oncorhynchus mykiss	R, M	14.7	140	2.501	No. Other studies with same species used flow through design.	Mann et al. 2004
Oncorhynchus mykiss	FT, M	3.88	130	0.75	Yes.	Morgan and Wood, 2004
Ceriodaphnia dubia	S, M	0.92	70	0.52	Yes.	Rodgers et al. 1997
Daphnia magna	S, M	1.06	70	0.59	Yes.	Rodgers et al. 1997
Hyalella azteca	S, M	6.8	70	3.81	Yes.	Rodgers et al. 1997
Chironomus tentans	S, M	676	70	388.0	Yes.	Rodgers et al. 1997
Pimephales promelas	S, M	11.6	70	6.5	No. Other studies with same species used flow through design.	Rodgers et al. 1997
Pimephales promelas	FT, M	6.7	44	8.35	Yes.	Holcombe et al. 1983
Ictalurus punctatus	FT, M	17.3	44	21.55	Yes.	Holcombe et al. 1983
Aplexa hypnorum	S, M	241	50	241	Yes.	Holcombe et al. 1983
Daphnia magna	S, U	1.5	72	0.8	No. Other studies with same species measured chemical concentrations.	Leblanc 1980
Pimephales promelas	FT, M	10.7	45	12.83	Yes.	Lima 1982
Jordanella floridae	FT, M	9.2	45	11.03	Yes.	Lima 1982

Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Gammarus pseudolimnaeus	FT, M	4.5	45	5.39	Yes.	Lima 1982
Tanytarsus dissimiliis	FT, M	3160	45	3788	Yes.	Lima 1982
Pimephales promelas	FT, M	9	45	10.78	Yes.	Holcombe et al. 1987
Oncorhynchus mykiss	FT, M	6	45	7.19	Yes.	Holcombe et al. 1987
Ictalurus punctatus	FT, M	13	45	15.58	Yes.	Holcombe et al. 1987
Pimephales promelas	S, M	2.43	50	2.43	No. Other studies with same species used flow through design.	Forsythe 1996
Pimephales promelas	S, M	2.24	100	0.6799	No. Other studies with same species used flow through design.	Forsythe 1996
Pimephales promelas	S, M	2.79	200	0.2571	No. Other studies with same species used flow through design.	Forsythe 1996
Daphnia magna	S, U	10	240	0.673	No. Other studies with same species measured chemical concentrations.	Khangarot 1987
Pimephales promelas	FT, M	5.1	53	4.614	Yes.	Brooke et al. 1993
Hyalella azteca	FT, M	2.1	48	2.253	Yes.	Brooke et al. 1993
Ceriodaphnia dubia	S, M	0.4	88	0.1513	Yes.	Brooke et al. 1993

Species	Method	LC50 (µg/L total silver)	Hardness (mg/L)	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Oncorhynchus mykiss	FT, M	7.6	120	1.686	Yes.	Galvez et al. 2002

* Normalized to 50 mg/L hardness

Table 40. Freshwater acute studies not used from previous EPA criteria derivations.

Species	SMAV *(µg/L)	Reason	Reference
Gammarus pseudolimnaeus	4827	Repeat of Lima 1982 publication used in current derivation.	USEPA, 1980
Tanytarsus dissimiliis	3433	Repeat of Lima 1982 publication used in current derivation.	USEPA, 1980
Daphnia magna	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 41). Table 42 shows the ACR studies that met test acceptability requirements but were not used. Calculation results are as follows:

FAV = 0.3111 (hardness of 50 mg/L)

FACR = 5.028

CCC = 0.0619 (hardness of 50 mg/L)

CCC = $e^{(1.72 \times \ln(\text{hardness}) - 9.511)}$ x CF

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

Chronic criterion (total) = 0.2039 µg/L (hardness of 100 mg/L)

Chronic criterion (dissolved) = 0.17 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 41. 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	43	22	2		USEPA, 1980
Daphnia magna	0.81	0.45	1.8		Kolkmeier and Brooks, 2013
Daphnia magna	2.12	6.88	3.25	2.27	Bianchini, 2008
Mysidopsis bahia	250	18	14	14	USEPA, 1980
Oncorhynchus mykiss	6.5	1.624	4.00	4	Davies et al. 1978
Geometric mean				5.028	

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

Table 42. 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
Oncorhynchus mykiss	54	ACR was 10X greater than other study using the same species.	USEPA, 1980
Ceriodaphnia dubia	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 37). 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 scientific studies 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 18 GMAVs (Table 43). New studies since EPA last updated the saltwater acute silver criterion are found in Table 44. Calculation results are as follows:

FAV = 5.402

CMC = 2.7011

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

Acute criterion (total) = 2.701 µg/L

Acute criterion (dissolved) = 2.3 µg/L (rounded to 2 significant digits)

Table 43. Saltwater acute toxicity data used for criteria derivation reported as total recoverable silver.

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
1	4.7	Paralichthys dentatus	4.7
2	18.97	Strongylocentrotus purpuratus Stronglyocentrotus droebachiensis	15 24
3	20	Crassostrea viriginica	20
4	21	Mercenaria mercenaria	21
5	33	Argopecten irradians	33
6	33	Dendraster excentricus	33
7	33	Cancer magister	33
8	36	Acartia tonsa	36

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
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	404.5	Oncorhynchus mykiss	404.5
14	500	Pseudopieuronectes americanus	500
15	550	Apeltes quadracus	550
16	1400	Cyprinodon variegatus	1400
17	2250	Opsanus beta	2250
18	3830	Perna viridis	3830

Table 44. 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
Oncorhynchus mykiss	S, U	404.5	Yes.	Ferguson and Hogstrand, 1998
Stronglyocentrotus droebachiensis	S, M	24	Yes.	Dinnel et al. 1989
Strongylocentrotus purpuratus	S, M	15	Yes.	Dinnel et al. 1989
Dendraster excentricus	S, M	33	Yes.	Dinnel et al. 1989
Cancer magister	S, M	33	Yes.	Dinnel et al. 1989
Brachionus plicatilis	S, M	77.41	Yes.	Saunders, 2012
Oligocottus maculosus	R, M	331	Yes.	Shaw et al. 1998
Mysidopsis bahia	FT, M	305.9	Yes.	Ward and Kramer, 2002
Opsanus beta	R, M	2250	Yes.	Wood et al. 2004
Mysidopsis bahia	FT, M	141	Yes.	McKenney, 1982
Mysidopsis bahia	FT, M	300	Yes.	McKenney, 1982
Mysidopsis bahia	FT, M	300	Yes.	McKenney, 1982
Mysidopsis bahia	FT, M	64	Yes.	McKenney, 1982
Mysidopsis bahia	FT, M	298	Yes.	McKenney, 1982
Perna viridis	R, U	3830	Yes.	Vijayavel et al. 2007

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 41). Calculation results are as follows:

FAV = 5.402

FACR = 5.028

CCC = FAV / FACR = 1.074

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

Chronic criterion (total) = 0.9129 µg/L

Chronic criterion (dissolved) = 0.91 µg/L (rounded to 2 significant digits)

Zinc

Summary of Criteria Recommendations and Changes

The freshwater zinc criteria accounts for endangered species protection levels by incorporating new scientific studies available since EPA last updated the freshwater criteria in 1995. The freshwater zinc criteria are more stringent than EPA recommendations (Table 45; 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 45. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic zinc criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	114*^ (1-hour)	105*^ (4-day)	90^ (1-hour)	81^ (4-day)
EPA	120*^ (1-hour)	120*^ (4-day)	90^	81^
Adopted	67*^ (1-hour)	24*^ (4-day)	No change	No change

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

^ 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 46. New studies that met data acceptability requirements are presented in Table 47. The freshwater acute criterion for zinc was derived using 70 GMAVs. According to EPA 1985 guidelines, rank two through four are used when the number of GMAVs exceed 59. Calculation results are as follows:

FAV = 76.65 (hardness of 50 mg/L)

CMC = 38.32 µg/L (total; hardness of 50 mg/L)

CMC = $e^{(0.8473 \times \ln(\text{hardness} + 0.3313)} \times CF$

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

Acute criterion (total) = 68.94 µg/L (hardness of 100 mg/L)

Acute criterion (dissolved) = 67 µg/L (hardness of 100 mg/L; rounded to two significant digits)

Table 46. 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	61.38	Euchlanis dilatatast	61.38
3	70.29	Ceriodaphnia dubia Ceriodaphnia reticulata	97.46 50.7

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
4	75.88	Hyalella azteca	75.88
5	76.13	Leptoxis ampla	76.13
6	102.3	Limnodrilus hoffmeisteri	102.3
7	102.5	Acipenser transmontanus	102.5
8	119.4	Morone saxatilis	119.4
9	175.7	Cottus bairdi	175.7
10	176.5	Lampsilis rafinesqueana Lampsilis siliquoidea	171.6 181.7
11	227.8	Agosia chrysogaster	227.8
12	231.8	Lymnaea stagnalis	231.8
13	255.4	Pomacea paludosa	255.4
14	305.7	Daphnia magna Daphnia pulex Daphnia carinata Daphnia prolata	240.8 252.9 188.9 759.7
15	344.6	Bryocamptus zschokkei	344.6
16	373.8	Somatogyrus sp.	373.8
17	474.5	Prosopium williamsoni	474.5
18	750.3	Oncorhynchus mykiss Oncorhynchus kisutch Oncorhynchus nerka Oncorhynchus tshawytscha Oncorhynchus clarkii	623.7 1628 1502 446.4 349.2
19	772.3	Anaxyrus boreas boreas	772.3
20	790	Oreochromis mossambicus	790
21	801.1	Physa gyrina Physa heterostropha	589.9 1088
22	856.0	Villosa umbrans Villosa nebulosa	1479 495.4
23	863.0	Pimephales promelas	863.0
24	1224	Salvelinus fontinalis	1224
25	>1257	Limnodrilus hoffmeisteri	>1257
26	1307	Pectinatella magnifica	1307
27	1370	Salmo salar Salmo trutta	2176 862.9
28	1578	Helisoma campanulatum	1578
29	1607	Plumatella emarginata	1607
30	1672	Jordanella floridae	1672
31	1707	Lophopodella carteri	1707
32	1746	Catostomus latipinnis	583.4

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
		Catostomus commersoni	5228
33	1769	Drunella grandis	1769
34	1913	Atyaephyra desmarestii	1913
35	1946	Rhinichthys cataractae	1946
36	2136	Xyrauchen texanus	2136
37	2545	Platygobio gracilis	2545
38	2791	Gila elegans	2791
39	2836	Ptychocheilus lucius Ptychocheilus oregonesis	1222 6580
40	2933	Hydra viridissima Hydra vulgaris Hydra oligactis	1719 3537 4150
41	3265	Lirceus alabamae	3265
42	4341	Xiphophorus maculatus	4341
43	4900	Corbicula fluminea	4900
44	5135	Hyla chrysocelis	5135
45	5588	Tubifex tubifex	5588
46	6000	Notemigonus crysoleucas	6000
47	6053	Poecilia reticulata	6053
48	6315	Nais elinguis Nais sp.	2167 18400
49	7233	Cyprinus carpio	7233
50	8100	Gammarus sp.	8100
51	8157	Asellus bicrenate Asellus communis	5731 11610
52	8483	Lepomis gibbosus Lepomis macrochirus	18790 3830
53	8760	Chironomus riparius Chironomus plumosus	3506 21890
54	8974	Melanoides tuberculata	8974
55	9712	Lumbriculus variegatus	9712
56	10250	Carassius auratus	10250
57	11305	Rana pipiens	11305
58	11899	Baetis tricaudatus	11899
59	13630	Anguilla rostrata	13630
60	16820	Amnicola sp.	16820
61	17940	Fundulus diaphanous	17940
62	19176	Xenopus laevis	19176
63	19800	Crangonyx pseudogracilis	19800
64	21608	Branchiura sowerbyi	21608

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
65	>48500	Lepidostoma sp.	>48500
66	56458	Rhithrogena hageni	56458
67	>67543	Chloroperlidae	>67543
68	>67543	Ephemerella sp.	>67543
69	69062	Cinygmula sp.	69062
70	88960	Argia sp.	88960

* Normalized to 50 mg/L hardness

Table 47. 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
Tubifex tubifex	S, U	11150	113	5588	Yes.	Chatterjee et al. 2019
Branchiura sowerbyi	S, U	51097	120	24335	Yes. 24-hour LC50.	Dhara et al. 2020
Pimephales promelas	S, M	839	110	429.4	No. Other studies using the same species had a flow through design.	Lynch et al. 2016
Daphnia magna	S, M	696	90	423	Yes.	Meyer et al. 2015
Daphnia magna	S, M	330	90	200.6	Yes.	Santos-Medrano & Rico-Martinez 2015
Daphnia prolata	S, M	1250	90	759.7	Yes.	Santos-Medrano & Rico-Martinez 2015
Lampsilis rafinesqueana	S, M	163	44	181.7	Yes.	Wang et al. 2010
Lampsilis siliquoidea	S, M	145	41	171.6	Yes.	Wang et al. 2010
Hyalella azteca	S, M	101.2	107	53.13	Yes.	Wang et al. 2020
Oncorhynchus mykiss	FT, M	162	20	352.1	Yes	Alsop et al. 1999
Oncorhynchus mykiss	FT, M	869	120	413.9	Yes	Alsop et al. 1999
Oncorhynchus mykiss	FT, M	103	10	402.8	Yes	Alsop and Wood, 1999
Oncorhynchus mykiss	FT, M	2615	120	1245	Yes.	Alsop and Wood, 2000
Daphnia magna	S, M	121	46	129.9	Yes.	Barata et al. 1998
Daphnia magna	R, M	1425	150	561.9	No. Concentrations were not measured.	Bianchini et al. 2002
Pimephales promelas	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
Pimephales promelas	R, M	745.3	49.3	754.2	No. Other studies using the same species had a flow through design.	Bringolf et al. 2006
Pimephales promelas	R, M	876.1	61.4	736.2	No. Other studies using the same species had a flow through design.	Bringolf et al. 2006
Cottus bairdi	FT, U	439	154	169.2	Yes.	Brinkman & Woodling 2005
Rhithrogena hageni	FT, M	51636	45	56458	Yes.	Brinkman & Johnston 2012
Oncorhynchus clarkii	FT, M	189.2	47.4	197.9	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Oncorhynchus clarkii	FT, M	1452	144	592.5	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Oncorhynchus clarkii stomias	FT, M	321.1	47.4	335.9	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Oncorhynchus clarkii stomias	FT, M	1534	144	625.9	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Oncorhynchus clarkii virginalis	FT, M	145.2	41.7	169.3	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Oncorhynchus clarkii virginalis	FT, M	1063	144	434.0	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Prosopium williamsoni	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
Prosopium williamsoni	FT, M	437.6	41.1	516.7	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Prosopium williamsoni	FT, M	481.6	47.8	500.3	Yes. Combined with other Brinkman & Johnston 2012 values	Brinkman & Johnston 2012
Cottus bairdi	FT, M	338.4	99.5	188.9	Yes.	Brinkman & Johnston 2012
Rhinichthys cataractae	FT, M	1943	49.9	1946	Yes.	Brinkman & Johnston 2012
Platygobio gracilis	FT, M	2648	52.4	2545	Yes.	Brinkman & Johnston 2012
Anaxyrus boreas boreas	FT, M	863.0	57	772.3	Yes.	Brinkman & Johnston 2012
Baetis tricaudatus	FT, M	10327	42.3	11899	Yes.	Brinkman & Johnston 2012
Cinygmula sp.	FT, M	70348	51.1	69062	Yes.	Brinkman & Johnston 2012
Drunella doddsi	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
Chloroperlidae	FT, M	>68800	51.1	>67543	Yes.	Brinkman & Johnston 2012
Ephemerella sp.	FT, M	>68800	51.1	>67543	Yes.	Brinkman & Johnston 2012
Lepidostoma sp.	S, M	>48500	50	>48500	Yes.	Brinkman & Johnston 2012
Bryocamptus zschokkei	R, M	620	100	344.6	Yes.	Brown et al. 2005
Ptychocheilus lucius	S, U	3340	199	1036	Yes.	Buhl 1996
Gila elegans	S, U	5350	199	1660	Yes.	Buhl 1996
Xyrauchen texanus	S, U	2920	199	906	Yes.	Buhl 1996
Acipenser transmontanus	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
Oncorhynchus mykiss	FT, M	233.0	100	129.5	Yes.	Calfee et al. 2014
Salmo trutta	FT, M	890.6	51.9	862.9	Yes.	Davies et al. 2000
Salvelinus fontinalis	FT, M	1109	84.2	713.4	Yes.	Davies et al. 2001
Ceriodaphnia dubia	R, M	119.3	80	80.13	Yes.	Diamond et al. 1997
Ceriodaphnia dubia	R, M	203.5	80	136.6	Yes.	Diamond et al. 1997
Ceriodaphnia dubia	R, M	186.7	80	125.4	Yes.	Diamond et al. 1997
Ceriodaphnia dubia	R, M	307.4	80	206.4	Yes.	Diamond et al. 1997
Pimephales promelas	R, M	387.0	80	259.9	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
Pimephales promelas	R, M	296.8	80	199.3	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
Pimephales promelas	R, M	100	80	67.15	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
Pimephales promelas	R, M	380	80	255.1	No. Other studies using the same species had a flow through design.	Diamond et al. 1997
Acipenser transmontanus	R, M	153.4	76	107.6	Yes.	Vardy et al. 2014
Oncorhynchus mykiss	S, U	12800	250	3273	No. Other studies using the same species had a flow through design.	Gundogdu 2008
Pomacea paludosa	R, M	136.0	28	222.3	Yes.	Hoang & Tong 2015
Pomacea paludosa	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
Pomacea paludosa	R, M	462.2	103	250.5	Yes.	Hoang & Tong 2015
Pomacea paludosa	R, M	587.9	108	306.2	Yes.	Hoang & Tong 2015
Pomacea paludosa	R, M	1098	230	301.4	Yes.	Hoang & Tong 2015
Hydra vulgaris	S, M	7400	204	2248	Yes.	Karntanut & Pascoe 2000
Hydra vularis (Zurich)	S, M	14000	210	4150	Yes.	Karntanut & Pascoe 2002
Hydra vulgaris	S, M	13000	210	3854	Yes.	Karntanut & Pascoe 2002
Hydra oligactis	S, M	14000	210	4150	Yes.	Karntanut & Pascoe 2002
Hydra viridissima	S, M	11000	210	3261	Yes.	Karntanut & Pascoe 2002
Hydra viridissima	S, M	2500	207	750.2	Yes.	Karntanut & Pascoe 2002
Daphnia magna	R, U	157.5	105	83.98	Yes.	Lazorchak et al. 2009
Pimephales promelas	S, M	839.5	110	430.4	No. Other studies using the same species had a flow through design.	Lynch et al. 2016
Oncorhynchus mykiss	R, M	130	24	242.1	No. Other studies using the same species had a flow through design.	Mebane et al. 2008
Ceriodaphnia dubia	R, M	119	181	40.01	Yes.	Naddy et al. 2015
Oncorhynchus mykiss	S, M	304	181	102.2	No. Other studies using the same species had a flow through design.	Naddy et al. 2015
Atyaephyra desmarestii	S, M	7810	263	1913	Yes.	Pestana et al. 2007
Nais elinguis	R, M	912	18	2167	Yes.	Shuhaimi et al. 2012
Lepomis macrochirus	FT, M	4500	214	1313	Yes.	Van der Schalie et al. 2004
Cottus bairdi	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
Drunella grandis	FT, M	1352	36.4	1769	Yes.	Brinkman & Vieira 2008
Daphnia magna	S, M	173.5	100	96.44	Yes.	Cooper et al. 2009
Daphnia carinata	S, M	339.8	100	188.9	Yes.	Cooper et al. 2009
Chironomus plumosus	S, U	32600	80	21890	Yes.	Fargasova 2001
Daphnia magna	S, U	550	90	334.3	Yes.	Jellyman et al. 2011
Ptychocheilus lucius	S, U	1700	197	532.0	Yes.	Hamilton 1995
Xyrauchen texanus	S, U	8900	197	2785	Yes.	Hamilton 1995
Gila elegans	S, U	15000	197	4694	Yes.	Hamilton 1995
Ptychocheilus lucius	S, U	8400	150	3311	Yes.	Hamilton & Buhl 1997
Xyrauchen texanus	S, U	9800	150	3863	Yes.	Hamilton & Buhl 1997
Catostomus latipinnis	S, U	1480	150	583.4	Yes.	Hamilton & Buhl 1997
Hydra vulgaris	S, U	2300	19.5	5108	Yes.	Holdway et al. 2001
Hydra viridissima	S, U	935	19.5	2076	Yes.	Holdway et al. 2001
Daphnia magna	S, M	1319	150	520.0	Yes	Yim et al. 2006
Daphnia magna	S, M	306.7	44	341.8	Yes	Yim et al. 2006
Hyla chrysocelis	S, M	4696	45	5135	Yes.	Gottschalk 1995
Rana pipiens	S, M	10339	45	11305	Yes.	Gottschalk 1995
Daphnia magna	R, M	233	250	59.58	Yes.	Li et al. 2019
Limnodrilus hoffmeisteri	R, M	400	250	102.3	Yes.	Li et al. 2019
Chironomus riparius	R, M	13710	250	3506	Yes.	Li et al. 2019
Neocloeon triangulifer	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
Villosa umbrans	R, U	1302	43	1479	Yes.	Gibson et al. 2018
Villosa nebulosa	R, U	436	43	495.4	Yes.	Gibson et al. 2018
Leptoxis ampla	R, U	67	43	76.13	Yes.	Gibson et al. 2018
Somatogyrus sp.	R, U	329	43	373.8	Yes.	Gibson et al. 2018
Euchlanis dilatata	S, M	101	90	61.38	Yes.	Hernandez-Flores et al. 2020
Ceriodaphnia dubia	R, M	139.1	100	75.59	Yes.	Ivey et al. 2017
Daphnia magna	R, M	653.4	100	355.2	Yes.	Ivey et al. 2017
Hyalella azteca	R, M	199.4	100	108.4	Yes.	Ivey et al. 2017
Physa gyrina	R, M	380.4	100	206.8	Yes. Other Physa gyrina study available is flow-through but this study showed higher sensitivity so both were used.	Ivey et al. 2017
Lymnaea stagnalis	R, M	426.4	100	231.8	Yes.	Ivey et al. 2017
Melanoides tuberculata	R, M	3900	18.7	8974	Yes.	Shuhaimi-Othman et al. 2012
Poecilia reticulata	S, U	12650	18	30060	No. Other studies using the same test species have measured test concentrations.	Khunyakari et al. 2001

* Normalized to hardness of 50 mg/L

Freshwater Chronic Zinc Criterion

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). We found adequate data to meet the eight family minimum data requirements for the chronic zinc criterion. The data used to derive the freshwater chronic zinc criterion are presented in Table 48. New studies that met data acceptability requirements are presented in Table 49. The freshwater chronic criterion for zinc was derived using 17 GMCVs. Calculation results are as follows:

FCV = 13.80 (hardness of 50 mg/L)

CCC = $e^{(0.8473 \times \ln(\text{hardness}) - 0.6900)}$ x CF

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

Chronic criterion (total) = 24.83 µg/L (hardness of 100 mg/L)

Chronic criterion (dissolved) = 24 µg/L (hardness of 100 mg/L; rounded to two significant digits)

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

Rank	GMCV* (µg/L)	Species	SMCV* (µg/L)
1	16.24	Lampsilis siliquoidea	16.24
2	19.13	Hyalella azteca	19.13
3	25.95	Ceriodaphnia dubia	25.95
4	40.58	Jordanella floridae	40.58
4	53.73	Daphnia magna Daphnia pulex	31.88 90.54
6	64.59	Cottus bairdi	64.59
7	69.04	Acipenser transmontanus	69.04
8	71.80	Lymnaea stagnalis	71.80
9	109.1	Centroptilum triangulifer	109.1
10	150.5	Pimephales promelas	150.5
11	239.3	Bufo boreas	239.3
12	251.9	Salmo trutta	251.9
13	<266.7	Poecilla reticulata	<266.7
14	352.7	Oncorhynchus mykiss Oncorhynchus clarkii Oncorhynchus tshawytscha	198.6 330.9 667.7
15	380.5	Prosopium williamsoni	380.5
16	400.4	Salvelinus fontinalis	400.4
17	>7861	Clistoronia magnifica	>7861

Table 49. Freshwater chronic studies that met data acceptability requirements for zinc criteria development (S = static, R = static renewal, FT = flow-through, U = unmeasured test concentrations, M = measured test concentrations).

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Hyalella azteca	FT, M		34.42	100	19.13	Yes.	Wang et al. 2020
Lampsilis siliquoidea	FT, M		19.35	100	10.76	Yes.	Wang et al. 2020
Lampsilis siliquoidea	FT, M		69.20	170	24.54	Yes.	Wang et al. 2010
Cottus bairdi	FT, M		258.9	154	258.9	Yes.	Brinkman and Woodling 2005
Acipenser transmontanus	FT, M		100.4	100.4	55.81	Yes.	Wang et al. 2014
Oncorhynchus mykiss	FT, M		171.4	100	95.27	Yes.	Wang et al. 2014
Cottus biardi	FT, M		38.37	46.3	40.95	Yes.	Davies et al. 2001
Salvelinus fontinalis	FT, M		422.9	84.2	271.9	Yes.	Davies et al. 2001
Ceriodaphnia dubia	R, M		18.32	100	10.18	Yes.	Cooper et al. 2009
Oncorhynchus mykiss	FT, M		1521	191	488.7	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		116.1	29.1	183.6	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		251.2	102	137.3	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		1162	396	201.2	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		89.43	29.2	141.1	Yes.	De Schamplere et al. 2004

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Oncorhynchus mykiss	FT, M		89.88	45.1	98.09	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		229.1	139	96.35	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		239.6	228	66.24	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		245.8	332	49.43	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		574.4	29.1	908.7	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		418.6	28.7	669.8	Yes.	De Schamplere et al. 2004
Oncorhynchus mykiss	FT, M		203.3	28.42	328.3	Yes.	De Schamplere et al. 2004
Daphnia magna	R, M		83.32	250	21.31	Yes.	Muyssen 2007
Daphnia magna	R, M		147.6	52	142.7	Yes.	Chapman et al. manuscript
Daphnia magna	R, M		59.45	104	31.96	Yes.	Chapman et al. manuscript
Daphnia magna	R, M		46.73	211	13.80	Yes.	Chapman et al. manuscript
Daphnia pulex	R, M		158.7	97	90.54	Yes.	Parkerton et al. 1988
Clistoronia mangifica	FT, M		>5243	31	>7861	Yes.	Nebeker et al. 1984
Oncorhynchus nerka	FT, M		>242	35	>327.4	No. Other species within Oncorhynchus genus have definitive LC50 values.	Chapman 1978
Oncorhynchus tshawytscha	FT, M		371.1	25	667.7	Yes.	Chapman 1975

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Oncorhynchus mykiss	FT, M		276.7	26	481.5	Yes.	Sinley et al. 1974
Oncorhynchus mykiss	FT, M		603	25	1085	Yes.	Cairns et al. 1982
Salvelinus fontinalis	FT, M		854.7	45.9	919.0	Yes.	Holcombe et al. 1979
Pimephales promelas	FT, M		106.3	46	114.1	Yes.	Benoit and Holcombe 1978
Pimephales promelas	FT, M		186.6	46.5	198.5	Yes.	Norberg-King 1989
Jordanella floridae	FT, M		36.41	44	40.58	Yes.	Spehar 1976a,b
Poecilia reitculata	FT, M		<173	30	<266.7	Yes.	Pierson 1981
Cottus biardi	FT, M	75	76.06	103	41.23	Yes.	Besser et al. 2007
Ceriodaphnia dubia	FT, M	67	67.95	292	15.23	Yes.	Besser et al. 2021
Ceriodaphnia dubia	FT, M	75	76.06	24	141.7	Yes.	Besser et al. 2021
Ceriodaphnia dubia	FT, M	90	91.28	18	216.9	Yes.	Besser et al. 2021
Ceriodaphnia dubia	FT, M	43	43.61	323	8.976	Yes.	Besser et al. 2021
Ceriodaphnia dubia	FT, M	39	39.55	377	7.142	Yes.	Besser et al. 2021
Oncorhynchus clarkii	FT, M	134	135.9	31.1	203.2	Yes.	Brinkman and Hansen 2004
Oncorhynchus clarkii	FT, M	1343	1362	149.4	538.8	Yes.	Brinkman and Hansen 2004

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Oncorhynchus mykiss	FT, M	81	82.15	33.3	115.9	Yes.	Brinkman and Hansen 2004
Oncorhynchus mykiss	FT, M	313	317.4	150.9	124.5	Yes.	Brinkman and Hansen 2004
Oncorhynchus mykiss	FT, M	74	75.05	33.2	106.2	Yes.	Brinkman and Hansen 2004
Oncorhynchus mykiss	FT, M	325	329.6	145.4	133.4	Yes.	Brinkman and Hansen 2004
Prosopium williamsoni	FT, M	422	428.0	47.8	444.6	Yes.	Brinkman and Vieira 2008
Prosopium williamsoni	FT, M	309	313.4	47.8	325.6	Yes.	Brinkman and Vieira 2008
Salmo trutta	FT, M	303	307.3	50.9	302.7	Yes.	Davies and Brinkman 1999
Salmo trutta	FT, M	381	386.4	54.1	361.4	Yes.	Davies and Brinkman 1999
Salmo trutta	FT, M	187	189.7	54.4	176.6	Yes.	Davies and Brinkman 1999
Salmo trutta	FT, M	219	222.1	206.7	66.73	Yes.	Davies and Brinkman 1999
Salmo trutta	FT, M	1009	1023	54	958.7	Yes.	Davies and Brinkman 1999
Bufo boreas	FT, M	263.6	267.3	57	239.3	Yes.	Davies and Brinkman 1999
Cottus bairdi	FT, M	267	270.8	156	103.3	Yes.	Davies et al. 2002
Salmo trutta	FT, M	196	198.8	47.7	206.9	Yes.	Davies et al. 2002
Salvelinus fontinalis	FT, M	245	248.5	48.1	256.8	Yes.	Davies et al. 2002

Species	Method	Chronic Value (ug/L dissolved zinc)	Chronic Value (µg/L total zinc)	Hardness (mg/L)	Normalized Chronic Value* (µg/L)	Used in Derivation?	Reference
Daphnia magna	R, M	82.16	83.32	250	21.31	Yes.	Muyssen and Janssen 2007
Acipenser transmontanus	FT, M	112	113.6	70	85.41	Yes.	Vardy et al. 2011
Daphnia magna	R, M	104.3	105.8	182.3	35.35	Yes.	Pereira et al. 2017
Daphnia magna	R, M	73.5	74.54	182.3	24.91	Yes.	Pereira et al. 2017
Daphnia magna	R, M	125.1	126.9	182.3	42.40	Yes.	Pereira et al. 2017
Centroptilum triangulifer	R, M	138	140.0	67.1	109.1	Yes.	Wesner et al. 2014

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 50). We are not aware of any concerns that would result in the disapproval of the 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 50. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	1.1 (instantaneous)	0.001 (24-hour)	0.13 (instantaneous)	0.001 (24-hour)
EPA	1.1 (instantaneous)	0.001 (24-hour)	0.13 (instantaneous)	0.001 (24-hour)
Proposed	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 6PPD-q **(**N-(1,3-Dimethylbutyl)-N′-phenyl-p-phenylenediamine-quinone) criterion is presented in Table 51. The common EPA methodology for developing criteria primarily relies on toxicity data from eight taxonomic families. We currently have quantitative and definitive freshwater acute toxicity values for three out of eight families for 6PPD-q and very limited chronic data. When using qualitative and quantitative data, seven out of eight families are met.

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).

As an exercise, we calculated a 6PPD-q criterion using EPA's single species alternative method. 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 53). 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. 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 and 96 hours and reported an almost 2-fold increase in toxicity between LC50s at 24 and 96 hours. Using the Brinkmann et al. (2022) data describing toxicity between 24 and 96 hours, we extrapolated the 48% increase in toxicity to the three coho salmon 24-hour LC50 values. The revised criterion adjusted based on a 96-hour test duration is 17 ng/L. There are concerns and uncertainties adjusting LC50 values for test duration based on a single study (i.e., Brinkman et al. 2022) and for a different species (i.e., rainbow trout). 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 when combined with the insensitive Chinook salmon toxicity data. 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[8] to derive a 5th 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 six 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 concentration or greater

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[8] https://www.epa.gov/chemical-research/species-sensitivity-distribution-ssd-toolbox

than 6PPD-q solubility, indicating that aquatic invertebrates are not sensitive to 6PPD-q. The 5th percentile of the species sensitivity distribution is 8 ng/L.

We also considered using methods outlined in EPA's recent release of a screening level value for 6PPD-quinone (USEPA, 2024; Appendix C). We used EPA's methods (that utilizes time-weighted average LC50s) but updated the dataset with three newer studies released in 2024 (Liao et al. 2024; Philibert et al. 2024; Shankar et al. 2024) and removed one study from EPA's dataset (Varshney et al. 2022 zebrafish data) because the species is not a resident in North America and does not serve as a surrogate for native North American aquatic species. Philibert et al. (2024) and Shankar et al. (2024) LC50 values required adjustment to represent 6PPD-q loss over the study duration as outlined in USEPA (2024). EPA assumes a 20% loss of 6PPD-q over the duration of the test. We used reported losses from initial to final concentrations reported in Philibert et al. (2024) and EPA's assumption of 20% loss in Shankar et al. (2024). When calculating the LC50 for Shank et al. (2024), we took an average of the initial measured concentrations for each replicate concentration and applied it to all replicates within a treatment whether measured or not. We did not use the highest reported nominal concentration (i.e., 3000 ng/L) because water samples were not measured and there was only one replicate. The LC50 value did not change when excluding the 3000 ng/L treatment level. We used EPA's Toxicity Relationship Analysis Program (TRAP) software to adjust and recalculate LC50 values for 6PPD-q loss using a logistic regression and log-transforming the data.

EPA applied each *Oncorhynchus* species SMAV as a GMAV within the dataset calculations because of large differences in toxicity between species within this genus. We support this method when definitive LC50 values are available and the SMAV is ranked within the four lowest GMAVs. However, we found this method inadequate when an *Oncorhynchus* species was not sensitive (i.e., outside the lowest four ranked GMAVs) and LC50 values were non-definitive. Therefore, *Oncorhynchus* species with SMAVs not in the four lowest GMAVs (i.e., ranked 5th or higher) were combined and a GMAV was calculated. This method accounts for the high sensitivity of individual species within the Oncorhynchus genus without overinflating the number of GMAVs used in criterion calculation and recognizes their importance as a commercially, culturally, or recreationally important species. The 5th percentile of the species sensitivity distribution and EPA's screening level value methods using a combination of SMAVs/GMAVs resulted in a final criterion value of 8 and 12 ng/L, respectively (Appendix C). Given criticisms on using a species sensitivity distribution during public comment on the proposal, we have used EPA's screening level methods to calculate the final criterion for 6PPD-quinone. We have decided to move forward with a FW acute criterion of 12 ng/L. We support that 12 ng/L will be protective of coho salmon and other aquatic life for the following reasons:

- 12 ng/L is approximately 3.5-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. These LC5 and LC10s likely underestimate toxicity because they are based on 24-hour toxicity studies while standard toxicity tests with vertebrates are 96-hours and are the suggested test duration for criteria development.
- 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. These LC5 and LC10s likely underestimate toxicity because they are based on 24-hour toxicity studies while standard toxicity tests with vertebrates are 96-hours and are the suggested test duration for criteria development.
- The species sensitivity distribution is based on 24-hour LC50 values and underestimate toxicity compared with 96-hour standard acute toxicity tests that EPA guidelines recommend

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 12 ng/L.

Table 51. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	-	-	-	-
Adopted	0.012 (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 52. The adopted freshwater acute criterion for 6PPD-q of 0.012 µg/L was derived using 11 SMAVs/GMAVs.

Table 52. Acute toxicity data used in 6PPD-q criterion calculations using methods outlined in USEPA (2024).

Rank	SMAV/GMAV* (µg/L)	Species	SMAV* (µg/L)
1	0.06134	Oncorhynchus kisutch	0.06134
2	0.08872	Oncorhynchus clarkii	0.08872
3	0.4279	Salvelinus fontinalis Salvelinus leucomaenis pluvius Salvelinus namaycush	0.3072 0.51 0.5186
4	0.8306	Oncorhynchus mykiss	0.8306
5	>9.65	Pimephales promelas	>9.65

Rank	SMAV/GMAV* (µg/L)	Species	SMAV* (µg/L)
6	>11.7	Planorbella pilsbryi	>11.7
7	>12.7	Acipenser transmontanus	>12.7
8	>43	Hyalella azteca	>43
9	>46	Daphnia magna	>46
10	65.68	Oncorhynchus gorbuscha Oncorhynchus nerka Oncorhynchus tshawytscha	>9.25 >40 65.68
11	>232	Hexagenia sp.	>232

Table 53. Acute toxicity data considered for criteria development for 6PPD-q.

Species	LC50 (µg/L)	Adjusted LC50 (µg/L)*	Used for Derivation?	Reference
Oncorhynchus kisutch	0.095	0.09216	Yes.	Tian et al. 2022
Oncorhynchus kisutch	0.095	0.07752	Yes.	Tian et al. 2022
Oncorhynchus kisutch	0.0410	0.0363	Yes.	Lo et al. 2023
Oncorhynchus kisutch	0.0804	0.0546	Yes.	Greer et al. 2023
Oncorhynchus mykiss	1.00	1.00	Yes.	Brinkman et al. 2022
Oncorhynchus mykiss	2.26	1.786	Yes.	Di et al. 2022
Oncorhynchus mykiss	0.9	0.9	Yes.	Liao et al. 2024
Oncorhynchus tshawytscha	82.1	65.68	Yes.	Greer et al. 2023
Oncorhynchus tshawytscha	>67.3	>53.85	No. LC50 is not definitive and other data for the same species is definitive.	Lo et al. 2023
Oncorhynchus nerka	>50	>40	Not used in final calculations because other species within the same genus	Greer et al. 2023

Species	LC50 (µg/L)	Adjusted LC50 (µg/L)*	Used for Derivation?	Reference
			have definitive LC50 values.	
Oncorhynchus gorbuscha	>12.8		Not used in final calculations because other species within the same genus have definitive LC50 values.	Foldvik et al. 2024
Salvelinus fontinalis	0.59	0.59	Yes.	Brinkman et al. 2022
Salvelinus fontinalis	0.200	0.16	Yes.	Philibert et al. 2024
Salvelinus namaycush	0.50	0.5186	Yes.	Roberts et al. 2024
Salvelinus leucomaenis Pluvius	0.510		Yes. Species is not a North American resident but serves as a surrogate for other Salvelinus species in North America.	Hiki et al. 2022
Salvelinus alpinus	>14.2		No. LC50 is not definitive. Other studies within the same genus have definitive LC50 values.	Brinkman et al. 2022
Pimephales promelas	>9.65	>9.65	Yes.	Anderson-Bain et al. 2023
Planorbella pilsbryi	>11.7	11.7	Yes.	Prosser et al. 2023
Hexagenia sp.	>232	>232	Yes.	Prosser et al. 2023
Acipenser transmontanus	>12.7		Yes.	Brinkman et al. 2022

Species	LC50 (µg/L)	Adjusted LC50 (µg/L)*	Used for Derivation?	Reference
Oryzias latipes	>34		No. Species is not a resident in North America.	Hiki et al. 2021
Hyalella azteca	>43		Yes.	Hiki et al. 2021
Daphnia magna	>46		Yes.	Hiki et al. 2021
Danio rerio	>54		No. LC50 is not definitive. Species is not a resident in North America.	Hiki et al. 2021
Danio rerio	132.9	106.3	No. Species is not a resident in North America and is only a surrogate for other resident invasive species in North America.	Varshney et al. 2022
Gobiocypris rarus	>500		No. LC50 is not definitive. Species is not a resident in North America.	Di et al. 2022
Salmo salar	>12.2		No. Test duration does not meet EPA standard methods.	Foldvik et al. 2022
Salmo trutta	>12.2		No. Test duration does not meet EPA standard methods.	Foldvik et al. 2022
Oncorhynchus clarkii	0.09328	0.08872	Yes.	Shankar et al. 2024

*Adjustment of LC50 values representing average concentrations over exposure duration

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 54). EPA does not have saltwater recommendations for acrolein. We are not aware of any concerns that would result in the disapproval of the EPA's recommended acrolein criteria.

Table 54. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic acrolein criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	3 (1-hour)	3 (4-day)	-	-
Adopted	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 55). 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 any concerns that would result in the disapproval of the EPA recommended aldrin criteria in Region 10 states.

Table 55. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic aldrin criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	2.5 (instantaneous)	0.0019 (24-hour)	0.71 (instantaneous)	0.0019 (24-hour)
EPA	3 (instantaneous)	-	1.3 (instantaneous)	-
Adopted	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 56). We are not aware of any concerns that would result in the disapproval of the EPA recommended carbaryl criteria in Region 10 states. There are no saltwater chronic recommendations for carbaryl.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	2.1 (1-hour)	2.1 (4-day)	1.6 (1-hour)	-
Adopted	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 57). We are not aware of any concerns that would result in the disapproval of the EPA recommended carbaryl criteria in Region 10 states. We propose no changes to Washington's current chlordane criteria.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	2.4 (instantaneous)	0.0043 (24-hour)	0.09 (instantaneous)	0.004 (24-hour)
EPA	2.4 (instantaneous)	0.0043 (24-hour)	0.09 (instantaneous)	0.004 (24-hour)
Adopted	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 58). EPA does not have saltwater recommendations for chloride. We are not aware of any concerns that would result in the disapproval of the EPA recommended chloride criteria in Region 10 states. We propose no changes to Washington's current chloride criteria.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	860000 (1-hour)	230000 (4-day)	-	-
EPA	860000 (1-hour)	230000 (4-day)	-	-
Adopted	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 59). We are not aware of any concerns that would result in the disapproval of the 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 59. Comparison of Washington’s current freshwater (FW) and saltwater (SW) acute and chronic chlorine criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	19 (1-hour)	11 (4-day)	13 (1-hour)	7.5 (4-day)
EPA	19 (1-hour)	11 (4-day)	13 (1-hour)	7.5 (4-day)
Adopted	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 60). We are not aware of any concerns that would result in the disapproval of the EPA recommended chlorpyrifos criteria in Region 10 states. We propose no changes to Washington’s current chlorpyrifos criteria.

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

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

Cyanide

Summary of Criteria Recommendations and Changes

The freshwater acute and chronic cyanide criteria are more stringent than EPA recommendations (Table 61). The freshwater criteria are based on any new scientific studies since EPA last updated the cyanide criteria in 1995 (USEPA, 1996) and used the 1st percentile of the toxicity data distribution to ensure protection of Washington's endangered species. The cyanide saltwater criteria are identical to EPA recommendations.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	22 (1-hour)	5.2 (4-day)	1 (1-hour)	1 (4-day)
EPA	22 (1-hour)	5.2 (4-day)	1 (1-hour)	1 (4-day)
Adopted	8.2 (1-hour)	1.9 (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 62. New studies that met data acceptability requirements are presented in Table 63. Studies that were used in previous EPA derivations but not in the freshwater acute cyanide derivation are presented in Table 64. The freshwater acute criterion for cyanide was derived using 17 GMAVs and the 1st percentile of the toxicity data distribution. Calculation results are as follows:

FAV = 16.35

CMC = 8.173 µg/L

Acute criterion = 8.2 µg/L (rounded to two significant digits)

Table 62. Freshwater acute toxicity data used for criteria derivation.

Rank	GMAV (µg/L)	Species	SMAV (µg/L)
1	31.03	Daphnia magna Daphnia pulex	10.08 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
8	102	Micropterus salmoides	102
9	125.1	Pimephales promelas	125.1
10	147	Poecilia reticulata	147
11	167	Gammarus pseudolimnaeus	167
12	223	Oreochromis mossambicus	223
13	318	Carassius auratus	318
14	426	Pternoarcys dorsata	426
15	432	Physa heterostropha	432
16	530	Cyprinus carpio	530
17	2326	Asellus communis	2326

Table 63. 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)	**LC50** (µg/L free CN)	Used in Derivation?	Reference
Salmo salar	R, M	90	90	No. Other study used flow through design with measured concentrations.	Tryland & Grande 1983
Salmo salar	FT, M	73	73	Yes.	Alabaster 1983
Daphnia magna	FT, U	19	10.1	Yes.	Jaafarzadeh et al. 2013
Lepomis macrochirus	FT, M	110	110	Yes.	Van der Schalie et al. 2004
Cyprinus carpio	R, M	1000	530	Yes.	David et al. 2010
Oreochromis mossambicus	R, M	420	223	Yes.	David et al. 2010

Table 64. Freshwater acute studies not used from previous EPA criteria derivations.

Species	SMAV (µg/L)	Reason	Reference
Daphnia magna	160	Static unmeasured test. New studies available on flow-through test. LC50 is also 10x greater than other study available.	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 acute criterion using the 1st percentile to calculate the chronic criterion. Calculations results were as follows:

FACR = 8.57

FAV = 16.35

CCC = 1.907

Chronic criterion = 1.9 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 65). We are not aware of any concerns that would result in the disapproval of the EPA recommended demeton criteria in Region 10 states.

Table 65. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic demeton criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-

EPA	-	0.1 (-)	-	0.1 (-)
Adopted	-	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 66). We are not aware of any concerns that would result in the disapproval of the EPA recommended diazinon criteria in Region 10 states.

Table 66. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic diazinon criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	0.17 (1-hour)	0.17 (4-day)	0.82 (1-hour)	0.82 (4-day)
Adopted	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 67). 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 67. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic dieldrin criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	2.5 (instantaneous)	0.0019 (24-hour)	0.71 (instantaneous)	0.0019 (24-hour)
EPA	0.24 (1-hour)	0.056 (4-day)	0.71 (instantaneous)	0.0019 (24-hour)
Adopted	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 68). We are not aware of any concerns that would result in the disapproval of the EPA recommended endosulfan criteria 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 68. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
EPA	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
Adopted	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 69). We are not aware of any concerns that would result in the disapproval of the EPA recommended endosulfan criteria 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 69. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
EPA	0.22 (instantaneous)	0.056 (24-hour)	0.034 (instantaneous)	0.0087 (24-hour)
Adopted	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 70). 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 70. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic endrin criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	0.18 (instantaneous)	0.0023 (24-hour)	0.037 (instantaneous)	0.0023 (24-hour)
EPA	0.086 (1-hour)	0.036 (4-day)	0.037 (instantaneous)	0.0023 (24-hour)
Adopted	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 71). 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 71; 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 71. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	2 (instantaneous)	0.08 (24-hour)	0.16 (instantaneous)	-
EPA	0.95 (1-hour)	-	0.16 (instantaneous)	-
Adopted	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 72). We are not aware of any concerns that would result in the disapproval of the EPA recommended guthion criteria in Region 10 states.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	-	0.01 (-)	-	0.01 (-)
Adopted	-	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 any concerns that would result in the disapproval of the EPA recommended heptachlor criteria in Region 10 states. We propose no changes to Washington's current heptachlor criteria (Table 73).

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	0.52 (instantaneous)	0.0038 (24-hour)	0.053 (instantaneous)	0.0036 (24-hour)
EPA	0.52 (instantaneous)	0.0038 (24-hour)	0.053 (instantaneous)	0.0036 (24-hour)
Adopted	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 74). EPA recommendations for heptachlor epoxide does not use EPA 1985 standard methods for deriving toxics and are based on limited toxicity studies.

Table 74. 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 adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	0.52 (instantaneous)	0.0038 (24-hour)	0.053 (instantaneous)	0.0036 (24-hour)
Adopted	-	-	-	-

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 75). We are not aware of any concerns that would result in the disapproval of the EPA recommended malathion criteria in Region 10 states.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	-	0.1 (-)	-	0.1 (-)
Adopted	-	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 76). We are not aware of any concerns that would result in the disapproval of the EPA recommended methoxychlor criteria in Region 10 states.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	-	0.03 (-)	-	0.03 (-)
Adopted	-	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 77). We are not aware of any concerns that would result in the disapproval of the EPA recommended methoxychlor criteria in Region 10 states.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	-	0.001 (-)	-	0.001 (-)
Adopted	-	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 78). 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 scientific studies 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 78).

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	28 (1-hour)	6.6 (4-day)	7 (1-hour)	1.7 (4-day)
Adopted	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 any concerns that would result in the disapproval of the EPA recommended parathion criteria in Region 10 states. We propose no changes to Washington's current parathion criteria (Table 79).

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

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

Pentachlorophenol

Summary of Criteria Recommendations and Changes

The freshwater pentachlorophenol criteria accounts for endangered species protection levels by incorporating the new scientific studies available since EPA last updated the criteria in 1995 (USEPA, 1996). The freshwater pentachlorophenol criteria are more stringent than EPA recommendations (Table 80). 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 scientific studies available since EPA last updated the criteria in 1986.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	20* (1-hour)	13* (4-day)	13 (1-hour)	7.9 (4-day)
EPA	19* (1-hour)	15* (4-day)	13 (1-hour)	7.9 (4-day)
Adopted	11* (1-hour)	5.4* (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 81. New studies that met data acceptability requirements are presented in Table 82. The freshwater acute criterion for pentachlorophenol was derived using 70 GMAVs. According to EPA 1985 guidelines, rank two through four are used when the number of GMAVs exceed 59. Calculation results are as follows:

FAV = 5.901(pH of 6.5)

CMC = 2.951 ug/L (pH of 6.5)

CMC = $e^{\wedge[1.005(\mathrm{pH}) - 5.450]}$

Acute criterion = 11 µg/L (at pH = 7.8; rounded to two significant digits)

Table 81. 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	4.355	Cyprinus carpio	4.355
5	7.321	Triphysaria pusilla	7.321
6	7.840	Acipenser brevirostrum Acipenser oxyrinchus	10.371 <5.926
7	8.803	Hyalella azteca	8.803
8	12.55	Entosphenus tridentatus	12.55
9	21.96	Elliptio dilatate	21.96
10	22.93	Lithobates sphenocephalus	22.93
11	26.54	Ictalurus punctatus	26.54

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
12	28.69	Oncorhynchus mykiss Oncorhynchus kisutch Oncorhynchus nerka Oncorhynchus tshawytscha Oncorhynchus apache Oncorhynchus clarkii	33.63 31.82 32.85 25.85 19.93 30.79
13	33.91	Rana catesbeiana	33.91
14	34.13	Salvelinus fontinalis	34.13
15	42.40	Lepomis macrochirus	42.40
16	51.56	Simocephalus vetulus	51.56
17	58.18	Chaetocorophium lucasi	58.18
18	58.47	Varichaeta pacifica	58.47
19	60.43	Aplexa hypnorum	60.43
20	60.5	Gambusia affinis	60.5
21	60.61	Anaxyrus boreas boreas	60.61
22	65.53	Carassius auratus	65.53
23	65.80	Pimephales promelas	65.80
24	76.74	Ceriodaphnia dubia Ceriodaphnia reticulata	87.73 67.13
25	91.48	Gammarus pseudolimnaeus	91.48
26	95.17	Asplanchna girodi	95.17
27	105.0	Micropterus salmoides	105.0
28	105.1	Leptodea fragilis	105.1
29	109.8	Philodina acuticornis	109.8
30	120.0	Brachionus calyciflorus	120.0
31	122.1	Daphnia pulex Daphnia magna Daphnia carinata	90.83 78.51 255.1
32	128.4	Deleatidium sp.	128.4
33	132.1	Physa gyrina	132.1
34	146.7	Utterbackia imbecillis	146.7
35	151.3	Corbicula fluminea	151.3
36	155.8	Ligumia subrostrate	155.8
37	155.9	Branchiura sowerbyi	155.9
38	161.2	Megalonaias nervosa	161.2
39	172.1	Crangonyx pseudogracilis	172.1
40	182.5	Limnodrilus hoffmeisteri	182.5
41	195.4	Poecilia reticulata	195.4
42	212.3	Heteropneustes fossilis	212.3
43	224.2	Tubifex tubifex	224.2

Rank	GMAV* (µg/L)	Species	SMAV* (µg/L)
44	234.3	Clarias batrachus	234.3
45	246.3	Lampsilis cardium Lampsilis siliquoidea	240.9 251.8
46	281.9	Channa punctatus	281.9
47	306.7	Jordanella floridae	306.7
48	308.8	Lumbriculus variegatus	308.8
49	317.5	Quistradrilus multisetosus	317.5
50	361.6	Spirosperma ferox Spirosperma nikoiskyl	239.5 545.8
51	403.2	Gillia altilis	403.2
52	408.2	Stylodrilus heringianus	408.2
53	417.7	Rhyacodirilus montana	417.7
54	484.3	Prionchulus punctatus	484.3
55	492.3	Sphaerium novaezelandiae	492.3
56	805.6	Tanais standfordi	805.6
57	1145	Tobrilus gracilis	1145
58	1585	Dorylaimus stagnalis	1585
59	1672	Aporcelaimellus obtusicaudatus	1672
60	2818	Tylenchus elegans	2818
61	3881	Chironomus riparius	3881
62	8408	Plectus acuminatus	8408
63	10610	Sepedon fuscipennis	10610
64	11621	Diplogasteritus species	11621
65	11260	Tanytarsus dissimilis	11260
66	11914	Caenorhabditis elegans	11914
67	>14968	Rhabditis species	>14968
68	>14968	Cephalobus persegnis	>14968
69	35872	Culex pipiens fatigans	35872
70	>43920	Orconectes immunis	>43920

* Normalized to pH of 6.5

Table 82. 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
Entosphenus tridentatus	FT, M	31	7.4	12.55	Yes.	Anderson et al. 2010
Corbicula fluminea	R, M	250	7	151.3	Yes.	Basack et al. 1997
Lithobates sphenocephalus	S, M	140	8.3	22.93	Yes.	Bridges et al. 2002
Anaxyrus boreas boreas	S, M	370	8.3	60.61	Yes.	Bridges et al. 2002
Lepomis macrochirus	S, M	192	8.3	31.45	Yes.	Bridges et al. 2002
Oncorhynchus mykiss	S, M	160	8.2	28.98	Yes.	Dwyer et al. 2000
Pimephales promelas	S, M	250	8.3	40.95	Yes.	Dwyer et al. 2000
Oncorhynchus apache	S, M	110	8.2	19.93	Yes.	Dwyer et al. 2000
Oncorhynchus clarkii	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
Oncorhynchus clarkii	S, M	170	8.2	30.79	Yes.	Dwyer et al. 2000
Gila elegans	S, M	230	8.3	37.68	Yes.	Dwyer et al. 2000
Ptychocheilus lucius	S, M	240	8.3	39.32	Yes.	Dwyer et al. 2000
Xyrauchen texanus	S, M	280	8.3	45.87	Yes.	Dwyer et al. 2000
Acipenser brevirostrum	S, M	70	8.4	10.37	Yes.	Dwyer et al. 2000
Acipenser oxyrinchus	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
Hyalella azteca	R, U	4	8.0	0.8859	Yes.	McNulty et al. 1999
Leptodea fragilis	S, M	580	8.2	105.1	Yes.	Milam et al. 2005
Lampsilis cardium	S, M	1330	8.2	240.9	Yes.	Milam et al. 2005
Lampsilis siliquoidea	S, M	1390	8.2	251.8	Yes.	Milam et al. 2005
Megalonaias nervosa	S, M	890	8.2	161.2	Yes.	Milam et al. 2005
Ligumia subrostrate	S, M	860	8.2	155.8	Yes.	Milam et al. 2005
Utterbackia imbecillis	S, M	810	8.2	146.7	Yes.	Milam et al. 2005
Ceriodaphnia dubia	S, M	470	8.2	85.13	Yes.	Milam et al. 2005
Daphnia magna	S, M	680	8.2	123.2	Yes.	Milam et al. 2005
Chironomus riparius	R, U	1421	6.8	1051	Yes.	Morales et al. 2014
Daphnia magna	S, U	150	7.3	67.13	Yes.	Oda et al. 2006
Brachionus calyciflorus	S, U	262	7.5	95.90	Yes.	Preston et al. 2001
Brachionus calyciflorus	S, U	1310	7.5	479.5	Yes.	Radix et al. 2000
Daphnia carinata	S, U	570	7.3	255.1	Yes.	Willis 1999
Ceriodaphnia dubia	S, U	202	7.3	90.40	Yes.	Willis 1999
Ceriodaphnia pulchella	S, U	1790	7.3	801.1	Yes.	Willis 1999
Simocephalus vetulus	S, U	140	7.3	62.65	Yes.	Willis 1999
Daphnia magna	S, U	187	7.3	83.69	Yes.	Willis 1999
Deleatidium sp.	S, U	287	7.3	128.4	Yes.	Willis 1999
Chaetocorophium lucasi	S, U	130	7.3	58.18	Yes.	Willis 1999
Sphaerium novaezelandiae	S, U	1100	7.3	492.3	Yes.	Willis 1999

Species	Method	LC50 (µg/L)	pH	Normalized LC50* (µg/L)	Used in Derivation?	Reference
Lumbriculus variegatus	S, U	690	7.3	308.8	Yes.	Willis 1999
Tanais standfordi	S, U	1800	7.3	805.6	Yes.	Willis 1999
Simocephalus vetulus	S, M	140	7.8	37.91	Yes.	Willis et al. 1995
Pimephales promelas	FT, M	564	7.8	152.7	Yes. Combined with other LC50 values from Broderius et al. 1995.	Broderius et al. 1995
Pimephales promelas	FT, M	449	7.8	121.6	Yes. Combined with other LC50 values from Broderius et al. 1995.	Broderius et al. 1995
Pimephales promelas	FT, M	350	7.8	94.77	Yes. Combined with other LC50 values from Broderius et al. 1995.	Broderius et al. 1995
Heteropneustes fossilis	FT, M	580	7.5	212.3	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
Clarias batrachus	FT, M	640	7.5	234.3	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
Channa punctatus	FT, M	770	7.5	281.9	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
Culex pipiens	FT, M	98000	7.5	35872	Yes. Calculated mean pH value of range provided.	Farah et al. 2004
Prionchulus punctatus	S, M	293	6.0	484.3	Yes.	Kammenga et al. 1994
Dorylaimus stagnalis	S, M	958.8	6.0	1585	Yes.	Kammenga et al. 1994
Aporcelaimellus obtusicaudatus	S, M	1012	6.0	1672	Yes.	Kammenga et al. 1994
Tobrilus gracilis	S, M	692.5	6.0	1145	Yes.	Kammenga et al. 1994
Plectus acuminatus	S, M	5087	6.0	8408	Yes.	Kammenga et al. 1994
Cephalobus persegnis	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
Rhabditis sp.	S, M	9056	6.0	>14968	Yes.	Kammenga et al. 1994
Diplogasteritus sp.	S, M	7031	6.0	11621	Yes.	Kammenga et al. 1994
Tylenchus elegans	S, M	1705	6.0	2818	Yes.	Kammenga et al. 1994
Philodina acuticornis	S, U	300	7.5	109.8	Yes.	McDaniel & Snell 1999
Asplanchna girodi	S, U	260	7.5	95.17	Yes.	McDaniel & Snell 1999
Asplanchna girodi	S, U	160	7.5	58.57	Yes.	McDaniel & Snell 1999
Elliptio dilatate	S, U	60	7.5	21.96	Yes.	McDaniel & Snell 1999
Triphysaria pusilla	S, U	20	7.5	7.321	Yes.	McDaniel & Snell 1999
Lecane quadrientata	S, U	10	7.5	3.660	Yes.	McDaniel & Snell 1999
Keratella cochelaris	S, U	7.5	7.5	2.745	Yes.	McDaniel & Snell 1999
Plationus patulus	S, U	3.3	7.5	1.208	Yes.	McDaniel & Snell 1999
Brachionus calyciflorus	S, U	210	7.5	76.87	Yes.	Preston et al. 1999
Caenorhabditis elegans	S, M	44000	7.8	11914	Yes.	Cressman & Williams 1997

* Normalized to pH of 6.5

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 83). Calculation results are as follows:

FAV = 5.901 (pH of 6.5)

FACR = 4.044

CCC = FAV / FACR

CCC = 1.459 µg/L (pH of 6.5)

CCC = $e^{\wedge[1.005(pH) - 6.155]}$

Chronic criterion = 5.4 µg/L (at pH = 7.8; rounded to two significant digits)

Table 83. 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	600	240	2.5	2.5	USEPA, 1986b
Simocephalus vetulus	160	177.2	0.9029		USEPA, 1986b
Simocephalus vetulus	196	221.2	0.8861	0.8944	USEPA, 1986b
Oncorhynchus mykiss	66	14.46	4.564	4.564	USEPA, 1986b
Pimephales promelas	224.9	57.25	3.928		USEPA, 1986b
Pimephales promelas	95	23.89	3.977		USEPA, 1986b
Pimephales promelas	218	40.08	5.439		USEPA, 1986b
Pimephales promelas	261	48.99	5.328		USEPA, 1986b
Pimephales promelas	378	89.23	4.236	4.701	USEPA, 1986b

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR*	Species Mean ACR	Reference
Cyprinodon variegatus	442	64.31	6.873	6.873	USEPA, 1986b
Lymnaea stagnalis	170	27.91	6.091	6.091	Besser et al. 2009
Pyrgulopsis idahoensis	143	16.25	8.801	8.801	Besser et al. 2009
Geometric mean				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 84. New studies that met data acceptability requirements are presented in Table 85. The 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 84. Saltwater acute toxicity data used for criteria derivation.

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

Table 85. 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
Cyprinodon variegatus	S, U	50	No. Other studies with the same species used a flow through design and measured test concentrations.	Sappington et al. 2001
Cyprinodon bovinus	S, U	80	Yes.	Sappington et al. 2001
Eurytemora affinis	S, M	96	Yes.	Lindley 1999
Acartia bifilosa	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 86). Calculation results are as follows:

FAV = 26.87

FACR = 4.044

CCC = FAV / FACR = 6.652

Chronic criterion = 6.7 µg/L (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[1]	Species Mean ACR	Reference
Daphnia magna	600	240	2.5	2.5	USEPA, 1986b
Simocephalus vetulus	160	177.2	0.9029		USEPA, 1986b
Simocephalus vetulus	196	221.2	0.8861	0.8944	USEPA, 1986b
Oncorhynchus mykiss	66	14.46	4.564	4.564	USEPA, 1986b
Pimephales promelas	224.9	57.25	3.928		USEPA, 1986b
Pimephales promelas	95	23.89	3.977		USEPA, 1986b
Pimephales promelas	218	40.08	5.439		USEPA, 1986b
Pimephales promelas	261	48.99	5.328		USEPA, 1986b
Pimephales promelas	378	89.23	4.236	4.701	USEPA, 1986b
Cyprinodon variegatus	442	64.31	6.873	6.873	USEPA, 1986b

Species	Acute Value (µg/L)	Chronic Value (µg/L)	ACR[1]	Species Mean ACR	Reference
Lymnaea stagnalis	170	27.91	6.091	6.091	Besser et al. 2009
Pyrgulopsis idahoensis	143	16.25	8.801	8.801	Besser et al. 2009
Geometric mean				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 is adopting EPA draft recommendations for PFOS in freshwater and saltwater (Table 87). We are not aware of any concerns that would result in the disapproval of the EPA recommended PFOS criteria in Region 10 states.

Table 87. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic PFOS criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

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

[1] All water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy.

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

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

[4] 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 (Table 88; 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. Washington is adopting EPA draft recommendations for PFOS in freshwater and saltwater (Table 87). We are not aware of any concerns that would result in the disapproval of the EPA recommended PFOA criteria in Region 10 states.

Table 88. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic PFOA criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

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

[1] All water column and tissue criteria are intended to be independently applicable and no one criterion takes primacy.

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

[3] Tissue criteria derived from the chronic water column concentration with the use of bioaccumulation factors and are expressed as wet weight (ww) concentrations.
[4] 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 89). 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 remove our freshwater and saltwater acute PCB criteria to align with EPA recommendations because of existing protections the criteria provide for aquatic life. We are not aware of any concerns that would result in the disapproval of the EPA recommended PCB criteria in Region 10 states.

Table 89. Comparison of Washington's current freshwater (FW) and saltwater (SW) acute and chronic PCBs criteria (duration in parentheses) with EPA recommendations and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	2 (24-hour)	0.014 (24-hour)	10 (24-hour)	0.03 (24-hour)
EPA	-	0.014 (24-hour)	-	0.03 (24-hour)
Adopted	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 90). EPA recommendations are based on very limited toxicity data. We evaluated new scientific studies 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 90. Comparison of Washington current freshwater (FW) and saltwater (SW) acute and chronic hydrogen sulfide criteria, EPA recommendations, and the newly adopted criteria.

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	-	2 (24-hour)	-	2 (24-hour)
Adopted	-	-	-	-

Toxaphene

Summary of Criteria Recommendations and Changes

Washington's freshwater and saltwater toxaphene criteria are identical to EPA recommendations. We are not aware of any concerns that would result in the disapproval of the EPA recommended toxaphene criteria in Region 10 states. We propose no changes to Washington's current toxaphene criteria (Table 91).

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	0.73 (1-hour)	0.0002 (4-day)	0.21 (1-hour)	0.0002 (4-day)
EPA	0.73 (1-hour)	0.0002 (4-day)	0.21 (1-hour)	0.0002 (4-day)
Adopted	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 92). We are not aware of any concerns that would result in the disapproval of the EPA recommended tributyltin criteria in Region 10 states.

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

	FW Acute (µg/L)	FW Chronic (µg/L)	SW Acute (µg/L)	SW Chronic (µg/L)
Washington	-	-	-	-
EPA	0.46 (1-hour)	0.072 (4-day)	0.42 (1-hour)	0.0074 (4-day)
Adopted	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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Villavicencio, G., Urrestarazu, P., Arbildua, J. and Rodriguez, P.H., 2011. Application of an acute biotic ligand model to predict chronic copper toxicity to Daphnia magna in natural waters of Chile and reconstituted synthetic waters. *Environmental Toxicology and Chemistry*, *30*(10), pp.2319-2325.

Wang, N., Ingersoll, C.G., Ivey, C.D., Hardesty, D.K., May, T.W., Augspurger, T., Roberts, A.D., Van Genderen, E. and Barnhart, M.C., 2010. Sensitivity of early life stages of freshwater mussels (Unionidae) to acute and chronic toxicity of lead, cadmium, and zinc in water. *Environmental Toxicology and Chemistry*, *29*(9), pp.2053-2063.

Wang, N., Mebane, C.A., Kunz, J.L., Ingersoll, C.G., Brumbaugh, W.G., Santore, R.C., Gorsuch, J.W. and Arnold, W.R., 2011. Influence of dissolved organic carbon on toxicity of copper to a unionid mussel (Villosa iris) and a cladoceran (Ceriodaphnia dubia) in acute and chronic water exposures. *Environmental Toxicology and Chemistry*, *30*(9), pp.2115-2125.

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[9] https://gaftp.epa.gov/region10/ORAI/Revised_BE/Main_010220_clean.pdf

Wang, N., Ingersoll, C.G., Dorman, R.A., Brumbaugh, W.G., Mebane, C.A., Kunz, J.L. and Hardesty, D.K., 2014. Chronic sensitivity of white sturgeon (Acipenser transmontanus) and rainbow trout (Oncorhynchus mykiss) to cadmium, copper, lead, or zinc in laboratory water-only exposures. *Environmental toxicology and chemistry*, *33*(10), pp.2246-2258.

Wang, N., Kunz, J.L., Ivey, C.D., Ingersoll, C.G., Barnhart, M.C. and Glidewell, E.A., 2017. Toxicity of chromium (vi) to two mussels and an amphipod in water-only exposures with or without a co-stressor of elevated temperature, zinc, or nitrate. *Archives of environmental contamination and toxicology*, *72*, pp.449-460.

Wang, N., Kunz, J.L., Cleveland, D.M., Steevens, J.A., Hammer, E.J., Van Genderen, E., Ryan, A.C. and Schlekat, C.E., 2020. Evaluation of acute and chronic toxicity of nickel and zinc to 2 sensitive freshwater benthic invertebrates using refined testing methods. *Environmental Toxicology and Chemistry*, *39*(11), pp.2256-2268.

Winner, R.W., 1985. Bioaccumulation and toxicity of copper as affected by interactions between humic acid and water hardness. *Water Research*, *19*(4), pp.449-455.

Appendix A. ECOTOX Database Results and References

The Environmental Protection Agency (EPA) Ecotoxicology Knowledgebase (ECOTOX) database was a primary source of new scientific studies 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 (Hybognathus amarus) and Fathead Minnow (Pimephales promelas) 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	

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. ECOREF #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 (Pimephales promelas). Environ. Toxicol. Chem.12:913-924, 1993. ECOREF #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. ECOREF #45073	Repeated information
Fargasova,A.. Ecotoxicology of Metals Related to Freshwater Benthos. Gen. Physiol. Biophys.18(Focus Issue): 48-53, 1999. ECOREF #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 Notopterus notopterus. Environ. Ecol.8(2): 576-579, 1990. ECOREF #3440	Non-north american test species
Gupta,A.K., and P. Chakrabarti. Toxicity of Arsenic to Freshwater Fishes Mystus vittatus (Bloch) and Puntius javanicus (Blkr.). Environ. Ecol.11(4): 808-811, 1993. ECOREF #4456	Non-north american test species
Hamilton,S.J., and K.J. Buhl. Safety Assessment of Selected Inorganic Elements to Fry of Chinook Salmon (Oncorhynchus tshawytscha). Ecotoxicol. Environ. Saf.20(3): 307-324, 1990. ECOREF #3526	
Hamilton,S.J., and K.J. Buhl. Hazard Evaluation of Inorganics, Singly and in Mixtures, to Flannelmouth Sucker Catostomus latipinnis in the San Juan River, New Mexico. Ecotoxicol. Environ. Saf.38(3): 296-308, 1997. ECOREF #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. ECOREF #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, Notemigonus crysoleucas, to Five Metals. J. Fish Biol.35(3): 447-456, 1989. ECOREF #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. ECOREF #45021	
Hu,J., D. Wang, B.E. Forthaus, and J. Wang. Quantifying the Effect of Nanoparticles on As(V) Ecotoxicity Exemplified by Nano-Fe2O3 (Magnetic) and Nano-Al2O3. Environ. Toxicol. Chem.31(12): 2870-2876, 2012. ECOREF #165681	Nanoparticle study
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. Ellersieck. 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 heteroclitus) to Seawater and Effects of Arsenic. Am. J. Physiol., Regul. Integr. Comp. Physiol.292(2): R1052 - R1060, 2007. ECOREF #101073	Saltwater based study

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	
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
Aniche,D.C., F.V. Oluwale, and B.O. Ogbolu. Effect of Exposure to Sub-Lethal Potassium Cyanide on Growth Rate, Survival Rate, and Histopathology in Juvenile Heteroclarias (Heterobranchus longifilis X Clarias gariepinus). J. Fish. Environ.43(1): 10 p., 2019. ECOREF #189877	Non-resident North American test species
Carbaugh,C.M., M.W. Widder, C.S. Phillips, D.A. Jackson, V.T. Divito, W.H. Van Der Schalie, and K.P. Glover. Assessment of Zebrafish Embryo Photomotor Response Sensitivity and Phase-Specific Patterns Following Acute- and Long-Duration Exposure to Neurotoxic Chemicals and Chemical Weapon Precursors. J. Appl. Toxicol.40(9): 1272-1283, 2020. ECOREF #190570	Non-resident North American test species
David,M., J. Sangeetha, and E.R. Harish. Sodium Cyanide Induced Alteration in the Whole Animal Oxygen Consumption and Behavioural Pattern of Freshwater Fish Labeo rohita. J. Environ. Biol.36(2): 405-408, 2015. ECOREF #190167	Non-resident North American test species
Fonseca,R.C., N.A. De Souza, T.C. Lima Correa, L.F. Garcia, L.G. Vieira Dos Reis, and A.G. Rodriguez. Assessment of Toxic Potential of Cerrado Fruit Seeds Using Artemia salina Bioassay. Food Sci. Technol.33(2): 251-256, 2013. ECOREF #190443	Non-resident North American test species

Lin,P., J. Miao, L. Pan, L. Zheng, X. Wang, Y. Lin, and J. Wu. Acute and Chronic Toxicity Effects of Acrylonitrile to the Juvenile Marine Flounder Paralichthys olivaceus. Environ. Sci. Pollut. Res. Int.25(35): 35301-35311, 2018. ECOREF #190421	Not cyanide exposure only; 2-propenenitrile
Madeira,D., J. Andrade, M.C. Leal, V. Ferreira, R.J.M. Rocha, R. Rosa, and R. Calado. Synergistic Effects of Ocean Warming and Cyanide Poisoning in an Ornamental Tropical Reef Fish. Front. Mar. Sci.7:11 p., 2020. ECOREF #190436	Marine test organism
Neuparth,T., R. Capela, L. Rey-Salgueiro, S.M. Moreira, M.M. Santos, and M.A. Reis-Henriques. Simulation of a Hazardous and Noxious Substances (HNS) Spill in the Marine Environment: Lethal and Sublethal Effects of Acrylonitrile to the European Seabass. Chemosphere93(6): 978-985, 2013. ECOREF #190070	Not cyanide exposure only; 2-propenenitrile
Ramzy,E.M.. Toxicity and Stability of Sodium Cyanide in Fresh Water Fish Nile Tilapia. Water Sci.28(1): 42-50, 2014. ECOREF #190292	No replicates and lacks study details
Werorilangi,S., S. Yusuf, A. Massinai, Rastina, A. Niartiningsih, A. Tahir, R. Nimzet, M. Afdal, A.Z. Karimah, and W. U. Acute Toxicity of Cyanide (KCN) on Two Types of Marine Larvae: Acropora sp. Planulae and D-Veliger Larvae of Tridacna squamosa. IOP Conf. Ser. Earth Environ. Sci.253:1-9, 2019. ECOREF #190452	Marine test organism
Zheng,L., L. Pan, J. Miao, Y. Lin, and J. Wu. Application of a Series of Biomarkers in Scallop Chlamys farreri to Assess the Toxic Effects After Exposure to a Priority Hazardous and Noxious Substance (HNS)-Acrylonitrile. Environ. Toxicol. Pharmacol.64:122-130, 2018. ECOREF #190454	Not cyanide exposure only; 2-propenenitrile
Zheng,L., L. Pan, P. Lin, J. Miao, X. Wang, Y. Lin, and J. Wu. Evaluating the Toxic Effects of Three Priority Hazardous and Noxious Substances (HNS) to Rotifer Brachionus plicatilis. Environ. Sci. Pollut. Res. Int.24(35): 27277-27287, 2017. ECOREF #190453	Not cyanide exposure only; 2-propenenitrile

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 (Rana pipiens): Bioaccumulation and Reduced Swimming Performance. Ecotoxicology18(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 (Oncorhynchus mykiss). Toxicology77(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 . Can. J. Fish. Aquat. Sci.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 Daphnia magna. Environ. Toxicol. Chem.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 Hyalella azteca and Chironomus dilutus in Water-Only and Spiked-Sediment Toxicity Tests. Ecotoxicol. Environ. Saf.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. Bull. Environ. Contam. Toxicol.69(3): 421-429, 2002. ECOREF #78709	Study used arsenate; EPA used arsenite to derive arsenic criteria
Vellinger,C., E. Gismondi, V. Felten, P. Rousselle, K. Mehennaoui, M. Parant, and P. Usseglio-Polatera. Single and Combined Effects of Cadmium and Arsenate in Gammarus pulex (Crustacea, Amphipoda): Understanding the Links Between Physiological and Behavioural Responses. Aquat. Toxicol.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 Ceriodaphnia dubia. *Journal of Applied Toxicology*, *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. *Environmental Toxicology and Chemistry: An International Journal*, *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 Ambystoma maculatum embryos: Toxicity, teratogenicity,	Study used arsenate; EPA used arsenite to derive arsenic criteria

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

Chromium III

Freshwater Acute

Table A 4 List of citations from EPA ECOTOX database reviewed for chromium iii 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, Cyprinus carpio from Saudi Arabia. Pak. J. Zool.28(4): 361-363, 1996. ECOREF #46875	Hexavalent chromium study; doesn't provide study details; fish life stage not provided; purity of chromium
Al-Akel,A.S., and M.J.K. Shamsi. Hexavalent Chromium: Toxicity and Impact on Carbohydrate Metabolism and Haematological Parameters of Carp (Cyprinus carpio L.) from Saudi Arabia. Aquat. Sci.58(1): 24-30, 1996. ECOREF #19485	Hexavalent chromium study
Anusuya,D., and I. Christy. Effects of Chromium Toxicity on Hatching and Development of Tadpoles of Bufo melanostictus. J. Environ. Biol.20(4): 321-323, 1999. ECOREF #47043	Non-north american test species used
Arkhipchuk,V.V., C. Blaise, and M.V. Malinovskaya. Use of Hydra for Chronic Toxicity Assessment of Waters Intended for Human Consumption. Environ. Pollut.142(2): 200-211, 2006. ECOREF #90306	Chronic study of ambient water; not relevant
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. Arch. Environ. Contam. Toxicol.50(4): 496-502, 2006. ECOREF #119599	
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. ECOREF #119520	Used older fish; not sensitive life stage
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 Biotoxicity Screening. J. Appl. Toxicol.34:214-219, 2014. ECOREF #169111	Hexavalent chromium study
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. ECOREF #18325	Hexavalent chromium study

Citation	Notes
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. ECOREF #74230	Non-north american test 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. ECOREF #14017	Cyst based toxicity test; not relevant
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	Transgenic nematode used at test species
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. ECOREF #60132	Hexavalent chromium used; non-north american test species
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. ECOREF #174961	Does not include chromium III in study
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. ECOREF #114244	Sediment used in toxicity test
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. ECOREF #152904	Pesticide study; chromium III not used
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. ECOREF #72944	Doesn’t specificy chromium species
Fargasova,A.. Ecotoxicology of Metals Related to Freshwater Benthos. Gen. Physiol. Biophys.18(Focus Issue): 48-53, 1999. ECOREF #61824	Hexavalent chromium study
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	Hexavalent chromium 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 is from mixture with chelating agents

Citation	Notes
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
Kazlauskiene,N., A. Burba, and G. Svecevicius. Acute Toxicity of Five Galvanic Heavy Metals to Hydrobionts. Ekologiia1:33-36, 1994. ECOREF #17573	Not relevant test species (hydrobionts)
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 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 toxicity test; not relevant
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 toxicity test; not relevant
Lin,K., S. Zhou, C. Xu, and W. Liu. Enantiomeric Resolution and Biotoxicity of Methamidophos. J. Agric. Food Chem.54(21): 8134-8138, 2006. ECOREF #99572	Pesticide toxicity test; not relevant
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	Sludge used in toxicity test; not relevant
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 species preexposed to sludge; not relevant
Madoni,P., and M.G. Romeo. Acute Toxicity of Heavy Metals Towards Freshwater Ciliated Protists. Environ. Pollut.141(1): 1-7, 2006. ECOREF #95678	Hexavalent chromium study
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	Sediment used in testing
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	Used hexavalent chromium
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	Used hexavalent chromium

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 toxicity study; 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	Used hexavalent chromium
Oliveira-Filho,E.C., and F.J.R. Paumgartten. 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	Insecticide study; not relevant
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	Doesn’t specificy chromium species
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	Used hexavalent chromium
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.
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
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
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	Used hexavalent chromium
Sornaraj,R., P. Baskaran, and S. Thanalakshmi. Effects of Heavy Metals on Some Physiological Responses of Air-Breathing Fish Channa punctatus (Bloch). Environ. Ecol.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. Chemosphere68(4): 628-636, 2007. ECOREF #118678	Sludge media; not relevant

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	Mixture study with pesticides; not relevant
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	Bacteria toxicity test; 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. Bull. Environ. Contam. Toxicol.80(1): 63-67, 2008. ECOREF #111291	No hardness data; generational study
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 Mesocyclops pehpeiensis. Bull. Environ. Contam. Toxicol.73(1): 190-196, 2004. ECOREF #80006	Animals field collected hong kong; non north american
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 Daphnia magna. Sci. Total Environ.667:435-443, 2019. ECOREF #182580	PFOS/PFOA toxicity test; not relevant
Zhang,Q., and C. Wang. Toxicity of Binary Mixtures of Enantiomers in Chiral Organophosphorus Insecticides: The Significance of Joint Effects Between Enantiomers. Chirality25(11): 787-792, 2013. ECOREF #165491	Examined toxicity of insecticides; not relevant

Chromium VI

Freshwater Acute

Table A 5. 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, Cyprinus carpio from Saudi Arabia. Pak. J. Zool.28(4): 361-363, 1996. ECOREF #46875	Doesn't provide study details; fish life stage not provided; purity of chromium missing

Citation	Notes
Al-Akel,A.S., and M.J.K. Shamsi. Hexavalent Chromium: Toxicity and Impact on Carbohydrate Metabolism and Haematological Parameters of Carp (Cyprinus carpio L.) from Saudi Arabia. Aquat. Sci.58(1): 24-30, 1996. ECOREF #19485	Repeat of LC50 determined from Al-Akel 1996
Anusuya,D., and I. Christy. Effects of Chromium Toxicity on Hatching and Development of Tadpoles of Bufo melanostictus. J. Environ. Biol.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. Environ. Pollut.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. Arch. Environ. Contam. Toxicol.50(4): 496-502, 2006. ECOREF #119599	
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. ECOREF #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 Biotoxicity Screening. J. Appl. Toxicol.34:214-219, 2014. ECOREF #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. ECOREF #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. ECOREF #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. ECOREF #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. ECOREF #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. ECOREF #60132	Non-north american species used

Citation	Notes
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. ECOREF #174961	Did not include chromium VI exposure
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. ECOREF #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. ECOREF #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. ECOREF #72944	Ambient estuary water used in testing
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
Kazlauskiene,N., A. Burba, and G. Svecevicius. Acute Toxicity of Five Galvanic Heavy Metals to Hydrobionts. Ekologiia1:33-36, 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

Citation	Notes
Lin,K., S. Zhou, C. Xu, and W. Liu. Enantiomeric Resolution and Biotoxicity 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	
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. Paumgartten. 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	

Citation	Notes
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	
Sornaraj,R., P. Baskaran, and S. Thanalakshmi. Effects of Heavy Metals on Some Physiological Responses of Air-Breathing Fish Channa punctatus (Bloch). Environ. Ecol.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. Chemosphere68(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 Ceriodaphnia dubia. Environ. Pollut.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 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	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. Bull. Environ. Contam. Toxicol.80(1): 63-67, 2008. ECOREF #111291	Chromium III study
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 Mesocyclops pehpeiensis. Bull. Environ. Contam. Toxicol.73(1): 190-196, 2004. ECOREF #80006	
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	Test did not use chromium

Citation	Notes
Study on PFOS and PFOA in Daphnia magna. Sci. Total Environ.667:435-443, 2019. ECOREF #182580	
Zhang,Q., and C. Wang. Toxicity of Binary Mixtures of Enantiomers in Chiral Organophosphorus Insecticides: The Significance of Joint Effects Between Enantiomers. Chirality25(11): 787-792, 2013. ECOREF #165491	Pesticide study; did not use chromium

Open Literature

Table A 6. 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 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
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. Chemosphere, 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. Environmental Science and Pollution Research, 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 Ceriodaphnia dubia. Journal of Applied Toxicology, 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 A 7. 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. Arch. Environ. Contam. Toxicol.50(4): 496-502, 2006. ECOREF #119599	
Carriquiriborde,P., and A.E. Ronco. Distinctive Accumulation Patterns of Cd(II), Cu(II), and Cr(VI) in Tissue of the South American Teleost, Pejerrey (Odontesthes bonariensis). Aquat. Toxicol.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 Daphnia magna Straus Evaluated in Acute, Chronic, and Acetylcholinesterase Inhibition Tests. Ecotoxicol. Environ. Saf.45(3): 253-259, 2000. ECOREF #48695	Test concentrations were not measured for the chronic study
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	Test concentrations were not measured in the chronic study and static renewal test design was employed
Mishra,A.K., and B. Mohanty. Chronic Exposure to Sublethal Hexavalent Chromium Affects Organ Histopathology and Serum Cortisol Profile of a Teleost, Channa punctatus (Bloch). Sci. Total Environ.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 Hypsiboas pulchellus Embryos and Tadpoles. Dis. Aquat. Org.72(3): 261-267, 2006. ECOREF #101072	This species is not a resident in North America
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	Did not use flow-through design
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	Only one test concentration
Pickering,Q.H., and J.M. Lazorchak. Evaluation of the Robustness of the Fathead Minnow, Pimephales promelas, Larval Survival and Growth Test, U.S. EPA Method 1000.0. Environ. Toxicol. Chem.14(4): 653-659, 1995. ECOREF #45200	Acceptable but ACR cannot be calculated

Citation	Notes
Sofyan,A.. Toxicity of Metals to Green Algae and Ceriodaphnia dubia: The Importance of Water Column and Dietary Exposures. Ph.D.Thesis, University of Kentucky, Lexington, KY:161 p., 2004. ECOREF #78692	Chromium III study

Cyanide

Freshwater Acute

Table A 8. 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, Salmo salar L. at Low Concentrations of Dissolved Oxygen. J. Fish Biol.22(2): 215-222, 1983. ECOREF #10252	
Bailey,H.C., D.H.W. Liu, and H.A. Javitz. Time/Toxicity Relationships in Short-Term Static, Dynamic, and Plug-Flow Bioassays. ASTM Spec. Tech. Publ.:193-212, 1985. ECOREF #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: Rep.No.6,Dep.of Fish.Resour.,Univ.of Idaho,Moscow,ID:243-254, 1982. ECOREF #86404	Database reference
Broderius,S., and M. Kahl. Acute Toxicity of Organic Chemical Mixtures to the Fathead Minnow. Aquat. Toxicol.6:307-322, 1985. ECOREF #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 (Pimephales promelas), Vol. 1. Center for Lake Superior Environmental Studies, University of Wisconsin-Superior, Superior, WI:414 p., 1984. ECOREF #12448	Repeat of data
Buccafusco,R.J., S.J. Ells, and G.A. LeBlanc. Acute Toxicity of Priority Pollutants to Bluegill (Lepomis macrochirus). Bull. Environ. Contam. Toxicol.26(4): 446-452, 1981. ECOREF #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. ECOREF #152135	EPA used in 1984 cyanide derivation
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

Citation	Notes
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	Repeated and more detail provided in David et al. 2010
David, M., Haragi, S.B., Patil, V.K., Halappa, R., Chittaragi, J.B., Marigoudar, S.R., and Chebbi, S.G., 2010. Assessment of sodium cyanide toxicity on freshwater teleosts. Recent Research in Science and Technology, 2(2).	
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; wrong language
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 (Perters). Drug Chem. Toxicol.35(2): 178-183, 2012. ECOREF #160874	Test fish were collected from natural ponds that were not characterized for background contaminants. Study details are limited.
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 Lepidocepalichithys 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 Salmo gairdneri Rich. for Determining the Acute Toxicity of Aggressive Substances as Well as Measurement Results for. Acta Hydrochim. Hydrobiol.9(1): 3-15, 1981. ECOREF #5639	EPA used in 1984 derivation
Slabbert,J.L., and E.A. Venter. Biological Assays for Aquatic Toxicity Testing. Water Sci. Technol.39(10/11): 367-373, 1999. ECOREF #61447	Non-north american test species; lacking a methods section in the publication
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. J. Fish Biol.27(suppl.A): 197-207, 1985. ECOREF #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.), Proc.of USA-USSR Symp., Jul.30-Aug.1, 1984, Borok, Jaroslavl Oblast, U.S.EPA, Athens, GA:55-71, 1984. ECOREF #67837	Unable to locate article
Tong,Z., Z. Huailan, and J. Hongjun. Chronic Toxicity of Acrylonitrile and Acetonitrile to Daphnia magna in 14-d and 21-d Toxicity Tests. Bull. Environ. Contam. Toxicol.57(4): 655-659, 1996. ECOREF #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. J. Toxicol. Sci.7(3): 193-203, 1982. ECOREF #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. Vatten39:168-174, 1983. ECOREF #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). Acta Hydrochim. Hydrobiol.11(2): 169-179, 1983. ECOREF #12314	Should have been considered in last EPA derivation
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
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	
Wellens,H.. Comparison of the Sensitivity of Brachydanio rerio and Leuciscus idus by Testing the Fish Toxicity of Chemicals and Wastewaters. Z. Wasser-Abwasser-Forsch.51(2): 49-52, 1982. ECOREF #11037	Wrong language
Zhang,T., H. Jin, and H. Zhu. Quality Criteria of Acrylonitrile for the Protection of Aquatic Life in China. Chemosphere32(10): 2083-2093, 1996. ECOREF #16884	Organisms exposed to acrylonitrile

Freshwater Chronic

Table A 9. 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, Clarias gariepinus (Burchell, 1822). Ecotoxicol. Environ. Saf.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 (Daphnia magna). 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. Text. Chem. Color.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 and test duration too short for chronic test
Szabo,A., S.M. Ruby, F. Rogan, and Z. Amit. Changes in Brain Dopamine Levels, Oocyte Growth and Spermatogenesis in Rainbow Trout, Oncorhynchus mykiss, Following Sublethal Cyanide Exposure. Arch. Environ. Contam. Toxicol.21(1): 152-157, 1991. ECOREF #117809	Endpoints not relevant
Tong,Z., Z. Huailan, and J. Hongjun. Chronic Toxicity of Acrylonitrile and Acetonitrile to Daphnia magna in 14-d and 21-d Toxicity Tests. Bull. Environ. Contam. Toxicol.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. Chemosphere32(10): 2083-2093, 1996. ECOREF #16884	Exposed to acrylonitrile

Nickel

Freshwater Acute

Table A 10. 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	No hardness data reported
Alkahem,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	Did not have adequate study details; material purity; age of organisms was not the most sensitive
Alkahem,H.F.. Effects of Nickel on Carbohydrate Metabolism of Oreochromis niloticus. Dirasat Ser. B Pure Appl. Sci.22(1): 83-88, 1995. ECOREF #20533	Could not locate
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	Non-resident North America test species
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	Non-resident North America test species
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	
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

Citation	Notes
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. Svecevicius. Acute Toxicity of Five Galvanic Heavy Metals to Hydrobionts. Ekologiia1:33-36, 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	
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
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

Citation	Notes
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. Behravesh, 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	
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	
Sornaraj,R., P. Baskaran, and S. Thanalakshmi. Effects of Heavy Metals on Some Physiological Responses of Air-Breathing Fish Channa punctatus (Bloch). Environ. Ecol.13(1): 202-207, 1995. ECOREF #17380	Non-north american test species used

Citation	Notes
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. Environ. Toxicol. Chem.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: Caenorhabditis elegans LC50. Aquat. Toxicol.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 Ceriodaphnia dubia. Environ. Pollut.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?. 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
Virk,S., and R.C. Sharma. Effect of Nickel and Chromium on Various Life Stages of Cyprinus carpio Linn. Indian J. Ecol.22(2): 77-81, 1995. ECOREF #18750	
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 Mesocyclops pehpeiensis. Bull. Environ. Contam. Toxicol.73(1): 190-196, 2004. ECOREF #80006	No hardness data reported

Open Literature

Table A 11. 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 Eurytemora affinis to its bioaccumulation of trace metals. Chemosphere, 220, pp.505-513.	LC50s are sex specific (male and female); tests were 96 hr and not the standard 48-hr for invertebrates

Citation	Notes
Panneerselvam, K., Marigoudar, S.R. and Dhandapani, M., 2018. Toxicity of nickel on the selected species of marine diatoms and copepods. Bulletin of environmental contamination and toxicology, 100, pp.331-337.	Marine study
Okamoto, A., Masunaga, S. and Tatarazako, N., 2021. Chronic toxicity of 50 metals to Ceriodaphnia dubia. Journal of Applied Toxicology, 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. Environmental Science and Pollution Research, 25, pp.3588-3595.	
Ansari, S., Ansari, B.A. and Ansari, B.A., 2015. Effects of heavy metals on the embryo and larvae of Zebrafish, Danio rerio (Cyprinidae). Scholars Academic Journal of Biosciences, 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 Hyalella azteca cryptic species complex: Mortality, growth, and bioaccumulation parameters. Environmental toxicology and chemistry, 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 Hydra attenuata at environmentally relevant concentrations. Science of the Total Environment, 665, pp.848-854.	Multi-well plates test chambers; 48-hour LC50 not reported; fed during study
Besser, J. M., Ivey, C. D., Steevens, J. A., Cleveland, D., Soucek, D., Dickinson, A., Van Genderen, E. J., Ryan, A. C., Schlekat, C. E., & Garman, E. (2021). Modeling the Bioavailability of Nickel and Zinc to Ceriodaphnia dubia and Neocloeon triangulifer in Toxicity Tests with Natural Waters. Environ Toxicol Chem.	
Besser, J. M., Dorman, R., Ivey, C. D., Cleveland, D., & Steevens, J. A. (2020). Sensitivity of Warm-Water Fishes and Rainbow Trout to Selected Contaminants. Bulletin of environmental contamination and toxicology, 104(3), 321-326.	
Besser, J. M., Brumbaugh, W. G., Ingersoll, C. G., Ivey, C. D., Kunz, J. L., Kemble, N. E., ... & Garman, E. R. (2013). Chronic toxicity of nickel-spiked freshwater sediments: Variation in toxicity among eight invertebrate taxa and eight sediments. Environmental toxicology and chemistry, 32(11), 2495-2506.	Sediment study; used natural waters that were not characterized

Citation	Notes
Birge, W. J., Black, J. A., Hobson, J. F., Westerman, A. G., & Short, T. M. (1984). 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 early-life stages. Research report July 1983-August 1984 (No. PB-85-214666/XAB; RR-151). Kentucky Water Resources Research Inst., Lexington (USA).	
Boran H, Saffak S. (2018). Comparison of Dissolved Nickel and Nickel Nanoparticles Toxicity in Larval Zebrafish in Terms of Gene Expression and DNA Damage. Archives of Environmental Contamination and Toxicology; 74:193–202.	Zebrafish is a not a resident north american species
Borgmann, U., Couillard, Y., Doyle, P., & Dixon, D. G. (2005). Toxicity of sixty-three metals and metalloids to Hyalella azteca at two levels of water hardness. Environmental toxicology and chemistry, 24(3), 641-652.	Only LC50/EC50 reported
Bozich J, Hang M, Hamers R, Klaper R (2017). Core chemistry influences the toxicity of multicomponent metal oxide nanomaterials, lithium nickel manganese cobalt oxide, and lithium cobalt oxide to Daphnia magna. Environ Toxicol Chem. 36(9):2493-2502.	Not pure nickel exposure
Cairns, J., Thompson, K. W., & Hendricks, A. C. (1981). Effects of Fluctuating, Sublethal Applications of Heavy Metal Solutions Upon the Gill Ventilatory Response of Bluegills(Lepomis Macrochirus). EPA 600/S3-81-003.	EPA Considered
Chapman, G. A., Ota, S., & Recht, F. (1980). Effects of Water Hardness on the Toxicity of Metals to Daphnia Magna: Status Report-January 1980. US Environmental Protection Agency, Corvallis Environmental Research Laboratory.	
Crémazy, A., Brix, K.V. and Wood, C.M., 2018. Chronic toxicity of binary mixtures of six metals (Ag, Cd, Cu, Ni, Pb, and Zn) to the great pond snail Lymnaea stagnalis. *Environmental science & technology*, *52*(10), pp.5979-5988.	
Crémazy, A., Brix, K. V., Smith, D. S., Chen, W., Grosell, M., Schlekat, C. E., ... & Wood, C. M. (2020). A Mystery Tale: Nickel Is Fickle When Snails Fail—Investigating the Variability in Ni Toxicity to the Great Pond Snail. Integrated Environmental Assessment and Management, 16(6), 983-997.	Review paper
Dao TS, Le VN, Bui BT, Dinh KV, Wiegand C, Nguyen TS, Dao CT, Nguyen VD, To TH, Nguyen LSP, Vo TG, and Vo TMC (2017). Sensitivity of a tropical micro-crustacean (Daphnia lumholtzi) to trace metals tested in natural water of the Mekong River. Science of the Total Environment; 574:1360- 1370.	Used natural water for dilution water and was not characterized

Citation	Notes
Dave, G., & Xiu, R. (1991). Toxicity of mercury, copper, nickel, lead, and cobalt to embryos and larvae of zebrafish, Brachydanio rerio. Archives of Environmental Contamination and Toxicology, 21(1), 126-134.	Non-resident of North America
De Schamphelaere, K., Van Laer, L., Deleebeeck, N., Muyssen, B., Degryse, F., Smolders, E., & Janssen, C. (2006). Nickel speciation and ecotoxicity in European natural surface waters: development, refinement and validation of bioavailability models. Ghent University	Used natural waters for testing; concern for water quality
Deleebeeck, Nele M.E., Brita T.A. Muyssen, Frederick De Laender, Colin R. Janssen, Karel A.C. De Schamphelaere, 2007. Comparison of nickel toxicity to cladocerans in soft versus hard surface waters, Aquatic Toxicology, vol. 84, iss. 2, pp. 223-235.	Not used because only EC10 reported
Deleebeeck, Nele M.E., Karel A.C. De Schamphelaere, Dagobert G. Heijerick, Bart T.A. Bossuyt, and Colin R. Janssen, 2008. The acute toxicity of nickle to Daphnia magna: Predicted capacity of bioavailability models in artificial and natural waters, Ecotoxicology and Environmental Safety, vol. 70, iss. 1, pp. 67-78.	
Deleebeeck, Nele M.E., Karel A.C. De Schamphelaere, Colin R. Janssen, 2007. A bioavailability model predicting the toxicity of nickel to rainbow trout (Oncorhynchus mykiss) and fathead minnow (Pimephales promelas) in synthetic and natural waters, Ecotoxicology and Environmental Safety, vol. 67, iss. 1, pp 1-3.	Only NOEC reported; cannot calculate MATC or EC20 without more data
Deleebeeck, Nele M.E., Frederik De Laender, Victor A. Chepurnov, Wim Vyerman, Colin R. Janssen, Karel A.C. De Schamphelaere, 2009. A single bioavailability model can accurately predict Ni toxicity to green microalgae in soft and hard surface waters, Water Research, vol. 43, iss. 7, pp. 1935-1947.	Not used plant study; not shown to be sensitive
Deleebeeck, Nele M.E., Karel A.C. De Schamphelaere, Colin R. Janssen, 2009. Effects of Mg2+ and H+ on the toxicity of Ni2+ to the unicellular green alga Pseudokirchneriella subcapitata: Model development and validation with surface waters, Science of the Total Environment, vol. 407, iss. 6, pp. 1901-1914.	Plant study; EC50s reported rather than MATC/EC20
Doig, Lorne E., and Karsten Liber, 2006. Influence of dissolved organic matter on nickel bioavailability and toxicity to Hyalella azteca in water-only exposures, Aquatic Toxicology, vol. 76, iss. 3-4, pp. 203-216.	Study conducted with dissolved organic matter

Citation	Notes
Environment & Climate Change Canada. 2018. Nickel Toxicology Project Report: Chinook 28-Day Chronic Toxicity Test.Filová, Alexandra, Agáta Fargašová, and Marianna Molnárová. 2021. Cu, Ni, and Zn effects on basic physiological and stress parameters of Raphidocelis subcapitata algae. Environmental Science and Pollution Research, vol 28, iss 41, pp. 58426-58441. doi: 10.1007/s11356-021-14778-6	Plant study; EC50s reported rather than MATC/EC20
Ferreira, Abel L. G., Pedro Serra, Amadeu M. V. M. Soares, Susana Loureiro, 2010. The influence of natural stressors on the toxicity of nickel to Daphnia magna, Environmental Science and Pollution Research, vol. 17, pp. 1217-1229.	Hardness not reported for dilution water
Fort, Douglas J., Robert L. Rogers, John H. Thomas, William A. Hopkins, Christian Schlekat, 2006. Comparative Developmental Toxicity of Nickel to Gastrophryne carolinensis, Bufo terrestris, and Xenopus laevis, Archives of Environmental Contamination and Toxicology, vol. 51, pp. 703-710.	
Garcia-Garcia JD, Pena-Sanabria KA, Sanchez-Thomas R, Moreno-Sanchez R. (2018) Nickel accumulation by the green algae-like Euglena gracilis. Journal of Hazardous Materials; 343;10–18.	Plant study; not shown to be sensitive
Ghosh A, Kaviraj A, Saha S. (2018). Deposition, acute toxicity, and bioaccumulation of nickel in some freshwater organisms with best-fit functions modeling. Environ Sci Pollut Res; 25:3588–3595.	
Ghosh, Anupam, Anilava Kaviraj, Isabela Ewa Nielsen, Subrata Saha. 2021. A comparative evaluation of the effects of copper and nickel on the growth of the freshwater fish Cyprinus carpio and amelioration by Pistia stratiotes. Toxicology and Environmental Health Sciences, vol 13, iss 4, pp. 363-374, doi: 10.1007/s13530-021-00097-3	Only 1 or 2 test concentrations used per test
Gopalapillai, Yamini, Beverley Hale, and Bernard Vigneault, 2013. Effect of major cations (Ca2+, Mg2+, Na+, K+) and anions (SO42-, Cl-, NO3-) on Ni accumulation and toxicity in aquatic plant (Lemna minor L.): Implications for Ni risk assessment, Environmental Toxicology and Chemistry, vol. 32, iss. 4, pp. 810-821.	Plant study; not shown to be sensitive
He J, Wang C, Schlekat CE, Wu F, Middleton E, Garman E, Peters A. Validation of nickel bioavailability models for algae, invertebrates, and fish in Chinese surface waters. Environmental Toxicology and Chemistry. 2023 Jun;42(6):1257-65.	Used natural waters for testing; concern for water quality
Hernández-Flores, S., Santos-Medrano, G. E., Rubio-Franchini, I., & Rico-Martínez, R. (2020). Evaluation of bioconcentration and toxicity of five metals in the freshwater rotifer Euchlanis dilatata Ehrenberg, 1832. Environmental Science and Pollution Research, 27(12), 14058-14069.	No relevant endpoints provided

Citation	Notes
Klaine, Stephen J. and Sandra Knuteson, 2003. Toxicity of Nickel to Duckweeds. Clemson University, Pendelton, SC.	Plant study; not shown to be sensitive
Keller, Anne E. and Stephen G. Zam, 1991. The acute toxicity of selected metals to the freshwater mussel, Anodonta imbecilis, Environmental Toxicology and Chemistry, vol. 10, pp. 539-546	
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. Environ Toxicol Chem, 37: 2458-2466. doi:10.1002/etc.4210	Exposure period does not meeting chronic conditions
Hoang, Tham Chung, Joseph R. Tomasso, and Stephen J. Klaine, 2004. Influence of water quality and age on nickel toxicity to fathead minnows (Pimephales promelas), Environmental Toxicology and Chemistry, vol. 23, iss. 1, pp. 86-92.	
Holland, A., Wood, C. M., Smith, D. S., Correia, T. G., & Val, A. L. (2017). Nickel toxicity to cardinal tetra (Paracheirodon axelrodi) differs seasonally and among the black, white and clear river waters of the Amazon basin. Water research, 123, 21-29.	Non-resident NA species
Ivey CD, Besser JM, Ingersoll CG, Wang N, Rogers DC, Raimondo S, Bauer CR, Hammer EJ (2017). Acute sensitivity of the vernal pool fairy shrimp, Branchinecta lynchi (Anostraca; Branchinectidae), and surrogate species to 10 chemicals. Environ Toxicol Chem.; 36(3):797-806.	
Keller, Anne E., 2000. Water quality and toxicity data for unpublished unionid mussel tests. Memorandum to Rob Pepin and Cindy Roberts, September 1, 2000. 6 pages.	Non-resident NA species
Kim D, Chae Y, An Y-J. (2017). Mixture Toxicity of Nickel and Microplastics with Different Functional Groups on Daphnia magna. Environmental Science and Technology; 51:12852-12858.	
Kozlova, Tatiana, Chris M. Wood, and James C. McGeer, 2009. The effect of water chemistry on the acute toxicity of nickel to the cladoceran Daphnia pulex and the developmnet of a biotic ligand model, Aquatic Toxicology, vol. 91, pp. 221-228.	Can't associate hardness with LC50
Krzykwa JC, Saeid A, Jeffries MKS. (2019). Identifying sublethal endpoints for evaluating neurotoxic compounds utilizing the fish embryo toxicity test. Ecotoxicology and Environmental Safety; 170:521-529.	EC20/MATC not reported

Citation	Notes
Kszos, Lynn Adams, Arthur J. Stewart, and Paul A. Taylor, 1992. An evaluation of nickel toxicity to Ceriodaphnia dubia and Daphnia magna in a contaminated stream and in laboratory tests, Environmental Toxicology and Chemistry, vol. 11, pp. 1001-1012.	Used nominal concentrations for laboratory water tests
Lebrun, Jeremie D., Marine Perret, Emmanuelle Uher, Marie-Helene Tusseau-Vuillemin, and Catherine Gourlay-France, 2011. Waterborne nickel bioaccumulation in Gammarus pulex: Comparison of mechanistic models and influence of water cationic composition, Aquatic Toxicology, vol. 104, iss. 3-4, pp. 161-167.	Non-resident NA species
Leonard, Erin M. and Chris M. Wood, 2013. Acute toxicity, critical body residues, MichaelisMenton analysis of bioaccumulation, and ionoregulatory disturbance in response to waterborne nickel in four invertebrates: Chironomus riparius, Lymnaea stagnalis, Lumbriculus variegatus and Daphnia pulex, Comparative Biochemistry and Physiology, Part C, vol. 158, pp. 10-21.	
Leung J, Witt JDS, Norwood W, Dixon DG (2016). Implications of Cu and Ni toxicity in two members of the Hyalella azteca cryptic species complex: mortality, growth, and bioaccumulation parameters. Environ Toxicol Chem.; 35(11):2817-2826.	MATC/EC20/LC20 not reported
Li, Hao, Jun Yao, Robert Duran, Jianli Liu, Ning Min, Zhihui Chen, Xiaozhe Zhu, Chenchan Zhao, Bo Ma, Wancheng Pang, Miaomiao Li, Ying Cao, Bang Liu (2021). Toxic response of the freshwater green algae Chlorella pyrenoidosa to combined effect of flotation reagent butyl xanthate and nickel. Environmental Pollution, vol. 286, pp. 117285.	plant study; not shown to be sensitive
Lind, David, Kevin Alto, and Steven Chatterton, 1978. Regional copper-nickel study. Draft Report. Minnesota Environmental Quality Board, St. Paul, MN.	EPA should have considered
Macoustra, G. K., Jolley, D. F., Stauber, J. L., Koppel, D. J., & Holland, A. (2020). Speciation of nickel and its toxicity to Chlorella sp. in the presence of three distinct dissolved organic matter (DOM). Chemosphere, 128454.	Plant study; not shown to be sensitive
Mano, H., Shinohara, N., & Naito, W. (2020). Reproduction Sensitivity of Five Daphnia Species to Nickel. Journal of Water and Environment Technology, 18(6), 372-382.	MATC/EC20 not reported
Markich S. (2017). Sensitivity of the glochidia (larvae) of freshwater mussels (Bivalvia: Unionida: Hyriidae) to cadmium, cobalt, copper, lead, nickel and zinc: Differences between metals, species and exposure time. Science of the Total Environment; 601–602:1427–1436.	Non-resident North American species

Citation	Notes
Martinez, R. S., Sáenz, M. E., Alberdi, J. L., & Di Marzio, W. D. (2019). Comparative ecotoxicity of single and binary mixtures exposures of nickel and zinc on growth and biomarkers of Lemna gibba. Ecotoxicology, 28(6), 686-697.	Plant study; not shown to be sensitive
Martinez, S., Sáenz, M. E., Alberdi, J. L., & Di Marzio, W. D. (2020). Comparative ecotoxicity of single and binary mixtures exposures of cadmium and zinc on growth and biomarkers of Lemna gibba. Ecotoxicology, 29(5), 571-583.	Plant study; not shown to be sensitive
Martínez-Ruiz EB, Martínez-Jerónimo F. (2015). Nickel has biochemical, physiological, and structural effects on the green microalga Ankistrodesmus falcatus: An integrative study. Aquat Toxicol.; 169:27-36.	Plant study; not shown to be sensitive
Mebane, C. A., Schmidt, T. S., Miller, J. L., & Balistrieri, L. S. (2020). Bioaccumulation and Toxicity of Cadmium, Copper, Nickel, and Zinc and Their Mixtures to Aquatic Insect Communities. Environmental Toxicology and Chemistry, 39(4), 812-833.	Did not use standard testing methodology; EC50s reported
Meyer, Joseph S., Robert C. Santore, Joe P. Bobbit, Larry D. Debrey, Connie J. Boese, Paul R. Paquin, Herbert E. Allen, Harold L. Bergman, and Dominic M. DiToro, 1999. Binding of Nickel and Copper to Fish Gills Predicts Toxicity When Water Hardness Varies,But Free-Ion Activity Does Not, Environmental Science and Technology, vol. 33, pp. 913-916.	LC50 value not reported; subadult life stage used
Munzinger, Armin, 1990. Effects of nickel on Daphnia magna during chronic exposure and alterations in the toxicity to generations pre-exposed to nickel, Water Research, vol. 24, iss. 7, pp. 845-852.	
Nagai T, De Schamphelaere KA. (2016). The effect of binary mixtures of zinc, copper, cadmium, and nickel on the growth of the freshwater diatom Navicula pelliculosa and comparison with mixture toxicity model predictions. Environ Toxicol Chem.; 35(11):2765-2773.	Plant study; not shown to be sensitive
Nebeker, Alan V., Ann Stinchfield, Carol Savonen, and Gary A. Chapman, 1986. Effects of copper, nickel and zinc on three species of oregon freshwater snails, Environmental Toxicology and Chemistry, vol. 5, pp. 807-811.	
Nebeker, Alan V., Carol Savonen, Rocky J. Baker, and Joel K. McCrady, 1984. Effects if copper, nickel, and zinc on the life cycle of the caddisfly Clistoronia magnifica (Limnephilidae), Environmental Toxicology and Chemistry, vol. 3, pp. 645-649.	

Citation	Notes
Niyogi, S., Brix, K. V., & Grosell, M. (2014). Effects of chronic waterborne nickel exposure on growth, ion homeostasis, acid-base balance, and nickel uptake in the freshwater pulmonate snail, Lymnaea stagnalis. Aquatic toxicology, 150, 36-44. http://dx.doi.org/10.1016/j.aquatox.2014.02.012	
Nys C, Asselman J, Hochmuth JD, Janssen CR, Blust R, Smolders E, and De Schamphelaere KAC (2015). Mixture toxicity of nickel and zinc to Daphnia magna is noninteractive at low effect sizes but becomes synergistic at high effect sizes. Environmental Toxicology and Chemistry; 34(5):1091-1102.	EC50 reported; no chronic endpoints reported
Nys C, Janssen CR, Blust R, Smolders E, de Schamphelaere KAC (2016b). Reproductive toxicity of binary and ternary mixture combinations of nickel, zinc, and lead to Ceriodaphnia dubia is best predicted with the independent action model. Environmental Toxicology & Chemistry; 35(7):1796-1805.	
Nys C, Janssen CR, Van Sprang P, De Schamphelaere KA. (2016a). The effect of pH on chronic aquatic nickel toxicity is dependent on the pH itself: Extending the chronic nickel bioavailability models. Environ Toxicol Chem.; 35(5):1097-1106.	
Nys C, van Regenmortal T, Janssen CR, Blust R, Smolders E, De Schamphelaere KAC. (2017). Comparison of chronic mixture toxicity of Nickel-Zinc-Copper and Nickel-Zinc-Copper-Cadmium mixtures between Ceriodaphnia dubia and Pseudokirchneriella subcapitata. Environmental Toxicology and Chemistry; 36(4): 1056–1066.	
Nys, C., Van Regenmortel, T., & De Schamphelaere, K. (2019). The effects of nickel on the structure and functioning of a freshwater plankton community under high dissolved organic carbon conditions: A microcosm experiment. Environmental toxicology and chemistry, 38(9), 1923-1939.	Microcosm experiment with multiple variables
Oláh V, Hepp A, Mészáros I. (2015). Comparative study on the sensitivity of turions and active fronds of giant duckweed (Spirodela polyrhiza (L.) Schleiden) to heavy metal treatments. Chemosphere. 2015;132:40-6.	Plant study; not shown to be sensitive
Pane, E.F., J.G. Richards, and C.M. Wood, 2003. Acute waterborne nickel toxicity in the rainbow trout (Oncorhynchus mykiss) occurs by a respiratory rather than ionoregulatory mechanism, Aquatic Toxicology, vol. 63, pp. 65-82.	
Pane, Eric F., Clint Smith, James C. McGeer, and Chris M. Wood, 2003. Mechanisms of Acute and Chronic Waterborne Nickel Toxicity in the Freshwater Cladoceran, Daphnia magna, Environmental Science and Technology, vol. 37, pp. 4382-4389.	

Citation	Notes
Pereira CMS, Everaert G, Blust R, De Schamphelaere KAC. (2018). Multigenerational effects of nickel on Daphnia magna depend on temperature and the magnitude of the effect in the first generationYES. Environmental Toxicology and Chemistry; 37(7):1877–1888.	Multigenerational effects confounds study results
Pereira, Cecilia M.S., David Deruytter, Ronny Blust, and Karel A.C. De Schamphelaere. (2017). Effect of temperature on chronic toxicity of copper, zinc, and nickel to Daphnia magna. Environmental Toxicology and Chemistry, vol. 36, iss. 7, pp. 1909-1916.	
Pereira, Cecilia M.S., Karel Vlaeminck, Karel Viaene, and Karel A.C. De Schamphelaere. 2019. The Unexpected Absence of Nickel Effects on a Daphnia Population at 3 Temperatures is Correctly Predicted by a Dynamic Energy Budget Individual-Based Model. Enivronmental Toxicology, vol. 38, iss. 7, pp 1423-1433.	Not relevant endpoints or study design
Perez E, Hoang TC. (2018). Responses of Daphnia magna to chronic exposure of cadium and nickel mixtures. Chemosphere; 208:991-1001.	Doesn't report measured concentrations when describing effect endpoints
Peters A, Merrington G, Schlekat C, De Schamphelaere K, Stauber J, Batley G, Harford A, van Dam R, Pease C, Mooney T, Warne M, Hickey C, Glazebrook P, Chapman J, Smith R, Krassoi R. (2018). Validation of the Nickel Biotic Ligand Model for Locally Relevant Species in Australian Freshwaters. Environmental Toxicology and Chemistry; 37(10): 2566-2574.	MATC/EC20 not reported
Pickering, Quentin H. and Croswell Henderson, 1966. The acute toxicity of some heavy metals to different species of warmwater fishes, Air and Water Pollution , vol. 10, iss. 6, pp. 453-463.	
Pickering, Quentin H., 1974. Chronic toxicity of nickel to the fathead minnow, Journal (Water Pollution Control Federation), pp. 760-765.	
Popp A, Cope WG, McGregor MA, Kwak TJ, Augspurger T, Levine JF and Koch L. (2018). A comparison of the chemical sensitivities between in vitro and in vivo propagated juvenile freshwater mussels: implications for standard toxicity testing. Environmental Toxicology and Chemistry; 37(12):3077-3085.	
Pyle, G.G., S.M. Swanson, and D.M. Lahmkuhl, 2002. The influence of water hardness, pH, and suspended solids on nickel toxicity to larval fathead minnows (Pimephales promelas), Water, Air, and Soil Pollution, vol. 133, pp. 215-226.	
Rugnini L, Costa G, Congestri R, Bruno L. (2017). Testing of two different strains of green microalgae for Cu and Ni removal from aqueous media. Science of the Total Environment; 601–602:959–967.	Plant study; not shown to be sensitive

Citation	Notes
Santore, Robert C., Kelly Croteau, Adam C. Ryan, Christian Schlekat, Elizabeth Middleton, Emily Garman, and Tham Hoang. 2021. A Review of Water Quality Factors that Affect Nickel Bioavailability to Aquatic Organisms: Refinement of the Biotic Ligand Model for Nickel in Acute and Chronic Exposures. Environmental Toxicology and Chemistry, vol. 40, iss. 8, pp. 2121-2134.	Review paper
Santos, F. M., Mazur, L. P., Mayer, D. A., Vilar, V. J., & Pires, J. C. (2019). Inhibition effect of zinc, cadmium, and nickel ions in microalgal growth and nutrient uptake from water: an experimental approach. Chemical Engineering Journal, 366, 358-367.	Plant study; not shown to be sensitive
Schubauer-Berigan, Mary K., Joseph R. Dierkes, Philip D. Monson, and Gerald T. Ankley, 1993. pHdependent toxicity of Cd, Cu, Ni, Pb, and Zn to Ceriodaphnia dubia, Pimephales promelas, Hyalella azteca and Lumbriculus variegatus, Environmental Toxicology and Chemistry, vol. 12, pp. 1261-1266.	
Schlekat, Christian E., Eric Van Genderen, Karel A.C. De Schamphelaere, Paula M.C. Antunes, Emily C. Rogevich, and William A. Stubblefield, 2010. Cross-species extrapolation of chronic nickel Biotic Ligand Models, Science of the Total Environment, vol. 408, pp. 6148-6157.	Nickel concentrations not reported in natural waters used for testing
Schroeder, J.E., U. Borgmann, and D.G. Dixon, 2010. Evaluation of the Biotic Ligand Model to predict long-term toxicity of nickel to Hyalella azteca, Environmental Toxicology and Chemistry, vol. 29, iss. 11, pp. 2498-2504.	EC20/MATC not reported; only LC50s
Singh, M., Khan, H., Verma, Y., & Rana, S. V. S. (2019). Distinctive fingerprints of genotoxicity induced by As, Cr, Cd, and Ni in a freshwater fish. Environmental Science and Pollution Research, 26(19), 19445-19452.	Non-resident of North America
Sivula L, Vehniainen E-R, Karjalainen AK, Kukkonen JVK. (2018). Toxicity of biomining effluents to Daphnia magna: Acute toxicity and transcriptomic biomarkers. Chemosphere; 210:304-311.	24-hr LC50s and used natural waters
Soucek, D.J., Dickinson, A., Schlekat, C., Van Genderen, E. and Hammer, E.J., 2020. Acute and chronic toxicity of nickel and zinc to a laboratory cultured mayfly (Neocloeon triangulifer) in aqueous but fed exposures. *Environmental toxicology and chemistry*, *39*(6), pp.1196-1206.	
Sztrum, Abelardo Andres, Jose Luis D'Eramo, and Jorge Herkovits, 2011. Nickel toxicity in embryos and larvae of the South American toad: effects on cell differentiation, morphogenesis, and oxygen consumption, Environmental Toxicology & Chemistry, vol. 30. iss. 5, pp. 1146-1152.	Non-resident of North America

Citation	Notes
Traudt EM, Ranville JF, Smith SA, Meyer JS. A test of the additivity of acute toxicity of binary-metal mixtures of Ni with Cd, Cu, and Zn to Daphnia magna, using the inflection point of the concentration–response curves. Environmental toxicology and chemistry. 2016 Jul;35(7):1843-51.	No hardness data
Traudt EM, Ranville JF, Meyer JS. Acute toxicity of ternary Cd–Cu–Ni and Cd–Ni–Zn mixtures to daphnia magna: dominant metal pairs change along a concentration gradient. Environmental science & technology. 2017 Apr 18;51(8):4471-81.	Unsure of data interpretation
Van Regenmortel T and De Schamphelaere KAC. (2018). Mixtures of Cu, Ni, and Zn act mostly noninteractively on Pseudokirchneriella subcapitata growth in natural waters. Environmental Toxicology and Chemistry; 37(2):587–598.	Plant study; not shown to be sensitive
Wang N, Ivey CD, Ingersoll CG, Brumbaugh WG, Alvarez D, Hammer EJ, Bauer CR, Augspurger T, Raimondo S, and Barnhart MC. (2017). Acute sensitivity of a broad range of freshwater mussels to chemicals with different modes of toxic action. Environmental Toxicology and Chemistry; 36(3):786-796.	
Wang, N., Kunz, J. L., Cleveland, D. M., Steevens, J. A., Hammer, E. J., Van Genderen, E., ... & Schlekat, C. E. (2020). Evaluation of Acute and Chronic Toxicity of Nickel and Zinc to 2 Sensitive Freshwater Benthic Invertebrates Using Refined Testing Methods. Environmental Toxicology and Chemistry, 39(11), 2256-2268.	
Virk, S. and Sharma, R.C., 1995. Effect of nickel and chromium on various life stages of Cyprinus carpio Linn. Indian Journal of Ecology, 22(2), pp.77-81.	
Yang, Yongmeng, Yue Yu, Rong Zhou, Yan Yang, and Yuanqing Bu. 2021. The effect of combined exposure of zinc and nickel on the development of zebrafish. Journal of Applied Toxicology, vol. 41, iss. 11, pp. 1765-1778. doi: 10.1002/jat.4159	Non-resident of North America
Yokota, Shohei, Kazuichi Nakamura, Ryo Kamata. (2019). A comparative study of nickel nanoparticle and ionic nickel toxicities in zebrafish: histopathological changes and oxidative stress. The Journal of Toxicological Sciences, vol. 44, iss. 11, pp. 737-751.	Non-resident of North America
Yong, W. K., Sim, K. S., Poong, S. W., Wei, D., Phang, S. M., & Lim, P. E. (2019). Physiological and metabolic responses of Scenedesmus quadricauda (Chlorophyceae) to nickel toxicity and warming. 3 Biotech, 9(8), 1-11	Plant study; not shown to be sensitive

Freshwater Chronic

Table A 12. 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 (Oncorhynchus mykiss). Environ. Toxicol. Chem.23(9): 2221-2228, 2004. ECOREF #80785	
Jaworska,M., A. Gorczyca, J. Sepiol, and P. Tomasik. Effect of Metal Ions on the Entomopathogenic Nematode Heterorhabditis bacteriophora Poinar (Nematode: Heterohabditidae) Under Laboratory Conditions. Water Air Soil Pollut.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 (Ceriodaphnia dubia) and an Amphipod (Hyalella azteca). Environ. Toxicol. Chem.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 (Danio rerio) Embryos and Larvae. Ecotoxicol. Environ. Saf.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. Environ. Sci. Technol.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. J. Fish Biol.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 Chironomus riparius Serve as Indicators for Water and Sediment Pollution? A Laboratory Approach. J. Soils Sediments10(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 Hyalella azteca and Chironomus dilutus in Water-Only and Spiked-Sediment Toxicity Tests. Ecotoxicol. Environ. Saf.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. Environ. Toxicol. Chem.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 (Pimephales promelas). Water Air Soil Pollut.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 (Oncorhynchus mykiss): An Exclusively Branchial Phenomenon. Aquat. Toxicol.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 Daphnia magna. Ecotoxicol. Environ. Saf.74(1): 99-110, 2011. ECOREF #166654	NOEC was 0 ug/L and thus could not calculate MATC value
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
Zuiderveen,J.A., and W.J. Birge. The Relationship Between Chronic Values in Toxicity Tests with Ceriodaphnia dubia. ASTM Spec. Tech. Publ.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 Ceriodaphnia dubia and Neocloeon triangulifer in Toxicity Tests with Natural Waters. Environ. Toxicol. Chem.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 Lymnaea stagnalis. Environ. Sci. Technol.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. Muyssen, 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 Daphnia magna in Artificial and Natural Waters. Environ. Toxicol. Chem.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 (Ceriodaphnia dubia) and an Amphipod (Hyalella azteca). Environ. Toxicol. Chem.23(3): 691-696, 2004. ECOREF #106584	Repeat

Open Literature

Table A13. 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. Environmental toxicology and chemistry, 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 Ceriodaphnia dubia and Pseudokirchneriella subcapitata. Environmental Toxicology and Chemistry, 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, Lymnaea stagnalis. Aquatic toxicology, 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. Environmental toxicology and chemistry, 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., Schlekat, C.E., Garman, E.R. and Stauber, J.L., 2020. Deriving a chronic guideline value for nickel in tropical and temperate marine waters. Environmental Toxicology and Chemistry, 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 (Oncorhynchus mykiss) and fathead minnow (Pimephales promelas) in synthetic and natural waters. Ecotoxicology and Environmental Safety, 67(1), pp.1-13.	Good study but ACRs not reported; data usable for 8 family method
Besser, J. M., Brumbaugh, W. G., Ingersoll, C. G., Ivey, C. D., Kunz, J. L., Kemble, N. E., ... & Garman, E. R. (2013). Chronic toxicity of nickel-spiked freshwater sediments: Variation in toxicity among eight invertebrate taxa and eight sediments. Environmental toxicology and chemistry, 32(11), 2495-2506.	Sediment study
Besser, J. M., Dorman, R., Ivey, C. D., Cleveland, D., & Steevens, J. A. (2020). Sensitivity of Warm-Water Fishes and Rainbow Trout to Selected Contaminants. Bulletin of environmental contamination and toxicology, 104(3), 321-326.	No hardness for chronic study reported or test design

Citation	Notes
Besser, J.M., Brumbaugh, W.G., Kemble, N.E., Ivey, C.D., Kunz, J.L., Ingersoll, C.G., and Rudel, David, 2011, Toxicity of nickel-spiked freshwater sediments to benthic invertebrates—Spiking methodology, species sensitivity, and nickel bioavailability: U.S. Geological Survey Scientific Investigations Report 2011–5225, 53 p. plus appendixes	Sediment study
Birge, W. J., Black, J. A., Hobson, J. F., Westerman, A. G., & Short, T. M. (1984). 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 early-life stages. Research report July 1983-August 1984 (No. PB-85-214666/XAB; RR-151). Kentucky Water Resources Research Inst., Lexington (USA).	
Borgmann, U., Couillard, Y., Doyle, P., & Dixon, D. G. (2005). Toxicity of sixty-three metals and metalloids to Hyalella azteca at two levels of water hardness. Environmental toxicology and chemistry, 24(3), 641-652.	Only LC50/EC50 reported
Bozich J, Hang M, Hamers R, Klaper R (2017). Core chemistry influences the toxicity of multicomponent metal oxide nanomaterials, lithium nickel manganese cobalt oxide, and lithium cobalt oxide to Daphnia magna. Environ Toxicol Chem. 36(9):2493-2502.	Not pure nickel exposure
Chapman, G. A., Ota, S., & Recht, F. (1980). Effects of Water Hardness on the Toxicity of Metals to Daphnia Magna: Status Report-January 1980. US Environmental Protection Agency, Corvallis Environmental Research Laboratory.	EPA considered in past derivations
Crémazy, A., Brix, K. V., Smith, D. S., Chen, W., Grosell, M., Schlekat, C. E., ... & Wood, C. M. (2020). A Mystery Tale: Nickel Is Fickle When Snails Fail—Investigating the Variability in Ni Toxicity to the Great Pond Snail. Integrated Environmental Assessment and Management, 16(6), 983-997.	Review paper
Dao TS, Le VN, Bui BT, Dinh KV, Wiegand C, Nguyen TS, Dao CT, Nguyen VD, To TH, Nguyen LSP, Vo TG, and Vo TMC (2017). Sensitivity of a tropical micro-crustacean (Daphnia lumholtzi) to trace metals tested in natural water of the Mekong River. Science of the Total Environment; 574:1360-1370.	Concern for contaminants in natural water used for testing
Dave, G., & Xiu, R. (1991). Toxicity of mercury, copper, nickel, lead, and cobalt to embryos and larvae of zebrafish, Brachydanio rerio. Archives of Environmental Contamination and Toxicology, 21(1), 126-134.	non-resident of North America
Deleebeeck, Nele M.E., Brita T.A. Muyssen, Frederick De Laender, Colin R. Janssen, Karel A.C. De Schamphelaere, 2007. Comparison of nickel toxicity to cladocerans in soft versus hard surface waters, Aquatic Toxicology, vol. 84, iss. 2, pp. 223-235.	Not used because EC10 reported

Citation	Notes
Deleebeeck, Nele M.E., Frederik De Laender, Victor A. Chepurnov, Wim Vyerman, Colin R. Janssen, Karel A.C. De Schamphelaere, 2009. A single bioavailability model can accurately predict Ni toxicity to green microalgae in soft and hard surface waters, Water Research, vol. 43, iss. 7, pp. 1935-1947.	not used plant study; not shown to be sensitive
Deleebeeck, Nele M.E., Karel A.C. De Schamphelaere, Colin R. Janssen, 2007. A bioavailability model predicting the toxicity of nickel to rainbow trout (Oncorhynchus mykiss) and fathead minnow (Pimephales promelas) in synthetic and natural waters, Ecotoxicology and Environmental Safety, vol. 67, iss. 1, pp 1-3.	Only NOEC reported; cannot calculate MATC or EC20 without more data
Deleebeeck, Nele M.E., Karel A.C. De Schamphelaere, Colin R. Janssen, 2009. Effects of Mg2+ and H+ on the toxicity of Ni2+ to the unicellular green alga Pseudokirchneriella subcapitata: Model development and validation with surface waters, Science of the Total Environment, vol. 407, iss. 6, pp. 1901-1914.	plant study; EC50s reported rather than MATC/EC20
Environment & Climate Change Canada. 2018. Nickel Toxicology Project Report: Chinook 28-Day Chronic Toxicity Test.Filová, Alexandra, Agáta Fargašová, and Marianna Molnárová. 2021. Cu, Ni, and Zn effects on basic physiological and stress parameters of Raphidocelis subcapitata algae. Environmental Science and Pollution Research, vol 28, iss 41, pp. 58426-58441. doi: 10.1007/s11356-021-14778-6	plant study; EC50s reported rather than MATC/EC20
Garcia-Garcia JD, Pena-Sanabria KA, Sanchez-Thomas R, Moreno-Sanchez R. (2018) Nickel accumulation by the green algae-like Euglena gracilis. Journal of Hazardous Materials; 343;10–18.	plant study; not shown to be sensitive
Ghosh, Anupam, Anilava Kaviraj, Isabela Ewa Nielsen, Subrata Saha. 2021. A comparative evaluation of the effects of copper and nickel on the growth of the freshwater fish Cyprinus carpio and amelioration by Pistia stratiotes. Toxicology and Environmental Health Sciences, vol 13, iss 4, pp. 363-374, doi: 10.1007/s13530-021-00097-3	Only 1 or 2 test concentrations used per test
Gopalapillai, Yamini, Beverley Hale, and Bernard Vigneault, 2013. Effect of major cations (Ca2+, Mg2+, Na+, K+) and anions (SO42-, Cl-, NO3-) on Ni accumulation and toxicity in aquatic plant (Lemna minor L.): Implications for Ni risk assessment, Environmental Toxicology and Chemistry, vol. 32, iss. 4, pp. 810-821.	plant study
He J, Wang C, Schlekat CE, Wu F, Middleton E, Garman E, Peters A. Validation of nickel bioavailability models for algae, invertebrates, and fish in Chinese surface waters. Environmental Toxicology and Chemistry. 2023 Jun;42(6):1257-65.	Used natural waters for testing; concern for water quality

Citation	Notes
Hernández-Flores, S., Santos-Medrano, G. E., Rubio-Franchini, I., & Rico-Martínez, R. (2020). Evaluation of bioconcentration and toxicity of five metals in the freshwater rotifer Euchlanis dilatata Ehrenberg, 1832. Environmental Science and Pollution Research, 27(12), 14058-14069.	no relevant endpoints provided
Hopfer, Sidney M., Marilyn C. Plowman, Kevin R. Sweeney, John A. Bantle, and F. William Sunderman Jr., 1991. Teratogenicity of Ni2+ in Xenopus laevis, Assayed by the FETAX Procedure, Biological Trace Element Research, vol. 29, iss. 3, pp. 203-216.	Prior to 1995; EPA considered
Klaine, Stephen J. and Sandra Knuteson, 2003. Toxicity of Nickel to Duckweeds. Clemson University, Pendelton, SC.	Plant study; not shown to be sensitive
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. Environ Toxicol Chem, 37: 2458-2466. doi:10.1002/etc.4210	Exposure period does not meeting chronic conditions
Krzykwa JC, Saeid A, Jeffries MKS. (2019). Identifying sublethal endpoints for evaluating neurotoxic compounds utilizing the fish embryo toxicity test. Ecotoxicology and Environmental Safety; 170:521-529.	EC20/MATC not reported
Kszos, Lynn Adams, Arthur J. Stewart, and Paul A. Taylor, 1992. An evaluation of nickel toxicity to Ceriodaphnia dubia and Daphnia magna in a contaminated stream and in laboratory tests, Environmental Toxicology and Chemistry, vol. 11, pp. 1001-1012.	Used nominal concentrations for laboratory water tests; natural waters used for testing had background contamination
Leung J, Witt JDS, Norwood W, Dixon DG (2016). Implications of Cu and Ni toxicity in two members of the Hyalella azteca cryptic species complex: mortality, growth, and bioaccumulation parameters. Environ Toxicol Chem.; 35(11):2817-2826.	MATC/EC20/LC20 not reported
Li, Hao, Jun Yao, Robert Duran, Jianli Liu, Ning Min, Zhihui Chen, Xiaozhe Zhu, Chenchan Zhao, Bo Ma, Wancheng Pang, Miaomiao Li, Ying Cao, Bang Liu (2021). Toxic response of the freshwater green algae Chlorella pyrenoidosa to combined effect of flotation reagent butyl xanthate and nickel. Environmental Pollution, vol. 286, pp. 117285.	Plant study; not shown to be sensitive
Lind, David, Kevin Alto, and Steven Chatterton, 1978. Regional copper-nickel study. Draft Report. Minnesota Environmental Quality Board, St. Paul, MN.	EPA previous considered in derivation
Macoustra, G. K., Jolley, D. F., Stauber, J. L., Koppel, D. J., & Holland, A. (2020). Speciation of nickel and its toxicity to Chlorella sp. in the presence of three distinct dissolved organic matter (DOM). Chemosphere, 128454.	Plant study; not shown to be sensitive
Mano, H., Shinohara, N., & Naito, W. (2020). Reproduction Sensitivity of Five Daphnia Species to Nickel. Journal of Water and Environment Technology, 18(6), 372-382.	MATC/EC20 not reported

Citation	Notes
Martinez, R. S., Sáenz, M. E., Alberdi, J. L., & Di Marzio, W. D. (2019). Comparative ecotoxicity of single and binary mixtures exposures of nickel and zinc on growth and biomarkers of Lemna gibba. Ecotoxicology, 28(6), 686-697.	Plant study; not shown to be sensitive
Martinez, S., Sáenz, M. E., Alberdi, J. L., & Di Marzio, W. D. (2020). Comparative ecotoxicity of single and binary mixtures exposures of cadmium and zinc on growth and biomarkers of Lemna gibba. Ecotoxicology, 29(5), 571-583.	Plant study; not shown to be sensitive
Martínez-Ruiz EB, Martínez-Jerónimo F. (2015). Nickel has biochemical, physiological, and structural effects on the green microalga Ankistrodesmus falcatus: An integrative study. Aquat Toxicol.; 169:27-36.	Plant study; not shown to be sensitive
Mebane, C. A., Schmidt, T. S., Miller, J. L., & Balistrieri, L. S. (2020). Bioaccumulation and Toxicity of Cadmium, Copper, Nickel, and Zinc and Their Mixtures to Aquatic Insect Communities. Environmental Toxicology and Chemistry, 39(4), 812-833.	Did not use standard testing methodology; EC50s reported
Munzinger, Armin, 1990. Effects of nickel on Daphnia magna during chronic exposure and alterations in the toxicity to generations pre-exposed to nickel, Water Research, vol. 24, iss. 7, pp. 845-852.	Considered in previous EPA derivation
Nagai T, De Schamphelaere KA. (2016). The effect of binary mixtures of zinc, copper, cadmium, and nickel on the growth of the freshwater diatom Navicula pelliculosa and comparison with mixture toxicity model predictions. Environ Toxicol Chem.; 35(11):2765-2773.	Plant study; not shown to be sensitive
Nebeker, Alan V., Ann Stinchfield, Carol Savonen, and Gary A. Chapman, 1986. Effects of copper, nickel and zinc on three species of oregon freshwater snails, Environmental Toxicology and Chemistry, vol. 5, pp. 807-811.	Already considered by EPA
Nebeker, Alan V., Carol Savonen, Rocky J. Baker, and Joel K. McCrady, 1984. Effects if copper, nickel, and zinc on the life cycle of the caddisfly Clistoronia magnifica (Limnephilidae), Environmental Toxicology and Chemistry, vol. 3, pp. 645-649.	Considered in previous EPA derivation
Niyogi, S., Brix, K. V., & Grosell, M. (2014). Effects of chronic waterborne nickel exposure on growth, ion homeostasis, acid-base balance, and nickel uptake in the freshwater pulmonate snail, Lymnaea stagnalis. Aquatic toxicology, 150, 36-44. http://dx.doi.org/10.1016/j.aquatox.2014.02.012	Already used
Nys C, Asselman J, Hochmuth JD, Janssen CR, Blust R, Smolders E, and De Schamphelaere KAC (2015). Mixture toxicity of nickel and zinc to Daphnia magna is noninteractive at low effect sizes but becomes synergistic at high effect sizes. Environmental Toxicology and Chemistry; 34(5):1091-1102.	EC50 reported; no chronic endpoints reported

Citation	Notes
Nys C, Janssen CR, Blust R, Smolders E, de Schamphelaere KAC (2016). Reproductive toxicity of binary and ternary mixture combinations of nickel, zinc, and lead to Ceriodaphnia dubia is best predicted with the independent action model. Environmental Toxicology & Chemistry; 35(7):1796-1805.	EC50 reported; no chronic endpoints reported
Nys C, Janssen CR, Van Sprang P, De Schamphelaere KA. (2016). The effect of pH on chronic aquatic nickel toxicity is dependent on the pH itself: Extending the chronic nickel bioavailability models. Environ Toxicol Chem.; 35(5):1097-1106.	
Nys C, van Regenmortal T, Janssen CR, Blust R, Smolders E, De Schamphelaere KAC. (2017). Comparison of chronic mixture toxicity of Nickel-Zinc-Copper and Nickel-Zinc-Copper-Cadmium mixtures between Ceriodaphnia dubia and Pseudokirchneriella subcapitata. Environmental Toxicology and Chemistry; 36(4): 1056–1066.	Rejected because test design; natural waters used for testing not characterized
Nys, C., Van Regenmortel, T., & De Schamphelaere, K. (2019). The effects of nickel on the structure and functioning of a freshwater plankton community under high dissolved organic carbon conditions: A microcosm experiment. Environmental toxicology and chemistry, 38(9), 1923-1939.	Microcosm experiment with multiple variables
Oláh V, Hepp A, Mészáros I. (2015). Comparative study on the sensitivity of turions and active fronds of giant duckweed (Spirodela polyrhiza (L.) Schleiden) to heavy metal treatments. Chemosphere. 2015;132:40-6.	Plant study; not shown to be sensitive
Pereira CMS, Everaert G, Blust R, De Schamphelaere KAC. (2018). Multigenerational effects of nickel on Daphnia magna depend on temperature and the magnitude of the effect in the first generationYES. Environmental Toxicology and Chemistry; 37(7):1877–1888.	Could not find hardness data
Pereira, Cecilia M.S., David Deruytter, Ronny Blust, and Karel A.C. De Schamphelaere. (2017). Effect of temperature on chronic toxicity of copper, zinc, and nickel to Daphnia magna. Environmental Toxicology and Chemistry, vol. 36, iss. 7, pp. 1909-1916.	
Pereira, Cecilia M.S., Karel Vlaeminck, Karel Viaene, and Karel A.C. De Schamphelaere. 2019. The Unexpected Absence of Nickel Effects on a Daphnia Population at 3 Temperatures is Correctly Predicted by a Dynamic Energy Budget Individual-Based Model. Enivronmental Toxicology, vol. 38, iss. 7, pp 1423-1433.	Not relevant endpoints or study design
Perez E, Hoang TC. (2018). Responses of Daphnia magna to chronic exposure of cadium and nickel mixtures. Chemosphere; 208:991-1001.	Doesn't report measured concentrations when describing effect endpoints
Peters A, Merrington G, Schlekat C, De Schamphelaere K, Stauber J, Batley G, Harford A, van Dam R, Pease C, Mooney T, Warne M, Hickey C, Glazebrook P, Chapman J, Smith R, Krassoi R.	MATC/EC20 not reported

Citation	Notes
(2018). Validation of the Nickel Biotic Ligand Model for Locally Relevant Species in Australian Freshwaters. Environmental Toxicology and Chemistry; 37(10): 2566-2574.	
Pickering, Quentin H., 1974. Chronic toxicity of nickel to the fathead minnow, Journal (Water Pollution Control Federation), pp. 760-765.	Used in previous EPA derivations
Rugnini L, Costa G, Congestri R, Bruno L. (2017). Testing of two different strains of green microalgae for Cu and Ni removal from aqueous media. Science of the Total Environment; 601–602:959–967.	Plant study; not shown to be sensitive
Santore, Robert C., Kelly Croteau, Adam C. Ryan, Christian Schlekat, Elizabeth Middleton, Emily Garman, and Tham Hoang. 2021. A Review of Water Quality Factors that Affect Nickel Bioavailability to Aquatic Organisms: Refinement of the Biotic Ligand Model for Nickel in Acute and Chronic Exposures. Environmental Toxicology and Chemistry, vol. 40, iss. 8, pp. 2121-2134.	Review paper
Santos, F. M., Mazur, L. P., Mayer, D. A., Vilar, V. J., & Pires, J. C. (2019). Inhibition effect of zinc, cadmium, and nickel ions in microalgal growth and nutrient uptake from water: an experimental approach. Chemical Engineering Journal, 366, 358-367.	Plant study; not shown to be sensitive
Schlekat, Christian E., Eric Van Genderen, Karel A.C. De Schamphelaere, Paula M.C. Antunes, Emily C. Rogevich, and William A. Stubblefield, 2010. Cross-species extrapolation of chronic nickel Biotic Ligand Models, Science of the Total Environment, vol. 408, pp. 6148-6157.	Nickel concentrations not reported in natural waters used for testing
Schroeder, J.E., U. Borgmann, and D.G. Dixon, 2010. Evaluation of the Biotic Ligand Model to predict longterm toxicity of nickel to Hyalella azteca, Environmental Toxicology and Chemistry, vol. 29, iss. 11, pp. 2498-2504.	Did not use flow through design
Shuhaimi-Othman, M., Y. Nadzifah, N.S. Umirah, and A.K. Ahmad, 2012. Toxicity of metals to tadpoles of the common Sunda toad, Duttaphrynus melanostictus, Toxicological & Environmental Chemistry, vol. 94, iss. 2, pp. 364-376.	Non-resident of North America
Singh, M., Khan, H., Verma, Y., & Rana, S. V. S. (2019). Distinctive fingerprints of genotoxicity induced by As, Cr, Cd, and Ni in a freshwater fish. Environmental Science and Pollution Research, 26(19), 19445-19452.	Non-resident of North America
Soucek, D. J., Dickinson, A., Schlekat, C., Van Genderen, E., & Hammer, E. J. (2020). Acute and Chronic Toxicity of Nickel and Zinc to a Laboratory Cultured Mayfly (Neocloeon triangulifer) in Aqueous but Fed Exposures. Environmental toxicology and chemistry, 39(6), 1196-1206.	Already used
Sztrum, Abelardo Andres, Jose Luis D'Eramo, and Jorge Herkovits, 2011. Nickel toxicity in embryos and larvae of the South American toad: effects on cell differentiation, morphogenesis, and oxygen consumption, Environmental Toxicology & Chemistry, vol. 30. iss. 5, pp. 1146-1152.	Non-resident of North America

Citation	Notes
Van Regenmortel T and De Schamphelaere KAC. (2018). Mixtures of Cu, Ni, and Zn act mostly noninteractively on Pseudokirchneriella subcapitata growth in natural waters. Environmental Toxicology and Chemistry; 37(2):587–598.	Plant study; not shown to be sensitive
Wang, N., Kunz, J. L., Cleveland, D. M., Steevens, J. A., Hammer, E. J., Van Genderen, E., ... & Schlekat, C. E. (2020). Evaluation of Acute and Chronic Toxicity of Nickel and Zinc to 2 Sensitive Freshwater Benthic Invertebrates Using Refined Testing Methods. Environmental Toxicology and Chemistry, 39(11), 2256-2268.	Already used
Yang, Yongmeng, Yue Yu, Rong Zhou, Yan Yang, and Yuanqing Bu. 2021. The effect of combined exposure of zinc and nickel on the development of zebrafish. Journal of Applied Toxicology, vol. 41, iss. 11, pp. 1765-1778. doi: 10.1002/jat.4159	Non-resident of North America
Yokota, Shohei, Kazuichi Nakamura, Ryo Kamata. (2019). A comparative study of nickel nanoparticle and ionic nickel toxicities in zebrafish: histopathological changes and oxidative stress. The Journal of Toxicological Sciences, vol. 44, iss. 11, pp. 737-751.	Non-resident of North America
Yong, W. K., Sim, K. S., Poong, S. W., Wei, D., Phang, S. M., & Lim, P. E. (2019). Physiological and metabolic responses of Scenedesmus quadricauda (Chlorophyceae) to nickel toxicity and warming. 3 Biotech, 9(8), 1-11	Plant study; not shown to be sensitive
De Schamphelaere, K., Van Laer, L., Deleebeeck, N., Muyssen, B., Degryse, F., Smolders, E., & Janssen, C. (2006). Nickel speciation and ecotoxicity in European natural surface waters: development, refinement and validation of bioavailability models. Ghent University	Used natural waters for testing; concern for water quality

Pentachlorophenol

Freshwater Acute

Table A 14. 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

Citation	Notes
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	
Donkin,S.G., and P.L. Williams. Influence of Developmental Stage, Salts and Food Presence on Various End Points Using Caenorhabditis elegans for Aquatic Toxicity Testing. Environ. Toxicol. Chem.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	

Citation	Notes
Species: Part I. Acute Toxicity of Five Chemicals. Arch. Environ. Contam. Toxicol.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. Chemosphere55(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 (Dreissena polymorpha) Under Varying Conditions of Temperature and pH. Ecotoxicol. Environ. Saf.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. ASTM Spec. Tech. Publ.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 Xenopus laevis. ASTM Spec. Tech. Publ.: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 Brachionus calyciflorus. Aquat. Toxicol.28(3/4): 243-258, 1994. ECOREF #16572	Cytotoxicity test
Jin,X., J. Zha, Y. Xu, J.P. Giesy, and Z. Wang. Toxicity of Pentachlorophenol to Native Aquatic Species in the Yangtze River. Environ. Sci. Pollut. Res.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 Daphnia magna Clones as a General Cellular Response to Stress. Aquat. Toxicol.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. Arch. Environ. Contam. Toxicol.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

Citation	Notes
Kim,K.T., Y.G. Lee, and S.D. Kim. Combined Toxicity of Copper and Phenol Derivatives to Daphnia magna: Effect of Complexation Reaction. Environ. Int.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. Water Res.29(2): 431-442, 1995. ECOREF #13717	Test design and endpoints not appropriate for criteria derivation. LC50 was based on 5 hour exposure.
Kishino,T., and K. Kobayashi. Acute Toxicity and Structure-Activity Relationships of Chlorophenols in Fish. Water Res.30(2): 387-392, 1996. ECOREF #16366	Test design and endpoints not appropriate for criteria derivation
Kishino,T., and K. Kobayshi. Studies on the Mechanism of Toxicity of Chlorophenols Found in Fish Through Quantitative Structure-Activity Relationships. Water Res.30(2): 393-399, 1996. ECOREF #16365	Test design and endpoints not appropriate for criteria derivation
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 Ceriodaphnia dubia. Water Environ. Res.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. Environ. Toxicol. Chem.19(1): 123-132, 2000. ECOREF #51911	LC50s not provided
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	

Citation	Notes
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	
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. Environ. Int.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. Ecotoxicol. Environ. Saf.47(2): 186-194, 2000. ECOREF #60083	
Saka,M.. Examination of an Amphibian-Based Assay Using the Larvae of Xenopus laevis and Ambystoma mexicanum. Ecotoxicol. Environ. Saf.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. Ellersieck. Contaminant Sensitivity of Threatened and Endangered Fishes Compared to Standard Surrogate Species. Environ. Toxicol. Chem.20(12): 2869-2876, 2001. ECOREF #65396	Repeat of dwyer info

Citation	Notes
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 (Danio rerio) Embryos. Toxicol. Sci.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 Nothobranchius guentheri as a Tool for Rapid Acute Toxicity Screening. Environ. Toxicol. Chem.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 Daphnia magna Test. Proc. Estonian Acad. Sci.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 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	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. J. Appl. Toxicol.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. Environ. Toxicol. Chem.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 Simocephalus vetulus (Schoedler, 1858) (Crustacea: Cladocera). N. Z. J. Mar. Freshw. Res.29(2): 289-294, 1995. ECOREF #18919	
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 A 15. 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 A 16. 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 Artemia nauplii. Environ. Toxicol. Water Qual.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. Nippon Suisan Gakkaishi(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 Gammarus duebeni. Water Res.32(3): 569-578, 1998. ECOREF #18971	Non-north american test species; no evidence of its presence on the coast North America.

Citation	Notes
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. J. Exp. Mar. Biol. Ecol.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. Endangered Aquatic Vertebrates: Comparative and Probabilistic-Based Toxicology. 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 Platynereis dumerilii (Polychaeta: Nereidae). Environ. Toxicol. Water Qual.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 (Mysid Siriella armata) and Freshwater (Cladoceran Daphnia magna) Ecotoxicological Models. Ecotoxicology24(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 Tigriopus fulvus. Chem. Ecol.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. Environ. Toxicol. Chem.20(12): 2869-2876, 2001. ECOREF #65396	
Silva,J., L. Troncoso, E. Bay-Schmith, and A. Larrain. Utilization of Odontesthes regia (Atherinidae) from the South Eastern Pacific as a Test Organism for Bioassays: Study of Its Sensitivity to Six Chemicals. Bull. Environ. Contam. Toxicol.66(5): 570-575, 2001. ECOREF #62074	Non-north american test species; Lacks some method details
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 A 17. 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	Non-resident North American test species
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 Critial 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 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	

Citation	Notes
Buccafusco,R.J., S.J. Ells, and G.A. LeBlanc. Acute Toxicity of Priority Pollutants to Bluegill (Lepomis macrochirus). 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 Daphnia magna. 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. Koplish, 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	
Galvez,F., and C.M. Wood. The Mechanisms and Costs of Physiological and Toxicological Acclimation to Waterborne Silver in Juvenile Rainbow Trout (Oncorhynchus mykiss). 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	No hardness data

Citation	Notes
(Anguilla anguilla) and the Rainbow Trout (Oncorhynchus mykiss). Aquat. Toxicol.48(2-3): 327-342, 2000. ECOREF #49762	
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 acclimization 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 (Oncorhynchus mykiss), Fathead Minnows (Pimephales promelas), and Water Fleas (Daphnia magna). 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
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

Citation	Notes
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. Wenholz, 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. Paradice, 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	
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

Citation	Notes
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
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

Citation	Notes
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 A 18. 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 Daphnia magna and Pimephales promelas. Environmental toxicology and chemistry, 31(11), pp.2557-2563.	No hardness data

Freshwater Chronic

Table A 19. 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 Ceriodaphnia dubia. Environ. Toxicol. Chem.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 Chironomus tentans in Two Freshwater Sediments. Environ. Toxicol. Chem.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 (Salmo gairdneri). Water Res.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. Environ. Toxicol. Chem.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 Stenonema modestum (Heptageniidae) in Subacute Toxicity Assessments. Environ. Toxicol. Chem.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	Considered previously by EPA in 1980 derivation
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	Considered previously by EPA in 1980 derivation

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 Daphnia magna: A Comparative Study of Standardized Chronic Endpoints and Progeny Phototaxis. Ecotoxicology22(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 (Pimephales promelas). Environ. Toxicol. Chem.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 (Oncorhynchus mykiss). Environ. Toxicol. Chem.24(7): 1642-1647, 2005. ECOREF #83081	Only 2 test concentrations
Naddy,R.B., A.B. Rehner, G.R. McNerney, 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. Environ. Toxicol. Chem.26(9): 1922-1930, 2007. ECOREF #104889	
Naddy,R.B., J.W. Gorsuch, A.B. Rehner, G.R. McNerney, R.A. Bell, and J.R. Kramer. Chronic Toxicity of Silver Nitrate to Ceriodaphnia dubia and Daphnia magna, and Potential Mitigating Factors. Aquat. Toxicol.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 Daphnia magna. Environ. Toxicol. Chem.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. Environ. Toxicol. Chem.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 Lymnaea stagnalis. Environ. Sci. Technol.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 Daphnia magna? A Critial Assessment of the Acute-to-Chronic Toxicity Ratio for Silver. Ecotoxicol. Environ. Saf.71:32-40, 2008. ECOREF #104819	Repeat of other studies

Open Literature

Table A 20. 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 Ceriodaphnia dubia. Journal of Applied Toxicology, 41(3), pp.375-386.	Very little study details; Effect level reported as inhibitory concentrations; did not use flow through design

Saltwater Acute

Table A 21. 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. Arch. Environ. Contam. Toxicol.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. Environ. Toxicol. Chem.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 (Cyprinodon variegatus). Bull. Environ. Contam. Toxicol.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. Environ. Toxicol. Chem.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. Aquat. Toxicol.89(3): 158-166, 2008. ECOREF #107127	Non-resident North American test species
Lussier,S.M., J.H. Gentile, and J. Walker. Acute and Chronic Effects of Heavy Metals and Cyanide on Mysidopsis bahia (Crustacea: Mysidacea). Aquat. Toxicol.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 Byssogenesis in Perna viridis (Linn.). Indian J. Mar. Sci.12(2): 125-127, 1983. ECOREF #11120	Non-resident North American test species; should have been considered in last EPA update
McKenney,C.L.,Jr., and S.H. Hong. Interlaboratory Comparison of Chronic Toxicity Testing Using the Estuarine Mysid (Mysidopsis bahia): 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 Tigriopus brevicornis (Muller). Lethal and Sublethal Effects at Different Development Stages (Effets Biologiques de Deux Metaux . J. Rech. Oceanogr.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. Arch. Environ. Contam. Toxicol.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 Tigriopus brevicornis. J. Rech. Oceanogr.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 Neanthes arenaceodentata. ASTM Spec. Tech. Publ.: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, Brachionus plicatilis. 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	

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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	
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 A 22. 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	Not adequate detail on study design
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
Arambasic,M.B., S. Bjelic, and G. Subakov. Acute Toxicity of Heavy Metals (Copper, Lead, Zinc), Phenol and Sodium on Allium cepa L.., Lepidium sativum L. and Daphnia magna St.: Comparative Investigations and the Practical Applications. Water Res.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 Daphnia magna Straus to Essential and Non-Essential Metals. Aquat. Toxicol.42(2): 115-137, 1998. ECOREF #19146	

Citation	Notes
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 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 Daphnia magna. Part 2: Toxicity Results. Environ. Toxicol. Chem.21(6): 1294-1300, 2002. ECOREF #66362	
Bianchini,A., and P. Carvalho de Castilho. Effects of Zinc Exposure on Oxygen Consumption and Gill Na+, K+-ATPase of the Estuarine Crab Chasmagnathus granulata Dana, 1851 (Decapoda - Grapsidae). Bull. Environ. Contam. Toxicol.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 (Pimephales promelas). Arch. Environ. Contam. Toxicol.51(3): 438-444, 2006. ECOREF #96586	
Brinkman,S., and J. Woodling. Zinc Toxicity to the Mottled Sculpin (Cottus bairdi) in High-Hardness Water. Environ. Toxicol. Chem.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 (Salmo trutta) to Zinc and Copper Singly and in Combination with Cadmium or Copper. Arch. Environ. Contam. Toxicol.67(2): 214-223, 2014. ECOREF #169219	Acclimization chronic study
Brinkman,S.F., and W.D. Johnston. Acute Toxicity of Aqueous Copper, Cadmium, and Zinc to the Mayfly Rhithrogena hageni. Arch. Environ. Contam. Toxicol.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. Arch. Environ. Contam. Toxicol.62(2): 272-281, 2012. ECOREF #161667	
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 used
Brooks,A., R.M. White, and D.C. Paton. Effects of Heavy Metals on the Survival of Diacypris compacta (Herbst) (Ostracoda) from the Coorong, South Australia. Int. J. Salt Lake Res.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. Environ. Toxicol. Chem.24(6): 1528-1531, 2005. ECOREF #84071	

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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). Arch. Environ. Contam. Toxicol.30(1): 84-92, 1996. ECOREF #16423	
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. 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 (Acipenser transmontanus) and Rainbow Trout (Oncorhynchus mykiss) to Copper, Cadmium, or Zinc in Water-Only Laboratory Exposures. Environ. Toxicol. Chem.33(10): 2259-2272, 2014. ECOREF #188154	
Canli,M.. Dietary and Water-Borne Zn Exposures Affect Energy Reserves and Subsequent Zn Tolerance of Daphnia magna. Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.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 Thamnocephalus platyurus as Test Species in Comparison with Streptocephalus proboscideus (Crustacea: Branchiopoda: Anostraca). Environ. Toxicol. Water Qual.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. Mar. Environ. Res.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 Acrosscheilus paradoxus. Dongwu Xuekan5(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. Aquat. Toxicol.61(1/2): 53-64, 2002. ECOREF #65728	Transgenic test organism
Ciji,P.P., and S.B. Nandan. Toxicity of Copper and Zinc to Puntius parrah (Day, 1865). Mar. Environ. Res.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 Hyalella azteca to Diazinon, Alkylphenol Ethoxylates, Copper, Cadmium, and Zinc. Arch. Environ. Contam. Toxicol.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 Ceriodaphnia dubia and Daphnia carinata. Ecotoxicol. Environ. Saf.72:1523-1528, 2009. ECOREF #115778	

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Crane,M.. Effect of Zinc on Four Populations and Two Generations of Gammarus pulex (L.). Freshw. Biol.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 Poecilia vivipara (Osteichthyes, Cyprinodontiformes). Fresenius Environ. Bull.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 Channa punctatus. Bull. Environ. Contam. Toxicol.52(6): 893-897, 1994. ECOREF #13692	Non-north american test species used
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	Could not find
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	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 Caenorhabditis elegans. Environ. Toxicol. Chem.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 Daphnia magna Straus. Chemosphere45(4/5): 553-560, 2001. ECOREF #61028	No hardness data
Diamond,J.M., D.E. Koplish, 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	
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. Environ. Toxicol.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. Toxicol. Ind. Health26(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 (Acipenser transmontanus). Report to Teck American Incorporated, Saskatoon, SK, Canada:19 p., 2011. ECOREF #188257	

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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. Chem. Spec. Bioavail.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, Adenophlebia auriculata (Ephemeroptera, Leptophlebiidae): Method Development. Afr. J. Aquat. Sci.27(1): 31-38, 2002. ECOREF #84132	Non-north american test species used
Fargasova,A.. Winter Third- to Fourth-Instar Larvae of Chironomus plumosus as Bioassay Tools for Assessment of Acute Toxicity of Metals and Their Binary Combinations. Ecotoxicol. Environ. Saf.48(1): 1-5, 2001. ECOREF #59843	
Fargasova,A.. Cd, Cu, Zn, Al and Their Binary Combinations Acute Toxicity for Chironomus plumosus Larvae. Fresenius Environ. Bull.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. ASTM Spec. Tech. Publ.4:93-109, 1996. ECOREF #45211	Not relevant for criteria derivation
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, Parreysia cylindrica (Annandale and Prashad). Nat. Environ. Pollut. Technol.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 Leporinus obtusidens. Chemosphere69(1): 170-175, 2007. ECOREF #100038	Non-north american test species used
Gomez,S., C. Villar, and C. Bonetto. Zinc Toxicity in the Fish Cnesterodon decemmaculatus in the Parana River and Rio de la Plata Estuary. Environ. Pollut.99(2): 159-165, 1998. ECOREF #19136	Non-north american test species used
Gottschalk,J.A.. Copper and Zinc Toxicity to the Gray Treefrog (Hyla chrysocelis) and the Northern Leopard Frog (Rana pipiens). M.S. Thesis, Clemson University, Clemson, SC:68 p., 1995. ECOREF #169548	
Gray,H.M.. The Ecotoxicology of Zinc on a Freshwater Leech, Nephelopsis obscura. 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 (Onchorhyncus mykiss). J. Fish. Sci.2(5): 711-721, 2008. ECOREF #115298	
Gupta,A.K., and S.K. Sharma. Bioaccumulation of Zinc in Cirrhinus mrigala (Hamilton) Fingerlings During Short-Term Static Bioassay. J. Environ. Biol.15(3): 231-237, 1994. ECOREF #12768	Non-north american test species used

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Guy,C.P., A.E. Pinkney, and M.H. Taylor. Effects of Sediment-Bound Zinc Contamination on Early Life Stages of the Mummichog (Fundulus heteroclitus 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 Lecane quadridentata 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 Catostomus latipinnis 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	Hardness not reported
Heinlaan,M., A. Ivask, I. Blinova, H.C. Dubourguier, and A. Kahru. Toxicity of Nanosized and Bulk ZnO, CuO and TiO2 to Bacteria Vibrio fischeri and Crustaceans Daphnia magna and Thamnocephalus platyurus. 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 Bufo arenarum 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 (Pomacea paludosa) 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
Holdway,D.A., K. Lok, and M. Semaan. The Acute and Chronic Toxicity of Cadmium and Zinc to Two Hydra Species. Environ. Toxicol.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 (Acipenser transmontanus) and Rainbow Trout (Oncorhynchus mykiss) to Cadmium, Copper, Lead, or Zinc in Laboratory Water-Only Exposures. Sci. Investig. Rep.:120 p., 2014. ECOREF #169495	Repeat of Wang; older life stage used

Citation	Notes
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 Didymosphenia geminata: An Ecotoxicity Assessment of Four Potential Biocides. Arch. Environ. Contam. Toxicol.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 Brachionus havanaensis (Rotifera: Brachionidae). J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control42(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 Gambusia affinis (B&G). J. Environ. Biol.18(4): 409-413, 1997. ECOREF #19028	Not adequate study details; replicates?
Karntanut,W., and D. Pascoe. A Comparison of Methods for Measuring Acute Toxicity to Hydra vulgaris. Chemosphere41:1543-1548, 2000. ECOREF #50836	
Karntanut,W., and D. Pascoe. The Toxicity of Copper, Cadmium and Zinc to Four Different Hydra (Cnidaria: Hydrozoa). Chemosphere47(10): 1059-1064, 2002. ECOREF #65809	
Karntanut,W., and D. Pascoe. Effects of Removing Symbiotic Green Algae on the Response of Hydra viridissima (Pallas 1776) to Metals. Ecotoxicol. Environ. Saf.60(3): 301-305, 2005. ECOREF #77767	
Kazlauskiene,N., A. Burba, and G. Svecevicius. Acute Toxicity of Five Galvanic Heavy Metals to Hydrobionts. Ekologiia1:33-36, 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 Poecilia reticulata (Peters). J. Environ. Biol.22(2): 141-144, 2001. ECOREF #62227	
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. Mar. Environ. Res.46(1-5): 563-566, 1998. ECOREF #67658	Only three test concentrations used; doesn't provide detail on study design
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

Citation	Notes
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
McWilliam,R.A., and D.J. Baird. Postexposure Feeding Depression: A new Toxicity Endpoint for Use in Laboratory Studies with Daphnia magna. Environ. Toxicol. Chem.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. Water Air Soil Pollut.:21 p., 2007. ECOREF #97672	

Citation	Notes
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. Water Air Soil Pollut.188(1-4): 41-66, 2008. ECOREF #111766	Repeat of other Mebane study
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	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 Hediste diversicolor Chronically Exposed in Their Environment. Mar. Biol.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 Ceriodaphnia dubia and Rainbow Trout (Oncorhynchus mykiss). Environ. Toxicol. Chem.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 Ceriodaphnia dubia and Rainbow Trout (Oncorhynchus mykiss). Environ. Toxicol. Chem.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 (Chlorella vulgaris) Level on the Demographic Characters of Moina macrocopa (Crustacea: Cladocera). J. Environ. Sci. Health. Part A, Environ. Sci. Eng. Toxic Hazard. Substance Control42(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. Bull. Environ. Contam. Toxicol.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 Clarias submaginatus. J. Aquat. Sci.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 Macrobrachium lanchesteri. Malays. J. Sci.23(2): 11-18, 2004. ECOREF #100582	Non-north american test species used
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: Atyaephyra desmarestii (Decapoda) and Echinogammarus meridionalis (Amphipoda). Chemosphere68(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 Mugil cephalus Fingerlings. Int. J. Chem. Sci.9(2): 477-480, 2011. ECOREF #166665	Saltwater species used for testing

Citation	Notes
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 Schistosoma mansoni, Biomphalaria alexandrina. Int. J. Zool. Res.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. Comp. Biochem. Physiol. C Comp. Pharmacol. Toxicol.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. Verh. Int. Ver. Theor. Angew. Limnol.26(5): 2391-2392, 1998. ECOREF #83191	Wrong language
Sakamoto,M., Y. Ogamino, and Y. Tanaka. Leptodora kindtii: A Cladoceran Species Highly Sensitive to Toxic Chemicals. Limnology11(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). Environ. Monit. Assess.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. Bull. Environ. Contam. Toxicol.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 Daphnids. Environ. Toxicol. Chem.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 Nothobranchius guentheri as a Tool for Rapid Acute Toxicity Screening. Environ. Toxicol. Chem.18(10): 2258-2261, 1999. ECOREF #20487	Non-north american test species used
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.A. Ramle, and A. Abas. Sensitivity of the Freshwater Prawn, Macrobrachium lanchesteri (Crustacea: Decapoda), to Heavy Metals. Toxicol. Ind. Health:8 p., 2011. ECOREF #166618	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	

Citation	Notes
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	
Shuhaimi-Othman,M., and D. Pascoe. Acute Toxicity of Copper, Zinc and Cadmium to the Freshwater Amphipod Hyalella azteca. Malays. Appl. Biol.30:1-8, 2001. ECOREF #169735	Not adequate test design information
Shukla,V., M. Dhankhar, and K.V. Sastry. Heavy Metal Toxicity on Labeo rohita. J. Ecotoxicol. Environ. Monit.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 Channa punctatus (Bloch). Environ. Ecol.13(1): 202-207, 1995. ECOREF #17380	Non-north american test species used
Svecevicius,G.. Acute Toxicity of Zinc to Common Freshwater Fishes of Lithuania. Acta Zool. Litu.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 Catla catla (Hamilton, 1822) for Toxicological Studies. Chemosphere90(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: Caenorhabditis elegans LC50. Aquat. Toxicol.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 Daphnia magna, Using the Inflection Point of the Concentration-Response Curves. Environ. Toxicol. Chem.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 Daphnia magna Neonates. Environ. Toxicol. Chem.36(1): 113-119, 2017. ECOREF #188152	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 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	Protozoa test species not relevant

Citation	Notes
Sensitivity of the Ciliate to 14 Pure Chemicals. Ecotoxicol. Environ. Saf.41(3): 231-244, 1998. ECOREF #20057	
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
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 (Poecilia reticulata). Environ. Toxicol. Chem.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 (Melanotaenia fluviatilis). Environ. Toxicol.15(3): 165-173, 2000. ECOREF #76127	Non-north american test species used

Citation	Notes
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 Mesocyclops pehpeiensis. Bull. Environ. Contam. Toxicol.73(1): 190-196, 2004. ECOREF #80006	No hardness data reported
Woodling,J., S. Brinkman, and S. Albeke. Acute and Chronic Toxicity of Zinc to the Mottled Sculpin Cottus bairdi. Environ. Toxicol. Chem.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, Anguilla japonica. Dongwu Xuekan7(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 Daphnia magna: Prediction of Acid Mine Drainage Toxicity. J. Hazard. Mater.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. J. Environ. Monit.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 Daphnia magna. J. Nanopart. Res.11:67-75, 2009. ECOREF #153603	Nanoparticle study
Zou,E., and S. Bu. Acute Toxicity of Copper, Cadmium, and Zinc to the Water Flea, Moina irrasa (Cladocera). Bull. Environ. Contam. Toxicol.52(5): 742-748, 1994. ECOREF #13762	Less than value for hardness; hardness too low

Open Literature

Table A 23. 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 Caenorhabditis elegans. Environmental toxicology and chemistry, 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 Fundulus heteroclitus exposed to sublethal waterborne zinc at different salinities. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 166, pp.96-104.	Saltwater study

Citation	Notes
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. Environmental Science and Pollution Research, 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, Theodoxus niloticus (Reeve, 1856). The Egyptian Journal of Aquatic Research, 44(2), pp.83-87.	Non-north American test species
Ivey CD, Besser JM, Ingersoll CG, Wang N, Rogers DC, Raimondo S, Bauer CR, Hammer EJ (2017). Acute sensitivity of the vernal pool fairy shrimp, Branchinecta lynchi (Anostraca; Branchinectidae), and surrogate species to 10 chemicals. Environ Toxicol Chem.; 36(3):797-806.	

Freshwater Chronic

Table A 24. 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 Xenopus laevis. Environ. Sci. Technol.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 Daphnia Species. Ecotoxicol. Environ. Saf.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 Rhinella arenarum. Environ. Sci. Pollut. Res. Int.27(3): 3034-3042, 2020. ECOREF #182173	Non-north american test species used
Atli,G., and M. Canli. Responses of Metallothionein and Reduced Glutathione in a Freshwater Fish Oreochromis niloticus Following Metal Exposures. Environ. Toxicol. Pharmacol.25(1): 33-38, 2008. ECOREF #117067	DId not find relevant endpoints
Balch,G.C., R.D. Evans, P. Welbourn, and R. Prairie. Weight Loss and Net Abnormalities of Hydropsyche betteni (Caddisfly) Larvae Exposed to Aqueous Zinc. Environ. Toxicol. Chem.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 Bufo arabicus Tadpoles. Ecotoxicol. Environ. Saf.74(4): 918-923, 2011. ECOREF #161496	Non-north american test species used

Citation	Notes
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	Doesn't include zinc exposure
Bieniarz,K., P. Epler, and M. Sokolowska-Mikolajczyk. Goldfish (Carassius auratus gibelio Bloch) Breeding in Different Concentrations of Zinc. Pol. Arch. Hydrobiol.43(3): 365-371, 1996. ECOREF #84088	Wrong language
Borgmann,U., and W.P. Norwood. Toxicity and Accumulation of Zinc and Copper in Hyalella azteca Exposed to Metal-Spiked Sediments. Can. J. Fish. Aquat. Sci.54:1046-1054, 1997. ECOREF #67044	Sediment study
Brinkman,S., and J. Woodling. Zinc Toxicity to the Mottled Sculpin (Cottus bairdi) in High-Hardness Water. Environ. Toxicol. Chem.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 (Salmo trutta) to Zinc and Copper Singly and in Combination with Cadmium or Copper. Arch. Environ. Contam. Toxicol.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 Rhinella arenarum both Alone and in Combination. J. Toxicol. Environ. Health Part A72(14): 884-890, 2009. ECOREF #117667	Non-north american test species used
Brown,J.M.. Net Effects of Batrachochytrium dendrobatidis (Bd) and Fungicides on Anurans Across Life Stages. M.S.Thesis, University of South Florida, Tampa, FL:48 p., 2013. ECOREF #175870	Fungicide study
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	Static renewal study; flow through required
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	

Citation	Notes
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	Did not characterize lake dilution water;
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
Guo,F., R. Tu, and W.X. Wang. Different Responses of Abalone Haliotis discus hannai to Waterborne and Dietary-Borne Copper and Zinc Exposure. Ecotoxicol. Environ. Saf.91:10-17, 2013. ECOREF #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 D. magna: Development of a Surface Response Model. Arch. Environ. Contam. Toxicol.44(2): 210-217, 2003. ECOREF #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 Daphnia magna. Ecotoxicol. Environ. Saf.62:1-10, 2005. ECOREF #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 (Acipenser	Found in Wang et al. 2014

Citation	Notes
transmontanus) and Rainbow Trout (Oncorhynchus mykiss) to Cadmium, Copper, Lead, or Zinc in Laboratory Water-Only Exposures. Sci. Investig. Rep.:120 p., 2014. ECOREF #169495	
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	
Lazorchak,J.M., and M.E. Smith. Rainbow Trout (Oncorhynchus mykiss) and Brook Trout (Salvelinus fontinalis) 7-Day Survival and Growth Test Method. Arch. Environ. Contam. Toxicol.53(3): 397-405, 2007. ECOREF #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". Bull. Environ. Contam. Toxicol.54(4): 626-632, 1995. ECOREF #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 Procambarus clarkii: Simulation of the Aznalcollar Mining Spill. Cienc. Mar.31(1B): 197-202, 2005. ECOREF #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. Water Air Soil Pollut.:21 p., 2007. ECOREF #97672	Less than value reported; other studies have definitive chronic values
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. Water Air Soil Pollut.188(1-4): 41-66, 2008. ECOREF #111766	Repeat
Muyssen,B.T.A., K.A.C. De Schamphelaere, and C.R. Janssen. Mechanisms of Chronic Waterborne Zn Toxicity in Daphnia magna. Aquat. Toxicol.77(4): 393-401, 2006. ECOREF #97407	NOEC/LC50 not provided and no significant differences for relevant endpoints
Muyssen,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	
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; did not use flow through design
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	Only one test concentration
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

Citation	Notes
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 A 25. 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 Ceriodaphnia dubia. Journal of Applied Toxicology, 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 (Lithobates [Rana] chiricahuensis). Bulletin of environmental contamination and toxicology, 99, pp.679-683.	Questionable data due to unusual dose-response results
Wang, N, Kunz, J.L, Cleveland, D.M, Steevens, J.A., Hammer, E.J., Van Gendersen, E., Ryan, A.C., & Schlekat, C.E. (2020). Evaluation of Acute and Chronic Toxicity of Nickel and Zinc to Two Sensitive Freshwater Benthic Invertebrates Using Refined Testing Methods. Manuscript submitted for publication.	
Azuara-García, R., Sarma, S. S., & Nandini, S. (2006). The combined effects of zinc and alga on the life table demography of Anuraeopsis fissa and Brachionus rubens (Rotifera). Journal of	MATC/EC20 not reported; study duration not reported

Citation	Notes
environmental science and health. Part A, Toxic/hazardous substances & environmental engineering, 41(4), 559–572.	
Belanger, s. E., Farris, J.L., Cherry, D.S., Cairns, J. (1986). "Growth of Asiatic Clams (Corbicula Sp.) during and after long-term zinc exposure in field-located and laboratory atificial streams." Arch Environ Contam Toxicol 15: 427-434.	
Benoit DA, Holcombe GW. 1978. Toxic effects of zinc on fathead minnows Pimephales promelas in soft water. J Fish Biol 13:701-708.	
Besser JM, Mebane CA, Mount DR, Ivey CD, Kunz JL, Greer IE, May TW, Ingersoll CG. 2007. Sensitivity of mottled sculpins (Cottus bairdi) and rainbow trout (Oncorhynchus mykiss) to acute and chronic toxicity of cadmium, copper, and zinc. Environ Toxicol Chem 26:1657-1665.	
Besser JM, Ivey CD, Steevens JA, Cleveland D, Soucek D, Dickinson A, Van Genderen EJ, Ryan AC, Schlekat CE, Garman E, Middleton E, Santore R. 2021. Modeling the bioavailability of nickel and zinc to Ceriodaphnia dubia and Neocloeon triangulifer in toxicity tests with natural waters. Environmental Toxicology and Chemistry, in Review.	
Blesinger KE, Christensen GM, Fiandt JT. 1986. Effects of metal salt mixtures on Daphnia magna reproduction. Ecotoxicol Environ Saf 11:9-14.	Less than value; definitive values for the same species exist
Borgmann U, Norwood WP, Clarke C. 1993. Accumulation, regulation and toxicity of copper, zinc, lead and mercury in Hyalella azteca. Hydrobiologia 259:79-89.	Control survival was only 63% at the end of the study.
Brinkman SF, Hansen D. 2004. Effect of hardness on zinc toxicity to Colorado River cutthroat (Onchorhynchus clarkii pleuriticus) and rainbow trout (Oncorhynchus mykiss) embryos and fry. Water Pollution Studies, Federal Aid in Fish and Wildlife Restoration Project F-243-R11. Colorado Division of Wildlife, Fort Collins, CO, USA.	
Brinkman SF, Vieira NMK. 2007. Water pollution studies. Federal Aid Project F-243R-17. Colorado Division of Wildlife, Fort Collins, CO, USA.	
Brinkman S, Woodling J. 2005. Zinc toxicity to the mottled sculpin (Cottus bairdi) in high-hardness water. Environ Toxicol Chem 24:1515-1517.	
Cairns MA, Garton RR, Tubb RA. 1982. Use of fish ventilation frequency to estimate chronically safe toxicant concentrations. Trans Am Fish Soc 111:70-77.	
Chapman GA. 1978. Toxicities of cadmium, copper, and zinc to four juvenile stages of chinook salmon and steelhead. Trans Am Fish Soc 107:841-847.	
Chapman GA. 1975. Toxicity of copper, cadmium and zinc to Pacific Northwest salmonids. U.S. Environmental Protection Agency, Corvallis, OR, USA.	

Citation	Notes
Chapman GA, Ota S, Recht F. 1980. Effects of water hardness on the toxicity of metals to Daphnia magna. U.S. Environmental Protection Agency, Corvallis, OR, USA.	
Cooper NL, Bidwell JR, Kumar A. 2009. Toxicity of copper, lead, and zinc mixtures to Ceriodaphnia dubia and Daphnia carinata. Ecotoxicol Environ Saf 72:1523-1528.	
Crémazy A, Brix KV, Wood CM. 2018. Chronic Toxicity of Binary Mixtures of Six Metals (Ag, Cd, Cu, Ni, Pb, and Zn) to the Great Pond Snail Lymnaea stagnalis. Environ Sci Technol 52(10):5979-5988.	
Davies PH, Brinkman S. 1999. Water pollution studies. Federal Aid Project #F-243R-6. Colorado Division of Wildlife, Fort Collins, CO, USA.	
Davies PH, Brinkman S, Hansen D. 2000. Water pollution studies. Federal Aid Project #F-243R-6. Colorado Division of Wildlife, Fort Collins, CO, USA.	
Davies PH, Brinkman S, Hansen D. 2002. Water pollution studies. Federal Aid Project #F-243R-9. Colorado Division of Wildlife, Fort Collins, CO, USA.	
Davies PH, Brinkman S, Hansen D. 2003. Water pollution studies. Federal Aid Project F-243-R10. Colorado Division of Wildlife, Fort Collins, CO, USA. De Schamphelaere KAC, Janssen CR. 2004. 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 38:6201-6209.	NOEC/EC10/EC50 reported; require EC20 or MATC
De Schamphelaere KAC, Heijerick DG, Janssen CR. 2003. Development and validation of biotic ligand models for predicting chronic zinc toxicity to fish, daphnids and algae. University of Ghent, Gent, Belgium.	EC10/EC50 reported; require EC20 or MATC
Fettweis, A., De Schamphelaere, K. and Smolders E. 2018. Zinc toxicity to Daphnia magna in a two-species microcosm can be predicted from single-species test data: The effects of phosphorus supply and pH. Environ Toxicol Chem, 37: 2153-2164.	EC10/EC50s reported; require EC20 or MATC
Sinley JR, Goettl Jr JP, Davies PH. 1974. The effects zinc on rainbow trout (Salmo gairdneri) in hard and soft water. Bull Environ Contam Toxicol 12:193-201.	
Holcombe GW, Benoit DA, Leonard EN. 1979. Long-term effects of zinc exposures on brook trout (Salvelinus fontinalis). Trans Am Fish Soc 108:76-87.	
Källqvist, T., Rosseland, B. O., Hytterød, S., & Kristensen, T. (2003). Effect of zinc on the early life stages of brown trout (Salmo trutta) at different levels of water hardness.	Natural water used with background zinc concentrations
Münzinger A, Monicelli F. 1991. A comparison of the sensitivity of three Daphnia magna populations under chronic heavy metal stress. Ecotoxicology and environmental safety, 22(1), 24–31.	Zinc not measured during study

Citation	Notes
Naddy, R.B., Cohen, A.S. and Stubblefield, W.A. 2015. The interactive toxicity of cadmium, copper, and zinc to Ceriodaphnia dubia and rainbow trout (Oncorhynchus mykiss). Environ Toxicol Chem, 34: 809-815.	EC10/EC50s reported; require EC20 or MATC
Nebeker AV, Savonen C, Baker RJ, McCrady JK. 1984. Effects of copper, nickel and zinc on the life cycle of the caddisfly Clistorina magnifica (Limnephilidae). Environ Toxicol Chem 3:645-649.	
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	
Parkerton TF, Stewart SM, Dickson KL, Rodger Jr DH, Saleh FY. 1988. Evaluation of the indicator species procedure for deriving site-specific water quality criteria for zinc. In Adams WJ, Chapman GA, Landis WG, eds, Aquatic Toxicology and Hazard Assessment: 10th Volume, ASTM STP 971. Vol 10. American Society for Testing and Materials, Philadelphia, PA, pp 423-435.	
Pereira, C.M., Deruytter, D., Blust, R. and De Schamphelaere, K.A. 2017. Effect of temperature on chronic toxicity of copper, zinc, and nickel to Daphnia magna. Environ Toxicol Chem, 36:1909-1916.	
Pierson KB. 1981. Effects of chronic zinc exposure on the growth, sexual maturity, reproduction, and bioaccumulation of the guppy, Poecilia reticulata. Can J Fish Aquat Sci 38:23-31.	
Sibley PK, Ankley GT, Cotter AM, Leonard EN. 1996. Predicting chronic toxicity of sediments spiked with zinc: An evaluation of the acid-volatile sulfide model using a life-cycle test with the midge Chironomus tentans. Environ Toxicol Chem 15:2102-2112.	Sediment study
Spehar RL. 1976. Cadmium and zinc toxicity to flagfish, Jordanella floridae. J Fish Res Board Can 33:1939-1945	
Van Regenmortel, T., Berteloot, O., Janssen, C.R. and De Schamphelaere, K.A.C. 2017. Analyzing the capacity of the Daphnia magna and Pseudokirchneriella subcapitata bioavailability models to predict chronic zinc toxicity at high pH and low calcium concentrations and formulation of a generalized bioavailability model for D. magna . Environ Toxicol Chem, 36: 2781-2798.	Only EC10/EC50s reported; require EC20 or MATC
Vardy, D. W. T., A. R.Sigurdson, J. L.Doering, J. A.Zhang, X. W.Giesy, J. P.Hecker, M. (2011). "EFFECTS OF SUBCHRONIC EXPOSURE OF EARLY LIFE STAGES OF WHITE STURGEON (ACIPENSER TRANSMONTANUS) TO COPPER, CADMIUM, AND ZINC." Environmental Toxicology and Chemistry 30: 2497-2505.	
Wang N, Ingersoll CG, Ivey CD, Hardesty DK, May TW, Augspurger T, Roberts AD, Van Genderen E, Barnhart MC. 2010. Sensitivity of early life stages of freshwater mussels (Unionidae) to acute and chronic toxicity of lead, cadmium, and zinc in water. Environ Toxicol Chem 29:2053-2063.	

Citation	Notes
Wesner, J., Kraus, J.M., Schmidt, T.S., Walters, D., Clements, W. (2014). "Metamorphosis enhances the effects of metal exposure on the mayfly, Centroptilum triangulifer." Environ Sci Technol 48: 10415-10422.	
Woodling J, Brinkman S, Albeke S. 2002. Acute and chronic toxicity of zinc to the mottled sculpin Cottus bairdi. Environ Toxicol Chem 21:1922-1926.	

Appendix B. Multiple Linear Regression Dataset and Decisions

Database Qualifiers and Management Decisions

- Locations removed: irrigation ditches, proximity to saltwater 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. 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 samples were removed with 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

- 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
- 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 (pH, DOC, hardness)

- 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

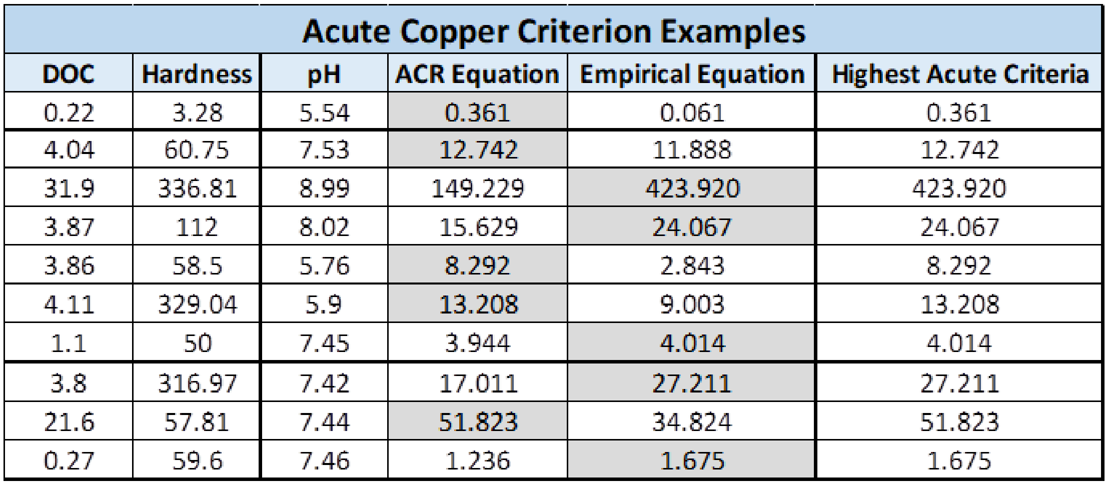
Count of concurrent samples for TOC conversion factor – 6,317

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.

Different Scenarios for the Freshwater Acute Copper Criteria

Examples of applying the freshwater acute copper criteria to a diverse water quality dataset to determine the applicable criteria. The higher criteria generated of the ACR-based and empirical-based equations represent the applicable criteria.



Acute Copper Criterion Examples

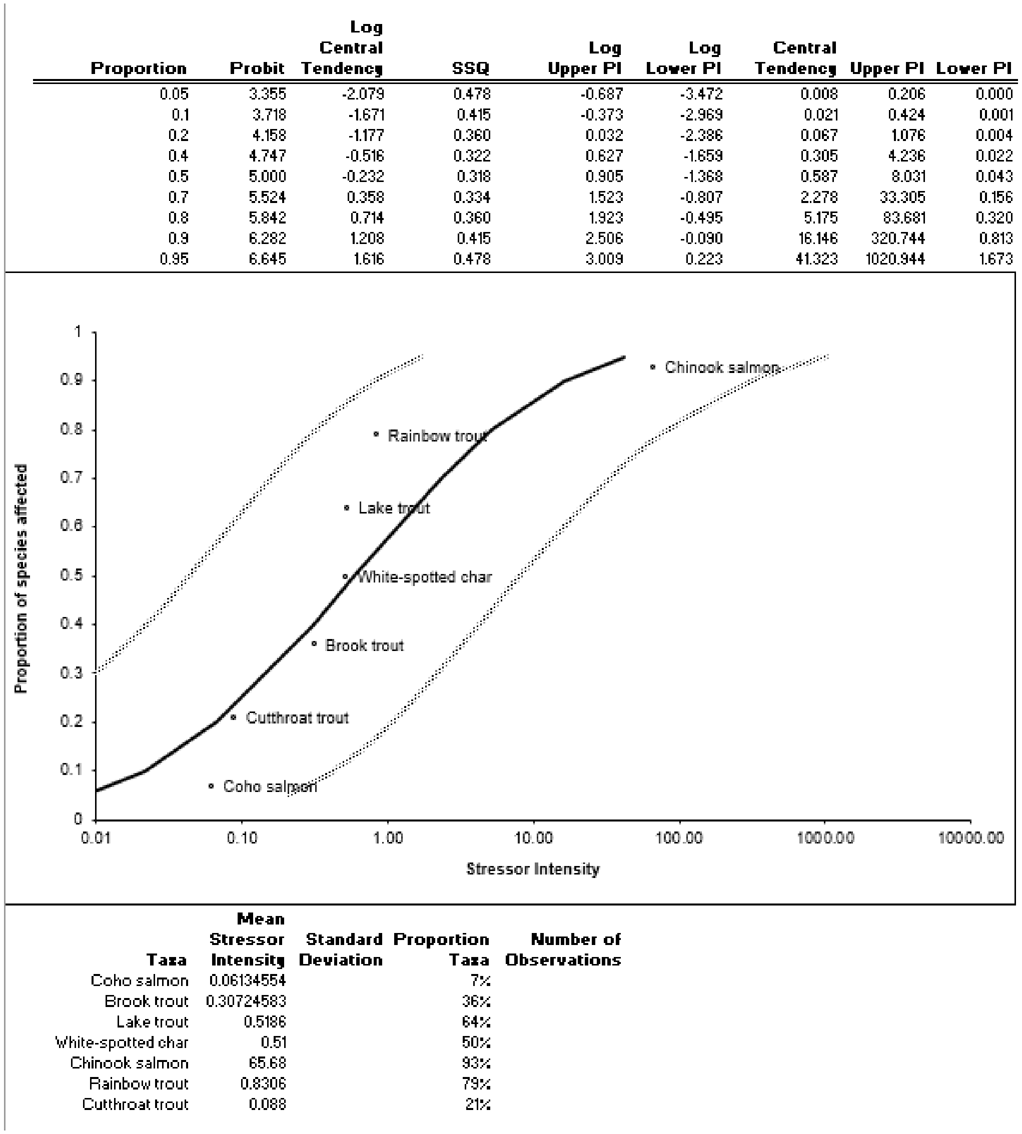
DOC	Hardness	pH	ACR Equation	Empirical Equation	Highest Acute Criteria
0.22	3.28	5.54	0.361	0.061	0.361
4.04	60.75	7.53	12.742	11.888	12.742
31.9	336.81	8.99	149.229	423.920	423.920
3.87	112	8.02	15.629	24.067	24.067
3.86	58.5	5.76	8.292	2.843	8.292
4.11	329.04	5.9	13.208	9.003	13.208
1.1	50	7.45	3.944	4.014	4.014
3.8	316.97	7.42	17.011	27.211	27.211
21.6	57.81	7.44	51.823	34.824	51.823
0.27	59.6	7.46	1.236	1.675	1.675

Figure B 1: Acute Copper Criterion Examples

Appendix C. 6PPD-quinone Supporting Information

Table C 1 Input values for the final criterion for 6PPD-quinone.

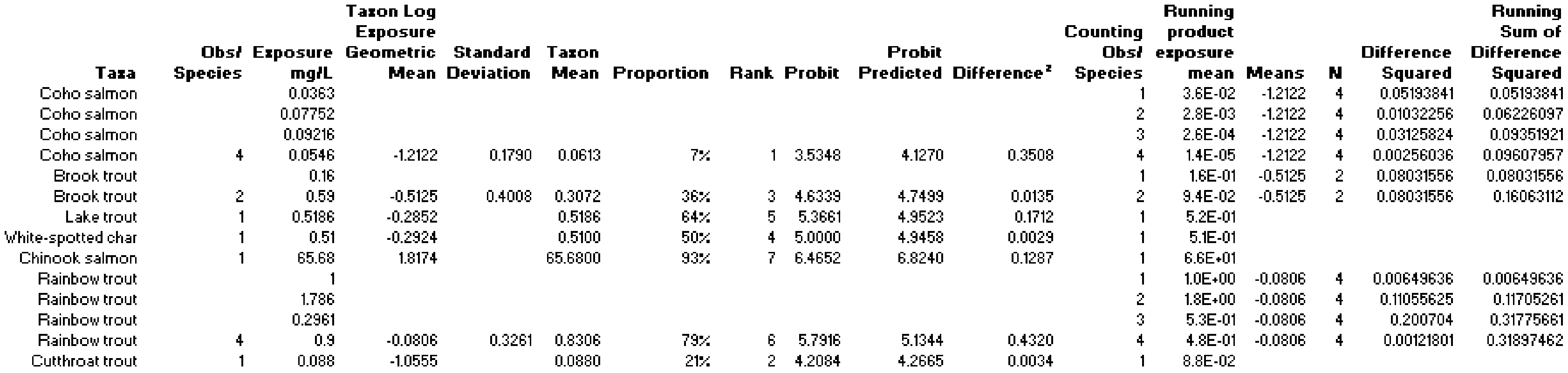
Input						
N	GMAV	Rank	Ln(GMAV)	Ln(GMAV)^{2}	P=R/(N+1)	Sqrt(P)
11	0.06134	1	-2.79	7.79	0.083	0.289
	0.4279	3	-0.85	0.72	0.250	0.500
	0.8306	4	-0.19	0.03	0.333	0.577
	0.00872	2	-2.42	5.87	0.167	0.408
		Sum:	-6.25	14.41	0.83	1.77
		S2 = 100.48				
		S = 10.02				
		L = -6.01				
		A = -3.77				
Recalculated FAV and CMC:		FAV = 0.0231				
		CMC = 0.0116				



Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	-2.079	0.478	-0.687	-3.472	0.008	0.206	0.000
0.1	3.718	-1.671	0.415	-0.373	-2.969	0.021	0.424	0.001
0.2	4.158	-1.177	0.360	0.032	-2.386	0.067	1.076	0.004
0.4	4.747	-0.516	0.322	0.627	-1.659	0.305	4.236	0.022
0.5	5.000	-0.232	0.318	0.905	-1.368	0.587	8.031	0.043
0.7	5.524	0.358	0.334	1.523	-0.807	2.278	33.305	0.156
0.8	5.842	0.714	0.360	1.923	-0.495	5.175	83.681	0.320
0.9	6.282	1.208	0.415	2.506	-0.090	16.146	320.744	0.813
0.95	6.645	1.616	0.478	3.009	0.223	41.323	1020.944	1.673

Taxa	Mean Stressor Intensity	Standard Deviation	Proportion Taxa	Number of Observations
Coho salmon	0.06134554		7%	
Brook trout	0.30724583		36%	
Lake trout	0.5186		64%	
White-spotted char	0.51		50%	
Chinook salmon	65.68		93%	
Rainbow trout	0.8306		79%	
Cutthroat trout	0.088		21%	

Figure C 1. Species sensitivity distribution results using EPA SSD Toolbox.



Taxa	Obs/ Species	Exposure mg/L	Taxon Log Exposure Geometric Mean	Standard Deviation	Taxon Mean	Proportion	Rank	Probit	Probit Predicted	Difference^2	Counting Obs/ Species	Running product exposure mean	Means	N	Difference Squared	Running Sum of Difference Squared
Coho salmon		0.0363									1	3.6E-02	-1.2122	4	0.05193841	0.05193841
Coho salmon		0.07752									2	2.8E-03	-1.2122	4	0.01032256	0.06226097
Coho salmon		0.09216									3	2.6E-04	-1.2122	4	0.03125824	0.09351921
Coho salmon	4	0.0546	-1.2122	0.1790	0.0613	7%	1	3.5348	4.1270	0.3508	4	1.4E-05	-1.2122	4	0.00256036	0.09607957
Brook trout		0.16									1	1.6E-01	-0.5125	2	0.08031556	0.08031556
Brook trout	2	0.59	-0.5125	0.4008	0.3072	36%	3	4.6339	4.7499	0.0135	2	9.4E-02	-0.5125	2	0.08031556	0.16063112
Lake trout	1	0.5186	-0.2852		0.5186	64%	5	5.3661	4.9523	0.1712	1	5.2E-01				
White-spotted char	1	0.51	-0.2924		0.5100	50%	4	5.0000	4.9458	0.0029	1	5.1E-01				
Chinook salmon	1	65.68	1.8174		65.6800	93%	7	6.4652	6.8240	0.1287	1	6.6E+01				
Rainbow trout		1									1	1.0E+00	-0.0806	4	0.00649636	0.00649636
Rainbow trout		1.786									2	1.8E+00	-0.0806	4	0.11055625	0.11705261
Rainbow trout		0.2961									3	5.3E-01	-0.0806	4	0.200704	0.31775661
Rainbow trout	4	0.9	-0.0806	0.3261	0.8306	79%	6	5.7916	5.1344	0.4320	4	4.8E-01	-0.0806	4	0.00121801	0.31897462
Cutthroat trout	1	0.088	-1.0555		0.0880	21%	2	4.2084	4.2665	0.0034	1	8.8E-02				

Figure C 2: Data inputs for the species sensitivity distribution calculations.

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 Final Regulatory Analysis[10].

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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[10] https://apps.ecology.wa.gov/publications/summarypages/2410033.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 rather than statewide default criteria. Statewide default criteria are conservative-based criteria representing the most sensitive water bodies. An analysis of average statewide water quality conditions better represents receiving water bodies where discharges are likely to occur. 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 newly adopted 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 newly adopted acute and chronic aquatic life criteria. The application of dilution factors to the newly adopted 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 adopted 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 newly adopted 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 not 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 adopted criteria. The maximum reported discharge levels in DMR data from 46 different individual permits are anticipated to exceed potential limits based on the adopted 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 adopted criteria.

Toxic chemical	Industrial NPDES	Municipal NPDES
Acrolein	2	1
Aluminum	2	-
Arsenic	2	3
Cadmium	3	3
Chromium VI	4	2
Copper	15	7
Cyanide	2	4
Mercury	-	3
Nickel	6	3
Pentachlorophenol	4	-
Selenium	3	1
Silver	3	6
Zinc	18	8

State Waste Discharge Permit: Individual Pretreatment Permit

There are 48 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 48 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 540 different permits are anticipated to exceed limits based on the adopted 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 adopted 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 adopted 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 adopted 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 adopted are based on the MLR model and will now require hardness, pH, and dissolved organic carbon levels to calculate criteria. The copper criteria will also include default copper criteria based on a 5th 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 5th 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 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 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 and approved, 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 adopted 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 adopted rulemaking from Ecology's EIM database. We evaluated the amount of data that exceeds the current criteria versus the adopted 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 adopted 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 adopted. The default criteria for aluminum and copper criteria are very conservative and represent the most sensitive water bodies. Using average statewide water quality data better represents conditions and criteria that are likely to be observed.

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 adopted criteria for new toxics or toxics becoming more stringent.

Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Adopted Criteria	Percent Increase in Exceedances	Notes
6PPD-quinone FW Acute	4	N/A	75.0%	75.0%	
Acrolein FW Acute	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Acrolein FW Chronic	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Aluminum FW Acute	452	N/A	0.00%	N/A	Used statewide mean input values for concurrently sampled pH, hardness, and DOC for the aluminum MLR model.
Aluminum FW Chronic	452	N/A	1.55%	N/A	Used statewide mean input values for concurrently sampled pH, hardness, and DOC for the aluminum MLR model.
Arsenic FW Acute	799	0.13%	0.13%	0.00%	
Arsenic FW Chronic	799	1.00%	2.75%	1.75%	
Cadmium FW Acute	335	3.28%	4.48%	1.20%	

Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Adopted Criteria	Percent Increase in Exceedances	Notes
Cadmium FW Chronic	335	4.48%	7.16%	2.68%	
Cadmium SW Acute	14	0.00%	0.00%	0.00%	
Cadmium SW Chronic	14	0.00%	0.00%	0.00%	
Carbaryl FW Acute	532	N/A	20.68%	N/A	
Carbaryl FW Chronic	532	N/A	20.68%	N/A	
Carbaryl SW Acute	1	N/A	0.00%	N/A	
Chromium III FW Acute	0	N/A	N/A	N/A	No chromium III samples.
Chromium III FW Chronic	0	N/A	N/A	N/A	No chromium III samples.
Chromium VI FW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Copper FW Acute	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.
Copper FW Chronic	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 Adopted Criteria	Percent Increase in Exceedances	Notes
					input values for concurrently sampled pH, hardness, and DOC for the copper MLR model.
Cyanide FW Acute	21	4.76%	9.52%	4.76%	
Cyanide FW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Demeton FW Chronic	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Demeton SW Chronic	0	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Diazinon FW Acute	551	N/A	0.73%		
Diazinon FW Chronic	551	N/A	0.73%		
Diazinon SW Acute	4	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Diazinon SW Chronic	4	N/A	0.00%	N/A	Criteria < Reporting Limit. Removed non-detects. No

Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Adopted Criteria	Percent Increase in Exceedances	Notes
					samples to evaluate.
Dieldrin FW Acute	255	0.00%	0.39%	0.39%	
Endrin FW Acute	225	0.00%	8.44%	8.44%	
Gamma-BHC FW Acute	225	0.00%	0.00%	0.00%	
Guthion FW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Guthion SW Chronic	0	N/A	N/A	N/A	No saltwater samples.
Malathion FW Chronic	535	N/A	1.12%	N/A	
Malathion SW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Mercury FW Acute	392	0.00%	0.00%	0.00%	
Methoxychlor FW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Methoxychlor SW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Mirex FW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No

Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Adopted Criteria	Percent Increase in Exceedances	Notes
					samples to evaluate.
Mirex SW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Nickel FW Acute	410	0.00%	0.24%	0.24%	
Nickel FW Chronic	410	0.24%	0.98%	0.74%	
Nonylphenol FW Acute	3	N/A	0.00%	0.00%	
Nonylphenol FW Chronic	3	N/A	0.00%	0.00%	
Nonylphenol SW Acute	15	N/A	0.00%	0.00%	
Nonylphenol SW Chronic	15	N/A	0.00%	0.00%	
Pentachlorophenol FW Acute	596	0.00%	5.20%	5.20%	
Pentachlorophenol FW Chronic	596	0.00%	5.20%	5.20%	
Pentachlorophenol SW Chronic	0	N/A	N/A	N/A	Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
PFOS FW Acute	0	N/A	N/A	N/A	
PFOS FW Chronic	0	N/A	N/A	N/A	
PFOS SW Acute	0	N/A	N/A	N/A	
PFOS SW Chronic	0	N/A	N/A	N/A	
PFOA FW Acute	0	N/A	N/A	N/A	
PFOA FW Chronic	0	N/A	N/A	N/A	
PFOA SW Acute	0	N/A	N/A	N/A	
PFOA SW Chronic	0	N/A	N/A	N/A	
Selenium FW Acute	126	0.79%	N/A	N/A	Adopted criteria does not include acute criteria.

Toxic Criteria	No. of Samples	Percent Exceedance Current Criteria	Percent Exceedance Adopted Criteria	Percent Increase in Exceedances	Notes
Selenium FW Chronic	126	0.79%	3.97%	3.18%	
Silver FW Acute	516	0.19%	1.37%	1.18%	Some Reporting Limits less than the criteria were removed.
Silver FW Chronic	409	N/A	6.11%	N/A	Currently do not have chronic criteria. Criteria < Reporting Limit. Removed non-detects. No samples to evaluate.
Silver SW Chronic	8	0.00%	0.00%	0.00%	
Tributyltin FW Acute	0	N/A	N/A	N/A	
Tributyltin FW Chronic	0	N/A	N/A	N/A	
Tributyltin SW Acute	0	N/A	N/A	N/A	
Tributyltin SW Chronic	0	N/A	N/A	N/A	
Zinc FW Acute	6706	1.17%	2.12%	0.95%	
Zinc FW Chronic	6706	1.35%	8.93%	7.58%	