#### STATE OF NEW MEXICO WATER QUALITY CONTROL COMMISSION

#### IN THE MATTER OF: THE PETITION TO AMEND THE STANDARDS FOR INTERSTATE AND INTRASTATE SURFACE WATERS 20.6.4. NMAC

No. WQCC 24-31 (R)

Triad National Security, LLC, Newport News Nuclear BWXT-Los Alamos, LLC, and U.S. Department of Energy, Office of Environmental Management,

Petitioners.

#### NEW MEXICO ENVIRONMENT DEPARTMENT'S <u>AMENDED NOTICE OF INTENT TO PRESENT DIRECT TECHNICAL TESTIMONY</u>

Pursuant to 20.1.6.202 NMAC and the Second Pre-Hearing Order issued by the Hearing

Officer on September 11, 2024, the New Mexico Environment Department ("Department" or

"NMED") submits this Notice of Intent to Present Direct Technical Testimony for the hearing in

this matter currently scheduled to begin on January 14, 2025.

#### 1. Entity for whom the witnesses will testify

The witnesses will testify for the Surface Water Quality Bureau of the Water Protection

Division of the Department.

#### 2. Identity of witnesses

The Department will call the following witnesses to present technical testimony at the hearing:

Michael Baca is the Water Quality Standards Coordinator for the Surface Water Quality Bureau. His resume is attached as **NMED Exhibit 2**. Mr. Baca's direct written testimony is attached as **NMED Exhibit 1**. Lynette Guevara is the Program Manager for the Monitoring, Assessment, and Standards Section of the Surface Water Quality Bureau. Her resume is attached as **NMED Exhibit 3**. NMED does not intend to present direct testimony by Ms. Guevara, but may present her as a rebuttal witness, and will make her available to assist in answering questions that may go beyond the expertise of the direct witness.

Shelly Lemon is the Surface Water Quality Bureau Chief. Her resume is attached as **NMED Exhibit 4**. NMED does not intend to present direct testimony by Ms. Lemon, but may present her as a rebuttal witness, and will make her available to assist in answering questions that may go beyond the expertise of the direct witness.

The Department reserves the right to call any additional witnesses to provide direct or rebuttal testimony in response to any other notice of intent filed, to public comment provided, or otherwise, in this matter.

#### 3. Location(s) at which witnesses will be present

The witnesses will be present in person in Santa Fe.

#### 4. Estimated duration of direct oral testimony of witnesses

Pursuant to the *Second Pre-Hearing Order*, the estimated duration of Mr. Baca's direct oral testimony is 30 minutes.

#### 5. List of exhibits to be offered by the Department at the hearing

A list of exhibits that the Department intends to offer into evidence in this matter is attached to this Notice of Intent. The Department reserves the right to introduce and move for the admission of any other exhibit in support of rebuttal testimony at the hearing in this matter. Respectfully submitted,

### NEW MEXICO ENVIRONMENT DEPARTMENT

By: <u>/s/ Brecken L. Scott</u> Brecken L. Scott Assistant General Counsel PO Box 5469 Santa Fe, New Mexico 87502-5469 (505) 490-1177 Brecken.scott@env.nm.gov

#### **CERTIFICATE OF SERVICE**

I hereby certify that a true and correct copy of the foregoing New Mexico Environment

Department's Amended Notice of Intent to Present Direct Technical Testimony was filed with the

Water Quality Control Commission Administrator and served via electronic mail on the following

parties in this matter on December 20, 2024.

Pamela Jones Pamela.jones@env.nm.gov Administrator for the Water Quality Control Commission

Felicia Orth Felicia.orth@gmail.com *Hearing Officer* 

Blaine Moffatt New Mexico Department of Justice blmoffatt@nmdoj.gov Counsel for the Water Quality Control inspector@sunshineaudit.com Commission

Kari Olson Louis W. Rose Spencer Fane, LLP kaolson@spencerfane.com lrose@spencerfane.com Counsel for Newport News Nuclear BWXT-Los Alamos, LLC

Maureen Dolan Maxine McReynolds dolan@lanl.gov mcreynolds@lanl.gov Counsel for Triad National Security, LLC John Evans Robert Reine John.H.Evans@em.doe.gov Robert.Reine@em.doe.gov Counsel for U.S. Department of Energy, Office of Environmental Management, Los Alamos Field Office

Nicholas R. Maxwell P.O. Box 1064 Hobbs, New Mexico 88241 (575) 441-3560 Pro se

/s/ Brecken L. Scott

Brecken L. Scott

#### LIST OF EXHIBITS

Exhibit #	Title	Total # of pages
NMED Exhibit 1	Direct Testimony of Michael Baca	12
NMED Exhibit 2	Resume of Michael Baca	2
NMED Exhibit 3	Resume of Lynette Guevara	3
NMED Exhibit 4	Resume of Shelly Lemon	4
NMED Exhibit 5	EPA 1995 Updates: Water Quality Criteria Docume for the Protection of Aquatic Life in Ambient Water	nts 15
NMED Exhibit 6	EPA Aquatic Life Ambient Freshwater Quality Crite Copper 2007 Revision	ria - 2
NMED Exhibit 7	EPA Aquatic Life Ambient Freshwater Quality Crite Copper	ria - 204
NMED Exhibit 8	EPA Metals Cooperative Research and Development Agreement (CRADA) Phase I Report	44
NMED Exhibit 9	WQCC 24-31 NMED Provide to the Public Docume	ntation 13
NMED Exhibit 10	WQCC 24-31 NMED Public Notice Documentation	6
NMED Exhibit 11	Affidavits of Publication – <i>Albuquerque Journal</i> and <i>New Mexico Register</i>	3

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#### DIRECT TECHNICAL TESTIMONY OF MICHAEL BACA

#### I. INTRODUCTION

My name is Michael Baca, and I am presenting this written testimony (NMED Exhibit 3 4 1) on behalf of the New Mexico Environment Department ("NMED" or "Department") 5 concerning the proposal to amend the State of New Mexico's Standards for Interstate and 6 Intrastate Surface Waters ("Water Quality Standards" or "WQS"), codified at Title 20, Chapter 7 6, Part 4 of the New Mexico Administrative Code (20.6.4 NMAC) for specified waters on the 8 Pajarito Plateau. Triad National Security, LLC, Newport News Nuclear BWXT-Los Alamos, 9 LLC, and the United States Department of Energy, Office of Environmental Management, Los 10 Alamos Field Office (collectively, the "Petitioners"), are proposing Copper ("Cu") site-specific 11 water quality criteria ("SSWQC") for specified waters on the Pajarito Plateau under 20.6.4.900 12 NMAC. These proposed WQS amendments follow the provisions of 20.6.4.10(F) NMAC 13 allowing for such amendments. My testimony will provide background on the framework for 14 Water Quality Standards including site-specific criteria, outline the administrative processes and 15 procedures for amendments (20.1.6 NMAC and 20.6.4 NMAC), and describe the NMED's 16 coordination with the petitioners on stakeholder engagement, criteria development, and 17 providing public notice of the rulemaking hearing.

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#### II. QUALIFICATIONS

I hold a Bachelor of Arts in Chemistry from Carleton College, and I am currently
employed as the Surface Water Quality Bureau ("SWQB") Monitoring, Assessment, and
Standards Section ("MASS") Standards and Outreach Team Supervisor, and serve as the Water
Quality Standards Coordinator for the SWQB. In this position, I lead the development, review,
revision, and maintenance of surface water quality standards; supervise SWQB's Quality

1 Assurance Officer to ensure data are collected and verified under approved standard operating 2 procedures and data collection planning documents; and provide direction to staff working on 3 SWOB special initiatives related to harmful algal blooms and volunteer data collection. 4 I began working for the Department in February of 2005 as an Environmental Scientist 5 and Specialist – Operational in the Environmental Health Bureau in the Gallup Field Office. In 6 this position I provided training, issued permits, conducted compliance inspections and 7 completed enforcement actions for the Food Safety, Onsite Wastewater, and Public Pool and 8 Spa Safety Programs. I was promoted to Environmental Scientist and Specialist – Advanced in 9 July of 2006 to serve as the Pool Specialist in northwestern New Mexico. I continued my duties 10 in the food and onsite wastewater programs while taking on additional responsibilities as the 11 subject matter expert and certified trainer for the pool program. In this role, I ensured consistent 12 administration, implementation, and enforcement of the program across the district and 13 provided internal and external training, technical guidance, and policy development at a state 14 level. 15 I started working for the NMED Air Quality Bureau in July of 2008 as an 16 Environmental Analyst – Advanced in their Control Strategies Section in Las Cruces. In this 17 position, I served as the border liaison and worked on climate, particulate matter and ozone 18 pollution issues. I worked with stakeholders in formal and informal settings on cross 19 jurisdictional air quality and climate concerns in the tri-state, bi-national Paso del Norte Airshed 20 near Sunland Park, New Mexico, El Paso, Texas and Ciudad Juárez, Mexico. I developed ozone 21 and particulate matter air quality management plans and participated in special studies 22 regarding emissions inventories, monitoring, and photochemical modeling. I developed New 23 Mexico's recommendation for an ozone nonattainment area in and around Sunland Park in

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1	southern Doña Ana County, as well as portions of that area's nonattainment State								
2	Implementation Plan ("SIP") under the federal Clean Air Act ("CAA").								
3	From December of 2018 to September 2023, I served as the Control Strategies manager								
4	in Santa Fe, with a staff of six that develop air quality rules and the SIP; track and comment on								
5	federal air quality and climate rules, guidance, and regulatory actions; manage and participate in								
6	air quality studies; lead and participate in regional and local climate change and air quality								
7	improvement groups and committees; implement air quality management plans and grant								
8	programs; and facilitate stakeholder engagement, outreach and education events.								
9	I have led and been a part of several rulemaking efforts for NMED including the Ozone								
10	Precursor Rule (20.2.50 NMAC), Energy Transition Act Rule (20.2.101 NMAC), Regional								
11	Haze (draft 20.2.68 NMAC), Fugitive Dust (20.2.23 NMAC) and Permitting Rules for								
12	Nonattainment Areas (20.2.79 NMAC), covering emission sources in the Oil and Gas, Electric								
13	Power, and Construction Sectors.								
14	My team also managed the Diesel Emissions Reduction Act and the Volkswagen								
15	Environmental Mitigation Trust settlement, awarding nearly \$20 million dollars to replace								
16	heavily polluting diesel vehicles and equipment with cleaner burning alternative fueled models,								
17	including electric vehicles and charging stations. An accurate and up-to-date copy of my resume								
18	is included as <b>NMED Exhibit 2</b> .								
19	III. WATER QUALITY STANDARDS								
20	Under the New Mexico Water Quality Act ("WQA"), the Water Quality Control								
21	Commission ("WQCC" or "Commission") is responsible for adopting Water Quality Standards.								
22	NMSA 1978, § 74-6-4(D). The standards must at a minimum protect public health or welfare,								
23	enhance the quality of water and serve the purposes of the WQA. Id. The federal Clean Water								

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1	Act ("CWA") regulations provide similar direction: "States adopt water quality standards to
2	protect public health or welfare, enhance the quality of water and serve the purposes of the Clean
3	Water Act." 40 C.F.R. § 131.2. Section 101(a)(2) of the CWA requires that, wherever attainable,
4	water quality shall provide for the protection and propagation of fish, shellfish and wildlife and
5	for recreation in and on the water. 33 U.S.C. § 1251(a). In accordance with 40 C.F.R. Section
6	131.10(a), each State must specify appropriate water uses to be achieved and protected. The
7	requirements as outlined under 40 C.F.R. 131 and the CWA have been codified under the Water
8	Quality Standards at 20.6.4 NMAC.
9	A water quality standard "defines the goals for a water body, or portion thereof, by
10	designating the use or uses to be made of the water and by setting criteria necessary to protect the
11	uses." 40 C.F.R. § 131.2. The designated uses in New Mexico's Surface Water Quality
12	Standards, set forth in 20.6.4.900 NMAC, are:
13 14 15 16 17 18 19 20 21 22	<ul> <li>fish culture</li> <li>public water supply</li> <li>industrial water supply</li> <li>domestic water supply</li> <li>irrigation and irrigation storage</li> <li>primary and secondary contact</li> <li>livestock watering</li> <li>wildlife habitat, and</li> <li>aquatic life (coldwater, coolwater, warmwater and four other subcategories)</li> </ul> The Standards also establish water quality criteria that will protect the designated uses of
23	a water body. These criteria can be general narrative criteria that apply to all waters, or numeric
24	criteria that apply to a specific designated use or water quality segment. An example of a
25	narrative criterion is that for plant nutrients, which states, "Plant nutrients from other than natural
26	causes shall not be present in concentrations that will produce undesirable aquatic life or result in
27	a dominance of nuisance species in surface waters of the state." 20.6.4.13(E) NMAC. Examples

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of numeric criteria include the current hardness-dependent acute and chronic aquatic life criteria
 for dissolved copper, which are calculated and expressed as a function of hardness, found in
 20.6.4.900(I) NMAC.

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#### IV. HISTORY OF COPPER WATER QUALITY CRITERIA

5 New Mexico's current dissolved copper criteria are based on the U.S. Environmental 6 Protection Agency's ("EPA") 1995 Updates: Water Quality Criteria Documents for the 7 Protection of Aquatic Life in Ambient Water (NMED Exhibit 5). Although copper is a 8 naturally occurring essential trace mineral, exposure to excessive copper can negatively 9 impact aquatic life survival, growth, and reproduction as well as alter brain function, enzyme 10 activity, blood chemistry, and metabolism (NMED Exhibits 6 and 7). Potential sources of 11 excessive copper in surface waters include but are not limited to mining activities, erosion, 12 leaching from distribution pipes, wastewater from industrial processes, road runoff (brake 13 pads), biocide use (copper sulphate), wood preservatives, and asphalt or roofing materials 14 (NMED Exhibits 6 and 7). 15 In 2007, EPA updated their copper criteria recommendations to consider the 16 characteristics of the receiving water using a biotic ligand model ("BLM") (NMED Exhibit 17 7). The copper BLM is a metal bioavailability model that uses receiving water body 18 characteristics and monitoring data to calculate Cu SSWQC (NMED Exhibit 7). The BLM 19 requires ten input parameters to 1) predict copper toxicity to aquatic life based on site-specific 20 water quality, and 2) calculate applicable criteria based on this toxicity (NMED Exhibit 7). 21 Most states, including New Mexico, have been slow to adopt and implement EPA's 2007 22 copper BLM approach primarily due to 1) the lack of adequate input parameter data to 23 calculate the criteria, 2) the inability to consistently build these additional monitoring costs

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1	into their monitoring strategies due to staff and financial resource constraints, and 3) the
2	additional challenges of implementing variable criteria that change depending on the
3	characteristics of the receiving water at the time of sampling. For example, permittees
4	discharging into waters based on the proposed BLM approach would need to collect all
5	necessary input parameters of the ambient receiving water as well as effluent in order to
6	calculate the applicable criteria at the time of discharge using the BLM model, unless default
7	input values are derived and utilized for missing data inputs. Implementation of BLM-based
8	criteria requires sufficient data to characterize the variability in the receiving water to ensure
9	the criteria are protective of the most critical receiving water conditions. Based in part on
10	these concerns, NMED did not propose or recommend adoption of the EPA's 2007
11	recommended freshwater criteria for copper statewide during prior triennial reviews.
12 13	V. AMENDMENT OF WATER QUALITY STANDARDS TO PROPOSE SITE-SPECIFIC COPPER CRITERIA
14	Under the WQA, any person (including NMED) may at any time petition the
15	Commission to adopt, amend or repeal a water quality standard. NMSA 1978, § 74-6-6(B). In
16	accordance with 20.6.4.10(F)(3) NMAC, an entity other than NMED can petition the
17	Commission to adopt site-specific criteria provided the petition: identifies the specific waters to
18	which the site-specific criteria would apply, explains the rationale for proposing the site-specific
19	criteria, describes the methods used to notify and solicit input from potential stakeholders and the
20	general public in the affected area and present and respond to the public input received, and
21	presents and justifies the derivation of the proposed site-specific criteria. In addition, the
22	derivation of site-specific criteria must be based on a scientifically defensible method.
23	20.6.4.10(F)(4) NMAC. The Commission must hold a public hearing and consider technical
24	testimony to adopt new or amended standards. NMSA 1978, § 74-6-6(A). New or revised
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1	standards must be submitted by the State to EPA for approval. 40 C.F.R. § 131.20.
2	SSWQC may be adopted based on CWA Section 304(a) guidance, modified 304(a)
3	guidance to reflect site-specific conditions, or other scientifically defensible methods 40 C.F.R. §
4	131.11; 20.6.4.10(F)(4) NMAC. The Commission may adopt SSWQC based on relevant site-
5	specific conditions like physical or chemical characteristics at a site that alter the bioavailability
6	and/or toxicity or bioaccumulation of the chemical and more accurately expresses a
7	concentration for a water quality parameter to fully protect the designated use to which they
8	apply. 20.6.4.10(F)(1) NMAC and 20.6.4.10(F)(2) NMAC. Pursuant to 20.6.4.10(F)(4) NMAC,
9	the derivation of SSWQC must rely on a scientifically defensible method or the natural
10	background concentration. For reference and consistent with 20.6.4.10(F)(4)(a) NMAC, in 2017,
11	the Commission adopted site-specific copper criteria based on the water effect ratio ("WER") for
12	perennial, intermittent, and ephemeral watercourses within Smelter Tailing Soils Investigation
13	Unit lands at the Chino Mines Company in the Mimbres Closed Basin. 20.6.4.808 NMAC and
14	20.6.4.809 NMAC. The Mimbres SSWQC are calculated using dissolved organic carbon,
15	alkalinity, and hardness, which are measured in the watercourse.
16	EPA's 2007 copper BLM is included as an example of a scientifically defensible method
17	to derive site specific criteria in 20.6.4.10(F)(4)(c) NMAC. The Petitioners streamlined EPA's
18	BLM approach to propose multiple linear regression ("MLR") equations with pH, dissolved
19	organic carbon ("DOC"), and hardness input values to generate applicable acute and chronic
20	criteria. This approach is consistent with EPA's intention to develop and propose MLR models
21	for eight metals with only pH, DOC, and hardness input values used for criteria development
22	versus the entire BLM input suite because of these parameters' stronger influence on
23	bioavailability and correlation with other BLM parameters (NMED Exhibit 8). Due to the

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wealth of input parameter data available for waters on the Pajarito Plateau, the Petitioners were
 able to establish MLR equations that can be used to approximate copper BLM criteria with high
 accuracy.

4 NMED supports the scientific basis behind EPA's proposed MLR approach and will 5 assess the feasibility of adoption and implementation in New Mexico after EPA issues a final 6 report and recommendation. The implementation concerns regarding the additional resources 7 needed to collect the required concurrent monitoring data remain, even with the reduced 8 number of input parameters. In addition, collection and analysis of DOC samples has added 9 logistical and quality control challenges. While measured input data are preferred, some states 10 that have adopted BLM or MLR criteria allow for estimated or default values when measured 11 input data are not available based on proposed EPA approaches.

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#### VI. WQCC RULEMAKING AND PUBLIC NOTICE REQUIREMENTS

13 As I noted above, a petition to adopt SSWQC shall include the specific waters to which 14 the criteria apply (20.6.4.10(F)(3)(a) NMAC), a rationale for the proposing the site-specific 15 criteria (20.6.4.10(F)(3)(b) NMAC), and a description of stakeholder engagement including 16 methods of public notice and comment and responses to comment or input received 17 (20.6.4.10(F)(3)(c) NMAC). The petition must also present and justify the derivation of the 18 proposed criteria (20.6.4.10(F)(3)(d) NMAC) to the Commission following the WQCC 19 rulemaking procedures at 20.1.6 NMAC. 20 Rulemaking before the Commission begins when a person files a written petition and

statement of reasons to adopt, amend, or repeal a regulation in accordance with 20.1.6.200

22 NMAC. The petition must specify the statutory authority for the commission to adopt proposed

rules, estimate the amount of time to conduct the hearing, and include a copy of the entire rule

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1	with line numbers and proposed changes in redline fashion. 20.1.6.200(B) NMAC. The
2	Commission may grant a rulemaking hearing in accordance with 20.1.6.200(C) NMAC and
3	specify the procedures for conducting the hearing as outlined in 20.1.6.200(D) NMAC, including
4	provisions for public notice and public participation.
5	Public notice of rulemaking hearings must be provided to the public in accordance with
6	20.1.6.201(A) NMAC. The public notice must include publication in a newspaper of general
7	circulation, the New Mexico Register, and such other means as directed by the Commission or
8	required by law. 20.1.6.201(B) NMAC. The public notice of rulemaking must include: the
9	subject, a summary, and the purpose of the proposed rule, the legal authority for the rule and its
10	adoption, the technical basis for the proposed rule and how to find technical information,
11	governing laws of procedure, and information on how to present information and participate in
12	the hearing, examine documents, and download information. $20.1.6.201(C)(1) - (7)$ NMAC. The
13	public notice may also state the Commission's intent to make a decision on the proposed rule at
14	the conclusion of the hearing. 20.1.6.201(C)(8) NMAC. In addition to publication of notice, the
15	Commission must "provide to the public" $(20.1.6.7(P)(1) - (7) \text{ NMAC})$ by distributing
16	rulemaking information by:
17 18 19 20 21 22 23 24 25 26 27 28	<ul> <li>posting it on the commission's website,</li> <li>posting it on the New Mexico sunshine portal,</li> <li>making it available at the applicable constituent agency's district, field, and regional offices,</li> <li>sending it by email to persons who have made a written request for notice of announcements addressing the subject of the rulemaking proceeding and who have provided an email address to the commission administrator,</li> <li>sending it by email to persons who have participated in the rulemaking and who have provided an email address to the commission administrator,</li> <li>sending written notice that includes, at a minimum, an internet and street address where the information may be found to persons who provide a postal address; and</li> </ul>
29	interim and standing legislative committees.

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## VII. WORKPLAN COORDINATION, CRITERIA DEVELOPMENT, AND PUBLIC NOTICE PROVIDED

3 On July 7, 2020, the Department received a draft work plan from the Petitioners for the 4 development of SSWQC for the Pajarito Plateau. Although a work plan is not required for a site-5 specific criteria demonstration pursuant to 20.6.4.10(F) NMAC, a draft was developed and 6 submitted to the Department for review. This brought transparency and planning to the project to 7 facilitate common understanding and coordinate timelines and resources. 8 NMED and EPA reviewed and prepared general comments regarding the "Draft Work 9 Plan: Development of Site-Specific Copper Criteria for Surface Waters of the Pajarito Plateau 10 *New Mexico*" as originally submitted. The comments provided were intended to assist the 11 Petitioners with preparing a technical report, "Demonstration Report for Copper Site-Specific 12 Criteria for Surface Waters of the Pajarito Plateau" (Demonstration) with a comprehensive 13 analysis for consideration of copper SSWQC for waters on the Pajarito Plateau 14 (20.6.4.10(F)(3)(a)-(b) NMAC). The Petitioners developed a draft Demonstration based on the 15 early input and guidance provided by the Department through the work plan and review in 16 November of 2021. The Petitioners provided additional technical information, as requested, to 17 the Department in April of 2022. The Department reviewed the additional information from the 18 Petitioners and provided formal comments on the draft Demonstration on March 31, 2023. 19 The Petitioners addressed the Department's and EPA's comments in a subsequent draft 20 Demonstration and response to comments dated August 2023. Throughout the process, the 21 Petitioners solicited input from stakeholders and the general public and responded to all the input 22 they received (20.6.4.10.F(3)(c) NMAC). A final Demonstration report and description of the 23 public input process were provided with the Petition submitted to the Commission in this matter. 24 The public notice for the hearing was drafted and published by the Petitioners in the

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1 Albuquerque Journal and the New Mexico Register in accordance with the State Rules Act and 2 20.1.6.201 NMAC (NMED Exhibit 11). The Department assisted the Petitioners and 3 Commission with notification requirements and provided rulemaking information to the public, 4 as described in 20.1.6.7(P) NMAC. The Department completed the "provide to the public" 5 requirements it was responsible for on October 16, 2024 by: posting the notice of rulemaking to 6 the Commission's website, the New Mexico Sunshine Portal, at NMED's District and Field 7 Offices, and sending emails with the public notice of rulemaking to the SWQB Listserv 8 subscribers and to the Legislative Council Service (NMED Exhibit 9). Additionally, the 9 Department posted the public notice and rulemaking information on its events calendar, the 10 SWQB's website, the NMED Public Notice website, and created an entry for the Commission to 11 receive comments through the Department's Public Comment Portal (NMED Exhibit 10).

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#### VIII. CONCLUSION

Commission regulations allow for the adoption of site-specific criteria based on relevant, site-specific water body conditions and scientifically defensible methods when site-specific criteria fully protect the designated use to which they apply. Specific water body conditions include the chemical or physical characteristics of a site that alter the bioavailability or toxicity of a pollutant. The resulting site-specific criteria can be more or less stringent than the "default" criteria for a designated use, but they do not change the designated use of the water body.

In 2020, the Department and Petitioners reconnected on the topic of SSWQC for the Pajarito Plateau and conducted multiple scoping meetings to outline and discuss expectations and processes. The Petitioners developed a workplan for stakeholder engagement and technical report development. NMED observed that the Petitioners followed the workplan, completed stakeholder engagement activities, and held a public comment period on their draft proposed

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1	site-specific criteria. This included data collection, criteria development, public meetings,
2	responding to comments and making corresponding revisions, as necessary. As such, NMED
3	considers the Petitioners to have properly complied with the provisions of 20.6.4.10(F) NMAC
4	for site-specific criteria.
5	The proposed Pajarito Plateau Cu SSWQC as presented by the Petitioners are founded in
6	scientifically-sound BLM and related MLR approaches promoted by EPA that consider the water
7	quality conditions of the receiving water to better characterize bioavailability and consequent
8	toxicity. NMED recommends that the Commission adopt the proposed amendments. If the
9	Commission so adopts the proposed amendments, the SWQB would submit the revised water
10	quality standards, as published in the New Mexico Register, to EPA for formal review and final
11	approval action under Section 303(c) of the CWA. The rules would become effective for state
12	purposes thirty days after filing in accordance with the State Rules Act. NMSA 1978, Section
13	74-6-6(E). This concludes my direct testimony.

#### MICHAEL G. BACA

#### EDUCATION - September 1999-June 2004, Carleton College, Northfield, MN, B.A. in Chemistry

#### PROFESSIONAL EXPERIENCE - February 2005-Present, New Mexico Environment Department

October 2023 - Present, Surface Water Quality Bureau, Water Resources Manager I

Serve as the Water Quality Standards Coordinator and the supervisor for the Standards and Outreach Team. Oversee, lead, and assist in the development, revision, and implementation of New Mexico's surface water quality standards, including rulemakings and special projects. Provide technical testimony and exhibits for proposed water quality management plans and standards amendments presented before the Water Quality Control Commission, including third-party rulemakings, the Triennial Review and the Water Quality Management Plan and Continuing Planning Process. Organize public stakeholder engagement opportunities regarding proposed changes to standards to provide feedback and discussion with the public, regulated community, interests groups, nonprofit organizations, academia and state, local and federal government representatives and elected officials. Oversee the day-to-day activities of the team: managing, assigning and prioritizing tasks and projects, developing employees, providing technical and policy guidance, and administering personnel related actions such as evaluations, discipline, and hiring.

December 2018-September 2023, Air Quality Bureau, Staff Manager

Manage the daily operations of the Control Strategies Section including a staff six to implement and enforce the federal Clean Air Act in New Mexico through the development and revision of the State Implementation Plan and other air quality management plans and rules for the state. Assign and prioritize completion of tasks and projects to achieve the vision and mission of the Department and the Bureau's performance measures. Provide technical and policy guidance through the development of work products and administration of existing programs, policies, rules, regulations, and resources. Oversee, lead and assist with rulemaking and special projects including the adoption of rules and management plans by presenting testimony and exhibits before the Environmental Improvement Board. Manage air quality programs and projects to award contracts and grants, ensure timely submission of deliverables and technical reports, and review financial expenditures to meet contractual obligations and compliance with state procurement rules. Organize and develop public stakeholder engagement strategies to provide meaningful engagement opportunities and collaborations with the public, regulated community, interests groups, nonprofit organizations, academia and state, local and federal government representatives and elected officials. Complete timely HR actions to include training, employee evaluations, discipline, hiring and other personnel actions.

#### July 2008-December 2018, Air Quality Bureau, Environmental Analyst

Represent the Department as the air quality liaison with binational border air quality agencies and stakeholders, participating in the Joint Advisory Committee and the USEPA border programs. Develop and prepare technical testimony and exhibits for public hearings in front of the Environmental Improvement Board to present and defend air quality plans and rules for adoption in New Mexico, including state implementation plans required by the USEPA. Analyze ambient air quality monitoring data and prepare technical documents for submission to the USEPA for high wind blowing dust events that cause air pollution episodes. Conduct public education and outreach meetings and develop educational material regarding air quality, rule requirements, and rule development. Review and comment on permits, Environmental Impact Statements, and Environmental Assessments for compliance with

federal and state rules and standards. Manage air quality research projects and contracts in the border area to ensure timely submission of deliverables.

February 2005 -July 2008, Field Operations Division, Environmental Scientist and Specialist

Oversee public swimming pool program at a district level to ensure consistent permitting, inspection, and enforcement actions across six counties in northwest New Mexico. Review engineering plans and approve permits for construction of swimming pool and bath facilities. Conduct training for swimming pool department staff and operators. Permit and inspect restaurants and food processors, swimming pool facilities, and liquid waste disposal system installations and initiate enforcement actions for compliance with applicable regulations. Conduct public education and outreach to help the regulated community comply with environmental management principles, administrative requirements, and state regulations.

### LYNETTE STEVENS GUEVARA -

#### Summary of Qualifications:

Thirty+ years of experience in natural resources protection and management with emphasis on water quality monitoring, assessment, and restoration. Major strengths include project management and collaboration, data management and interpretation, technical report preparation and editing, and developing tools and techniques to increase efficiency.

#### **Professional Experience:**

#### 11/22 – present New Mexico Environment Dept. Surface Water Quality Bureau, Santa Fe, NM

#### Monitoring, Assessment, and Standards Section Program Manager

- Managed a group of fourteen technical staff including supervising three team leaders to:
  - Monitor, assess, and report on surface water quality conditions around New Mexico
  - Develop, revise, and maintain New Mexico's related surface water quality standards
  - Develop total maximum daily load (TMDL) planning documents to address impairments
  - Provide related assistance and support to other Bureau sections and stakeholders as needed
- Complete program management activities including grant writing, funding allocations, hiring, and performance reviews
- Prepare and implement EPA grants applications and revisions, associated workplans, and budgets designed to achieve Department and Bureau goals
- Actively participate on various EPA and state counterpart workgroups regarding water quality policy, implementation, guidance, and strategies to achieve Clean Water Act goals and deliverables
- Actively collaborate with other NMED Water Protection Division bureau management and staff on collaborative projects and initiatives to move the Department forward

#### 11/20- 10/22 New Mexico Environment Dept. Ground Water Quality Bureau, Santa Fe, NM

#### Pollution Prevention Section Reuse Team Leader

- Serve as in-house expert for above-ground use of reclaimed domestic wastewater and aquifer recovery and storage permits to encourage successful implementation of water reuse projects
- Maintain individual groundwater discharge permit case load, provide review and comment on all permits with reuse components, and contribute to the oversight of all discharge permits managed by the Section
- Research and propose IT modernization tools to provide e-Permitting and e-Reporting tools to increase efficiency, compliance, and transparency
- Manage CWA 319 grant including workplans, budgeting, and reporting
- Hire and supervise and manage a team of three technical staff

#### 08/01 – 11/20 New Mexico Environment Dept. Surface Water Quality Bureau, Santa Fe, NM

#### State on New Mexico Clean Water Act §303(d)/ §305(b) Assessment Coordinator (2001-2020)

Project management duties performed to develop and maintain the biennial Clean Water Act §303(d)/ §305(b) Integrated Report and List to Congress:

- Collated and assessed chemical, physical, and biological data to determine surface water quality impairments based on current water quality standards in 20.6.4 NMAC
- Developed and applied assessment protocols used to determine water quality attainment
- Developed automated assessment procedures in R statistical programming language
- Collaborated with NMED IT and USEPA Office of Water to merge and improve NMED inhouse and

national water quality monitoring and assessment databases

- Presented to the NM Water Quality Control Commission (WQCC) and EPA Region 6 for approval
- Prepared and presented testimony to the NM WQCC regarding Outstanding National Resource Waters (ONRW) nominations in the Valle Vidal and to defend impairment determinations
- Participated in various EPA and state counterpart workgroups and national conferences regarding Clean Water Act policy, procedures, and deliverables
- Collaborated with the USDA National Sedimentation Lab to develop sedimentation assessment protocols for the San Juan River basin
- Collaborated with the EPA Office of Research and Development and EPA Region 6 to develop sedimentation and nutrient assessment protocols and monitoring techniques

#### Monitoring and Assessment Section Program Manager (2004-2006)

- Managed a group of twelve technical staff including supervising three team leaders in order to monitor, assess, and report on surface water quality conditions around New Mexico
- Participated in grant writing, funding allocations, hiring, and performance reviews
- Developed Requests for Proposals and participated in selection of funding recipients
- Prepared and implemented strategic plans, associated workplans, and budgets designed to achieve Department and Bureau goals through implementation of several EPA grants
- Developed and presented budget requests for NMED and EPA to meet program goals

#### Monitoring and Assessment Section TMDL, GIS and Database Team Leader (2001-2003)

- Supervised and managed three technical staff to develop total maximum daily load (TMDL) water quality planning documents, GIS tools, and water quality databases for the Section
- Participated in hiring, performance reviews, and completing team goals to support the Bureau.
- Developed team timelines and specific TMDL, GIS, and database tasks and products needed to accomplish goals, and participated in the evolution of the Monitoring and Assessment Section
- Developed, public noticed, and presented TMDL water quality planning documents to stakeholders and the NM WQCC to address identified water quality impairments

#### 05/97 – 08/01 Navajo Nation, Window Rock, AZ

#### Hydrologist II, Navajo Nation EPA Water Quality Program (02/99 -08/01)

- Project management, including the proposal and implementation of watershed restoration projects; designing monitoring networks; preparing outreach materials, presentations, and technical reports; and coordinating activities with federal tribal and federal land management partners
- Developed bioassessment monitoring program, associated quality assurance project plans, and provided training to staff and students
- Coordinated surface water quality sampling, interpreted data, and prepared summary reports

#### Hydrologist II/Supervisor, Navajo Nation Water Management Branch (05/97 -02/99)

- Supervised and managed stream gage and watershed restoration staff, including hiring, training, evaluations, budgeting, and ensuring deliverables were met
- Project management of watershed restoration projects with tribal and federal land management partners, including the development of RFPs, contracts, workplans, work schedules, permits, project budgets, and monitoring networks
- Maintained nine active continuous stream gages coordinated with USGS, ordered needed equipment, surveyed benchmarks, measured stream flow, developed rating curves, and assisted with water monitoring design of irrigation canals

#### Education:

Post-baccalaureate coursework at University of Washington and Shoreline CC, Seattle, WA Master of Science (Watershed Science), Colorado State University, Fort Collins, CO

#### **Computer Skills:**

MS Office, Oracle database design team, SSTEMP modeling, RStudio programming, ArcGIS, website maintenance

#### **Interests / Hobbies:**

Founding treasurer of Wild Sage Co-op (now La Montanita) Gallup branch, past Parent-Teacher-Kid Association board member, bike-to-school and community trails advocate, mountain biking, skiing, hiking

#### **Publications and Presentations:**

- Guevara, L. 2003. The challenges and opportunities of implementing TMDLs in states with no instream flow program. In proceedings of ASAE Conference on Emerging TMDL Issues. Albuquerque, NM.
- Guevara, L. 2012. Determining sediment impairment in New Mexico using biologic and geomorphic sediment thresholds. In proceedings of *National Water Quality Monitoring Conference*. Portland, OR. Available at: <a href="http://acwi.gov/monitoring/conference/2012/">http://acwi.gov/monitoring/conference/2012/</a>.
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- Stevens, L.I. 1996. Benthic macroinvertebrates as indicators of water quality. Master's thesis. Department of Earth Resources, Colorado State University, Ft. Collins, CO.
- Viera, N., W. Clements, L. Guevara, and B. Jacobs. 2004. Resistance and resilience of stream insect communities to repeated hydrologic disturbances after a wildfire. Freshwater Biology 49: 1243-1259.

## Shelly Lemon

Santa Fe, New Mexico

#### **EDUCATION**

M.S. Hydrology University of Arizona – Tucson, AZ

B.S. Biology Minor in Chemistry/Math University of Arizona – Tucson, AZ

#### PROFESSIONAL EXPERIENCE

#### Bureau Chief – Surface Water Quality Bureau, NM Environment Department

August 2016 – Present

- NMED Surface Water Quality Bureau, Santa Fe, NM Manage the Surface Water Quality Bureau of the New Mexico Environment Department by planning, setting, and achieving goals set forth in the Department's Strategic Plan, EPA approved work plans, and program planning documents.
- Contribute to and implement Department strategic goals, objectives, and actions.
- Collaborate with the public, stakeholders, and decision makers (legislators, Governor's Office, etc.) to ensure that the goals of the Department are achieved.
- Oversee an operating budget of approximately \$11 million dollars that requires administration of general funds, special revenue funds, interagency transfers, and federal grants, including oversight of the Bureau's grants and contracts management.
- Develop, tailor, and implement administrative, programmatic, and financial operation procedures to ensure accountability and facilitate successful completion of projects.
- Directly or indirectly supervise 42 technical and administrative staff including hiring, work performance evaluations, and discipline, if needed. Ensure performance goals are met and activities are conducted in accordance with applicable statutes, policies, rules, permits, orders, and grant commitments.
- Develop and respond to legislative proposals and develop regulatory initiatives to promote and enhance surface water quality protections in New Mexico.
- Provide leadership and substantive expertise on technical and policy working groups, particularly in support of Department priority initiatives.
- Periodically meet with managers and staff to evaluate program effectiveness, identify strengths, weaknesses, and opportunities, and develop strategies to improve Bureau programmatic operating functions.
- Facilitate coordination between EPA, and other public and private entities involved in surface water quality protection, management, and regulation.
- Ensure that information requests are responded to in a timely and professional manner.
- Oversee short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Work with the Bureau's webmaster to create, update, and maintain webpages, resources, and links associated with activities of the Bureau.

#### Program Manager for Monitoring, Assessment and Standards

June 2015 – October 2016

- NMED Surface Water Quality Bureau, Santa Fe, NM Managed the Surface Water Quality Bureau's monitoring, assessment, and standards programs including writing, submitting, and managing the Clean Water Act Section 106 grants on an annual basis with semi-annual updates.
- Oversaw and evaluated the performance of 15 staff.
- Participated in the development and revision of state surface water quality standards and regulations including the 2013 Triennial Review presented during the Water Quality Control Commission's October 2015 hearing and subsequent deliberations. NMED Exhibit 4

- Planned water quality surveys throughout New Mexico that met budgetary constraints and data quality objectives.
- Reviewed, integrated, and assessed data for use in Clean Water Act required activities.
- Prepared water quality reports (e.g. watershed survey summaries, use attainability analyses, TMDLs, etc.) for the public and as a deliverable to EPA.
- Reviewed, updated, and developed protocols to standardize tasks including sample collection, data assessment, and report writing.
- Represented the Bureau at meetings, professional conferences, workshops, and Water Quality Control Commission meetings.
- Conducted short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Maintained analytical results in the Bureau's water quality database, prepared retrievals of stored data, and scheduled uploads of data to EPA's national database.
- Worked with the Bureau's webmaster to create, update, and maintain webpages, resources, and links associated with activities of the Section and Bureau.

#### Municipal Team Leader – Point Source Regulation Section

March 2014 – May 2015 NMED – Surface Water Quality Bureau, Santa Fe, NM

- Reviewed and evaluated the performance of the Municipal Team by providing meaningful, frequent, and ongoing input on work performance and prioritization of workloads.
- Cooperated with and supported the efforts of other Bureau sections. Facilitated positive working relationships with other state and federal agencies, stakeholders, and cooperators involved in National Pollutant Discharge Elimination System (NPDES) permitting activities.
- Reviewed, analyzed data, and prepared comments on NPDES permits submitted to the Bureau for certification under Section 401 of the Federal Clean Water Act. Ensured consistency in NPDES permit certifications.
- Investigated regulated facilities for compliance/non-compliance with applicable state and federal surface water quality laws, standards, and regulations, and prepared and submitted comprehensive inspection reports that documented the status of the facilities regarding the federal NPDES permit program and regulations.
- Collected accurate and detailed information and useable evidence during site investigations to supplement information contained in NPDES permits, to evaluate violations of state surface water quality standards and regulations, and to assist EPA with enforcement.
- Reviewed, analyzed, and prepared well-written, clear, concise, and factual comments on proposed or new amended federal and state agency policies and procedures, regulations, and technical recommendations.
- Developed standard operating procedures for wastewater sampling and compliance sampling. Evaluated and acquired sampling equipment necessary for monitoring NPDES permitted facilities.

Reviewed, analyzed data, and prepared comments relevant to regulatory requirements and surface water quality studies and findings on Environmental Assessments (EA) and Environmental Impact Statements (EIS) submitted to SWQB for review.

#### Acting Program Manager for Monitoring, Assessment and Standards

July 2012 – July 2013 NMED – Surface Water Quality Bureau, Santa Fe, NM

- Managed the Surface Water Quality Bureau's monitoring, assessment, and standards programs including writing, submitting, and managing the Clean Water Act Section 106 Monitoring Initiative grant on an annual basis with semi-annual updates.
- Oversaw and evaluated the performance of 15 staff.
- Participated in the development and revision of state surface water quality standards and regulations.

- Planned water quality surveys throughout New Mexico that met budgetary constraints and data quality objectives.
- Reviewed, integrated, and assessed data for use in Clean Water Act required activities.
- Prepared water quality reports (e.g. watershed survey summaries, use attainability analyses, TMDLs, etc.) for the public and as a deliverable to EPA.
- Developed protocols to standardize tasks including sample collection, data assessment, and report writing.
- Represented the Bureau at meetings, professional conferences, workshops, and Water Quality Control Commission meetings.
- Conducted short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Maintained analytical results in the Bureau's water quality database, prepared retrievals of stored data, and scheduled uploads of data to the EPA's national database.
- Worked with the Bureau's webmaster to create, update, and maintain webpages, resources, and links associated with activities of the Section and Bureau.

#### Monitoring Team Leader – Monitoring, Assessment and Standards

April 2011 – July 2013 NMED – Surface Water Quality Bureau, Santa Fe, NM

- Managed the statewide ambient monitoring program for the Bureau. The Monitoring Team is responsible for collecting water quality data and associated flow measurements in surface waters of the state. Data collected by the Monitoring Team is used to determine if the water body meets water quality standards and ensure designated uses are supported.
- Oversaw and evaluated the performance of 5 staff.
- Planned water quality surveys throughout New Mexico that met budgetary constraints and data quality objectives.
- Ensured adequate and appropriate data were collected to support a variety of Clean Water Act required activities (e.g., water quality standards amendments, TMDL development, NPDES permits, nonpoint source monitoring effectiveness, etc.).
- Prepared watershed survey summaries for the public and as a deliverable to EPA.
- Developed protocols to standardize tasks including sample collection, data assessment, and report writing. Specifically, responsible for developing, updating, and revising the *Field Sampling Plan* and *Physical Habitat* standard operating procedures.
- Maintained analytical results in the Bureau's water quality database, prepared retrievals of stored data, and scheduled uploads of data to EPA's national database.
- Conducted short-term investigations in response to citizen complaints, accidental spills, and other emergencies.
- Worked with the Bureau's webmaster to create, update, and maintain monitoring webpages, resources, and links.
- Represented the Bureau at meetings, professional conferences, and workshops.

#### Nutrients and Lakes Team Leader & TMDL Writer – Monitoring and Assessment

August 2004 – April 2011 NMED – Surface Water Quality Bureau, Santa Fe, NM

- Prepared watershed planning documents (i.e., TMDLs) to improve water quality and conducted public meetings to address stakeholder comments and concerns.
- Presented the final draft documents to the NM Water Quality Control Commission for inclusion and adoption into the State's Water Quality Management Plan.
- Oversaw the nutrient criteria development program for streams, rivers, and lakes.
- Headed efforts in hydrology and monitoring design to develop a *Hydrology Protocol* that distinguishes between ephemeral, intermittent, and perennial waters in New Mexico and to create a practical yet thorough 10-year monitoring and assessment strategy for the Bureau.
- Managed and evaluated the performance of 3 technical staff.

#### Graduate Research Assistant – Sustainability of semi-Arid Hydrology and Riparian Areas

January 2002 – January 2004

- Designed, coordinated, and implemented a hydrologic research project to determine the influence of land use and regional hydrology on surface water quality in a semi-arid stream.
- Organized and prepared an objective, scientifically sound thesis describing the methods, results, conclusions, and management implications of this research.
- Co-authored the journal article, "Spatial variability in dissolved organic matter and inorganic nitrogen concentrations in a semiarid stream, San Pedro River, Arizona" for the *Journal of Geophysical Research* Volume: 112, Issue: G3.

#### **Graduate Teaching Assistant** January 2002 – December 2003

University of Arizona, Tucson, AZ

SAHRA – University of Arizona, Tucson, AZ

- Assisted in the instruction of an "Introduction to Global Change" class for undergraduates and a "Fundamentals of Water Quality" class for graduates.
- Developed hands-on activities to enhance global awareness and environmental stewardship.
- Designed and facilitated a final project to encourage critical analysis and informed decision-making.

#### OTHER EXPERIENCE

Middle School Science Teacher | Academy of Technology and the Classics, Santa Fe, NM August 2013 – March 2014

- High School Science Teacher | Chino Valley High School, Chino Valley, AZ August 1998 – June 2001
- Teacher Fellow | Earth Watch Institute Bellavista Preserve, Ecuador Summer 1999 (2 weeks)
- Science Instructor | Nizhoni Upward Bound Summer Academy, Flagstaff, AZ Summer 1997, 1998 (6 weeks/Summer)
- Naturalist | San Joaquin Outdoor Education, La Honda, CA February 1995 – June 1995, August 1995 – June 1996
- Science Instructor & Dive Master | Catalina Island Marine Institute, Avalon, CA June 1993 – January 1995; Summer 1994, 1995, 1996 (10 week/Summer)

United States Environmental Protection Agency

Office of Water 4301

EPA-820-B-96-001 September 1996

# 1995 Updates:

## Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water

#### DISCLAIMER

This document has been reviewed by the Health and Ecological Criteria Division, Office of Science and Technology, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names and commercial products does not constitute endorsement of their use.

#### ACKNOWLEDGMENT

Technical support for preparation of this document was provided to the Office of Water by Charles E. Stephan, U.S. EPA, Office of Research and Development, Mid-Continent Ecology Division, Duluth, MN.

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#### INTRODUCTION

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The purpose of these updates is to apply the methodology and datasets used in the derivation of the GLI aquatic life criteria to the national aquatic life criteria for these pollutants in fresh water. The methodology is that described for Tier I in Appendix A to Part 132: Great Lakes Water Quality Initiative Methodologies for Development of Aquatic Life Criteria and Values (Federal Register 60:15393-15399; March 23, 1995). This methodology differs from that described in the 1985 Guidelines (U.S. EPA 1985) in the following important ways:

- a. The GLI methodology gives preference to species that are resident in the Great Lakes System. This has no impact on these criteria, however, because the sensitive species in these datasets that are considered commercially or recreationally important for the purposes of deriving national aquatic life criteria are the same as the sensitive species in these datasets that are considered commercially or recreationally important for the purposes of deriving GLI aquatic life criteria.
- b. The GLI methodology does not use the Final Residue Value (FRV) that was used in the 1985 Guidelines. Instead of using the FRV in the derivation of aquatic life criteria, human health and wildlife criteria are to be derived using guidelines that are designed to provide adequate protection to human health and wildlife.
- c. Acute-Chronic Ratios (ACRs) for saltwater species are not used in the derivation of criteria for freshwater species if the Minimum Data Requirements for chronic data are satisfied by data for freshwater species.

Other aspects of the methodology are generally identical to those presented in the 1985 Guidelines.

Although it is not part of the methodology, if the range of Species Mean Acute Values (SMAVs) or Species Mean Chronic Values (SMCVs) within a genus was greater than a factor of five, the Genus Mean Acute Value or Genus Mean Chronic Value was set equal to the lowest SMAV or SMCV in that genus to provide adequate protection to the tested species in the genus. Whenever this was done, it is footnoted in the relevant table.

The datasets used in these updates used new data that were considered to be of acceptable quality along with the data in the criteria documents previously published by the U.S. EPA, which are referenced in the section for each pollutant. "New data" are data that became available since the last literature search used in the preparation of the criteria document by U.S. EPA and prior to January 1993. Some errors in the U.S. EPA criteria documents were corrected and the new taxonomy for salmonids was used; some SMAVs and GMAVs are different from those in the U.S. EPA criteria documents due to the preference for results of "flow-through, measured" tests. Although some new data could have been used to revise the slopes relating acute and/or chronic toxicity to hardness or pH, it was decided that revision was not necessary at this time. Thus all of the slopes used herein are the same as those used in the criteria documents previously published by the U.S. EPA.

These updates affect criterion concentrations (i.e., Criterion Maximum Concentrations and/or Criterion Continuous Concentrations), but not averaging periods or frequencies of allowed exceedances. Four digits are given in the criterion concentrations because these are intermediate values in the derivation of permit limits.

The following abbreviations are used in this document: = Acute-Chronic Ratio ACR CCC = Criterion Continuous Concentration = Criterion Maximum Concentration CMC FAV = Final Acute Value FCV = Final Chronic Value = Genus Mean Acute Value ~ GMAV GMCV = Genus Mean Chronic Value FACR = Final Acute-Chronic Ratio SMACR = Species Mean Acute-Chronic Ratio SMAV = Species Mean Acute Value SMCV = Species Mean Chronic Value

#### 1995 UPDATE:

#### . Freshwater Aquatic Life Criterion for Copper

The new acceptable acute and chronic data for copper are given in Tables E1 and E2. These new data were used with those given in Tables 1 and 2 of the criteria document for copper (U.S. EPA 1985) to obtain the values given in Table E3. Because the toxicity of copper is hardness-dependent, all acute values in Table E3 have been adjusted to a hardness of 50 mg/L.

#### Criterion Maximum Concentration (CMC)

Data given in U.S. EPA (1985) for the species *Gammarus pulex* were not used because this species is not resident in North America. Several SMAVs given in Table E3 were derived from U.S. EPA (1985) by giving preference to results of "FT,M" tests.

The Final Acute Value (FAV) was calculated using the four lowest Genus Mean Acute Values in Table E3, resulting in an FAV of 14.57 ug/L at a hardness of 50 mg/L. This value did not need to be lowered to protect a commercially or recreationally important species. The CMC was calculated by dividing the FAV by 2, resulting in a CMC of 7.285 ug/L, as total recoverable copper, at a hardness of 50 mg/L. The CMC was related to hardness using the slope of 0.9422 that was derived in U.S. EPA (1985):

> 0.9422 (ln hardness) - 1.700CMC = e

#### Criterion Continuous Concentration (CCC)

Insufficient chronic toxicity data were available to calculate a Final Chronic Value (FCV) using the eight-family procedure. Sufficient chronic data were available to calculate a FCV by dividing the FAV by the Final Acute-Chronic Ratio (FACR). The new chronic test gave an ACR of 15.48 with the fathead minnow; the geometric mean of this value and the four ACRs for this species in U.S. EPA (1985) was 11.20. SMACRs were available for nine species (Table E3) and were higher for resistant species. To make the FACR appropriate for sensitive species, it was calculated from the two SMACRs that were determined with species whose SMAVs were close to the FAV. Thus the FACR was calculated as the geometric mean of 3.297 and 2.418 and was 2.823. The FCV = FAV/FACR = (14.57 ug/L)/(2.823) = 5.161 ug/L at a hardness of50 mg/L. This value did not need to be lowered to protect a commercially or recreationally important species. Thus the CCC

was 5.161 ug/L, as total recoverable copper, at a hardness of 50 mg/L. The CCC was related to hardness using the slope of 0.8545 that was derived in U.S. EPA (1985):

0.8545(ln hardness) - 1.702 ccc = e

#### The Criterion

The procedures described in the methodology indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms should not be affected unacceptably if the four-day average concentration of copper does not exceed the numerical value (in ug/L) given by the equation

more than once every three years on the average and if the one-hour average concentration does not exceed the numerical value (in ug/L) given by the equation

CMC = e 0.9422(ln hardness) - 1.700

more than once every three years on the average.

CCC

#### Table E1. New Acute Values for Copper

Species	Method*	Hardness (mg/L as CaCO <sub>3</sub> )	Acute Value (ug/L)	Adjusted Acute Value (ug/L)**	Reference
Cladoceran, Ceriodaphnia reticulata	s,u	240	23	5.2	Elnabarawy et al. 1986
Cladoceran, Daphnia magna	s,u	240	41	9.4	Elnabarawy et al. 1986
Cladoceran, Daphnia pulex	S,U	240	31	7.1	Elnabarawy et al. 1986
Amphipod, Crangonyx pseudogracilis	S,U	50	1290	1290	Martin and Holdich 1986
Asiatic clam, Corbicula manilensis	FT,M	1.7	>2600	>7184	Harrison et al. 1984
Midge, Chironomus decorus	S,M	44	739	834	Kosalwat and Knight 1987
Fathead minnow, Pimephales promelas	FT,M	43.9	96	109	Spehar and Fiandt 1986
Bluegill, Lepomis macrochirus	S,M	31.2	340	530***	Bailey et al. 1985
Bluegill, Lepomis macrochirus	FT,M	31.2	550	858	Bailey et at. 1985
Rainbow trout, Oncorhynchus mykiss	FT,M	9.2	2.8	14	Cusimano and Brakke 1986
Striped bass, Morone saxatilis	s,U	285	270	52	Palawski et al. 1985

•

\* S = static, FT = flow-through, U = unmeasured, M = measured.
\*\* Adjusted to a hardness of 50 mg/L using the slope of 0.9422.
\*\*\* Not used in the calculation of the SMAV because data were available for this species from a "FT,M" test.

E-3

Table E2. New Chronic Values for Copper

- - - -

Species		Test*	Acute Value (ug/L)	Chronic Value (ug/L)	Acute- Chronic Ratio	Reference
Fathead minnow, Pimephales prom	nelas	ELS	96	6.2	15.48	Spehar and Fiandt 1986

\* ELS = early life stage.



•	•			• '
Rank*	Genus Mean Acute Value (ug/L)**	e Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
43	10240	Stonefly, Acroneuria lycorias	10240	
42	> 7184	Asiatic clam, Corbicula manilensis	> 7184	
41 .	6200	Caddisfly, Unidentified sp.	6200	· 
40	4600	Damselfly, Unidentified sp.	4600	
39	4305	American eel, Anguilla rostrata	4305	
38	1990	Crayfish, Procambarus clarkii	1990	,
37	1877	Snail, Campeloma decisum	1877	156.2***
36	1397	Crayfish, Orconectes rusticus	1397	
35	1290	Amphipod, Crangonyx pseudogracilis	1290	
34	1057	Pumpkinseed, Lepomis gibbosus	640.9	· · · · ·
		Bluegill, Lepomis macrochirus	- 1742	37.96***
33	900	Snail, Amnicola sp.	900	·
32	790.6	Ban <b>ded</b> killifish, Fundulus diaphanus	790.6	
31	684.3	Mozambique tilapia Tilapia mossambica	684.3	
30	331.8	Strip <b>ed</b> shiner, Notropis chrysocephalus	331.8	
29	289	Goldfish, Carassius auratus	289	
28	242.7	Worm, Lumbriculus variegatus	242.7	- <b></b> -

E-5

Table E3. Ranked Genus Mean Acute Values for Copper
Table E3. (Cont.)

د. ب	Genus Mean Acute Valu	1 1e	Species Mean Acute Value	Species Mean Acute-Chronic
Rank*	(ug/L)**	Species	(ug/L)**	Ratio
27	196 1	Mosquitofish	196 1	·
21	199.1	Gambusia affinis	130.1	
26	170.2~	Midge, Chironomus tentans	197	
		Midge, Chironomus decorus	834	
		Midge, Chironomus sp.	30	X
25	166.2	Snail, Goniobasis livescens	166.2	
24	156.8	Common carp, Cyprinus carpio	156.8	
23	141.2	Rainbow darter Etheostoma caeruleum	86.67	
ی ۲۰۰۰ ۲۰۰۰ ۲۰۰۰		Orangethroat darter, Etheostoma spectabile	230.2	
22	135	Bryozoan, Pectinatella magnifica	135	· · · · · · · · · · · · · · · · · · ·
21	133	Chiselmouth, Acrocheilus alutaceus	133	· · · · · · · · · · · · · · · · · · ·
20	110.4	Brook trout, Salvelinus fontinalis	110.4	7.776***
19	109.9	Atlantic salmon, Salmo salar	109.9	
18	97.9	Bluntnose minnow, Pimephales notatus	72.16	26.36***
		Fathead minnow, Pimephales promelas	132.9	11.20***
17	90	Worm, Nais sp.	90	
16	86.67	Blacknose dace, Rhinichthys atratulus	86.67	<b></b>

Table E3. (Cont.)

Demint	Genus Mean Acute Valu	e	Species Mean Acute Value	Species Mean Acute-Chronic
Rank*	(ug/L) ^ ^	Spectes	(ug/L)~~	RACIO
15	83.97	Creek chub, Semotilus atromaculatus	83.97	
14	, 83	Guppy, Poecilia reticulata	83	
13	78.55	Central stoneroller, Campostoma anomálum	78.55	
12	73.99	Coho salmon, Oncorhynchus kisutch	87.1	
		Sockeye salmon, Oncorhynchus nerka	233.8	
		Cutthroat trout, Oncorhynchus clarki	66.26	
		Chinook salmon, Oncorhynchus tshawytscha	42.26	> 4.473***
		Rainbow trout, Oncorhynchus mykiss	38.89	
11	69.81	Brown bullhead, Ictalurus nebulosus	69.81	
10	56.21	Snail, Gyraulus circumstriatus	56.21	· · ·
9	53.08	Worm, Limnodrilus hoffmeisteri	53.08	,.
8	52~~	White perch, Morone americanus	5860	
		Striped bass, Morone saxatilis	52~~~	
7	39.33	Snail, Physa heterostropha	35.91	
	•	Snail, Physa integra	43.07	3.585***
6	37.05	Bryozoan, Lophopodella carteri	37.05	
5	37.05	Bryozoan, Plumatella emarginata	37.05	

Table E3. (Cont.)

Rank*	Genus Mean Acute Valu (ug/L)**	n le Species	Species Mean Acute Value (ug/L)**	Species Mean Acute-Chronic Ratio
·				
<b>. 4</b>	22.09	Amphipod, Gammarus pseudolimnaeus	22.09	3.297
3	16.74	Northern squawfish, Ptychocheilus oregonensis	16.74	
2	14.48	Cladoceran, Daphnia mágna	19,88	2.418
		Cladoceran, Daphnia pulex	16.5	~ <u>-</u> -
	, , , , , , , , , , , , , , , , , , , ,	Cladoceran, Daphnia pulicaria	9.263	
<b>1</b>	9.92	Cladoceran, Ceriodaphnia reticulata	9.92	· · · · · · · · · · · · · · · · · · ·
* Rank	ed from mo:	st resistant to most sensitiv	ve based on Genu	us Mean Acute

\*\* At hardness = 50 mg/L.

\*\*\* Not used in the calculation of the Final Acute-Chronic Ratio.

This GMAV was not set equal to the lowest SMAV because the species was not identified and so might have been C. tentans or C. decorus.

- This GMAV was set equal to the lower SMAV due to the large range in the SMAVs in this genus.
- ~~~ This SMAV was based on the results reported by Palawaki et al. (1985) because they were considered better data than those given in U.S. EPA (1985), although the data reported by Hughes (1973) supported the newer data.

At hardness = 50 mg/L:

FAV = 14.57 ug/L

 $CMC = FAV/2 = 7.285 \, ug/L$ 

As a function of hardness:

0.9422 (ln hardness) - 1.700 CMC = e

FACR = 2.823

At hardness = 50 mg/L:

 $FCV = FAV/FACR = (14.57 \text{ ug/L})/(2.823) = 5.161 \text{ ug/L} = CCC^{\circ}$ 

As a function of hardness:

0.8545(ln hardness) - 1.702 CCC = e

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United States Environmental Protection Agency

# AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA – COPPER 2007 REVISION

EPA is issuing revised national recommended freshwater aquatic life criteria for copper (Aquatic Life Ambient Freshwater Quality Criteria – Copper 2007 Revision). As a companion to the criteria document, EPA is also issuing a document to answer Frequently Asked Questions (FAQs) from states, tribes, permittees, and other interested stakeholders on implementing the revised nationally recommended criteria.

# Background

Copper is an abundant naturally occurring trace element found in the earth's crust that is also found in surface waters. Copper is a micronutrient at low concentrations and is essential to virtually all plants and animals. At higher concentrations copper can become toxic to aquatic life. Mining, leather and leather products, fabricated metal products, and electric equipment are a few of the industries with copper-bearing discharges that contribute to manmade discharges of copper into surface waters. Municipal effluents may also contribute additional copper loadings to surface waters.

Since EPA published the hardness-based recommendation for copper criteria in 1984, new data have become available on copper toxicity and its effects on aquatic life. The Biotic Ligand Model (BLM) – a metal bioavailability model that uses receiving water body characteristics to develop site-specific water quality criteria – utilizes the best available science and serves as the basis for the new national recommended criteria.

The BLM requires ten input parameters to calculate a freshwater copper criterion (a saltwater BLM is not yet available): temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. The BLM is used to derive the criteria rather than as a post-derivation adjustment as was the case with the hardness-based criteria. This allows the BLM-based criteria to be customized to the particular water under consideration.

BLM-based criteria can be more stringent than the current hardness-based copper criteria and in certain cases the current hardness-based copper criteria may be overly stringent for particular water bodies. We expect that application of this model will result in more appropriate criteria and eliminate the need for costly, time-consuming site-specific modifications using the water effect ratio.

The FAQs document answers common questions regarding data requirements for the BLM, options to facilitate implementation, monitoring, assessment, and permitting issues, and BLM training opportunities.

#### **Further Information**

For more information about the *Aquatic Life Ambient Freshwater Criteria – Copper 2007 Revision*, you may contact Luis Cruz at (202) 566-1095 or Charles Delos at (202) 566-1097, or via mail at the U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division, 1200 Pennsylvania Avenue, NW, Washington, D.C. 20460, or you may send an e-mail to <u>cruz.luis@epa.gov</u> or <u>delos.charles@epa.gov</u>.

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# EPA AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA - COPPER

2007 Revision

# AQUATIC LIFE AMBIENT FRESHWATER QUALITY CRITERIA - COPPER

# 2007 Revision

(CAS Registry Number 7440-50-8)

February 2007

U.S. Environmental Protection Agency Office of Water Office of Science and Technology Washington, DC

## NOTICES

This document has been reviewed in accordance with U.S. EPA policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document can be downloaded from EPA's website at: http://www.epa.gov/waterscience/criteria/aqlife.html

#### FOREWORD

Section 304(a)(l) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of criteria based upon consideration of comments received from independent peer reviewers and the public. Criteria contained in this document supplement any previously published EPA aquatic life criteria for the same pollutant(s).

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(l) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of health or ecological effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific waterbody uses are adopted by a state or tribe as water quality standards under section 303, they become enforceable maximum acceptable pollutant concentrations in ambient waters within that state or tribe. Water quality criteria adopted in state or tribal water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations states or tribes might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions. Alternatively, states or tribes may use different data and assumptions than EPA in deriving numeric criteria that are scientifically defensible and protective of designated uses. It is not until their adoption as part of state or tribal water quality standards that criteria become regulatory. Guidelines to assist the states and tribes in modifying the criteria presented in this document are contained in the Water Quality Standards Handbook (U.S. EPA 1994). The handbook and additional guidance on the development of water quality standards and other waterrelated programs of this agency have been developed by the Office of Water.

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

> Ephraim S. King, Director Office of Science and Technology

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# ACRONYMS

ACR	Acute-Chronic Ratio
BL	Biotic Ligand
BLM	Biotic Ligand Model
CCC	Criterion Continuous Concentration
CF	Conversion Factors
CMC	Criterion Maximum Concentration
CWA	Clean Water Act
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
EC	Effect Concentration
EPA	Environmental Protection Agency
FACR	Final Acute-Chronic Ratio
FAV	Final Acute Value
FCV	Final Chronic Value
FIAM	Free Ion Activity Model
GMAV	Genus Mean Acute Value
GSIM	Gill Surface Interaction Model
LC50	Lethal Concentration at 50 Percent Effect Level
LOAEC	Lowest Observed Adverse Effect Concentration
NASQAN	National Stream Quality Accounting Network
NOAEC	No Observed Adverse Effect Concentration
pН	Negative logarithm of the concentration (mol/L) of the $H_3O^+[H^+]$ ion; scale range
	from 0 to 14
SMAV	Species Mean Acute Values
STORET	EPA STOrage and RETrieval Data System
WER	Water-Effect Ratio
WET	Whole Effluent Toxicity
WQC	Water Quality Criteria

#### **1.0 INTRODUCTION**

Copper is an abundant trace element found in the earth's crust and is a naturally occurring element that is generally present in surface waters (Nriagu, 1979). Copper is a micronutrient for both plants and animals at low concentrations and is recognized as essential to virtually all plants and animals (Kapustka et al., 2004). However, it may become toxic to some forms of aquatic life at elevated concentrations. Thus, copper concentrations in natural environments, and its biological availability, are important. Naturally occurring concentrations of copper have been reported from 0.03 to 0.23  $\mu$ g/L in surface seawaters and from 0.20 to 30  $\mu$ g/L in freshwater systems (Bowen, 1985). Copper concentrations in locations receiving anthropogenic inputs can vary anywhere from levels that approach natural background to 100  $\mu$ g/L or more (e.g., Lopez and Lee, 1977; Nriagu, 1979; Hem, 1989) and have in some cases been reported in the 200,000  $\mu$ g/L range in mining areas (Davis and Ashenberg, 1989; Robins et al., 1997). Mining, leather and leather products, fabricated metal products, and electric equipment are a few of the industries with copper-bearing discharges that contribute to anthropogenic inputs of copper to surface waters (Patterson et al., 1998).

Over the past 20 years, the U.S. Environmental Protection Agency (EPA) has published a number of guidance documents containing aquatic life criteria recommendations for copper (e.g., U.S. EPA 1980, 1985, 1986, 1996). The present document contains EPA's latest criteria recommendations for protection of aquatic life in ambient freshwater from acute and chronic toxic effects from copper. These criteria are based on the latest available scientific information, supplementing EPA's previously published recommendations for copper. This criteria revision incorporated new data on the toxicity of copper and used the biotic ligand model (BLM), a metal bioavailability model, to update the freshwater criteria. With these scientific and technical revisions, the criteria will provide improved guidance on the concentrations of copper that will be protective of aquatic life. The BLM is not used in the saltwater criteria derivation because further development is required before it will be suitable for use to evaluate saltwater data.

This document provides updated guidance to states and authorized tribes to establish water quality standards under the Clean Water Act (CWA) to protect aquatic life from elevated copper exposure. Under the CWA, states and authorized tribes are to establish water quality criteria to protect designated uses. Although this document constitutes EPA's scientific recommendations regarding ambient concentrations of copper, it does not substitute for the CWA or EPA's regulations, nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, tribes, or the regulated community, and might not apply to a particular situation based on the circumstances. State and tribal decision makers retain the discretion in adopting approaches, on a case-by-case basis, that differ from this guidance when appropriate. EPA may change this guidance in the future.

Although the BLM has been used in place of the formerly applied hardness-based approach, the updated freshwater criteria derivations in this document are still based on the principles set forth in the *Guidelines for Deriving Numerical Water Quality Criteria for the Protection of Aquatic Life and Their Uses* (Stephan et al. 1985, hereafter referred to as the Guidelines). Section 2 of this document provides an overview of copper bioavailability and the BLM. Additional information on the generalized BLM framework, theoretical back ground, model calibration, and application for the BLM can be found in the published literature. Section 3 of this document discusses general

procedures and requirements for applying the BLM to criteria. Section 4 provides the derivation of criteria Final Acute Value (FAV) and Final Chronic Value (FCV) for freshwater organisms. Section 5 discusses plant data and Section 6 discusses other data not included in the criteria derivation. Sections 7 and 8 provide the final criteria statements and information on implementation. Various supplementary information is provided in several appendices.

#### 2.0 APPROACHES FOR EVALUATING COPPER BIOAVAILABILITY

#### 2.1 General Aspects of Copper Bioavailability

The toxicity of a chemical to an aquatic organism requires the transfer of the chemical from the external environment to biochemical receptors on or in the organism at which the toxic effects are elicited. Often, this transfer is not simply proportional to the total chemical concentration in the environment, but varies according to attributes of the organism, chemical, and exposure environment so that the chemical is more or less "bioavailable". Definitions of bioavailability vary markedly (e.g., National Research Council, 2003) and are often specific to certain situations, but a useful generic definition is the relative facility with which a chemical is transferred from the environment to a specified location in an organism of interest.

Of particular importance to bioavailability is that many chemicals exist in a variety of forms (chemical species). Such chemical speciation affects bioavailability because relative uptake rates can differ among chemical species and the relative concentrations of chemical species can differ among exposure conditions. At equilibrium in oxygenated waters, "free" copper exists as cupric ion - Cu(II) weakly associated with water molecules (CunH<sub>2</sub>O<sup>+2</sup>), but this species is usually a small percentage of the total copper. Most dissolved copper is part of stronger complexes with various ligands (complexing chemicals that interact with metals), including dissolved organic compounds, hydroxides, carbonates, and other inorganic ligands. Substantial amounts of copper can also be adsorbed to or incorporated into suspended particles. More information on copper speciation in freshwater can be found in Kramer et al. (1997), Bryan et al. (2002), and Smith et al. (2002).

Copper toxicity has been reported to vary markedly due to various physicochemical characteristics of the exposure water (e.g., either laboratory or field), including temperature, dissolved organic compounds, suspended particles, pH, and various inorganic cations and anions, including those composing hardness and alkalinity (see reviews by Sprague, 1968; Hunt, 1987; Campbell, 1995; Allen and Hansen, 1996; Paquin et al., 2002). Many of these physicochemical factors affect copper speciation, and their effects on copper toxicity therefore could be due to effects on copper bioavailability. That bioavailability is an important factor is evident from uptake of copper by aquatic organisms being reduced by various organic compounds and inorganic ligands known to complex copper (Muramoto, 1980; Buckley et al., 1984; Playle et al., 1993 a,b; MacRae et al., 1999).

A "ligand" is a complexing chemical (ion, molecule, or molecular group) that interacts with a metal like copper to form a larger complex. A "biotic ligand" is a complexing chemical that is a component of an organism (e.g. chemical site on a fish gill). For certain ligands, some studies have demonstrated that the concentration of free copper associated with a specified level of accumulation or toxicity changes little as the ligand concentration is varied, despite major changes in the

proportion of copper bound to the ligand (see review by Campbell, 1995). This suggests that, even at low concentrations, free copper is more important to bioavailability than the ligand-bound copper. This is expected if accumulation and toxicity are dependent on the binding of copper to a biochemical receptor "X" on the surface of the organism, forming a chemical species X-Cu (receptor-bound metal) that is a first limiting step in accumulation and toxicity. By standard chemical equilibrium expressions, the amount of such species and the consequent biological effects would be a function of the activity of just free copper (Morel, 1983 a), a relationship commonly referred to as the free ion activity model (FIAM). Ligand-bound copper (Cu-L) would contribute to copper bioavailability if (a) a species X-Cu-L is formed that is important to copper accumulation/toxicity, (b) the microenvironment near the organism surface is such that Cu-L dissociates and increases the free copper activity interacting with "X", or (c) copper uptake is via mechanisms that do not entail binding to such a receptor and can accommodate different copper species. Some studies have indicated dissolved complexes of copper do contribute to bioavailability (reviews by Sprague, 1968; Hunt, 1987; Campbell, 1995; Allen and Hansen, 1996; Paquin et al., 2002).

The effects of physicochemical factors on copper toxicity are diverse and the specific chemistry of the exposure water will determine whether or not there are appreciable effects on copper speciation and a resulting strong relationship of toxicity to free copper. Usually copper to xicity is reduced by increased water hardness (reviews by Sprague, 1968; Hunt, 1987; Campbell, 1995; Allen and Hansen, 1996; Paquin et al., 2002), which is composed of cations (primarily calcium and magnesium) that do not directly interact with copper in solution so as to reduce bioavailability. In some cases, the apparent effect of hardness on toxicity might be partly due to complexation of copper by higher concentrations of hydroxide and/or carbonate (increased pH and alkalinity) commonly associated with higher hardness. However, significant effects on toxicity often are still present when hardness is increased in association with anions which do not interact strongly with copper (Inglis and Davis, 1972; Chakoumakos et al., 1979; Miller and Mackay, 1980; Erickson et al., 1987). Hardness cations could have some limited effect on copper speciation by competing with copper for the same dissolved ligands, but increased hardness would then increase free copper and thus increase, not decrease, toxicity. Sodium has also been reported to affect copper toxicity (Erickson et al., 1996 b) and pH effects can be partly due to effects of hydrogen ion other than on copper speciation (Peterson et al., 1984).

The effects of hardness cations could be explained by the competing with copper for the biochemical receptor "X", thus reducing copper uptake (Zitko, 1976; Zitko et al., 1976; Pagenkopf, 1983). Reduced metal bioavailability due to increased hardness cations has been experimentally demonstrated (Playle et al., 1992; Meyer et al., 1999, 2002), although this does not specifically establish cation competition as the mechanism. Pagenkopf (1983) provided a mathematical description of a Gill Surface Interaction Model (GSIM) that addressed the effects on metal toxicity of both metal speciation and cations via the interactions of gill surface biochemical receptors with the free toxic metal, other metal species, hardness cations, and hydrogen ion.

The empirical evidence demonstrates that copper toxicity is affected by exposure conditions and that much of these effects is plausibly attributed to effects of ligands and cations on copper bioavailability. However, it should not be presumed that all of the observed effects of the physicochemical factors on copper toxicity reflect effects on bioavailability, or that bioavailability effects are just due to ligand complexation and cation competition. For example, acute copper toxicity in aquatic organisms has been related to disruption of osmoregulation, specifically sodium/potassium exchange (Lauren and MacDonald, 1986; Wood, 1992; Wood et al., 1997; Paquin et al., 2002), which can be affected by calcium other than by competition with copper for the same biochemical receptor. Similarly, reported effects of sodium and potassium on copper toxicity (Erickson et al., 1996 b) might simply reflect favorable or unfavorable ion exchange gradients, rather than any effect on copper bioavailability. Nevertheless, the effects of ligand complexation and cation competition on copper toxicity differs across exposure conditions.

#### 2.2 Existing Approaches

EPA aquatic life criteria for metals address the reported effects of hardness on metal toxicity using empirical regressions of toxic concentrations versus hardness for available toxicity data across a wide range of hardness (Stephan et al., 1985). Such regressions provided the relative amount by which the criteria change with hardness, but have certain limitations. The regressions were not just of hardness, but of any other factor that was correlated with hardness in the toxicity data set used for the regressions, particularly pH and alkalinity. Although these regressions therefore address more bioavailability issues than hardness alone, they best apply to waters in which the correlations among hardness, pH, and alkalinity are similar to the data used in the regressions. The separate effects of these factors are not addressed for exposure conditions in which these correlations are different. In addition, some physicochemical factors affecting metal toxicity, such as organic carbon, are not addressed at all.

Existing EPA metals criteria also address bioavailability by using dissolved metal as a better approximation for metal bioavailability than total metal (U.S. EPA, 1993). Although this approach accounts for the low bioavailability of metal on suspended particles, it does not address the major effects of various dissolved species on bioavailability. This approach could conceivably be further developed to include just part of the dissolved copper, but this not only requires resolving what species to include, how to weight them, and how to assess their concentrations, but also would not address the effects of cations and other factors that affect toxicity in addition to metal speciation. Such a "bioavailable fraction" approach is not justified, because no fraction of metals species provides a constant measure of toxicity.

To address more completely the modifying effects of water quality than the hardness regressions achieve, EPA issued guidance in the early 1980s on the water-effect ratio (WER) method (Carlson et al., 1984; U.S. EPA, 1983, 1992, 1994). The WER is "a biological method to compare bioavailability and toxicity in receiving waters versus laboratory test waters" (U.S. EPA, 1992). A WER is calculated by dividing the acute LC50 of the metal, determined in water collected from the receiving water of interest, by the LC50 of the metal determined in a standard laboratory water, after adjusting both test waters to the same hardness. The standard laboratory water LC50 is used as the denominator to reflect that this LC50 is measured in test water that has water quality characteristics representative of the test waters used to develop the Water Quality Criteria (WQC) toxicity database, at least as a good approximation. The national hardness-based acute criterion that reflects the effect of site water characteristics on toxicity. However, a WER accounts only for

4

interactions of water quality parameters and their effects on metal toxicity to the species tested and in the water sample collected at a specific location and at a specific time. There is also significant cost to generate a single WER.

Because of the limitations of these past approaches for addressing bioavailability in metals criteria, there is a need for an approach that (1) explicitly and quantitatively accounts for the effect of individual water quality parameters that modify metal toxicity and (2) can be applied more cost-effectively and easily, and hence more frequently across spatial and temporal scales. An assessment framework that incorporates the bioavailability mechanisms discussed in Section 2.1 was therefore used to address more comprehensively the effects of physicochemical exposure conditions on copper toxicity with lower costs than required by the WER approach.

### 2.3 The Biotic Ligand Model and Its Application to Criteria Development

The interactions of toxic metal species and other exposure water constituents with biological surface receptors described by Zitko (1976), Morel (1983), and Pagenkopf (1983) provided the basic conceptual and mathematical structure for the bioavailability model to be used here (Figure 1). Subsequent experimental work has supported various model tenets by demonstrating the effects of complexing ligands and competing cations on accumulation of toxic metals at fish gills and the relationship of toxic effects to accumulation, and has also provided estimates of various model parameters (Playle et al., 1992, 1993a,b; Janes and Playle, 1995; MacRae et al., 1999, Meyer et al., 1999, 2002; McGeer et al., 2002). Various efforts in metal speciation modeling also have provided the ability to do better speciation calculations, especially regarding complexation of metals by organic matter (e.g., Tipping, 1994). This experimental work has supported further metal toxicity model development (Meyer, 1999; Brown and Markich, 2000; McGeer et al., 2002; Di Toro et al., 2001; Santore et al., 2001; Paquin et al., 2002). This bioavailability modeling approach is now commonly termed "Biotic Ligand Models" to broaden the scope beyond gill surfaces and to acknowledge that the biochemical receptor "X" discussed in Section 2.1 is a metal-binding ligand that is treated similarly to ligands in the exposure water, except that it is on the organism and is the keystone for metal accumulation and toxicity.



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Briefly, available evidence indicates that both free copper and copper monohydroxide bind to a biotic ligand "Lb" on the organism's surface (Lb-Cu and Lb-CuOH) and that death occurs when a certain amount of the total biotic ligand sites are occupied by copper. This ligand must be at the organism surface because the model describes its interactions with the external exposure water. However, this does not mean that this ligand is the site of toxic action; rather it is only necessary to assume that copper accumulation at the site(s) of toxic action is proportional to binding at the biotic ligand (i.e., the biotic ligand controls bioavailability). Other cations also will bind to the biotic ligand, affecting copper bioavailability because higher concentrations of copper are needed for copper to reach toxic levels. The binding to the biotic ligand is considered to be at equilibrium, with apparent (activity-corrected) equilibrium constants  $K_{LbCu}$ ,  $K_{LbCuOH}$ , and  $K_{LbCj}$ , respectively, for free copper, copper hydroxide, and the "jth" competing cation. Chemical speciation in the exposure water is also considered to be at equilibrium, and chemical speciation calculations are conducted to compute the free copper, copper hydroxide, and competing cation activities to which the biotic ligand is exposed. Because binding to the actual biotic ligand cannot be measured, it is expected that accumulation relationships for some measurable variable (e.g., the total metal in gill tissue) provide a reasonable surrogate for the actual biotic ligand. Because criteria deal with concentrations eliciting a certain level of effects on groups of organisms (e.g., LC50s), model calculations are for an organism with characteristics appropriate for such group-wide statistics.

How the BLM is applied to criteria can be best discussed by starting with the following general expression for the BLM:

$$EC = EC_0 \cdot f_C \cdot f_L$$
 Equation 1

where EC is the total dissolved copper concentration eliciting an effect,  $EC_0$  is a baseline EC in the absence of any complexing ligands and competing cations,  $f_C$  should be a factor (<1) for how much competing cations increase EC, and  $f_L$  should be a factor (<1) for how much complexing ligands increase EC. For the BLM used here:

$$EC_{0} = \frac{f_{DT}}{(1 - f_{DT}) \cdot K_{DQ}}$$
Equation 2  
$$f_{C} = 1 + \sum_{j}^{m} \left( K_{C_{1}D} \cdot \left[ C_{j} \right] \right)$$
Equation 3  
$$f_{L} = \frac{1}{\alpha_{QU}^{*n}} + \frac{K_{DQ}QOH}{K_{DQQ}} \cdot \alpha_{QOH}$$
Equation 4

where  $f_{\text{LbT}}$  is the fraction of the biotic ligand sites that must be occupied by copper to elicit the toxicity of interest (e.g., a lethal accumulation divided by the accumulation capacity), *m* is the

number of competing cations included in the model, [Cj] is the concentration of the jth competing cation,  $\alpha_{Cu+2}$  is the ratio of free copper concentration to total dissolved copper concentration,  $\alpha_{CuOH}$  is the ratio for the copper hydroxide complex, and the ratio  $K_{LbCuOH}/K_{LbCu}$  specifies the bioavailability of CuOH relative to free copper. Thus, in the absence of complexing ligands and competing cations, the toxic concentration is only a function of the binding strength of free copper and the copper occupied fraction of biotic ligand sites needed to elicit toxicity. The increase in the effect concentrations and binding constants. The increase in the effect concentration due to competing cations is simply a sum of the products of their concentration fractions of the sum of the products of the relative bioavailabilities and concentration fractions of the species that bind to the biotic ligand (free copper and copper hydroxide).

If toxicity to all the biological species in the criteria (at least the most sensitive ones) were determined based on measured accumulation properties and the relationship of toxicity to accumulation, the above model equations would be directly applied in criteria calculations. However, this is not the case. Although gill accumulation properties and lethal accumulations have been measured for certain species and conditions, and this has been useful in validating BLM assumptions and formulations, the data that must be applied to the criteria consists of water effect concentration (ECs) for biological species for which this accumulation information is generally not available. The BLM therefore is needed, not to make absolute calculations regarding toxic concentrations, but to extrapolate toxic concentrations from one exposure condition to another:

$$EC_{A} = EC_{B} \cdot \frac{f_{C,A} \cdot f_{L,A}}{f_{C,B} \cdot f_{L,B}}$$
 Equation 5

where the A and B subscripts refer to different exposure conditions. The general procedure that was followed for criteria development here was to use the above equation to normalize all available toxicity data to a reference exposure condition, calculate criteria values at the reference condition, and again use the above equation to compute criteria at other conditions.

This means that the BLM assumptions and parameters that just pertain to  $EC_0$  are not important to its application to criteria, which actually simplifies model validation and parameterization needs. In particular, there is no need to estimate  $f_{LbT}$ , or the lethal accumulations and accumulation capacities that define this fraction. Furthermore, the absolute values of  $K_{LbCu}$  and  $K_{LbCuOH}$  do not need to be known, only their relative value (and if copper binding to the biotic ligand was dependent only on free copper, the value of  $K_{LbCu}$  would not be needed at all). Absolute values are only needed for the binding constants for the competing cations, as well as the various constants needed in speciation calculations to estimate  $\alpha_{Cu+2}$  and  $\alpha_{CuOH}$ . For BLM application to criteria, the important concern is whether  $f_C$  and  $f_L$  are suitably formulated and parameterized, and not with issues that relate to lethal accumulations and accumulation capacities.

#### 2.4 BLM Uncertainties and Performance

The BLM employed here uses equilibrium reactions of copper and other cations with a single, simple type of surface ligand as the focus for all the effects of physicochemical exposure conditions on toxicity, and thus is a simple, approximate representation for the complex set of chemical

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reactions and transfers involved with environmental copper concentrations eliciting toxicity. As already noted, cation effects might involve mechanisms other than competition for a surface ligand. The microenvironment at the gill might change copper speciation. Multiple mechanisms that do not react the same to external conditions might be involved in copper bioavailability and toxicity. Accumulation parameters based on bulk gill measurements will likely not be the same as those for the biotic ligand. Nonequilibrium processes might be important, especially regarding the relationship of copper-binding on a surface ligand to toxic action.

However, any model is a simplification of reality and the existence of uncertainties does not preclude a model from being useful and justified. Despite its simplicity, the BLM used here provides a reasonable mechanistic framework for the well-established effects of copper speciation, explicitly addressing the relative bioavailability of different copper species. It also includes a plausible mechanism that allows the effects of cations to be addressed and uses a comprehensive model for calculating the required concentrations of various chemical species. Even if the mechanistic descriptions are incomplete, this model allows the major empirical effects of complexing ligands and competing cations to be described in a more comprehensive and reasonable fashion than other approaches.

Because this model is used in criteria to predict relative effects of physicochemical exposure factors, its utility for criteria can be judged based on how well it predicts the relative effects of these factors in copper toxicity studies. Examples of BLM performance for various exposure factors and studies are provided in the technical support document for this criteria. Figure 2 shows one example from a study on the effects of various exposure conditions on the acute lethality of copper to fathead minnows. This set of exposures consisted of synthetic exposure solutions of various total ion concentrations with fixed ratios of the major cations and anions, at a fixed pH (8.0) and low dissolved organic matter (<0.5 mg/L). Observed dissolved LC50s (solid circles with uncertainty bars) varied by 24-fold for only a 9-fold change in total ions. These large effects reflect the combined influences of increased alkalinity (copper carbonate complex formation), hardness, and sodium. Considering the wide range of the observed LC50s and that the model was not fitted to these data, BLM-predicted LC50s (open symbols) were rather accurate, ranging from 55 to 87% (average 75%) of the observed value. More importantly for criteria, the predicted relative change across the range of total ion concentration was 20-fold, very close to that observed.

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Model performance can also be judged across a variety of factors as in Figure 3, which shows predicted versus observed LC50s for a large number of exposures in the cited study, which varied hardness, alkalinity, sodium, and pH together and separately over a wide range. Observed LC50s varied by about 60-fold, but predicted values deviated from observed values by only 0.12 log units (a factor of 1.3) on average, and at worst only slightly more than a factor of 2. Again, more information on model performance is provided in the Technical Support Document and the figures here just provide some examples demonstrating the utility of this model for use in criteria.



The use of the BLM to predict the bioavailability and toxicity of copper to aquatic organisms under site-specific conditions is a significant change from the previous Criterion Maximum Concentration (CMC) derivation methodology. Previous aquatic life criteria documents for copper (e.g., U.S. EPA, 1980, 1985, 1996) expressed the CMC as a function of water hardness. Now, EPA chooses to utilize the BLM to update its freshwater acute criterion because the BLM accounts for all important inorganic and organic ligand interactions of copper while also considering competitive interactions that influence binding of copper at the site of toxicity, or the "biotic ligand." The BLM's ability to incorporate metal speciation reactions and organism interactions allows prediction of metal effect levels to a variety of organisms over a wide range of water quality conditions. Accordingly, the BLM is an attractive tool for deriving water quality criteria. Application of the BLM has the potential to substantially reduce the need for site-specific modifications, such as Water Effect Ratio, to account for site-specific chemistry influences on metal toxicity.

The updated BLM-based WQC will in some cases be more stringent and in other cases less stringent than the hardness based WQC. As there is not a single WQC value to use for comparison purposes, it will only be possible to provide illustrative examples of each situation. It is the judgement of the EPA that the BLM-based WQC for Cu will provide an improved framework for evaluating a level of protection (LOP) that is consistent with the LOP that was intended by the 1985 Guidelines (i.e., a 1-in-3 year exceedance frequency that will be protective of 95% of the genera).

While the BLM is currently considered appropriate for use to derive an updated freshwater CMC for the acute WQC, further development is required before it will be suitable for use to

evaluate a saltwater CMC or a Criterion Continuous Concentration (CCC) or chronic value (freshwater or saltwater WQC).

# **3.0 INCORPORATION OF THE BLM INTO CRITERIA DERIVATIONS PROCEDURES**

#### 3.1 General Final Acute Value (FAV) Procedures

Application of the acute copper BLM to the derivation of the copper FAV is analogous to procedures already described in the Guidelines for metals criteria using empirical hardness regressions. For these hardness-dependent metals criteria, LC50s at various hardness are normalized to a reference hardness using the regression slopes. The normalized LC50s for each biological species are averaged to derive Species Mean Acute Values (SMAVs) at the reference hardness. The SMAVs within each genus are then averaged to derive Genus Mean Acute Values (GMAVs) at the reference hardness. The Guidelines' procedures for estimating the fifth percentile of the GMAVs are then used to derive the FAV at the reference hardness. FAVs for other hardness can then be derived using the hardness regression slope, and these FAVs are used to calculate the Criterion Maximum Concentration (CMC) by dividing the FAV by 2.0 and the Final Chronic Values (FCV) by dividing the FAV by the Final Acute-Chronic Ratio (FACR). Following the Guidelines, the Criterion Continuous Concentration (CCC) is set to the FCV unless other data justifies a lower value.

Extending this procedure to apply the BLM simply involves normalizing the LC50s to a reference exposure condition that includes all the physicochemical exposure factors important to the BLM, not just hardness. For this normalization, the BLM provides the factors  $f_{\rm C}$  and  $f_{\rm L}$  discussed in Section 2.3, these factors serving the same purpose as the hardness regression slope described above. Each LC50 to be used in criteria derivation would be normalized to the reference exposure conditions by the equation:

$$LC50_{R} = LC50_{A} \cdot \frac{f_{C,R} \cdot f_{L,R}}{f_{C,A} \cdot f_{L,A}}$$
 Equation 6

where the subscript A refers to the exposure conditions for the observed LC50 and the subscript R refers to the reference exposure conditions to which the LC50 is being normalized. These normalized LC50s are then used to derive the SMAVs, GMAVs, and FAV at the reference exposure condition as described above for the hardness-corrected criteria. The BLM is then used to derive FAVs at other exposures by the equation:

$$FAV_{B} = FAV_{R} \cdot \frac{f_{C,B} \cdot f_{L,B}}{f_{C,R} \cdot f_{L,R}}$$
 Equation 7

where the subscript B refers to the exposure conditions for which an FAV is desired. These BLM-derived FAVs are then used to derive CMCs and CCCs following standard Guidelines procedures.

For the criteria in this document, the reference exposure conditions to which LC50s are normalized and at which the reference FAV is calculated are as follows (see also footnote f in Table 1). The water chemistry used in the normalization was based on the EPA formulation for moderately-hard reconstituted water, but any other water chemistry could have been used. In this formulation the parameters included: temperature = 20°C, pH = 7.5, DOC = 0.5 mg/L, Ca = 14.0 mg/L, Mg = 12.1 mg/L, Na = 26.3 mg/L, K = 2.1 mg/L, SO<sub>4</sub> = 81.4 mg/L, Cl = 1.90 mg/L, Alkalinity = 65.0 mg/L and S = 0.0003 mg/L.

### 3.2 BLM Input Parameters

For applying an LC50 to criteria derivations and for determining an FAV at exposure conditions of interest, the necessary water quality input parameters for BLM calculations are temperature, pH, dissolved organic carbon, major geochemical cations (calcium, magnesium, sodium, and potassium), dissolved inorganic carbon (DIC, the sum of dissolved carbon dioxide, carbonic acid, bicarbonate, and carbonate), and other major geochemical anions (chloride, sulfate). DIC measurements are typically not made in the environment, and an alternative input parameter is alkalinity, which can be used with pH and temperature to estimate DIC. There is some evidence that other metals such as iron and aluminum can have an effect on copper toxicity to aquatic organisms, which might be due to interactions of these metals with the biotic ligand, effects of these metals on organic carbon complexation of copper, or adsorption of copper to iron and aluminum colloids which are present in filtrates used to measure dissolved copper. These metals are not currently included in routine BLM inputs, but users are encouraged to measure dissolved iron and aluminum as part of monitoring efforts to support possible future criteria applications.

A number of fixed parameters are also used in the BLM but are not required user inputs in criteria derivations. These include the variety of equilibrium constants used in copper speciation calculations, and also the binding constants for copper and various cations to the biotic ligand. The values for these constants were obtained from work by Playle and coworkers (Playle et al., 1992, 1993a,b) and also by inference from the relationship of toxicity to various water quality characteristics. More information about these parameters can be obtained from the technical support document.

### 3.3 Data Screening Procedures

To use a toxicity test in the derivation of BLM-based criteria, information must be available for the various water quality parameters described in Section 3.2. This is in contrast to past metals criteria, for which the only necessary water quality parameter was hardness. Many of these parameters are not routinely measured in toxicity tests and, if measured, are not necessarily reported in the primary literature for the test, especially for older toxicity tests. However, this information might be available from supplemental sources or be estimated based on other information. Therefore, in addition to reviewing the primary sources for relevant information, additional efforts were made to obtain or estimate the necessary water quality parameters for as many of the available LC50s as possible.

A detailed description of these efforts is provided in Appendix C, Estimation of Water Chemistry Parameters for Acute Copper Toxicity Tests, and are summarized as follows. Reports of acute copper toxicity tests identified in literature searches were reviewed to identify LC50s for possible inclusion in the criteria derivation. In addition to test acceptability standards specified in the Guidelines, the current effort also required that the LC50s be based on measured copper concentrations. LC50s based on nominal concentrations have been used in previous criteria, but there are enough measured LC50s for copper that this was considered to be no longer warranted, especially considering the more advanced bioavailability assessments represented by the BLM. For the identified LC50s, the primary reports were reviewed to record all reported information on dilution and test water chemistry. Any additional references specified by the authors were also obtained and reviewed. If test waters were synthetically prepared based on specified formulas, these were used to estimate parameters as appropriate. When critical water chemistry parameters were not available, authors were contacted regarding unpublished information or to measure missing water chemistry parameters in dilution source waters. If primary or corresponding authors could not be contacted, an attempt was made to contact secondary authors or personnel from the laboratories where the studies were conducted. Where actual water chemistry data were unavailable, data from other studies with the same water source were used as surrogate values if appropriate. Absent this, the U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN) and the EPA STOrage and RETrieval (STORET) were used to obtain data for ambient surface waters which were the source of water for a test. In some instances other available sources were contacted to obtained water chemistry data (e.g., city drinking water treatment personnel). The acquired data were scrutinized for representativeness and usefulness for estimating surrogate values to complete the water quality information for the dilution and/or test water that was used in the original studies. When the above sources could not be used, geochemical ion inputs were based on reported hardness measurements and regressions relationships constructed for the relationship of various ions to hardness from NASQAN data.

As with any modeling effort, the reliability of model output depends on the reliability of model inputs. Although the input data have been closely scrutinized, the reliability of the BLM-normalized LC50s are subject to the uncertainties of the estimation procedures described above. Therefore, a ranking system was devised to rank the quality of the chemical characterization of the test water. Studies with a rank of 1 contain all of the necessary parameters for BLM input based on measurements from either the test chambers or the water source. In general, studies in which the BLM input parameters were reported for test chamber samples take precedence over studies in which the parameters were reported only for the source water. A characterization ranking of 2 denotes those studies where not all parameters were measured, but reliable estimates of the requisite concentrations could be made. Similarly, a rank of 3 denotes studies in which all parameters except DOC were measured, but reliable estimates of DOC could be made. For the majority of the tests, a chemical characterization of 4+ was assigned because hardness, alkalinity, and pH were measured, and the ionic composition could be reliably estimated or calculated. A 4was assigned to those studies conducted using standard reconstituted water in which hardness, alkalinity, or pH was either measured or referenced, and the recipe for the water is known (ASTM, 2000; U.S. EPA, 1993). The chemical characterization rank of 5 was ascribed to studies in which

one of the key parameters (DOC, Ca, pH, alkalinity) was not measured, and when it could not be reliably estimated. If two or more key parameters (DOC, Ca, pH, alkalinity) were not measured and could not be reliably estimated, a study was given a chemical characterization rank of 6. Studies receiving a quality rating of greater than 4+ (i.e., higher than 4) were not used in the criteria development procedures because the estimates for some of the key input parameters were not thought to be reliable, all other studies were used.

#### **3.4** Conversion Factors

The LC50s used in deriving previous EPA metals criteria were based on total metal concentration (measured or nominal) and the criteria were consequently for total metals concentration. EPA afterwards made the decision that metals criteria should be based on dissolved metal because it was thought to better represent the bioavailable fraction of the metal (U.S. EPA, 1993). It was thus necessary to convert the criteria to a dissolved concentration basis. However, at that time, most toxicity tests reported only total concentration, so that a procedure was necessary to estimate the likely fractions of metals that were dissolved in typical toxicity tests. Studies were therefore conducted to determine these fractions under a variety of test conditions that mimicked the conditions in the tests used to derive the metals criteria (University of Wisconsin-Superior, 1995). These tests demonstrated high fractions of dissolved copper and resulted in a conversion factor (CF) of 0.96 for converting both the CMC and CCC for copper from a total to dissolved basis (Stephan, 1995). The BLM-derived criteria developed here also uses dissolved copper as the basis for criteria, assuming a negligible bioavailability for particulate copper. The conversion factor of 0.96 was also used to convert total to dissolved copper for any toxicity test for which dissolved copper measurements were not available.

### 3.5 Final Chronic Value (FCV) Procedures

Because the minimum eight family data requirements for chronic toxicity data were not met in order to calculate the FCV by the fifth percentile method used for the FAV and because insufficient information was available to develop a chronic BLM, EPA derived the CCC utilizing the Acute to Chronic Ratio (ACR) approach from the Guidelines (Stephan et al., 1985). To calculate the FCV at a specific water chemistry, the FAV at that chemistry is divided by the FACR. This entails the assumption that the acute BLM reasonably approximates the bioavailability relationships for chronic toxicity. Limited data available regarding effects of water chemistry on sublethal effects and chronic lethality do show substantial effects of organic matter, alkalinity, pH, and sodium (Winner, 1985; Erickson et al., 1996 a,b) similar to those in the acute BLM used here. For hardness, apparent effects are limited and uncertain, but the use of the acute BLM does not introduce major uncertainties in this regard because the effects of hardness by itself in the acute BLM are also limited.

# 4.0 DATA SUMMARY AND CRITERIA CALCULATION

### 4.1 Summary of Acute Toxicity to Freshwater Animals and Criteria Calculation

The screening procedure outlined in Sec. 3.3 (high quality data = 1, low quality data > 4, e.g. 4+) identified approximately 600 acute freshwater toxicity tests with aquatic organisms and copper

potentially acceptable for deriving criteria. Of these tests, approximately 100 were eliminated from the criteria derivation process because they did not report measured copper concentrations. Nearly 150 additional tests were eliminated from the calculation of the FAV because they received a quality rating of greater than 4 in the quality rating scheme described in section 3.3 described above.

Data from approximately 350 tests were used to derive normalized LC50 values, including 15 species of invertebrates, 22 species of fish, and 1 amphibian species (Table 1), representing 27 different genera. Species Mean Acute Values (SMAVs) at the reference chemistry were calculated from the normalized LC50s and Genus Mean Acute Values (GMAVs) at the normalization chemistry were calculated from the SMAVs.

SMAVs ranged from 2.37  $\mu$ g/L for the most sensitive species, *Daphnia pulicaria*, to 107,860  $\mu$ g/L for the least sensitive species, *Notemigonus crysoleucas*. Cladocerans were among the most sensitive species, with *D. pulicaria*, *D. magna*, *Ceriodaphnia dubia*, and *Scapholeberis sp.* being four out of the six most sensitive species. Invertebrates in general were more sensitive than fish, representing the 10 lowest SMAVs.

The 27 GMAVs calculated from the above-mentioned SMAVs ranged from 4.05  $\mu$ g/L for *Daphnia* to 107,860  $\mu$ g/L for *Notemigonus* (Table 3a). Nine of the 10 most sensitive genera were invertebrates. The salmonid genus *Oncorhynchus* was the most sensitive fish genus, with a GMAV of 31.39  $\mu$ g/L and an overall GMAV ranking of 10.

The ranked GMAVs are presented in Figure 4. Pursuant to procedures used to calculate the FAV, a FAV of 4.67  $\mu$ g/L was derived from the four GMAVs with cumulative probabilities closest to the 5th percentile toxicity value for all the tested genera (Table 3b). The presumption is that this



acute toxicity value represents the LC50 for an organism that is sensitive at the 5th percentile of the GMAV distribution. The CMC is the FAV divided by two. Therefore, the freshwater dissolved copper CMC for the reference chemistry presented is  $2.337 \mu g/L$ .

Site-water chemistry parameters are needed to evaluate a criterion. This is analogous to the situation that previously existed for the hardness-based WQC, where a hardness concentration was necessary in order to derive a criterion. Examples of CMC calculations at various water chemistry conditions are presented in Figure 5 and Appendix G.



### 4.1.1 Comparison With Earlier Hardness-Adjusted Criteria

EPA's earlier freshwater copper criteria recommendations were hardness-dependent values. One would expect a BLM-based criterion calculation procedure to yield the more appropriate criterion—appropriate in the sense that it accounts for the important water chemistry factors that affect toxicity, including DOC complexation, where the hardness correction does not. Application of the BLM in field situations where DOC is expected to be present at higher concentrations than those observed in laboratory studies would likely improve the performance of the BLM compared with the hardness adjustment. The reason is that the BLM would reasonably account for the typically observed increase in effect levels under such conditions, while the hardness-based approach would not (Figure 5).

As a comparison between the hardness typical of the previous copper criterion and this revised criterion using the BLM, both procedures were used to calculate criterion values for waters with a range in hardness as specified by the standard EPA recipes (U.S. EPA, 1993). The EPA formulations specify the concentration of various salts and reagents to be used in the synthesis of

laboratory test waters with specific hardness values (e.g., very soft, soft, moderately hard, hard, or very hard). As the water hardness increases in these recipes, pH and alkalinity also increase. This has implications for the BLM because the bioavailability of copper would be expected to decrease with increasing pH and alkalinity due to the increasing degree of complexation of copper with hydroxides and carbonates and decreasing proton competition with the metal at both DOM and biotic ligand binding sites. The BLM criterion for these waters agrees very well with that calculated by the hardness equation used in previous copper criterion documents (Figure 5). However, alkalinity and pH change as hardness changes in the EPA recipes. The BLM prediction is taking all of these changes in water quality into account.

It is possible to use the BLM to look only at the change in predicted WQC with changes in hardness (e.g., alkalinity and pH remaining constant). The hardness equation is based on waters where changes in hardness are accompanied by changes in pH and alkalinity. However, there are many possible natural waters where changes in hardness are not accompanied by changes in pH and alkalinity (such as water draining a region rich in gypsum). In these cases, the hardness equation based criterion will still assume a response that is characteristic of waters where hardness, alkalinity, and pH co-vary, and will likely be underprotective relative to the level of protection intended by the Guidelines, in high hardness waters. Conversely, in waters where the covariation between hardness, pH, and alkalinity is greater than is typical for data in Table 1, the hardness equation based criteria may be overprotective. Appendix G shows representative water quality criteria values using both the BLM and the hardness approach does not consider pH and DOC while the BLM approach takes those water quality parameters into consideration.

### 4.2 Formulation of the CCC

### 4.2.1 Evaluation of Chronic Toxicity Data

In aquatic to xicity tests, chronic values are usually defined as the geometric mean of the highest concentration of a toxic substance at which no adverse effect is observed (highest no observed adverse effect concentration, or NOAEC) and the lowest concentration of the toxic substance that causes an adverse effect (lowest observed adverse effect concentration, or LOAEC). The significance of the observed effects is determined by statistical tests comparing responses of organisms exposed to low-level and control concentrations of the toxic substance against responses of organisms exposed to elevated concentrations. Analysis of variance is the most common test employed for such comparisons. This approach, however, has the disadvantage of resulting in marked differences between the magnitudes of the effects corresponding to the individual chronic values, because of variation in the power of the statistical tests used, the concentrations tested, and the size and variability of the samples used (Stephan and Rogers, 1985).

An alternative approach to calculating chronic values focuses on the use of point estimates such as from regression analysis to define the dose-response relationship. With a regression equation or probit analysis, which defines the level of adverse effects as a function of increasing concentrations of the toxic substance, it is possible to determine the concentration that causes a specific small effect, such as a 5 to 30 percent reduction in response. To make chronic values reflect a uniform level of effect, regression and probit analyses were used, where possible, both to demonstrate that a significant concentration-effect relationship was present and to estimate chronic

values with a consistent level of effect. The most precise estimates of effect concentrations can generally be made for 50 percent reduction (EC50); however, such a major reduction is not necessarily consistent with criteria providing adequate protection. In contrast, a concentration that causes a low level of reduction, such as an EC5 or EC10, might not be statistically significantly different from the control treatment. As a compromise, the EC20 is used here to represent a low level of effect that is generally significantly different from the control treatment across the useful chronic datasets that are available for copper. The EC20 was also viewed as providing a level of protection similar to the geometric mean of the NOEC and LOEC. Since the EC20 is not directly dependent on the tested dilution series, similar EC20s should be expected irrespective of the tested concentrations, provided that the range of tested concentrations is appropriate.

Regression or probit analysis was utilized to evaluate a chronic dataset only in cases where the necessary data were available and the dataset met the following conditions: (1) it contained a control treatment (or low exposure data point) to anchor the curve at the low end, (2) it contained at least three concentrations, and (3) two of the data points had effect variable values below the control and above zero (i.e., "partial effects"). Control concentrations of copper were estimated in cases where no measurements were reported. These analyses were performed using the Toxicity Relationship Analysis Program software (version 1.0; U.S. EPA, Mid-Continental Ecology Division, Duluth, MN, USA). Additional detail regarding the aforementioned statistical procedures is available in the cited program.

When the data from an acceptable chronic test met the conditions for the logistic regression or probit analysis, the EC20 was the preferred chronic value. When data did not meet the conditions the chronic value was usually set to the geometric mean of the NOAEC and the LOAEC. However, when no treatment concentration was an NOAEC, the chronic value is reported as less than the lowest test ed concentration.

For life-cycle, partial life-cycle, and early life stage tests, the toxicological variable used in chronic value analyses was survival, reproduction, growth, emergence, or intrinsic growth rate. If copper apparently reduced both survival and growth (weight or length), the product of variables (biomass) was analyzed, rather than analyzing the variables separately. The most sensitive of the toxicological variables was generally selected as the chronic value for the particular study.

A species-by-species discussion of each acceptable chronic test on copper evaluated for this document is presented in Appendix F. Figures that present the data and regression/probability distribution line for each of the acceptable chronic test which contained sufficient acceptable data are also provided in Appendix F.

### 4.2.2 Calculation of Freshwater CCC

Acceptable freshwater chronic toxicity data from early life stage tests, partial life-cycle tests, and full life-cycle tests were available for 29 tests including data for 6 invertebrate species and 10 fish species (Table 2a). The 17 chronic values for invertebrate species range from 2.83 (*D. pulex*) to 34.6  $\mu$ g/L (*C. dubia*); and the 12 chronic values for the fish species range from <5 (brook trout) to 60.4  $\mu$ g/L (northern pike). Of the 29 chronic tests, comparable acute values are available for 18 of the tests (Table 2c). The relationship between acute toxicity values and ACRs is presented in Figure 6. The supporting acute and chronic test values for the ACRs and the species mean ACRs are

presented in Table 2c. For the 11 tests in Table 2a with chronic values both from a regression EC20 and the geometric mean of the NOAEC and LOAEC, the EC20 averaged 81% of the geometric mean, demonstrating the similar level of protection for the two approaches.

Overall, individual ACRs varied from <1 (0.55) for *C. dubia* (Oris et al., 1991) to 191.6 for the snail, *Campeloma decisum* (Arthur and Leonard, 1970). Species mean acute-chronic ratios ranged from 1.48 in saltwater for the sheepshead minnow (Hughes et al., 1989) to 171.2 in freshwater for the snail, *C. decisum*. Pursuant to the Guidelines (Stephan et al., 1985), consideration was given to calculating the FACR based on all ACRs within a factor of 10, but because there appeared to be a relationship between acute sensitivity and ACRs (Figure 6), the FACR was derived from data for species whose SMAVs were close to the FAV. The FACR of 3.22 was calculated as the geometric mean of the ACRs for sensitive freshwater species, *C. dubia*, *D. magna, D. pulex, O. tshawytscha*, and *O. mykiss* along with the one saltwater ACR for *C. variegatus* (Table 2b). Based on the normalization water chemistry conditions used for illustrative purposes in the document, the freshwater site specific FAV value is 4.67  $\mu$ g/L, which divided by the FACR of 3.22 results in a freshwater FCV of 1.45  $\mu$ g/L dissolved Cu.



#### 5.0 PLANT DATA

Copper has been widely used as an algicide and herbicide for nuisance aquatic plants (McKnight et al., 1983). Although copper is known as an inhibitor of photosynthesis and plant growth, toxicity data on individual species suitable for deriving aquatic life criteria (Table 4) are not numerous.

The relationship of copper toxicity to the complexing capacity of the water or the culture medium is now widely recognized (Gächter et al., 1973; Petersen, 1982), and several studies have used algae to "assay" the copper complexing capacity of both fresh and salt waters (Allen et al., 1983; Lumsden and Florence, 1983; Rueter, 1983). It has also been shown that algae are capable of excreting complexing substances in response to copper stress (McKnight and Morel, 1979; Swallow et al., 1978; van den Berg et al., 1979). Foster (1982) and Stokes and Hutchinson (1976) have identified resistant strains and/or species of algae from copper (or other metal) impacted environments. A portion of this resistance probably results from induction of the chelate-excretion mechanism. Chelate excretion by algae may also serve as a protective mechanism for other aquatic organisms in eutrophic waters; that is, where algae are capable of maintaining free copper activities below harmful concentrations.

Copper concentrations from 1 to 8,000 µg/L have been shown to inhibit growth of various freshwater plant species. Very few of these tests, though, were accompanied by analysis of actual copper exposure concentrations. No table exceptions are freshwater tests with green alga including *Chlamydomonas reinhardtii* (Schafer et al., 1993; Winner and Owen, 1991b), which is the only flow-through, measured test with an aquatic plant, *Chlorella vulgaris* and *Selenastrum capricornutum* (Blaylock et al., 1985). There is also a measured test with duckweed, *Lemna minor* (Taraldsen and Norberg-King, 1990).

A direct comparison between the freshwater plant data and the BLM derived criteria is difficult to make without a better understanding of the composition of the algal media used for different studies (e.g., DOC, hardness, and pH) because these factors influence the applicable criteria comparison. BLM derived criteria for certain water conditions, such as low to mid-range pH, hardness up to 100 mg/L as CaCO<sub>3</sub>, and low DOC are in the range of, if not lower than, the lowest reported toxic endpoints for freshwater algal species and would therefore appear protective of plant species. In other water quality conditions BLM-derived criteria may be significantly higher (see Figure 5).

Two publications provide data for the red algae *Champia parvula* that indicate that reproduction of this species is especially sensitive to copper. The methods manual (U.S. EPA 1988) for whole effluent toxicity (WET) testing contains the results of six experiments showing nominal reproduction LOECs from 48-hr exposures to 1.0 to 2.5  $\mu$ g/L copper (mean 2.0  $\mu$ g/L); these tests used a mixture of 50 percent sterile seawater and 50 percent GP2 medium copper. The second study by Morrison et al. (1989) evaluated interlaboratory variation of the 48-hr WET test procedure; this six-test study gave growth EC50 values from 0.8 to 1.9  $\mu$ g/L (mean 1.0  $\mu$ g/L). Thus, there are actually 12 tests that provide evidence of significant reproductive impairment in *C. parvula* at nominal copper concentrations between 0.8 and 2.5  $\mu$ g/L. For these studies though, the dilution water source was not identified.

One difficulty in assessing these data is the uncertainty of the copper concentration in the test solutions, primarily with respect to any background copper that might be found in the dilution water, especially with solutions compounded from sea salts or reagents. Thus, with a CCC of 1.9  $\mu$ g/L dissolved copper, the significance of a 1 or 2  $\mu$ g/L background copper level to a 1 to 3  $\mu$ g/L nominal effect level can be considerable.

The reproduction of other macroalgae appears to be generally sensitive to copper, but not to the extent of *Champia*. Many of these other macroalgae appear to have greater ecological significance than *Champia*, several forming significant intertidal and subtidal habitats for other saltwater organisms, as well as being a major food source for grazers. Reproductive and growth effects on the other species of macroalgae sometimes appear to occur at copper concentrations between 5 and 10  $\mu$ g/L (Appendix B, Other Data). Thus, most major macrophyte groups seem to be adequately protected by the CMC and CCC, but appear similar in sensitivity to some of the more sensitive groups of saltwater animals.

#### 6.0 OTHER DATA

Many of the data identified for this effort are listed in Appendix B, Other Data, for various reasons, including exposure durations other than 96 hours with the same species reported in Table 1, and some exposures lasting up to 30 days. Acute values for test durations less than 96 hours are available for several species not shown in Table 1. Still, these species have approximately the same sensitivities to copper as species in the same families listed in Table 1. Reported LC50s at 200 hours for chinook salmon and rainbow trout (Chapman, 1978) differ only slightly from 96-hour LC50s reported for these same species in the same water.

A number of other acute tests in Appendix B were conducted in dilution waters that were not considered appropriate for criteria development. Brungs et al. (1976) and Geckler et al. (1976) conducted tests with many species in stream water that contained a large amount of effluent from a sewage treatment plant. Wallen et al. (1957) tested mosquito fish in a turbid pond water. Until chemical measurements that correlate well with the toxicity of copper in a wide variety of waters are identified and widely used, results of tests in unusual dilution waters, such as those in Appendix B, will not be very useful for deriving water quality criteria.

Appendix B also includes tests based on physiological effects, such as changes in appetite, blood parameters, stamina, etc. These were included in Appendix B because they could not be directly interpreted for derivation of criteria. For the reasons stated in this section above, data in Appendix B was not used for criteria derivation.

A direct comparison of a particular test result to a BLM-derived criterion is not always straightforward, particularly if complete chemical characterization of the test water is not available. Such is the case for a number of studies included in Appendix B. While there are some test results with effect concentrations below the example criteria concentrations presented in this document, these same effect concentrations could be above criteria derived for other normalization chemistries, raising the question as to what is the appropriate comparison to make. For example, Appendix B includes an EC50 for *D. Pulex* of 3.6  $\mu$ g/L (Koivisto et al., 1992) at an approximate hardness of 25 mg/L (33 mg/L as CaCO<sub>3</sub>). Yet, example criteria at a hardness of 25 mg/L (as CaCO<sub>3</sub>) (including those in Figure 6) range from 0.23  $\mu$ g/L (DOC = 0.1 mg/L) to 4.09  $\mu$ g/L (DOC = 2.3 mg/L) based
on the DOC concentration selected for the synthetic water recipe. The chemical composition for the Koivisto et al. (1992) study would dictate what the appropriate BLM criteria comparison should be.

Based on the expectation that many of the test results presented in Appendix B were conducted in laboratory dilution water with low levels of DOC, the appropriate comparison would be to the criteria derived from low DOC waters. Comparing many of the values in Appendix B to the example criteria presented in this document, it appears that a large proportion of Appendix B values are above these concentration levels. This is a broad generalization though and as stated previously, all important water chemistry variables that affect toxicity of copper to aquatic organisms should be considered before making these types of comparisons.

Studies not considered suitable for criteria development were placed in Appendix G, Unused Data.

## 7.0 NATIONAL CRITERIA STATEMENT

The available toxicity data, when evaluated using the procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that freshwater aquatic life should be protected if the 24-hour average and four-day average concentrations do not respectively exceed the acute and chronic criteria concentrations calculated by the Biotic Ligand Model.

A return interval of 3 years between exceedances of the criterion continues to be EPA's general recommendation. However, the resilience of ecosystems and their ability to recover differ greatly. Therefore, scientific derivation of alternative frequencies for exceeding criteria may be appropriate.

## 8.0 IMPLEMENTATION

The use of water quality criteria in designing waste treatment facilities and appropriate effluent limits involves the use of an appropriate wasteload allocation model. Although dynamic models are preferred for application of these criteria, limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. EPA recommends the interim use of 1B3 or 1Q10 for criterion maximum concentration stream design flow and 4B3 or 7Q10 for the criterion continuous concentration design flow in steady-state models. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA, 1991).

With regard to BLM-derived freshwater criteria, to develop a site-specific criterion for a stream reach, one is faced with determining what single criterion is appropriate even though a BLM criterion calculated for the event corresponding to the input water chemistry conditions will be time-variable. This is not a new problem unique to the BLM—hardness-dependent metals criteria are also time-variable values. Although the variability of hardness over time can be characterized, EPA has not provided guidance on how to calculate site-specific criteria considering this variability. Multiple input parameters for the BLM could complicate the calculation of site-specific criteria because of their combined effects on variability. Another problem arise from potential scarcity of data from small stream reaches with small dischargers. The EPA is currently exploring two

approaches to fill data gaps in such situations. One potential approach is the selection of values based on geography, the second approach is based on correlations between measured parameters and missing parameter measurements. A companion document in the form of Supplementary Training Materials, addressing issues related to data requirements, implementation, permitting, and monitoring will be released via EPA's website following the publication of this criteria document.

Species <sup>a</sup>	Organism Age, Size, or Lifestage	Method <sup>b</sup>	Chemical <sup>c</sup>	Reported LC50 or EC50 (total µg/L) <sup>d</sup>	Reported LC50 or EC50 (Diss. μg/L) <sup>e</sup>	BLM Data Label	BLM Normalized LC50 or EC50 (μg/L) <sup>f</sup>	Species Mean Acute Value (µg/L) <sup>g</sup>	Reference
Worm,	adult (mixed age)	S,M,T	N	130		LUVA01S	37.81	48.41	Schubauer-Berigan et al. 1993
Lumbriculus variega	adult (mixed age)	S,M,T	N	270		LUVA02S	55.39		Schubauer-Berigan et al. 1993
	adult (mixed age)	S,M,T	N	500		LUVA03S	54.18		Schubauer-Berigan et al. 1993
Snail,	1.1-2.7 cm	F,M,T	S	2000		CADE01F	4319	3573	Arthur and Leonard 1970
Campeloma	1.1-2.7 cm	F,M,T	S	1400		CADE02F	2956		Arthur and Leonard 1970
Snail, <i>Juga plicifera</i>	adult	F,M,T	С	15		JUPL01F	12.31	12.31	Nebeker et al. 1986b
Snail, <i>Lithoglyphus virens</i>	adult	F,M,T	С	8		LIVI01F	6.67	6.67	Nebeker et al. 1986b
Snail,	0.4-0.7 cm	F,M,T	S	41		PHIN01F	21.81	20.41	Arthur and Leonard 1970
Physa integra	0.4-0.7 cm	F,M,T	S	37		PHIN02F	19.09		Arthur and Leonard 1970
Freshwater mussel,	juvenile	S,M,T	S	27		ACPE01S	10.36	11.33	Keller unpublished
Actinonaias	juvenile	S,M,T	S	<29		ACPE02S	12.39		Keller unpublished
Freshwater mussel,	1-2 d juv	S,M,T	S	86		UTIM01S	177.9	52.51	Keller and Zam 1991
Utterbackia imbecilli	1-2 d juv	S,M,T	S	199		UTIM02S	172.3		Keller and Zam 1991
	juvenile	S,M,T	Ν	76		UTIM03S	40.96		Keller unpublished
	iuvenile	S.M.T	Ν	85		UTIM04S	43.22		Keller unpublished
	iuvenile	S.M.T	Ν	41		UTIM05S	24.12		Keller unpublished
	juvenile	S,M,T	S	79		UTIM06S	39.04		Keller unpublished
	iuvenile	S.M.T	S	72		UTIM07S	39.96		Keller unpublished
	juvenile	S,M,T	S	38		UTIM08S	28.31		Keller unpublished
Cladoceran,	<4 h	S,M,T	C	19		CEDU01S	10.28	5.93	Carlson et al. 1986
Ceriodaphnia dubia	<4 h	S,M,T	С	17		CEDU02S	9.19		Carlson et al. 1986
'	<12 h	S,M,D		-	25	CEDU03S	7.98		Belanger et al. 1989
	<12 h	S,M,D		-	17	CEDU04S	5.25		Belanger et al. 1989
	<12 h	S,M,D		-	30	CEDU05S	9.80		Belanger et al. 1989
	<12 h	S,M,D		-	24	CEDU06S	7.63		Belanger et al. 1989
	<12 h	S,M,D		-	28	CEDU07S	9.06		Belanger et al. 1989
	<12 h	S,M,D		-	32	CEDU08S	10.56		Belanger et al. 1989
	<12 h	S,M,D		-	23	CEDU09S	7.28		Belanger et al. 1989
	<12 h	S,M,D		-	20	CEDU10S	6.25		Belanger et al. 1989
	<12 h	S,M,D		-	19	CEDU11S	5.91		Belanger et al. 1989
	<12 h	S,M,D		-	26	CEDU12S	3.10		Belanger et al. 1989
	<12 h	S,M,D		-	21	CEDU13S	2.46		Belanger et al. 1989
	<12 h	S,M,D		-	27	CEDU14S	3.24		Belanger et al. 1989
	<12 h	S,M,D		-	37	CEDU15S	4.66		Belanger et al. 1989
	<12 h	S,M,D		-	34	CEDU16S	4.22		Belanger et al. 1989
	<12 h	S,M,D		-	67	CEDU17S	5.50		Belanger et al. 1989
	<12 h	S,M,D		-	38	CEDU18S	2.72		Belanger et al. 1989
	<12 h	S,M,D		-	78	CEDU19S	6.74		Belanger et al. 1989
	<12 h	S,M,D		-	81	CEDU20S	7.10		Belanger et al. 1989
	<12 h	S,M,D		-	28	CEDU21S	4.10		Belanger and Cherry 1990

Species <sup>a</sup>	Organism Age, Size, or Lifestage	Method <sup>b</sup>	Chemical <sup>c</sup>	Reported LC50 or EC50 (total µg/L) <sup>d</sup>	Reported LC50 or EC50 (Diss. μg/L) <sup>e</sup>	BLM Data Label	BLM Normalized LC50 or EC50 (μg/L) <sup>f</sup>	Species Mean Acute Value (µg/L) <sup>g</sup>	Reference
	<12 h	S,M,D		-	84	CEDU22S	10.74		Belanger and Cherry 1990
	<12 h	S,M,T	S	13.4		CEDU23S	6.19		Oris et al. 1991
	<24 h	R,M,T,D	S	6.98	5.54	CEDU24R	5.03		Diamond et al. 1997b
Cladoceran,	1 d	S,M,T	С	9.1		DAMA01S	3.42	6.00	Nebeker et al. 1986a
Daphnia magna	1 d	S,M,T	С	11.7		DAMA02S	4.43		Nebeker et al. 1986a
	<2 h	S,M,T	С	6.6		DAMA03S	2.50		Nebeker et al. 1986a
	<2 h	S,M,T	С	9.9		DAMA04S	3.78		Nebeker et al. 1986a
	1 d	S,M,T	С	11.7		DAMA05S	13.46		Nebeker et al. 1986a
	<4 h	S,M,T	С	6.7		DAMA06S	8.21		Nebeker et al. 1986a
	1 d	S,M,T	С	9.1		DAMA07S	4.40		Nebeker et al. 1986a
	<2 h	S,M,T	С	5.2		DAMA08S	2.16		Nebeker et al. 1986a
	<24 h	S,M,T	S	41.2		DAMA09S	21.55		Baird et al. 1991
	<24 h	S,M,T	S	10.5		DAMA10S	5.63		Baird et al. 1991
	<24 h	S,M,T	S	20.6		DAMA11S	11.31		Baird et al. 1991
	<24 h	S,M,T	S	17.3		DAMA12S	9.48		Baird et al. 1991
	<24 h	S,M,T	S	70.7		DAMA13S	33.58		Baird et al. 1991
	<24 h	S,M,T	S	31.3		DAMA14S	16.90		Baird et al. 1991
	<24 h	S,M,I	S	7.1		DAMA15S	2.67		Meador 1991
	<24 h	S,M,I	S	16.4		DAMA16S	4.26		Meador 1991
	<24 h	S,M,I	S	39.9		DAMA17S	5.18		Meador 1991
	<24 h	S,M,I	S	18.7		DAMA18S	3.39		Meador 1991
	<24 h	S,M,I	S	18.9		DAMA19S	1.99		Meador 1991
	<24 h	S,M,I	S	39.7		DAMA20S	3.04		Meador 1991
	<24 h	S.M.I	S	46		DAMA21S	8.93		Meador 1991
	<24 h	S.M.I	S	71.9		DAMA22S	9.97		Meador 1991
	<24 h	S.M.I	S	57.2		DAMA23S	5.76		Meador 1991
	<24 h	S.M.I	S	67.8		DAMA24S	4.16		Meador 1991
	<24 h	S.M.T	C	26		DAMA25S	10.34		Chapman et al. Manuscript
	<24 h	S.M.T	C	30		DAMA26S	9.04		Chapman et al. Manuscript
	<24 h	S.M.T	C	38		DAMA27S	9.84		Chapman et al. Manuscript
	<24 h	S.M.T	C	69		DAMA28S	12.31		Chapman et al. Manuscript
	<24 h	S.M.T.D	S	4.8		DAMA29S	1.22		Long's MS Thesis
	<24 h	S.M.T.D	S	7.4		DAMA30S	16.29		Long's MS Thesis
	<24 h	S.M.T.D	S	6.5		DAMA31S	2.11		Long's MS Thesis
Cladoceran.		S.M.T	S	11.4		DAPC01S	1.63	2.73	Lind et al. Manuscript (1978)
Daphnia pulicaria		S.M.T	S	9.06		DAPC02S	1.04		Lind et al. Manuscript (1978)
- , p		S.M.T	S	7.24		DAPC03S	0.88		Lind et al. Manuscript (1978)
		S.M.T	S	10.8		DAPC04S	1.13		Lind et al. Manuscript (1978)
		S.M.T	s	55.4		DAPC05S	8.81		Lind et al. Manuscript (1978)
		S.M.T	s	55.3		DAPC06S	6.03		Lind et al. Manuscript (1978)
		S.M.T	S	53.3		DAPC07S	4.12		Lind et al. Manuscript (1978)
		S,M,T	S	97.2		DAPC08S	3.94		Lind et al. Manuscript (1978)

Species <sup>a</sup>	Organism Age, Size, or Lifestage	Method <sup>b</sup>	Chemical <sup>c</sup>	Reported LC50 or EC50 (total µg/L) <sup>d</sup>	Reported LC50 or EC50 (Diss. μg/L) <sup>e</sup>	BLM Data Label	BLM Normalized LC50 or EC50 (µg/L) <sup>f</sup>	Species Mean Acute Value (µg/L) <sup>g</sup>	Reference
		S,M,T	S	199		DAPC09S	3.01		Lind et al. Manuscript (1978)
		S,M,T	S	213		DAPC10S	7.63		Lind et al. Manuscript (1978)
		S,M,T	S	165		DAPC11S	5.78		Lind et al. Manuscript (1978)
		S,M,T	S	35.5		DAPC12S	1.83		Lind et al. Manuscript (1978)
		S,M,T	S	78.8		DAPC13S	2.36		Lind et al. Manuscript (1978)
		S,M,T	S	113		DAPC14S	1.06		Lind et al. Manuscript (1978)
		S,M,T	S	76.4		DAPC15S	2.36		Lind et al. Manuscript (1978)
		S,M,T	S	84.7		DAPC16S	6.62		Lind et al. Manuscript (1978)
		S,M,T	S	184		DAPC17S	7.14		Lind et al. Manuscript (1978)
		S,M,T	S	9.3		DAPC18S	1.11		Lind et al. Manuscript (1978)
		S,M,T	S	17.8		DAPC19S	2.11		Lind et al. Manuscript (1978)
		S,M,T	S	23.7		DAPC20S	2.67		Lind et al. Manuscript (1978)
		S,M,T	S	27.3		DAPC21S	2.77		Lind et al. Manuscript (1978)
		S,M,T	S	25.2		DAPC22S	2.81		Lind et al. Manuscript (1978)
		S,M,T	S	25.1		DAPC23S	2.60		Lind et al. Manuscript (1978)
		S,M,T	S	25.1		DAPC24S	2.31		Lind et al. Manuscript (1978)
Cladoceran, Scapholeberis sp.	adult	S,M,T	С	18		SCSP01S	9.73	9.73	Carlson et al. 1986
Amphipod,	1-3 d	F,M,T	S	22		GAPS01F	10.39	9.60	Arthur and Leonard 1970
Gammarus	1-3 d	F,M,T	S	19		GAPS02F	8.86		Arthur and Leonard 1970
Amphipod,	7-14 d	S,M,T	Ν	17		HYAZ01S	12.19	12.07	Schubauer-Berigan et al. 1993
Hyalella azteca	7-14 d	S,M,T	N	24		HYAZ02S	9.96		Schubauer-Berigan et al. 1993
	7-14 d	S,M,T	N	87		HYAZ03S	15.77		Schubauer-Berigan et al. 1993
	<7 d	S,M,T	S	24.3		HYAZ04S	8.26		Welsh 1996
	<7 d	S,M,T	S	23.8		HYAZ05S	8.09		Welsh 1996
	<7 d	S,M,T	S	8.2		HYAZ06S	15.49		Welsh 1996
	<7 d	S,M,T	S	10		HYAZ07S	18.80		Welsh 1996
Stonefly, Acroneuria lycorias		S,M,T	S	8300		ACLY01S	20636	20636	Warnick and Bell 1969
Midge, <i>Chironomus</i>	4th instar	S,M,T	S	739		CHDE01S	1987	1987	Kosalwat and Knight 1987
Shovelnose sturgeon, S <i>caphirhynchus</i>	fry, 6.01 cm, 0.719 g	S,M,T	S	160		SCPL01S	69.63	69.63	Dwyer et al. 1999
Apache trout, Oncorhynchus	larval, 0.38 g	S,M,T	S	70		ONAP01S	32.54	32.54	Dwyer et al. 1995
Lahontan cutthroat	larval, 0.34 g	S,M,T	S	80		ONCL01S	34.26	32.97	Dwyer et al. 1995
Oncorhynchus clarki henshawi	larval, 0.57 g	S,M,T	S	60		ONCL02S	24.73		Dwyer et al. 1995

Species <sup>a</sup>	Organism Age, Size, or Lifestage	Method <sup>b</sup>	Chemical <sup>c</sup>	Reported LC50 or EC50 (total µg/L) <sup>d</sup>	Reported LC50 or EC50 (Diss. µg/L) <sup>e</sup>	BLM Data Label	BLM Normalized LC50 or EC50 (μg/L) <sup>f</sup>	Species Mean Acute Value (µg/L) <sup>g</sup>	Reference
Cutthroat trout,	7.4 cm, 4.2 g	F,M,T,D	С	398.91	367	ONCL03F	67.30		Chakoumakos et al. 1979
Oncorhynchus clarki	6.9 cm, 3.2 g	F,M,T,D	С	197.87	186	ONCL04F	44.91		Chakoumakos et al. 1979
	8.8 cm, 9.7 g	F,M,T,D	С	41.35	36.8	ONCL05F	21.87		Chakoumakos et al. 1979
	8.1 cm, 4.4 g	F,M,T,D	С	282.93	232	ONCL06F	51.94		Chakoumakos et al. 1979
	6.8 cm, 2.7 g	F,M,T,D	С	186.21	162	ONCL07F	111.3		Chakoumakos et al. 1979
	7.0 cm, 3.2 g	F,M,T,D	С	85.58	73.6	ONCL08F	39.53		Chakoumakos et al. 1979
	8.5 cm, 5.2 g	F,M,T,D	С	116.67	91	ONCL09F	19.63		Chakoumakos et al. 1979
	7.7 cm, 4.4 g	F,M,T,D	С	56.20	44.4	ONCL10F	18.81		Chakoumakos et al. 1979
	8.9 cm, 5.7 g	F,M,T,D	С	21.22	15.7	ONCL11F	10.60		Chakoumakos et al. 1979
Pink salmon,	alevin (newly hatched	F,M,T	S	143		ONGO01F	41.65	40.13	Servizi and Martens 1978
Oncorhynchus gorbi	alevin	F,M,T	S	87		ONGO02F	19.70		Servizi and Martens 1978
, ,	fry	F,M,T	S	199		ONGO03F	78.76		Servizi and Martens 1978
Coho salmon,	6 g	R,M,T,I		164		ONKI01R	106.09	22.93	Buckley 1983
Oncorhynchus kisute	parr	F,M,T	С	33		ONKI02F	20.94		Chapman 1975
-	adult, 2.7 kg	F,M,T	С	46		ONKI03F	32.66		Chapman and Stevens 1978
	fry	F,M,T,D,I		61	49	ONKI04F	12.67		Mudge et al. 1993
	smolt	F,M,T,D,I		63	51	ONKI05F	13.19		Mudge et al. 1993
	fry	F,M,T,D,I		86	58	ONKI06F	11.95		Mudge et al. 1993
	parr	F,M,T,D,I		103	78	ONKI07F	22.98		Mudge et al. 1993
Rainbow trout,	larval, 0.67 g	S,M,T	S	110		ONMY01S	41.64	22.19	Dwyer et al. 1995
Oncorhynchus mykis	larval, 0.48 g	S,M,T	S	50		ONMY02S	25.26		Dwyer et al. 1995
	larval, 0.50 g	S,M,T	S	60		ONMY03S	29.46		Dwyer et al. 1995
	swim-up, 0.25 g	R,M,T,D	С	46.7	40	ONMY04R	10.90		Cacela et al. 1996
	swim-up, 0.25 g	R,M,T,D	С	24.2	19	ONMY05R	9.04		Cacela et al. 1996
	swim-up, 0.20-0.24 g	R,M,T,D	С	0	3.4	ONMY06R	5.02		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	С	0	8.1	ONMY07R	11.97		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	С	0	17.2	ONMY08R	13.80		Welsh et al. 2000
	swim-up, 0.20-0.24 g	R,M,T,D	С	0	32	ONMY09R	23.84		Welsh et al. 2000
	alevin	F,M,T	С	28		ONMY10F	20.30		Chapman 1975, 1978
	swim-up, 0.17 g	F,M,T	С	17		ONMY11F	12.54		Chapman 1975, 1978
	parr. 8.6 cm. 6.96 g	F.M.T	C	18		ONMY12F	9.87		Chapman 1975, 1978
5	smolt. 18.8 cm. 68.19	F.M.T	C	29		ONMY13F	22.48		Chapman 1975, 1978
	1 a	F.M.T.D	С	-	169	ONMY14F	23.41		Chakoumakos et al. 1979
	4.9 cm	F,M,T,D	C	-	85.3	ONMY15F	10.20		Chakoumakos et al. 1979
	6.0 cm, 2.1 g	F,M,T,D	С	-	83.3	ONMY16F	9.93		Chakoumakos et al. 1979
	6.1 cm, 2.5 a	F,M,T,D	C	-	103	ONMY17F	12.71		Chakoumakos et al. 1979
	2.6 g	F,M,T,D	C	-	274	ONMY18F	44.54		Chakoumakos et al. 1979
	4.3 a	F,M.T.D	C	-	128	ONMY19F	16.51		Chakoumakos et al. 1979
	9.2 cm. 9.4 a	F.M.T.D	Ċ	-	221	ONMY20F	33.33		Chakoumakos et al. 1979
	9.9 cm, 11.5 a	F.M.T.D	C	-	165	ONMY21F	22.70		Chakoumakos et al. 1979
	11.8 cm. 18.7 a	F.M.T.D	C	-	197	ONMY22F	28.60		Chakoumakos et al. 1979
	13.5 cm, 24.9 g	F,M,T,D	С	-	514	ONMY23F	99.97		Chakoumakos et al. 1979

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	13.4 cm, 25.6 g	F,M,T,D	С	-	243	ONMY24F	37.88		Chakoumakos et al. 1979
	6.7 cm, 2.65 g	F,M,T	С	2.8		ONMY25F	7.00		Cusimano et al. 1986
	parr	F,M,T,D,I		90	68	ONMY26F	19.73		Mudge et al. 1993
	swim-up, 0.29 g	F,M,T,D	С	19.6	18	ONMY27F	8.10		Cacela et al. 1996
	swim-up, 0.25 g	F,M,T,D	С	12.9	12	ONMY28F	32.15		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	С	5.9	5.7	ONMY29F	24.80		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	С	37.8	35	ONMY30F	16.16		Cacela et al. 1996
	swim-up, 0.26 g	F,M,T,D	С	25.1	18	ONMY31F	37.66		Cacela et al. 1996
	swim-up, 0.23 g	F,M,T,D	С	17.2	17	ONMY32F	24.19		Cacela et al. 1996
	0.64 g, 4.1 cm	F,M,T,D	С	101		ONMY33F	39.73		Hansen et al. 2000
	0.35 g, 3.4 cm	F,M,T,D	С	308		ONMY34F	85.83		Hansen et al. 2000
	0.68 g, 4.2 cm	F,M,T,D	С	93		ONMY35F	95.9		Hansen et al. 2000
	0.43 g, 3.7 cm	F,M,T,D	С	35.9		ONMY36F	50.83		Hansen et al. 2000
	0.29 g, 3.4 cm	F,M,T,D	С	54.4		ONMY37F	47.69		Hansen et al. 2000
Sockeye salmon,	alevin (newly hatched	F,M,T	S	190		ONNE01F	71.73	54.82	Servizi and Martens 1978
Oncorhynchus nerka	alevin	F,M,T	S	200		ONNE02F	79.52		Servizi and Martens 1978
-	alevin	F,M,T	S	100		ONNE03F	23.74		Servizi and Martens 1978
	alevin	F,M,T	S	110		ONNE04F	27.22		Servizi and Martens 1978
	alevin	F,M,T	S	130		ONNE05F	35.36		Servizi and Martens 1978
	fry	F,M,T	S	150		ONNE06F	45.37		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	210		ONNE07F	87.77		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	170		ONNE08F	57.53		Servizi and Martens 1978
	smolt, 5.5 g	F,M,T	S	190		ONNE09F	71.73		Servizi and Martens 1978
	smolt, 4,8 g	F,M,T	S	240		ONNE10F	114.4		Servizi and Martens 1978
Chinook salmon,	alevin, 0.05 g	F,M,T	С	26		ONTS01F	14.48	25.02	Chapman 1975, 1978
Oncorhynchus tshav	swim-up, 0.23 g	F,M,T	С	19		ONTS02F	10.44		Chapman 1975, 1978
-	parr, 9.6 cm, 11.58 g	F,M,T	С	38		ONTS03F	28.30		Chapman 1975, 1978
5	smolt, 14.4 cm, 32.46	F,M,T	С	26		ONTS04F	20.09		Chapman 1975, 1978
	3 mo, 1.35 g	F,M,T,I	С	10.2		ONTS05F	19.41		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	С	24.1		ONTS06F	30.91		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	С	82.5		ONTS07F	32.74		Chapman and McCrady 1977
	3 mo, 1.35 g	F,M,T,I	С	128.4		ONTS08F	20.66		Chapman and McCrady 1977
	swim-up, 0.36-0.45 g	F,M,T,D	С	0	7.4	ONTS09F	36.49		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	С	0	12.5	ONTS10F	30.85		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	С	0	14.3	ONTS11F	31.49		Welsh et al. 2000
	swim-up, 0.36-0.45 g	F,M,T,D	С	0	18.3	ONTS12F	48.56		Welsh et al. 2000

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Bull trout,	0.130 g, 2.6 cm	F,M,T,D	С	228		SACO01F	69.70	68.31	Hansen et al. 2000
Salvelinus confluent	0.555 g, 4.0 cm	F,M,T,D	С	207		SACO02F	63.62		Hansen et al. 2000
	0.774 g, 4.5 cm	F,M,T,D	С	66.6		SACO03F	74.18		Hansen et al. 2000
	1.520 g, 5.6 cm	F,M,T,D	С	50		SACO04F	63.60		Hansen et al. 2000
	1.160 g, 5.2 cm	F,M,T,D	С	89		SACO05F	71.11		Hansen et al. 2000
Chiselmouth, Acrocheilus	4.6 cm, 1.25 g	F,M,T	С	143		ACAL01F	216.3	216.3	Andros and Garton 1980
Bonytail chub, <i>Gila elegans</i>	larval, 0.29 g	S,M,T	S	200		GIEL01S	63.22	63.22	Dwyer et al. 1995
Golden shiner, Notemigonus crysoleucas		F,M,T	С	84600		NOCR01F	107860	107860	Hartwell et al. 1989
Fathead minnow,	adult, 40 mm	S,M,T	S	310		PIPR01S	266.3	69.63	Birge et al. 1983
Pimephales promela	adult, 40 mm	S,M,T	S	120		PIPR02S	105.61		Birge et al. 1983
	adult, 40 mm	S,M,T	S	390		PIPR03S	207.3		Birge et al. 1983; Benson & Birge
		S,M,T	С	55		PIPR04S	38.08		Carlson et al. 1986
		S,M,T	С	85		PIPR05S	70.71		Carlson et al. 1986
	<24 h	S,M,T	N	15		PIPR06S	11.23		Schubauer-Berigan et al. 1993
	<24 h	S,M,T	N	44		PIPR07S	18.03		Schubauer-Berigan et al. 1993
	<24 h	S,M, I	N	>200		PIPR08S	24.38		Schubauer-Berigan et al. 1993
	<24 II, 0.00 IIIg	S,IVI, I	5	4.02		PIPR095	0.07		Weish et al. 1995
	<24 h, 0.00 mg	S,IVI, T	5	0.2		DIDD11S	25.15		Weish et al. 1995
	<24 h, 0.00 mg	SMT	S	21.06		PIPR12S	17 67		Weish et al. 1993
	<24 h, 0.68 mg	SMT	S	35.97		PIPR13S	21.24		Weish et al. 1993
	<24 h, 0.68 mg	SMT	S	59.83		PIPR14S	16 64		Welsh et al. 1993
	<24 h, 0.68 mg	SMT	S	4 83		PIPR15S	5 92		Welsh et al. 1993
	<24 h 0.68 mg	SMT	S	70.28		PIPR16S	13 34		Welsh et al. 1993
	<24 h 0.68 mg	SMT	S	83.59		PIPR17S	8 22		Welsh et al. 1993
	<24 h. 0.68 mg	S.M.T	S	182		PIPR18S	13.91		Welsh et al. 1993
	larval. 0.32 g	S.M.T	S	290		PIPR19S	73.92		Dwver et al. 1995
	larval, 0.56 g	S.M.T	S	630		PIPR20S	157.9		Dwver et al. 1995
	larval, 0.45 g	S,M,T	S	400		PIPR21S	103.2		Dwyer et al. 1995
	larval, 0.39 g	S,M,T	S	390		PIPR22S	161.7		Dwyer et al. 1995
3	3.2-5.5 cm, 0.42-3.23	S,M,T	S	450		PIPR23S	152.9		Richards and Beitinger 1995
2	2.8-5.1 cm, 0.30-2.38	S,M,T	S	297		PIPR24S	77.75		Richards and Beitinger 1995
	1.9-4.6 cm, 0.13-1.55	S,M,T	S	311		PIPR25S	67.56		Richards and Beitinger 1995
3	3.0-4.8 cm, 0.23-1.36	S,M,T	S	513		PIPR26S	76.36		Richards and Beitinger 1995
	<24 h	S,M,T,D	S	62.23	53.96	PIPR27S	25.70		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	165.18	PIPR28S	87.89		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	68.58	59.46	PIPR29S	28.59		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	168.91	146.46	PIPR30S	89.18		Erickson et al. 1996a,b

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	<24 h	S,M,T,D	S	94.62	82.04	PIPR31S	49.27		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	143.51	124.43	PIPR32S	104.90		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	120.65	103.76	PIPR33S	86.54		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	167.32	PIPR34S	122.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	133.35	120.02	PIPR35S	75.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	184.15	169.42	PIPR36S	122.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	304.8	268.22	PIPR37S	78.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	292.1	242.44	PIPR38S	201.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	133.35	113.35	PIPR39S	100.75		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.71	77.88	PIPR40S	72.95		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	128.02	PIPR41S	112.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	177.8	151.13	PIPR42S	136.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	166.62	PIPR43S	136.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	163.83	PIPR44S	147.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	157.48	PIPR45S	125.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	234.95	199.71	PIPR46S	157.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	128.52	PIPR47S	127.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	171.45	150.88	PIPR48S	153.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	131.06	PIPR49S	114.57		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	184.15	160.21	PIPR50S	131.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	182.88	PIPR51S	130.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	180.85	PIPR52S	105.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	176.78	PIPR53S	128.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	222.25	188.91	PIPR54S	122.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	125.60	PIPR55S	111.87		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.7	117.35	PIPR56S	85.45		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.7	114.55	PIPR57S	83.10		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.4	126.49	PIPR58S	85.82		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.2	172.72	PIPR59S	110.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	196.85	167.32	PIPR60S	106.46		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	266.7	226.70	PIPR61S	133.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	99.06	84.20	PIPR62S	138.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	111.13	97.79	PIPR63S	165.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	78.74	70.08	PIPR64S	114.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.71	81.58	PIPR65S	121.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	85.09	77.43	PIPR66S	106.69		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	123.19	110.87	PIPR67S	124.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.1	151.89	PIPR68S	114.24		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.5	175.26	PIPR69S	89.93		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.1	145.29	PIPR70S	140.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	127	111.76	PIPR71S	100.16		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	92.08	79.18	PIPR72S	58.74		Erickson et al. 1996a,b

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	<24 h	S,M,T,D	S	66.68	60.01	PIPR73S	37.67		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	393.70	370.08	PIPR74S	163.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	317.50	292.10	PIPR75S	252.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	107.95	101.47	PIPR76S	169.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	67.95	62.51	PIPR77S	146.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	45.72	42.06	PIPR78S	126.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	177.80	172.47	PIPR79S	197.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	13.97	12.43	PIPR80S	28.13		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	304.80	271.27	PIPR81S	149.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	71.12	71.12	PIPR82S	105.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	83.82	79.63	PIPR83S	108.41		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	104.78	99.54	PIPR84S	114.7		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	139.70	132.72	PIPR85S	137.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	152.40	137.16	PIPR86S	114.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	260.35	182.25	PIPR87S	114.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	488.95	268.92	PIPR88S	122.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.20	188.98	PIPR89S	147.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	704.85	662.56	PIPR90S	185.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	952.50	904.88	PIPR91S	197.1		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1244.60	995.68	PIPR92S	188.3		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1485.90	891.54	PIPR93S	135.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	781.05	757.62	PIPR94S	181.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	476.25	404.81	PIPR95S	172.5		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	273.05	262.13	PIPR96S	191.4		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	22.23	20.45	PIPR97S	59.14		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	24.13	23.16	PIPR98S	64.08		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	36.83	34.99	PIPR99S	97.49		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	27.94	27.94	PIPR100S	78.99		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	26.67	26.67	PIPR101S	72.86		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	20.32	20.32	PIPR102S	50.73		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	26.67	26.67	PIPR103S	68.24		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	190.50	182.88	PIPR104S	146.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	109.86	96.67	PIPR105S	93.76		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	203.20	182.88	PIPR106S	128.86		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	209.55	190.69	PIPR107S	113.0		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	146.05	127.06	PIPR108S	101.01		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.10	148.59	PIPR109S	120.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	254.00	223.52	PIPR110S	137.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	311.15	283.15	PIPR111S	142.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	165.10	150.24	PIPR112S	106.74		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	920.75	644.53	PIPR113S	131.9		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1073.15	697.55	PIPR114S	116.5		Erickson et al. 1996a,b

Species <sup>a</sup>	Organism Age, Size, or Lifestage	Method <sup>b</sup>	Chemical <sup>c</sup>	Reported LC50 or EC50 (total µg/L) <sup>d</sup>	Reported LC50 or EC50 (Diss. µg/L) <sup>e</sup>	BLM Data Label	BLM Normalized LC50 or EC50 (μg/L) <sup>f</sup>	Species Mean Acute Value (µg/L) <sup>g</sup>	Reference
	<24 h	S,M,T,D	S	1003.30	752.48	PIPR115S	109.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	933.45	653.42	PIPR116S	123.2		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	742.95	646.37	PIPR117S	129.6		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	1879.60	939.80	PIPR118S	124.8		Erickson et al. 1996a,b
	<24 h	S,M,T,D	S	266.70	253.37	PIPR119S	176.1		Erickson et al. 1996a,b
		F,M,T	S	114.00		PIPR120F	17.99		Lind et al. Manuscript (1978)
		F,M,T	S	121.00		PIPR121F	19.70		Lind et al. Manuscript (1978)
		F,M,T	S	88.50		PIPR122F	13.27		Lind et al. Manuscript (1978)
		F,M,T	S	436.00		PIPR123F	78.50		Lind et al. Manuscript (1978)
		F,M,T	S	516.00		PIPR124F	50.09		Lind et al. Manuscript (1978)
		F,M,T	S	1586.00		PIPR125F	66.49		Lind et al. Manuscript (1978)
		F,M,T	S	1129.00		PIPR126F	73.03		Lind et al. Manuscript (1978)
		F,M,T	S	550.00		PIPR127F	42.76		Lind et al. Manuscript (1978)
		F,M,T	S	1001.00		PIPR128F	34.39		Lind et al. Manuscript (1978)
	30 d, 0.15 g	F,M,T,D	N	96.00	88.32	PIPR129F	39.58		Spehar and Fiandt 1986
	<24 h	F,M,T,D	S	31.75	27.94	PIPR130F	8.69		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	117.48	105.73	PIPR131F	37.88		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	48.26	40.06	PIPR132F	10.80		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	73.03	64.26	PIPR133F	22.19		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	59.06	49.02	PIPR134F	20.32		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	78.74	67.72	PIPR135F	18.51		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	22.23	18.67	PIPR136F	13.61		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	6.99	6.15	PIPR137F	10.94		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	22.23	20.45	PIPR138F	17.70		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	107.32	93.36	PIPR139F	67.09		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	292.10	245.36	PIPR140F	17.75		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	81.28	72.34	PIPR141F	41.16		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	298.45	229.81	PIPR142F	16.18		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	241.30	195.45	PIPR143F	24.40		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	133.35	109.35	PIPR144F	21.07		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	93.98	78.00	PIPR145F	50.83		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	67.95	45.52	PIPR146F	23.18		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	4.76	4.38	PIPR147F	40.09		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	13.97	12.43	PIPR148F	45.37		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	29.85	26.86	PIPR149F	59.43		Erickson et al. 1996a,b
	<24 h	F,M,T,D	S	59.69	51.33	PIPR150F	58.84		Erickson et al. 1996a,b
Northern squawfish,	larval, 0.32 g	S,M,T	S	380		PTLU01S	88.44	132.2	Dwyer et al. 1995
Ptychocheilus orego	larval, 0.34 g	S,M,T	S	480		PTLU02S	197.6		Dwyer et al. 1995

Species <sup>a</sup>	Organism Age, Size, or Lifestage	Method <sup>b</sup>	Chemical <sup>c</sup>	Reported LC50 or EC50 (total µg/L) <sup>d</sup>	Reported LC50 or EC50 (Diss. µg/L) <sup>e</sup>	BLM Data Label	BLM Normalized LC50 or EC50 (μg/L) <sup>f</sup>	Species Mean Acute Value (µg/L) <sup>g</sup>	Reference
Northern squawfish,	5.0 cm, 1.33 g	F,M,T	С	23		PTOR01F	17.02	14.61	Andros and Garton 1980
Ptychocheilus orego	7.2 cm, 3.69 g	F,M,T	С	18		PTOR02F	12.54		Andros and Garton 1980
Razorback sucker,	larval, 0.31 g	S,M,T	S	220		XYTE01S	63.78	78.66	Dwyer et al. 1995
Xyrauchen texanus	larval, 0.32 g	S,M,T	S	340		XYTE02S	97.0		Dwyer et al. 1995
Gila topminnow, Poeciliposis	2.72 cm, 0.219 g	S,M,T	S	160		POAC01S	56.15	56.15	Dwyer et al. 1999
Bluegill,	3.58 cm, 0.63 g	R,M,D	С	-	2200	LEMA01R	2202	2231	Blaylock et al. 1985
Lepomis macrochiru	12 cm, 35 g	F,M,T	S	1100		LEMA02F	2305		Benoit 1975
	2.8-6.8 cm	F,M,T	С	1000		LEMA03F	4200		Cairns et al. 1981
	3.58 cm, 0.63 g	F,M,D	С	-	1300	LEMA04F	1163		Blaylock et al. 1985
Fantail darter,	3.7 cm	S,M,T	S	330		ETFL01S	117.7	124.3	Lydy and Wissing 1988
Etheostoma flabellar	3.7 cm	S,M,T	S	341		ETFL02S	121.1		Lydy and Wissing 1988
	3.7 cm	S,M,T	S	373		ETFL03S	122.8		Lydy and Wissing 1988
	3.7 cm	S,M,T	S	392		ETFL04S	136.6		Lydy and Wissing 1988
Greenthroat darter, Etheostoma	2.26 cm, 0.133 g	S,M,T	S	260		ETLE01S	82.80	82.80	Dwyer et al. 1999
Johnny darter,	3.9 cm	S,M,T	S	493		ETNI01S	167.3	178.3	Lydy and Wissing 1988
Etheostoma nigrum	3.9 cm	S,M,T	S	483		ETNI02S	164.2		Lydy and Wissing 1988
	3.9 cm	S,M,T	S	602		ETNI03S	200.1		Lydy and Wissing 1988
	3.9 cm	S,M,T	S	548		ETNI04S	183.9		Lydy and Wissing 1988
Fountain darter, <i>Etheostoma rubrum</i>	2.02 cm, 0.062 g	S,M,T	S	60		ETRU01S	22.74	22.74	Dwyer et al. 1999
Boreal toad, Bufo boreas	tadpole, 0.012 g	S,M,T	S	120		BUBO01S	47.49	47.49	Dwyer et al. 1999

<sup>a</sup> Species appear in order taxonomically, with invertebrates listed first, fish, and an amphibian listed last. Species within each genus are ordered alphabetically. Within each species, tests are ordered by test method (static, renewal, flow-through) and date.

<sup>b</sup> S = static, R = renewal, F = flow-through, U = unmeasured, M = measured, T = exposure concentrations were measured as total copper, D = exposure concentrations were measured as dissolved copper.

 $^{c}$ S = copper sulfate, N = copper nitrate, C = copper chloride.

<sup>d</sup> Values in this column are total copper LC50 or EC50 values as reported by the author.

<sup>e</sup> Values in this column are dissolved copper LC50 or EC50 values either reported by the author or if the author did not report a dissolved value then a conversion factor (CF) was applied

to the total copper LC50 to estimate dissolved copper values.

「Normalization	n Chemistry											
Temp	pH	Diss Cu	DOC	%HA	Ca	Mg	Na	к	SO4	CI	Alkalinity	s
Deg C		ug/L	mg/L		mg/L	mg/L						
20.00	7.5	1.00	0.5	10.0	14.0	12.1	26.3	2.1	81.4	1.9	65.0	0.0003

g Underlined LC50s or EC50s not used to derive SMAV because considered extreme value.

						Chronic	: Values				
Species	Testª	Chemical	Endpoint	Hardness (mg/L as CaCO3)	Chronic Limits (μg/L)	Chronic Value <sup>b</sup> (µg/L)	ЕС20 <sup>ь</sup> (µg/L)	Species Mean Chronic Value (Total µg/L)	Genus Mean Chronic Value (Total µg/L)	ACR	Reference
Rotifer, Brachionus calyciflorus	LC,T	Copper sulfate	Intrinsic growth rate	85	2.5-5.0	3.54	-	3.54	3.54		Janssen et al. 1994
Snail, Campeloma decisum (Test 1)	LC,T	Copper sulfate	Survival	35-55	8-14.8	10.88	8.73	9.77	9.77	191.6	Arthur and Leonard 1970
Snail, Campeloma decisum (Test 2)	LC,T	Copper sulfate	Survival	35-55	8-14.8	10.88	10.94			153.0	Arthur and Leonard 1970
Cladoceran, Ceriodaphnia dubia (New River)	LC,D	-	Reproduction	179	6.3-9.9	7.90 <sup>c</sup> (8.23)	-	19.3	19.3	3.599	Belanger et al. 1989
Cladoceran, Ceriodaphnia dubia (Cinch River)	LC,D	-	Reproduction	94.1	<19.3-19.3	<19.3	19.36 <sup>c</sup> (20.17)			3.271	Belanger et al. 1989
Cladoceran, Ceriodaphnia dubia	LC,T	Copper sulfate	Survival and reproduction	57	-	24.50	-			0.547	Oris et al. 1991
Cladoceran, Ceriodaphnia dubia	LC,T	Copper sulfate	Survival and reproduction	57	-	34.60	-				Oris et al. 1991
Cladoceran, Ceriodaphnia dubia	LC,T,D	Copper chloride	Reproduction		12-32	19.59	9.17			2.069	Carlson et al. 1986
Cladoceran, Daphnia magna	LC,T	Copper chloride	Reproduction	85	10-30	17.32	-	14.1	8.96		Blaylock et al. 1985
Cladoceran, Daphnia magna	LC,T	Copper chloride	Carapace length	225	12.6-36.8	21.50	-				van Leeuwen et al. 1988
Cladoceran, Daphnia magna	LC,T	Copper chloride	Reproduction	51	11.4-16.3	13.63	12.58			2.067	Chapman et al. Manuscript
Cladoceran, Daphnia magna	LC,T	Copper chloride	Reproduction	104	20-43	29.33	19.89			1.697	Chapman et al. Manuscript
Cladoceran, Daphnia magna	LC,T	Copper chloride	Reproduction	211	7.2-12.6	9.53	6.06			11.39	Chapman et al. Manuscript
Cladoceran, Daphnia pulex	LC,T	Copper sulfate	Survival	57.5 (No HA)	4.0-6.0	4.90	2.83	5.68		9.104	Winner 1985
Cladoceran, Daphnia pulex	LC,T	Copper sulfate	Survival	115 (No HA)	5.0-10.0	7.07				3.904	Winner 1985
Cladoceran, Daphnia pulex	LC,T	Copper sulfate	Survival	230 (0.15 HA)	10-15	12.25	9.16			3.143	Winner 1985

						Chronic	: Values				
Species	Test <sup>a</sup>	Chemical	Endpoint	Hardness (mg/L as CaCO3)	Chronic Limits (µg/L)	Chronic Value <sup>b</sup> (µg/L)	EC20 <sup>ь</sup> (µg/L)	Species Mean Chronic Value (Total µg/L)	Genus Mean Chronic Value (Total µg/L)	ACR	Reference
Caddisfly, Clistoronia magnifica	LC,T	Copper chloride	Emergence (adult 1st gen)	26	8.3-13	10.39	7.67	7.67	7.67		Nebeker et al. 1984b
Rainbow trout, Oncorhynchus mykiss	ELS,T continuous	Copper chloride	Biomass	120			27.77	23.8	11.9	2.881	Seim et al. 1984
Rainbow trout, Oncorhynchus mykiss	ELS,T	Copper sulfate	Biomass	160-180	12-22	16.25	20.32				Besser et al. 2001
Chinook salmon, Oncorhynchus tshawytscha	ELS,T	Copper chloride	Biomass	20-45	<7.4	<7.4	5.92	5.92		5.594	Chapman 1975, 1982
Brown trout, Salmo trutta	ELS,T	Copper sulfate	Biomass	45.4	20.8-43.8	29.91	-	29.9	29.9		McKim et al. 1978
Brook trout, Salvelinus fontinalis	PLC,T	Copper sulfate	Biomass	35.0	<5 -5	<5	-	12.5	19.7		Sauter et al. 1976
Brook trout, Salvelinus fontinalis	ELS,T	Copper sulfate	Biomass	45.4	22.3-43.5	31.15	-				McKim et al. 1978
Lake trout, Salvelinus namaycush	ELS, T	Copper sulfate	Biomass	45.4	22.0-43.5	30.94	-	30.9			McKim et al. 1978
Northern pike, <i>Esox lucius</i>	ELS, T	Copper sulfate	Biomass	45.4	34.9-104.4	60.36	-	60.4	60.4		McKim et al. 1978
Bluntnose minnow Pimephales notatus	LC,T	Copper sulfate	Egg production	172-230	<18-18	18.00	-	18.0	13.0	12.88	Horning and Neiheisel 1979
Fathead minnow, Pimephales promelas	ELS,T,D	-	Biomass	45			9.38	9.38		11.40	Lind et al. manuscript
White sucker, Catostomus commersoni	ELS, T	Copper sulfate	Biomass	45.4	12.9-33.8	20.88	-	20.9	20.9		McKim et al. 1978
Bluegill (larval), Lepomis macrochirus	ELS,T,D	Copper sulfate	Survival	44-50	21-40	28.98	27.15	27.2	27.2	40.52	Benoit 1975

<sup>a</sup> LC = life-cycle; PLC = partial life-cyle; ELS = early life state; T = total copper; D = dissolved copper.

<sup>b</sup> Results are based on copper, not the chemical.

<sup>c</sup> Chronic values based on dissolved copper concentration.

#### Table 2b. Chronic Toxicity of Copper to Saltwater Animals

Species	Test	Chemical	Salinity (g/kg)	Limits (µg/L)	Chronic Value (µg/L)	Chronic Value Dissolved (μg/L)	ACR	Reference
Sheepshead minnow, Cyprinodon variegatus	ELS	Copper chloride	30	172-362	249	206.7	1.48	Hughes et al. 1989

#### Table 2c. Acute-Chronic Ratios

Species	Hardness (mg/L as CaCO <sub>3</sub> )	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	Reference	Overall Ratio for Species	
Snail,	35-55	1673 <sup>ª</sup>	8.73	191.61	Arthur and Leonard 1970		
Campeloma decisum	35-55	1673 <sup>ª</sup>	10.94	152.95	Arthur and Leonard 1970	171.19	
Cladoceran,		28.42 <sup>b</sup>	7.90	3.60			
Ceriodaphnia dubia		63.33 <sup>b</sup>	19.36	3.27			
	57	13.4	24.5	0.55	Oris et al. 1991		
			9.17	1.96		2.85 <sup>g</sup>	~
Cladoceran,	51	26	12.58	2.07	Chapman et al. Manuscript		
Daphnia magna	104	33.76 <sup>d</sup>	19.89	1.70	Chapman et al. Manuscript		
	211	69	6.06	11.39	Chapman et al. Manuscript	3.42	~
Cladoceran,	57.5	25.737	2.83	9.10			
Daphnia pulex	115	27.6	7.07	3.90			
	230	28.79	9.16	3.14		4.82	~
Rainbow trout, Oncorhynchus mykiss	120	80	27.77	2.88	Seim et al. 1984	2.88	~
Chinook salmon, Oncorhynchus tshawytscha	20-45	33.1	5.92	5.59	Chapman 1975, 1982	5.59	~
Bluntnose minnow, Pimephales notatus	172-230	231.9 <sup>e</sup>	18	12.88	Horning and Neiheisel 1979	12.88	
Fathead minnow, Pimephales promelas	45	106.875 <sup>f</sup>	9.38	11.40	Lind et al. 1978	11.40	
Bluegill, Lepomis macrochirus	21-40	1100	27.15	40.52	Benoit 1975	40.49	
Sheepshead minnow, Cyprinodon variegatus	-	368	249	1.48	Hughes et al. 1989	1.48	~

<sup>a</sup>Geometric mean of two values from Arthur and Leonard (1970) in Table 1.

<sup>b</sup>Geometric mean of five values from Belanger et al. (1989) in Table 1. ACR is based on dissolved metal measurements.

<sup>c</sup>Geometric mean of two values from Carlson et al. (1986) in Table 1.

<sup>d</sup>Geometric mean of two values from Chapman manuscript in Table 1.

<sup>e</sup>Geometric mean of two values of three values from Horning and Neiheisel (1979) in Appendix C.

<sup>f</sup>Geometric mean of three values from Lind et al. (1978) in Table 1.

<sup>g</sup>ACR from Oris et al. (1991) not used in calculating overall ratio for species because it is <1.

FACR Freshwater final acute-chronic ratio = 3.22 Saltwater final acute-chronic ratio = 3.22

# Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank	GMAV	Species	SMAV (µg/L)	ACR
27	107,860	Golden shiner, Notemigonus crysoleucas	107,860	
26	20,636	Stonefly, Acroneuria lycorias	20,636	
25	3,573	Snail, <i>Campeloma decisum</i>	3,573	171.19
24	2,231	Bluegill sunfish, Lepomis macrochirus	2,231	40.49
23	1,987	Midge, Chironomus decorus	1,987	
22	216.3	Chiselmouth, Acrocheilus alutaceus	216.3	
21	80.38	Fantail darter, Etheostoma flabellare	124.3	
		Greenthroat darter, Etheostoma lepidum	82.80	
		Johnny darter, Etheostoma nigrum	178.3	
		Fountain darter, Etheostoma rubrum	22.74	
20	78.66	Razorback sucker, Xyrauchen texanus	78.66	
19	69.63	Fathead minnow, Pimephales promelas	69.63	11.40
18	69.63	Shovelnose sturgeon, Scaphirhynchus platorynchus	69.63	
17	68.31	Bull trout, Salvelinus confluentus	68.31	
16	63.22	Bonytail chub, <i>Gila elegan</i> s	63.22	
15	56.15	Gila topminnow, Poeciliposis occidentalis	56.15	
14	52.51	Freshwater mussel, Utterbackia imbecillis	52.51	
13	48.41	Worm, Lumbriculus variegatus	48.41	
12	47.49	Boreal toad, <i>Bufo boreas</i>	47.49	
11	43.94	Colorado squawfish, Ptychocheilus lucius	132.2	
		Northern squawfish, Ptychocheilus oregonensis	14.61	
10	31.39	Apache trout, Oncorhynchus apache	32.54	
		Cutthroat trout, Oncorhynchus clarki	32.97	
		Pink salmon, Oncorhynchus gorbuscha	40.13	
		Coho salmon, Oncorhynchus kisutch	22.93	
		Rainbow trout, Oncorhynchus mykiss	22.19	2.88
		Sockeye salmon, Oncorhynchus nerka	54.82	
		Chinook salmon, Oncorhynchus tshawytscha	25.02	5.59
9	20.41	Snail, <i>Physa integra</i>	20.41	
8	12.31	Snail, <i>Juga plicifera</i>	12.31	
7	12.07	Amphipod, <i>Hyalella azteca</i>	12.07	
6	11.33	Freshwater mussel, Actinonaias pectorosa	11.33	
5	9.73	Cladoceran, Scapholeberis sp.	9.73	
4	9.60	Amphipod, Gammarus pseudolimnaeus	9.60	
3	6.67	Snail, <i>Lithoglyphus virens</i>	6.67	
2	5.93	Cladoceran, Ceriodaphnia dubia	5.93	2.85
1	4.05	Cladoceran, <i>Daphnia magna</i>	6.00	3.42
		Cladoceran, Daphnia pulicaria	2.73	

#### Table 3b. Freshwater Final Acute Value (FAV) and Criteria Calculations

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 27									
Rank	GMAV	InGMAV	(InGMAV) <sup>2</sup>	P = R/(n+1)	SQRT(P)				
4	9.600	2.261	5.114	0.143	0.378				
3	6.670	1.897	3.599	0.107	0.327				
2	5.930	1.780	3.170	0.071	0.267				
1	4.050	1.398	1.954	0.036	0.189				
Sum:		7.33671	13.83657	0.35714	1.16153				
S = L = A = Calculated FAV = Calculated CMC =	4.374 0.5641 1.542 <b>4.674452</b> 2.337								

Dissolved Copper Criterion Maximum Concentration (CMC) =  $2.337 \ \mu$ g/L (for example normalization chemistry see Table 1, footnote f) Criteria Lethal Accumulation (LA50) based on example normalization chemistry =  $0.03395 \$ nmol/g wet wt Criterion Continuous Concentration (CCC) =  $4.67445/3.22 = 1.4516932 \ \mu$ g/L (for example normalization chemistry see Table 1, footnote f)

S = Scale parameter or slope L = Location parameter or intercept

P = Cumulative probability

A = InFAV

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Result <sup>⊳</sup> (Total µg/L)	Reference
Blue-green alga, Anabaena flos-aqua	S,U	Copper sulfate	65.2	96 hr	EC75 (cell density)	200	Young and Lisk 1972
Bllue-green alga, Anabaena variabilis	S,U	Copper sulfate	65.2		EC85 (wet weight)	100	Young and Lisk 1972
Blue-green alga, <i>Anabaena</i> strain 7120		-	-		Lag in growth	64	Laube et al. 1980
Blue-green alga, Chroococcus paris	S,U	Copper nitrate	54.7	10 days	Growth reduction	100	Les and Walker 1984
Blue-green alga, Microcystis aeruginosa	S,U	Copper sulfate	54.9	8 days	Incipient inhibition	30	Bringmann 1975; Bringmann and Kuhn 1976, 1978a,b
Alga, Ankistrodesmus braunii		'			Growth reduction	640	Laube et al. 1980
Green alga, Chlamydomonas sp.	S,U	Copper sulfate	68	10 days	Growth inhibition	8,000	Cairns et al. 1978
Green alga, Chlamydomonas reinhardtii	S,M,T	-	90 - 133	72 hr	NOEC (deflagellation)	12.2-49.1	Winner and Owen 1991a
Green alga, Chlamydomonas reinhardtii	S,M,T	-	90 - 133	72 hr	NOEC (cell density)	12.2-43.0	Winner and Owen 1991a
Green alga, Chlamydomonas reinhardtii	F,M,T	-	24	10 days	EC50 (cell density)	31.5	Schafer et al. 1993
Green alga, Chlorella pyrenoidosa	S,U	-	-	96 hr	ca. 12 hr lag in growth	1	Steeman-Nielsen and Wium-Andersen 1970
Green alga, Chlorella pyrenoidosa	S,U	-	54.7	-	Growth inhibition	100	Steeman-Nielsen and Kamp-Nielsen 1970
Green alga, Chlorella pyrenoidosa	S,U	Copper sulfate	365	14 days	EC50 (dry weight)	78-100	Bednarz and Warkowska-Dratnal 1985
Green alga, Chlorella pyrenoidosa	S,U	Copper sulfate	36.5	14 days	EC50 (dry weight)	78-100	Bednarz and Warkowska-Dratnal 1985
Green alga, Chlorella pyrenoidosa	S,U	Copper sulfate	3.65	14 days	EC50 (dry weight)	78-100	Bednarz and Warkowska-Dratnal 1983/1984
Green alga, Chlorella saccharophila	S,U	Copper chloride	-	96 hr	96-h EC50	550	Rachlin et al. 1982
Green alga, Chlorella vulgaris	S,U	Copper sulfate	2,000	96 hr	Growth inhibition	200	Young and Lisk 1972
Green alga, Chlorella vulgaris	S,U	Copper chloride		33 days	EC20 (growth)	42	Rosko and Rachlin 1977
Green alga, Chlorella vulgaris	F,U	Copper sulfate	-	96 hr	EC50 or EC50 (cell numbers)	62	Ferard et al. 1983
Green alga, Chlorella vulgaris	S,M,D	Copper sulfate	-	96 hr	IC50	270	Ferard et al. 1983
Green alga, Chlorella vulgaris	S,M,T	Copper chloride	-	96 hr	EC50 (cell density)	200	Blaylock et al. 1985
Green alga, Chlorella vulgaris	S,U	Copper sulfate	17.1	7 days	15% reduction in cell density	100	Bilgrami and Kumar 1997

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Result <sup>b</sup> (Total µg/L)	Reference
Green alga, Scenedesmus quadricauda	S,U	Copper sulfate	68	10 days	Growth reduction	8,000	Cairns et al. 1978
Green alga, Scenedesmus quadricauda	S,U	Copper sulfate	181	7 days	LOEC (growth)	1,100	Bringmann and Kuhn 1977a, 1978a,b, 1979, 1980a
Green alga, Selenastrum capricornutum	S,U	Copper chloride	14.9	14 days	EC50 (cell volume)	85	Christensen et al. 1979
Green alga, Selenastrum capricornutum	S,U	Copper chloride	14.9	7 days	LOEC (growth)	50	Bartlett et al. 1974
Green alga, Selenastrum capricornutum	S,M,T	Copper chloride	24.2	96 hr	EC50 (cell count)	400	Blaylock et al. 1985
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	48.4	Blaise et al. 1986
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	44.3	Blaise et al. 1986
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	46.4	Blaise et al. 1986
Green alga, Selenastrum capricornutum	S,U	Copper chloride	15	2-3 wk	EC50 (biomass)	53.7	Turbak et al. 1986
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	14.9	5 days	Growth reduction	58	Nyholm 1990
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	69.9	St. Laurent et al. 1992
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	9.3	96 hr	EC50 (cell count)	65.7	St. Laurent et al. 1992
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	24.2	96 hr	EC50 (cell count)	54.4	Radetski et al. 1995
Green alga, Selenastrum capricornutum	R,U	Copper sulfate	24.2	96 hr	EC50 (cell count)	48.2	Radetski et al. 1995
Green alga, Selenastrum capricornutum	S,U	Copper sulfate	16	96 hr	EC50 (cell density)	38	Chen et al. 1997
Algae, mixed culture	S,U	Copper sulfate	-	-	Significant reduction in blue-green algae and nitrogen fixation	5	Elder and Horne 1978
Diatom, Cyclotella meneghiniana	S,U	Copper sulfate	68	10 days	Growth inhibition	8,000	Cairns et al. 1978
Diatom, Navicula incerta	S,U	Copper chloride	-	96 hr	EC50	10,429	Rachlin et al. 1983
Diatom, Nitzschia linearis	-	-	-	5 day	EC50	795-815	Academy of Natural Sciences 1960; Patrick et al. 1968
Diatom, Nitzschia palea	-	-	_	-	Complete growth inhibition	5	Steeman-Nielsen and Wium-Andersen 1970
Duckweed, Lemna minor	F	-	-	7 day	EC50	119	Walbridge 1977
Duckweed, <i>Lemna minor</i>	S,U	Copper sulfate	-	28 days	Significant plant damage	130	Brown and Rattigan 1979

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Result <sup>b</sup> (Total µg/L)	Reference
Duckweed, Lemna minor	S,U	-	0	96 hr	EC50 (frond number)	1,100	Wang 1986
Duckweed, <i>Lemna minor</i>	S,U	Copper sulfate	78	96 hr	EC50 (chlorophyll a reduction)	250	Eloranta et al. 1988
Duckweed, <i>Lemna minor</i>	R,M,T	Copper nitrate	39	96 hr	Reduced chlorophyll production	24	Taraldsen and Norberg-King 1990
Eurasian watermilfoil, Myriophyllum spicatum	S,U	-	89	32 days	EC50 (root weight)	250	Stanley 1974

<sup>a</sup> S=Static; R=Renewal; F=Flow-through; M=Measured; U=Unmeasured; T=Total metal conc. measured; D=dissolved metal conc. measured.

<sup>b</sup> Results are expressed as copper, not as the chemical.

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Appendices

Appendix A. Ranges in Calibration and Application Data Sets



Median, Range and Quartiles of Temperature in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of HA in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of pH in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of DOC in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of Ca in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of HA in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

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Median, Range and Quartiles of Na in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)


Median, Range and Quartiles of K in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of SO4 in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of CI in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)



Median, Range and Quartiles of Alkalinity in BLM Calibration and Application Datasets (All species, Median and Quartiles calculated directly from data i.e., no distributional assumptions)

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect Total Concentration (μg/L) <sup>b</sup>		Dissolved Concentration (µg/L)	Reference
Bacteria, Escherichia coli	S,U	Copper sulfate	-	48 hr	Threshold of inhibited glucose use; measured by pH change in media	80	-	Bringmann and Kuhn 1959a
Bacteria, Pseudomonas putida	S,U	Copper sulfate	81.1	16 hr	EC3 (cell numbers)	30	-	Bringmann and Kuhn 1976, 1977a, 1979, 1980a
Protozoan, <i>Entosiphon sulcatum</i>	S,U	Copper sulfate	81.9	72 hr	EC5 (cell numbers)	110	-	Bringmann 1978; Bringmann and Kuhn 1979, 1980a,
Protozoan, <i>Microrega heterostoma</i>	S,U	Copper sulfate	214	28 hr	Threshold of decreased feeding rate	50	-	Bringmann and Kuhn 1959b
Protozoan, Chilomonas paramecium	S,U	Copper sulfate	-	48 hr	Growth threshold	3,200	-	Bringmann and Kuhn 1980b, 1981
Protozoan, <i>Uronema parduezi</i>	S,U	Copper sulfate	-	20 hr	Growth threshold	140	-	Bringmann and Kuhn 1980b, 1981
Protozoa, mixed species	-	-	-	7 days	Reduced rate of colonization	167	-	Cairns et al. 1980
Protozoa, mixed species	S,M,T	Copper sulfate	-	15 days	Reduced rate of colonization	100	-	Buikema et al. 1983
Green alga, Cladophora glomerata	Dosed stream	Copper sulfate	226-310	10 mo	Decreased abundance from 21% down to 0%	า 120	-	Weber and McFarland 1981
Green alga, Chlamydomonas reinhardtii	-	Copper sulfate	76	72 hr	Deflagellation	6.7	-	Garvey et al. 1991
Green alga, Chlamydomonas reinhardtii	-	Copper sulfate	76	72 hr	Deflagellation	6.7	-	Garvey et al. 1991
Green alga, Chlamydomonas reinhardtii	-	Copper sulfate	76	72 hr	Deflagellation	16.3	-	Garvey et al. 1991
Green alga Chlamydomonas reinhardti	-	Copper sulfate	76	72 hr	Deflagellation	25.4	-	Garvey et al. 1991
Green alga, <i>Chlorella</i> sp.	S,U	Copper nitrate	-	28 hr	Inhibited photosynthesis	6.3	-	Gachter et al. 1973
Green alga, Chlorella pyrenoidosa	S,U	-	29.4	72 hr	IC50 (cell division rate)	16	-	Stauber and Florence 1989
Green alga, <i>Chlorella pyrenoidosa</i>	S,U	-	14.9	72 hr	IC50 (cell division rate)	24	-	Stauber and Florence 1989
Green alga, <i>Chlorella pyrenoidosa</i>	S,U	Copper sulfate	82	4 hr	Disturbed photosystem II	25	-	Vavilin et al. 1995
Green alga, <i>Eudorina californica</i>	S,U	Copper sulfate	19.1	-	Decrease in cell density	5,000	-	Young and Lisk 1972
Green alga (flagellate cells), <i>Haematococcus</i> sp.	S,U	Copper sulfate	2	24 hr	Inhibited growth during 96 hr recovery period	50	-	Pearlmutter and Buchheim 1983
Green alga, Scenedesmus quadricauda	S,U	Copper sulfate	214	96 hr	Threshold of effect on cell numbers	150	-	Bringmann and Kuhn 1959b
Green alga, Scenedesmus quadricauda	S,U	Copper sulfate	60	72 hr	EC3 (cell numbers)	1,100	-	Bringmann and Kuhn 1980a
Green alga, Scenedesmus quadricauda	S,U	Copper sulfate	34.8	24 hr	EC50 (photosynthesis)	100	-	Starodub et al. 1987

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Green alga,	S,U	Copper	34.8	24 hr	NOEC	50	-	Starodub et al. 1987
Scenedesmus quadricauda		sulfate			(growth)			
Green alga,	S,U	Copper	34.8	24 hr	NOEC	50	-	Starodub et al. 1987
Scenedesmus quadricauda		sulfate			(growth)			
Green alga,	S,U	Copper	34.8	24 hr	NOEC	>200	-	Starodub et al. 1987
Scenedesmus quadricauda		sulfate			(growth)			
Green alga, Selenastrum capricornutum	S,U	Copper chloride	14.9	7 days	Growth reduction	50	-	Bartlett et al.1974
Green alga.	S.U	Copper	29.3	72 hr	EC50	19	-	Vasseur et al. 1988
Selenastrum capricornutum	- , -	sulfate			(cell count)			
Green alga.	S.U	Copper	24.2	72 hr	EC50	41	-	Vasseur et al. 1988
Selenastrum capricornutum	-,-	sulfate			(cell count)			
Green alga.	S.U	Copper	24.2	72 hr	EC50	28	-	Vasseur et al. 1988
Selenastrum capricornutum	-,-	sulfate			(cell count)			
Green alga,	S,U	Copper	14.9	72 hr	EC50	60	-	Vasseur et al. 1988
Selenastrum capricornutum	,	sulfate			(cell count)			
Green alga,	S,U	Copper	24.2	72 hr	EC50	28.5	-	Benhra et al. 1997
Selenastrum capricornutum	-	sulfate			(cell count)			
Green alga,	F,U	Copper	15	24 hr	EC50	21	-	Chen et al. 1997
Selenastrum capricornutum		sulfate			(cell density)			
Diatom,	Dosed	Copper	226-310	10 mo	Decreased abundance from 21% dowr	120	-	Weber and McFarland 1981
Cocconeis placentula	stream	sulfate			to <1%			
Phytoplankton,	S,U	-	-	124 hr	Averaged 39% reduction in primary	10	-	Cote 1983
mixed species					production			
Macrophyte,	S,U	Copper	-	24 hr	EC50	150	-	Brown and Rattigan 1979
Elodea canadensis		sulfate			(photosynthesis)			
Microcosm	F,M,T,D	Copper	200	32 wk	LOEC	9.3	-	Hedtke 1984
		sulfate			(primary production)			
Microcosm	F,M,T,D	Copper	200	32 wk	NOEC	4	-	Hedtke 1984
		sulfate			(primary production)			
Microcosm	F,M,T	Copper sulfate	76.7	96 hr	Significant drop in no. of taxa and no. of individuals	15	-	Clements et al. 1988
Microcosm	F,M,T	Copper sulfate	58.5	10 days	Significant drop in no. of individuals	2.5	-	Clements et al. 1989
Microcosm	F,M,T	Copper	151	10 days	58% drop in no. of individuals	13.5	-	Clements et al. 1989
Microcosm	F,M,T	Copper	68	10 days	Significant drop in species richness	11.3	-	Clements et al. 1990
	<b>F M T</b>	sulfate		10	and no. of individuals	40 -		
IVIICROCOSM	F,M,I	Copper sulfate	80	10 days	Significant drop in species richness and no. of individuals	10.7	-	Ciements et al. 1990
Microcosm	S.M T	Copper	102	5 wk	14-28% drop in phytoplankton species	20	-	Winner and Owen 1991b
	C,, /	sulfate		•	richness			
Microcosm	F,M,T	-	160	28 days	LOEC	19.9	-	Pratt and Rosenberger 1993
					(species richness)			ž

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect Total Concentration (μg/L) <sup>b</sup>		Dissolved Concentration (µg/L)	Reference
Dosed stream	F,M,D	Copper sulfate	56	1 yr	Shifts in periphyton species abundance	5.208	-	Leland and Carter 1984
Dosed stream	F,M,D	Copper sulfate	56	1 yr	Reduced algal production	5.208	-	Leland and Carter 1985
Sponge, Ephydatia fluviatilis	S,U	Copper sulfate	200	10 days	Reduced growth by 33%	6	-	Francis and Harrison 1988
Sponge, <i>Ephydatia fluviatilis</i>	S,U	Copper sulfate	200	10 days	Reduced growth by 100%	19	-	Francis and Harrison 1988
Rotifer, Philodina acuticornis	S,U	Copper sulfate	45	48 hr	LC50 (5 <sup>0</sup> C)	1,300	-	Cairns et al. 1978
Rotifer, Philodina acuticornis	S,U	Copper sulfate	45	48 hr	LC50 (10 <sup>0</sup> C)	1,200	-	Cairns et al. 1978
Rotifer, Philodina acuticornis	S,U	Copper sulfate	45	48 hr	LC50 (15 <sup>0</sup> C)	1,130	-	Cairns et al. 1978
Rotifer, Philodina acuticornis	S,U	Copper sulfate	45	48 hr	LC50 (20 <sup>0</sup> C)	1,000	-	Cairns et al. 1978
Rotifer, Philodina acuticornis	S,U	Copper sulfate	45	48 hr	LC50 (25 <sup>0</sup> C)	950	-	Cairns et al. 1978
Rotifer, Brachionus calyciflorus	S, U	Copper sulfate	39.8	24 hr	EC50 (mobility)	200	-	Couillard et al. 1989
Rotifer (2 hr), <i>Brachionus calyciflorus</i>	S,U	Copper sulfate	-	2 hr	LOEC (swimming activity)	12.5	-	Charoy et al. 1995
Rotifer, Brachionus calyciflorus	S,U	Copper sulfate	90	24 hr	EC50 (mobility)	76	-	Ferrando et al. 1992
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper sulfate	90	5 hr	EC50 (filtration rate)	34	-	Ferrando et al. 1993a
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper sulfate	90	6 days	LOEC (reproduction decreased 26%)	5	-	Janssen et al. 1993
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper sulfate	90	5 hr	LOEC (reduced swimming speed)	12	-	Janssen et al. 1993
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper sulfate	85	3 days	LOEC (reproduction decreased 27%)	5	-	Janssen et al. 1994
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper sulfate	85	3 days	LOEC (reproduction decreased 29%)	5	-	Janssen et al. 1994
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper sulfate	85	8 days	LOEC (reproduction decreased 47%)	5	-	Janssen et al. 1994
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper chloride	170	35 min	LOEC (food ingestion rate)	100	-	Juchelka and Snell 1994
Rotifer (2 hr), Brachionus calyciflorus	S,U	Copper sulfate	63.2	24 hr	EC50 (mobility)	9.4	-	Porta and Ronco 1993
Rotifer (2 hr), Brachionus calyciflorus	S,U	-	90	2 days	LOEC (reproduction decreased 100%)	30	-	Snell and Moffat 1992
Rotifer (<2 hr), <i>Brachionus calyciflorus</i>	S, U	-	85	24 hr	EC50 (mobility)	26	-	Snell et al. 1991b

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Total Concentration (μg/L) <sup>b</sup>		Dissolved Concentration (µg/L)	Reference
Rotifer (<2 hr),	S, U	-	85	24 hr	EC50	18	-	Snell 1991;
Brachionus calyciflorus					(mobility; 10 <sup>0</sup> C)			Snell et al. 1991b
Rotifer (<2 hr),	S, U	-	85	24 hr	EC50	31	-	Snell 1991;
Brachionus calycifiorus					(mobility; 15° C)			Shell et al. 1991b
Rotifer (<2 hr), Brachionus calyciflorus	S, U	-	85	24 hr	EC50 (mobility; 20 <sup>0</sup> C)	31	-	Snell 1991; Snell et al. 1991b
Rotifer (<2 hr),	S, U	-	85	24 hr	EC50	26	-	Snell 1991;
Brachionus calyciflorus					(mobility; 25 <sup>0</sup> C)			Snell et al. 1991b
Rotifer (<2 hr),	S, U	-	85	24 hr	EC50	25	-	Snell 1991;
Brachionus calyciflorus					(mobility; 30 <sup>0</sup> C)			Snell et al. 1991b
Rotifer (<3 hr),	S, U	Copper	90	24 hr	LC50	19	-	Snell and Persoone 1989b
Brachionus rubens	0.11	sulfate			1.050	101		
Rotifer, Keratella cochlearis	S,U	Copper chloride	-	24 hr	LC50	101	-	Borgman and Ralph 1984
Worm,	S,U	Copper	45	48 hr	LC50	2,600	-	Cairns et al. 1978
Aeolosoma headleyi		sulfate			(5 <sup>°</sup> C)			
Worm,	S,U	Copper	45	48 hr	LC50	2,300	-	Cairns et al. 1978
Aeolosoma headleyi		sulfate			(10 <sup>0</sup> C)			
Worm,	S,U	Copper	45	48 hr	LC50	2,000	-	Cairns et al. 1978
Aeolosoma headleyi		sulfate			(15 <sup>0</sup> C)			
Worm,	S,U	Copper	45	48 hr	LC50	1,650	-	Cairns et al. 1978
Aeolosoma headleyi		sulfate			(20 <sup>0</sup> C)			
Worm,	S,U	Copper	45	48 hr	LC50	1,000	-	Cairns et al. 1978
Aeolosoma headleyi	,	sulfate			(50 C)	,		
Worm (adult),	S,U	Copper	30		LC50	150		Bailey and Liu, 1980
Lumbriculus variegatus	-	sulfate						
Worm (7 mg),	F,M,T	Copper	45	10 days	LC50	35	-	West et al. 1993
Lumbriculus variegatis		sulfate						
Tubificid worm,	S,U	Copper	100		LC50	102		Wurtz and Bridges 1961
Limnodrilus hoffmeisteri		sulfate						
Tubificid worm,	R, U	Copper	245		LC50	158		Khangarot 1991
Tubifex tubifex		sulfate						
Snail (11-27 mm),	F,M,T	Copper	45	6 wk	LOEC	14.8	-	Arthur and Leonard 1970
Campeloma decisum	÷ · ·	sulfate			(mortality)			
Snail,	S,U	Copper	100		LC50	108		Wurtz and Bridges 1961
Gyraulus circumstriatus	0.11	sulfate	151	40.1	1.050			
Snail,	S,U	Copper	154	48 hr	LC50	860	-	Cairns et al. 1976
Goniobasis livescens	S M D	Suifate	154	06 hr	1.050		200	Douloon et al. 1092
Shall, Conjobasis livescens	5,IVI,D	copper	104	90 nr	LCOU	-	390	rauison et al. 1983
Soniobasis ilvescens Spail	511	Copper	45	/8 hr	1 C 50	3 000	_	Cairps et al. 1978
Nitrocris sp	3,0	sulfate	75		(5 <sup>0</sup> C)	3,000	-	
Snail	511	Coppor	15	18 hr		2 400		Cairps et al. 1978
Nitrocris sp	3,0	sulfate	75		(10° C)	2,400	-	
	1	Sanato	1	L		I	1	

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (15 <sup>0</sup> C)	1,000	-	Cairns et al. 1978
Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (20 <sup>0</sup> C)	300	-	Cairns et al. 1978
Snail, <i>Nitrocris</i> sp.	S,U	Copper sulfate	45	48 hr	LC50 (25 <sup>0</sup> C)	210	-	Cairns et al. 1978
Snail, Lymnaea emarginata	S,U	Copper sulfate	154	48 hr	LC50	300	-	Cairns et al. 1976
Snail (adult), <i>Juga plicifera</i>	F,M,T	Copper chloride	23	30 days	LC50	6	-	Nebeker et al. 1986b
Snail (adult), <i>Lithoglyphus virens</i>	F,M,T	Copper chloride	23	30 days	LC50	4	-	Nebeker et al. 1986b
Snail, Physa heterostropha	S,U	Copper sulfate	100		LC50	69		Wurtz and Bridges 1961
Freshwater mussel (released glochidia), Actinonaias pectorosa	R,M	Copper sulfate	140	24 hr		132		Jacobson et al. 1997
Freshwater mussel (released glochidia), Actinonaias pectorosa	R,M	Copper sulfate	150	24 hr		93		Jacobson et al. 1997
Freshwater mussel (released glochidia), Actinonaias pectorosa	R,M	Copper sulfate	170	24 hr		67		Jacobson et al. 1997
Freshwater mussel (released glochidia), Actinonaias pectorosa	R,M	Copper sulfate	140	24 hr		42		Jacobson et al. 1997
Freshwater mussel (released glochidia), Actinonaias pectorosa	R,M	Copper sulfate	170	48 hr		51		Jacobson et al. 1997
Freshwater mussel (1-2 d), Anodonta grandis	S,M,T	Copper sulfate	70	24 hr	LC50	44	-	Jacobson et al. 1993
Freshwater mussel (1-2 d), Anodonta imbecilis	S,M,T	Copper sulfate	39	48 hr	LC50	171	-	Keller and Zam 1991
Freshwater mussel (1-2 d), Anodonta imbecilis	S,M,T	Copper sulfate	90	48 hr	LC50	388	-	Keller and Zam 1991
Freshwater mussel (released glochidia), Lampsilis fasciola	R,M,T	Copper sulfate	170	24 hr		48		Jacobson et al. 1997
Freshwater mussel (released glochidia), Lampsilis fasciola	R,M,T	Copper sulfate	160	24 hr		26		Jacobson et al. 1997
Freshwater mussel (released glochidia), Lampsilis fasciola	R,M,T	Copper sulfate	75	24 hr		46		Jacobson et al. 1997

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Freshwater mussel (released glochidia), Lampsilis fasciola	R,M,T	Copper sulfate	170	48 hr		40		Jacobson et al. 1997
Freshwater mussel (released glochidia), Medionidus conradicus	R,M,T	Copper sulfate	185	24 hr		69		Jacobson et al. 1997
Freshwater mussel (released glochidia), Medionidus conradicus	R,M,T	Copper sulfate	185	24 hr		40		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	185	24 hr		37		Jacobson et al. 1997
Freshwater mussel (released glochidia), Medionidus conradicus	R,M,T	Copper sulfate	170	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), Medionidus conradicus	R,M,T	Copper sulfate	160	24 hr		41		Jacobson et al. 1997
Freshwater mussel (released glochidia), Medionidus conradicus	R,M,T	Copper sulfate	150	24 hr		81		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Medionidus conradicus</i>	R,M,T	Copper sulfate	170	48 hr		16		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Pygranodon grandis</i>	R,M,T	Copper sulfate	170	24 hr		>160		Jacobson et al. 1997
Freshwater mussel (released glochidia), Pygranodon grandis	R,M,T	Copper sulfate	170	24 hr		347		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Pygranodon grandis</i>	R,M,T	Copper sulfate	50	24 hr		46		Jacobson et al. 1997
Freshwater mussel (1-2 d), <i>Villosa iris</i>	S,M,T	Copper sulfate	190	24 hr	LC50	83	-	Jacobson et al. 1993
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	190	24 hr		80		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	190	24 hr		73		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	185	24 hr		65		Jacobson et al. 1997

Tippendix D. Other Data on Effects of Copper on Freshwater Organisms	Appendix I	B. Other	Data on	Effects of	<b>Copper on</b>	Freshwater	Organisms
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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	185	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	170	24 hr		75		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	160	24 hr		36		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	155	24 hr		39		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	155	24 hr		37		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	150	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	55	24 hr		55		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	55	24 hr		38		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	50	24 hr		71		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	160	24 hr		46		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	170	48 hr		66		Jacobson et al. 1997
Freshwater mussel (released glochidia), <i>Villosa iris</i>	R,M,T	Copper sulfate	150	48 hr		46		Jacobson et al. 1997
Zebra mussel (1.6-2.0 cm), Dreissena polymorpha	R,M,T	Copper chloride	268	9 wk	EC50 +F106(filtration rate)	43	-	Kraak et al. 1992

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	n Effect Total Concentration (μg/L) <sup>b</sup>		Dissolved Concentration (µg/L)	Reference
Zebra mussel (1.6-2.0 cm),	R,M,T	Copper	268	10 wk	NOEC	13	-	Kraak et al. 1993
Dreissena polymorpha		chloride			(filtration rate)	10		
Asiatic clam (1.0-2.1 cm), Coprbicula fluminea	S,M,I	sulfate	64	96 hr (24hr LC50 also reported)	LC50	40	-	Rodgers et al. 1980
Asiatic clam (1.0-2.1 cm), Coprbicula fluminea	F,M,T	Copper sulfate	64	96 hr (24 hr LC50 also reported)	LC50	490	-	Rodgers et al. 1980
Asiatic clam (juvenile), Corbicula fluminea	F,M,D	Copper sulfate	78	30 days	43.3% mortality	14.48	-	Belanger et al. 1990
Asiatic clam (juvenile), Corbicula fluminea	F,M,D	Copper sulfate	78	30 days	Stopped shell growth	8.75	-	Belanger et al. 1990
Asiatic clam (adult), Corbicula fluminea	F,M,D	Copper sulfate	78	30 days	13.3% mortality	14.48	-	Belanger et al. 1990
Asiatic clam (adult), Corbicula fluminea	F,M,D	Copper sulfate	71	30 days	25% mortality	16.88	-	Belanger et al. 1990
Asiatic clam (adult), Corbicula fluminea	F,M,D	Copper sulfate	78	30 days	Inhibited shell growth	8.75	-	Belanger et al. 1990
Asiatic clam (adult), Corbicula fluminea	F,M,D	Copper sulfate	-	15-16 days	LC50	-	-	Belanger et al. 1991
Asiatic clam (adult), Corbicula fluminea	F,M,D	Copper sulfate	-	19 days	LC100	-	-	Belanger et al. 1991
Asiatic clam (veliger larva), Corbicula manilensis	S,M,T	Copper chloride	-	24 hr	34% mortality	10	-	Harrison et al. 1981, 1984
Asiatic clam (juvenile), Corbicula manilensis	S,M,T	Copper chloride	17	24 hr	LC50	100	-	Harrison et al. 1984
Asiatic clam (veliger), Corbicula manilensis	S,M,T	Copper chloride	17	24 hr	LC50	28	-	Harrison et al. 1984
Asiatic clam (trochophore), Corbicula manilensis	S,M,T	Copper chloride	17	8 hr	LC100	7.7	-	Harrison et al. 1984
Asiatic clam (adult), Corbicula manilensis	F,M,T	Copper chloride	17	7 days	LC50	3,638	-	Harrison et al. 1981, 1984
Asiatic clam (adult), Corbicula manilensis	F,M,T	Copper chloride	17	42 days	LC50	12	-	Harrison et al. 1981, 1984
Asiatic clam (4.3 g adult), Corbicula manilensis	F,M,T	Copper chloride	17	30 days	LC50	11	-	Harrison et al. 1984
Cladoceran, Bosmina longirostrus	S, U	Copper sulfate	33.8		EC50	1.6		Koivisto et al. 1992
Cladoceran (<24 hr), Daphnia ambigua	S,U	Copper sulfate	145	72 hr	LC50	86.5	-	Winner and Farrell 1976
Cladoceran (<24 hr), Daphnia ambigua	S,U	Copper sulfate	145	Life span (ca. 5 wk)	Chronic limits (inst. rate of population growth)	50	-	Winner and Farrell 1976
Cladoceran, Ceriodaphnia dubia	S,U	Copper sulfate	188		EC50	36.6		Bright 1995

<b>Appendix B</b>	Other	Data on	Effects of	Copper on	Freshwater	Organisms
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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran, Ceriodaphnia dubia	S,U	Copper sulfate	204		EC50	19.1		Bright 1995
Cladoceran, Ceriodaphnia dubia	S,U	Copper sulfate	428		EC50	36.4		Bright 1995
Cladoceran, Ceriodaphnia dubia	S,U	Copper sulfate	410		EC50	11.7		Bright 1995
Cladoceran, Ceriodaphnia dubia	S,U	Copper sulfate	494		EC50	12.3		Bright 1995
Cladoceran, Ceriodaphnia dubia	S,U	Copper sulfate	440		EC50	12		Bright 1995
Cladoceran, Ceriodaphnia dubia	S,U	Copper chloride	90	1 hr	NOEC (ingestion)	30	-	Juchelka and Snell 1994
Cladoceran (<24 hr), Ceriodaphnia dubia	S,M,D	Copper sulfate	6-10	48 hr	LC50	-	2.72	Suedel et al. 1996
Cladoceran (<12 hr), <i>Ceriodaphnia dubia</i>	S,M,D	-	113.6	48 hr	LC50	-	52	Belanger and Cherry 1990
Cladoceran (<12 hr), <i>Ceriodaphnia dubia</i>	S,M,D	-	113.6	48 hr	LC50	-	76	Belanger and Cherry 1990
Cladoceran (<12 hr), <i>Ceriodaphnia dubia</i>	S,M,D	-	113.6	48 hr	LC50	-	91	Belanger and Cherry 1990
Cladoceran (<48 h), <i>Ceriodaphnia dubia</i>	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	9.5	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), <i>Ceriodaphnia dubia</i>	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	28	-	Schubauer-Berigan et al. 1993
Cladoceran (<48 h), <i>Ceriodaphnia dubia</i>	S,M,T	Copper nitrate	280 - 300	48 hr	LC50	200	-	Schubauer-Berigan et al. 1993
Cladoceran (<24 hr), <i>Ceriodaphnia dubia</i>	S,M,T,D	Copper nitrate	100	48 hr	LC50	66	60.72	Spehar and Fiandt 1986
Cladoceran, <i>Ceriodaphnia dubia</i>	R,U	Copper nitrate	111	10 days	LC50	53	-	Cowgill and Milazzo 1991a
Cladoceran, Ceriodaphnia dubia	R,U	Copper nitrate	111	10 days	NOEC (reproduction)	96	-	Cowgill and Milazzo 1991a
Cladoceran, Ceriodaphnia dubia	R,U	Copper sulfate	90	-	LOEC (reproduction)	44	-	Zuiderveen and Birge 1997
Cladoceran, <i>Ceriodaphnia dubia</i>	R,U	Copper sulfate	90	-	LOEC (reproduction)	40	-	Zuiderveen and Birge 1997
Cladoceran, <i>Ceriodaphnia dubia</i>	R,M,T	-	20	-	IC50 (reproduction)	5	-	Jop et al. 1995
Cladoceran (<24 hrs), <i>Ceriodaphnia reticulata</i>	S, U	Copper chloride	240		EC50	23		Elnabarawy et al. 1986
Cladoceran, <i>Ceriodubia reticulata</i>	S,U	-	43-45		EC50	17		Mount and Norberg 1984
Cladoceran, Daphnia magna	-	Copper sulfate	-	72 hr	EC50 (mobility; 10 <sup>0</sup> C)	61	-	Braginskij and Shcherben 1978

cies	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect Total Concentration (µg/L) <sup>b</sup>		Dissolved Concentration (µg/L)	Reference
Cladoceran,	-	Copper	-	72 hr	EC50	70	-	Braginskij and Shcherben 1978
Daphnia magna		sulfate			(mobility; 15 <sup>v</sup> C)			
Cladoceran,	-	Copper	-	72 hr	EC50	21	-	Braginskij and Shcherben 1978
Daphnia magna		sulfate			(mobility; 20 <sup>0</sup> C)			
Cladoceran,	-	Copper	-	72 hr	EC50	9.3	-	Braginskij and Shcherben 1978
Daphnia magna		sulfate			(mobility; 30 <sup>0</sup> C)			
Cladoceran,	S,U	Copper	-	16 hr	EC 50	38	-	Anderson 1944
Daphnia magna		sulfate			(mobility)			
Cladoceran (<8 hr),	S,U	Copper	-	64 hr	Immobilization threshold	12.7	-	Anderson 1948
Daphnia magna		chloride						
Cladoceran (1 mm),	S,U	Copper	100	24 hr	EC 50	50	-	Bellavere and Gorbi 1981
Daphnia magna	0.11	nitrate		0.1.1	(mobility)	70		
Cladoceran (1 mm),	S,U	Copper	200	24 nr	EC 50	70	-	Bellavere and Gorbi 1981
Daphnia magna	0.11	nitrate	100	40 hz	(mobility)	054		Descrete and Delah 4002
Cladoceran,	5,0	-	100	48 nr	EC50 (mobility)	254	-	Borgmann and Raiph 1983
Cladagoran	011		100	40 hr		1 0 2 0		December and Delph 1082
Danhnia magna	3,0	-	100	49 11	EC30 (mobility)	1,239	-	Borginarin and Raiph 1965
Cladoceran	511	Conner	45	48 hr	EC50	90	_	Cairns et al. 1978
Danhnia magna	0,0	sulfate		40 11	$(mobility; f^0 C)$	50	_	
Cladoceran	511	Copper	45	/8 hr	EC50	70	_	Cairps et al. 1978
Danhnia magna	5,0	sulfate	40	40 11	$(mobility: 10^{\circ} C)$	70	-	
Cladocoran	811	Coppor	45	48 br		40		Cairps at al. 1078
Danhnia magna	3,0	sulfate	45	40 11	$(mobility, 15^{\circ} C)$	40	-	Callins et al. 1970
Cladageran	011	Connor	45	40 hr		7		Cairpa at al. 1079
Danhnia magna	5,0	Copper	45	40 11		/	-	Calms et al. 1976
	0.11	Suilate		04 hr	(mobility; 25°C)	50		Formanda and Andrew 1002
Cladoceran (4 days),	5,0	Copper	-	24 nr	EC50	59	-	Ferrando and Andreu 1993
Cladagoran (24, 49 hr)	811	Connor	00	24 br		290		Forrando et al. 1002
Danhnia magna	3,0	culfato	90	24 11	EC30 (mobility)	360	-	Ferrarido et al. 1992
Cladoceran	511	Copper	50		EC50	7		Oikari et al. 1992
Danhnia magna	5,0	sulfate	50		LC30	/		
Cladoceran	SU	Copper	_	48 hr	EC:50	45	_	Oikari et al. 1992
Daphnia magna	0,0	sulfate		40 11	(mobility)	40		
Cladoceran (<24 hr).	S.U	Copper	145	Life span	Chronic limits	70	-	Winner and Farrell 1976
Daphnia magna	-,-	sulfate		(ca. 18 wk)	(inst. rate of population growth)			
Cladoceran (<24 hrs),	S,M,D	Copper	72-80	48 hr	LC50	-	11.3	Suedel et al. 1996
Daphnia magna		sulfate						
Cladoceran (<24 hrs),	S,M,I	-	180	-	LC50	55.3	-	Borgmann and Charlton 1984
Daphnia magna								
Cladoceran (<24 hr),	S,M,I	Copper	100	48 hr	EC50	46.0	-	Meador 1991
Daphnia magna		sulfate			(mobility)			
Cladoceran (<24 hr),	S,M,I	Copper	100	48 hr	EC50	57.2	-	Meador 1991
Daphnia magna		sulfate			(mobility)			

Appendix B.	Other <b>D</b>	Data on	Effects of	Copper on	Freshwater	Organisms
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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr),	S,M,I	Copper	100	48 hr	EC50	67.8	-	Meador 1991
Daphnia magna		sulfate			(mobility)			
Cladoceran (<24 hr),	S,M,T	Copper	100	72 hr	EC50	52.8	-	Winner 1984b
Daphnia magna		sulfate			(mobility)			
Cladoceran (<24 hr),	S,M,T	Copper	100	72 hr	EC50	56.3	-	Winner 1984b
Daphnia magna		sulfate			(mobility)			
Cladoceran (<24 hr),	S,M,T	Copper	85	96 hr	EC50	130	-	Blaylock et al. 1985
Daphnia magna		chloride			(mobility)			
Cladoceran (24 hr),	R,U	Copper	-	48 hr	EC50	18	-	Kazlauskiene et al. 1994
Daphnia magna		sulfate			(mobility)			
Cladoceran (<24 hr),	S,U	Copper	145	72 hr	EC50	72	-	Winner and Farrell 1976
Daphnia parvula		sulfate			(mobility)			
Cladoceran (<24 hr),	S,U	Copper	145	72 hr	EC50	57	-	Winner and Farrell 1976
Daphnia parvula		sulfate			(mobility)			
Cladoceran (<24 hr),	S,U	Copper	145	Life span	Chronic limits (inst. rate of population	50	-	Winner and Farrell 1976
Daphnia parvula		sulfate		(ca. 10 wk)	growth)			
Cladoceran,	S,U	Copper	45		EC50	10		Cairns et al. 1978
Daphnia pulex		sulfate						
Cladoceran,	S,U	-	45		EC50	53		Mount and Norberg 1984
Daphnia pulex								
Cladoceran (<24 hrs),	S, U	Copper	240		EC50	31		Elnabarawy et al. 1986
Daphnia pulex		chloride						
Cladoceran (<24 hrs),	S, U	Copper	33.8		EC50	3.6		Koivisto et al. 1992
Daphnia pulex		sulfate						
Cladoceran (<24 hrs),	S,U	Copper	80-90		EC50	18		Roux et al. 1993
Daphnia pulex		chloride						
Cladoceran (<24 hrs),	S,U	Copper	80-90		EC50	24		Roux et al. 1993
Daphnia pulex		chloride						
Cladoceran (<24 hrs),	S,U	Copper	80-90		EC50	22		Roux et al. 1993
Daphnia pulex		chloride						
Cladoceran (<24 hr),	S,U	Copper	145	72 hr	EC50	86	-	Winner and Farrell 1976
Daphnia pulex		sulfate			(mobility)			
Cladoceran (<24 hr),	S,U	Copper	145	72 hr	EC50	54	-	Winner and Farrell 1976
Daphnia pulex		sulfate			(mobility)			
Cladoceran (<24 hr),	S,U	Copper	145	Life span	Chronic limits (inst. rate of population	50	-	Winner and Farrell 1976
Daphnia pulex		sulfate		(ca. 7 wk)	growth)			
Cladoceran,	S,U	Copper	45	48 hr	EC50	70	-	Cairns et al. 1978
Daphnia pulex		sulfate			(mobility)			
Cladoceran,	S,U	Copper	45	48 hr	EC50	60	-	Cairns et al. 1978
Daphnia pulex		sulfate			(mobility)			
Cladoceran,	S,U	Copper	45	48 hr	EC50	20	-	Cairns et al. 1978
Daphnia pulex		sulfate			(mobility)			
Cladoceran,	S,U	Copper	45	48 hr	EC50	56	-	Cairns et al. 1978
Daphnia pulex		sulfate			(mobility)			

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran (<24 hr),	S,U	Copper	200	24 hr	EC50	37.5	-	Lilius et al. 1995
Daphnia pulex		sulfate	100		(mobility)			
Cladoceran,	S,M,I	Copper	106	48 hr	EC50	29	-	Ingersoll and Winner 1982
Daphnia pulex		sulfate	100	101	(mobility)			
Cladoceran,	S,M,I	Copper	106	48 hr	EC50	20	-	Ingersoll and Winner 1982
Daphnia pulex		sulfate			(mobility)			
Cladoceran,	S,M,T	Copper	106	48 hr	EC50	25	-	Ingersoll and Winner 1982
Daphnia pulex		sulfate			(mobility)	-		-
Cladoceran,	R,U	Copper	85	21 days	Reduced fecundity	3	-	Roux et al. 1993
Daphnia pulex		sulfate						
Cladoceran,	R,M,T	Copper	106	70 days	Significantly shortened life span;	20	-	Ingersoll and Winner 1982
Daphnia pulex		sulfate			reduced brood size			
Cladoceran,	S,M,T	-	31	48 hr	EC50	55.4	-	Lind et al. manuscript
Daphnia pulicaria	_				(mobility; TOC=14 mg/L)			
Cladoceran,	S,M,T	-	29	49 hr	EC50	55.3	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=13 mg/L)			
Cladoceran,	S,M,T	-	28	50 hr	EC50	53.3	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=13 mg/L)			
Cladoceran,	S,M,T	-	28	50 hr	EC50	97.2	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=28 mg/L)			
Cladoceran,	S,M,T	-	100	51 hr	EC50	199	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=34 mg/L)			
Cladoceran,	S,M,T	-	86	52 hr	EC50	627	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=34 mg/L)			
Cladoceran,	S,M,T	-	84	53 hr	EC50	165	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=32 mg/L)			
Cladoceran,	S,M,T	-	16	54 hr	EC50	35.5	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=12 mg/L)			
Cladoceran,	S,M,T	-	151	55 hr	EC50	78.8	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=13 mg/L)			
Cladoceran,	S,M,T	-	96	56 hr	EC50	113	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=28 mg/L)			
Cladoceran,	S,M,T	-	26	57 hr	EC50	76.4	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=25 mg/L)			
Cladoceran,	S,M,T	-	84	58 hr	EC50	84.7	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=13 mg/L)			
Cladoceran,	S,M,T	-	92	59 hr	EC50	184	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=21 mg/L)			
Cladoceran,	S,M,T	-	106	60 hr	EC50	240	-	Lind et al. manuscript
Daphnia pulicaria					(mobility; TOC=34 mg/L)			
Cladoceran,	S,M,T	Copper	106	48 hr	LC50	240	-	Lind et al. manuscript
Daphnia pulicaria		sulfate						
Cladoceran,	S,M,T	Copper	8	24 hr	EC50	12	-	Giesy et al. 1983
Simocephalus serrulatus		nitrate			(mobility; TOC=11 mg/L)			

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Cladoceran, Simocephalus serrulatus	S,M,T	Copper	16	25 hr	EC50 (mobility: TOC=12.4 mg/L)	7.2	-	Giesy et al. 1983
Cladaaaran	SMT	Connor	16	26 hr		24.5		Cient et al. 1982
Simocenhalus serrulatus	5,IVI, I	copper	10	2011	(mobility: TOC=15.6 mg/l.)	24.0	-	Glesy et al. 1905
Cladoceran (<24 hr)	511	-	45		(mobility, 100–13.0 mg/L)	57		Mount and Norberg 1984
Simocenhalus vetulus	5,0	-	40			57		
Cladoceran (life cycle)	RII	Conner	_	13 days	LOEC	18	_	Koivisto and Ketola 1995
Bosmina longirostris	1,0	sulfate		10 0033	(intrinsic rate of population increase)	10		
Copepods (mixed sp), Primarily <i>Acanthocyclops</i> <i>vernalis</i> and <i>Diacyclops thomasi</i>	R,M,I	Copper chloride	-	1 wk	EC20 (growth)	42	-	Borgmann and Ralph 1984
Copepod (adults and copepodids V), Tropocyclops prasinus mexicanus	S, U	Copper sulfate	10			29		Lalande and Pinel-Alloul 1986
Copepod (adults and copepodids V), Tropocyclops prasinus mexicanus	S, U	Copper sulfate	10	96 hr	LC50	247	-	Lalande and Pinel-Alloul 1986
Amphipod (0.4 cm),	R,U	Copper	45-55			1290		Martin and Holdich 1986
Amphipod (4 mm), Crangonyx psuedogracilis	R,U	Copper	50	48 hr	LC50	2,440	-	Martin and Holdich 1986
Amphipod, Gammarus fasciatus	S,U	Copper	206	48 hr	LC50	210	-	Judy 1979
Amphipod, Gammarus lacustris	S,U	Copper sulfate	-	96 hr	LC50	1,500	-	Nebeker and Gaufin 1964
Amphipod (2-3 wk), <i>Hvallela azteca</i>	S,M,T	Copper sulfate	6-10	-	LC50	65.6	-	Suedel et al. 1996
Amphipod (0-1 wk), Hyallela azteca	R,M,T	Copper nitrate	130	10 wk	Significant mortality	25.4	-	Borgmann et al. 1993
Amphipod (7-14 days), Hyallela azteca	F,M,T	Copper sulfate	46	10 days	LC50	31	-	West et al. 1993
Crayfish (intermoult adult, 19.6 g), <i>Cambarus robustus</i>	S,M,D	-	10-12	96 hr	LC50	-	830	Taylor et al. 1995
Crayfish (1.9-3.2 cm), Orconectes limosus	S,M,T	Copper chloride	-	96 hr	LC50	600	-	Boutet and Chaisemartin 1973
Crayfish (3.0-3.5 cm), Orconectes rusticus	F,U	Copper sulfate	100-125			3,000		Hubschman 1967
Crayfish (embryo), Orconectes rusticus	F,U	Copper sulfate	113	2 wk	52% mortality of newly hatched young	250	-	Hubschman 1967

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Crayfish (3.14 mg dry wt.), Orconectes rusticus	F,U	Copper sulfate	113	2 wk	23% reduction in growth	15	-	Hubschman 1967
Crayfish (30-40 mm), <i>Orconectes</i> sp.		-	113	48 hr	LC50	2,370	-	Dobbs et al. 1994
Crayfish, Procambarus clarkii	F,M,T	Copper chloride	17	1358 hr	LC50	657	-	Rice and Harrison 1983
Mayfly (6th-8th instar), <i>Stenonema</i> sp.	S,M,T	-	110	48 hr	LC50	453	-	Dobbs et al. 1994
Mayfly, Cloeon dipterium	-	Copper sulfate	-	72 hr	LC50 (10 <sup>0</sup> C)	193	-	Braginskij and Shcherban 1978
Mayfly, Cloeon dipterium	-	-	-	72 hr	LC50 (15 <sup>0</sup> C)	95.2	-	Braginskij and Shcherban 1978
Mayfly, Cloeon dipterium	-	-	-	72 hr	LC50 (25 <sup>0</sup> C)	53	-	Braginskij and Shcherban 1978
Mayfly, Cloeon dipterium	-	-	-	72 hr	LC50 (30 <sup>0</sup> C)	4.8	-	Braginskij and Shcherban 1978
Mayfly, Ephemerella grandis	F,M,T	Copper sulfate	50	14 days	LC50	180-200	-	Nehring 1976
Mayfly, Ephemerella subvaria	S,M	Copper sulfate	44	48 hr	LC50	320	-	Warnick and Bell 1969
Mayfly (6th-8th instar), Isonychia bicolor	S,M,T	-	110	48 hr	LC50	223	-	Dobbs et al. 1994
Stonefly, Pteronarcys californica	F,M,T	Copper sulfate	50	14 days	LC50	12,000	-	Nehring 1976
Caddisfly, <i>Hydropsyche betteni</i>	S,M,T	Copper sulfate	44	14 days	LC50	32,000	-	Warnick and Bell 1969
Midge (2nd instar), Chironomus riparius	S,M,T	-	110	48 hr	LC50	1,170	-	Dobbs et al. 1994
Midge (1st instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	42.7			16.7		Gauss et al. 1985
Midge (1st instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	109.6			36.5		Gauss et al. 1985
Midge (1st instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	172.3			98.2		Gauss et al. 1985
Midge (4th instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	42.7			211		Gauss et al. 1985
Midge (4th instar), <i>Chironomus tentans</i>	S,U	Copper sulfate	109.6			977		Gauss et al. 1985
Midge (4th instar), Chironomus tentans	S,U	Copper sulfate	172.3			1184		Gauss et al. 1985
Midge, Chironomus tentans	S,U	Copper sulfate	25			327		Khangarot and Ray 1989
Midge (2nd instar), Chironomus tentans	S,M,T	Copper sulfate	8	96 hr	LC50	630	-	Suedel et al. 1996

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Midge (4th instar), Chironomus tentans	F,M,T	Copper chloride	36	20 days	LC50	77.5	-	Nebeker et al. 1984b
Midge (embryo), Tanytarsus dissimilis	S,M,T	Copper chloride	46.8	10 days	LC50	16.3	-	Anderson et al. 1980
Midge, Unidentified	F,M,T,D	Copper sulfate	200	32 wk	Emergence	30	-	Hedtke 1984
Bryozoan (2-3 day ancestrula), Lophopodella carteri	S,U	-	190-220			510		Pardue and Wood 1980
Bryozoan (2-3 day ancestrula), Pectinatella magnifica	S,U	-	190-220			140		Pardue and Wood 1980
Bryozoan (2-3 day ancestrula), <i>Plumatella emarginata</i>	S,U	-	190-220			140		Pardue and Wood 1980
American eel (5.5 cm glass eel stage), <i>Anguilla rostrata</i>	S,U	Copper sulfate	40-48	96 hr	LC50	2,540		Hinton and Eversole 1978
American eel (9.7 cm black eel stage), <i>Anguilla rostrata</i>	S,U	Copper sulfate	40-48	96 hr	LC50	3,200		Hinton and Eversole 1979
American eel, Anguilla rostrata	S,M,T	Copper nitrate	53	96 hr	LC50	6,400	-	Rehwoldt et al. 1971
American eel, Anguilla rostrata	S,M,T	Copper nitrate	55	96 hr	LC50	6,000	-	Rehwoldt et al. 1972
Arctic grayling (larva), Thymallus arcticus	S,U	Copper sulfate	41.3	96 hr	LC50	67.5		Buhl and Hamilton 1990
Arctic grayling (larva), Thymallus arcticus	S,U	Copper sulfate	41.3	96 hr	LC50	23.9		Buhl and Hamilton 1990
Arctic grayling (larva), Thymallus arcticus	S,U	Copper sulfate	41.3	96 hr	LC50	131		Buhl and Hamilton 1990
Arctic grayling (swim-up), Thymallus arcticus	S,U	Copper sulfate	41.3	96 hr	LC50	9.6		Buhl and Hamilton 1990
Arctic grayling (0.20 g juvenile), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	2.7		Buhl and Hamilton 1990
Arctic grayling (0.34 g juvenile), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	2.58		Buhl and Hamilton 1990
Arctic grayling (0.81 g juvenile), <i>Thymallus arcticus</i>	S,U	Copper sulfate	41.3	96 hr	LC50	49.3		Buhl and Hamilton 1990
Arctic grayling (0.85 g juvenile), Thymallus arcticus	S,U	Copper sulfate	41.3	96 hr	LC50	30		Buhl and Hamilton 1990
Coho salmon (larva), Oncorhynchus kisutch	S,U	Copper sulfate	41.3	96 hr	LC50	21		Buhl and Hamilton 1990
Coho salmon (larva), Oncorhynchus kisutch	S,U	Copper sulfate	41.3	96 hr	LC50	19.3		Buhl and Hamilton 1990
Coho salmon (0.41 g juvenile), Oncorhynchus kisutch	S,U	Copper sulfate	41.3	96 hr	LC50	15.1		Buhl and Hamilton 1990

<b>Appendix B</b>	Other	Data on	Effects of	Copper on	Freshwater	Organisms
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Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Coho salmon (0.47 g juvenile), Oncorhynchus kisutch	S,U	Copper sulfate	41.3	96 hr	LC50	23.9		Buhl and Hamilton 1990
Coho salmon (0.87 g juvenile), Oncorhynchus kisutch	S,U	Copper sulfate	41.3	96 hr	LC50	31.9		Buhl and Hamilton 1990
Coho salmon (10 cm), Oncorhynchus kisutch	S,U	Copper sulfate	-	72 hr	LC50	280	-	Holland et al. 1960
Coho salmon (9.7 cm), Oncorhynchus kisutch	S,U	Copper sulfate	-	72 hr	LC50	190	-	Holland et al. 1960
Coho salmon (9.7 cm), Oncorhynchus kisutch	S,U	Copper sulfate	-	72 hr	LC50	480	-	Holland et al. 1960
Coho salmon (juvenile), Oncorhynchus kisutch	R,M,T,I	-	33	96 hr	LC50 (TOC=7.3 mg/L)	164	-	Buckley 1983
Coho salmon (juvenile), Oncorhynchus kisutch	R,M,T,I	-	33	96 hr	LC50	286		Buckley 1983
Coho salmon (6.3 cm), Oncorhynchus kisutch	F,U	Copper sulfate	-	30 days	LC50	360	-	Holland et al. 1960
Coho salmon (6.3 cm), Oncorhynchus kisutch	F,U	Copper sulfate	-	72 hr	LC50	370	-	Holland et al. 1960
Coho salmon (smolts), Oncorhynchus kisutch	F,M,T	Copper chloride	91	144 hr	Decrease in survival upon transfer to 30 ppt seawater	20	-	Lorz and McPherson 1976
Coho salmon (smolts >10 cm), Oncorhynchus kisutch	F,M,T	Copper chloride	91	165 days	Decrease in downstream migration after release	5	-	Lorz and McPherson 1976
Coho salmon (7.8 cm), Oncorhynchus kisutch	F,M,T	Copper acetate	276	14 wk	15% reduction in growth	70	-	Buckley et al. 1982
Coho salmon (7.8 cm), Oncorhynchus kisutch	-	-	276	7 days	LC50	220	-	Buckley et al. 1982
Coho salmon (3-8 g), Oncorhynchus kisutch	F,M,T	Copper acetate	280	7 days	LC50	275	-	McCarter and Roch 1983
Coho salmon (3-8 g), Oncorhynchus kisutch	F,M,T	Copper acetate	280	7 days	LC50 (acclimated to copper for 2 wk)	383	-	McCarter and Roch 1983
Coho salmon (parr), O <i>ncorhynchus kisutch</i>	F,M,T,D,I	-	24.4	61 days	NOEC (growth and survival)	22	-	Mudge et al. 1993
Coho salmon, Oncorhynchus kisutch	F,M,T,D,I	-	31.1	60 days	NOEC (growth and survival)	18	-	Mudge et al. 1993
Coho salmon (parr), Oncorhynchus kisutch	F,M,T,D,I	-	31	61 days	NOEC (growth and survival)	33	-	Mudge et al. 1993
Rainbow trout (15-40g) Oncorhynchus mykiss	F,M,	Copper chloride		120 hr	LA50 (50% mortality)	~1.4 ug Cu/g gill	-	MacRae et al. 1999
Sockeye salmon (yeasrling), Oncorhynchus nerka	S,U	Copper sulfate	12	1-24 hr	Drastic increase in plasma corticosteroids	64	-	Donaldson and Dye 1975
Sockeye salmon (fry, 0.132 g, 2.95 cm), Oncorhynchus nerka	R,M,T	Copper chloride	36-46	96 hr	LC50	220	-	Davis and Shand 1978

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Sockeye salmon (fry, 0.132 g, 2.95 cm), Oncorhynchus nerka	R,M,T	Copper chloride	36-46	96 hr	LC50	210	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), <i>Oncorhynchus nerka</i>	R,M,T	Copper chloride	36-46	96 hr	LC50	240	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), Oncorhynchus nerka	R,M,T	Copper chloride	36-46	96 hr	LC50	103	-	Davis and Shand 1978
Sockeye salmon (fry, 0.132 g, 2.95 cm), <i>Oncorhynchus nerka</i>	R,M,T	Copper chloride	36-46	96 hr	LC50	240	-	Davis and Shand 1978
Chinook salmon (18-21 weeks), Oncorhynchus tshawytscha	S,U	Copper sulfate	211	96 hr	LC50	58		Hamilton and Buhl 1990
Chinook salmon (18-21 weeks), Oncorhynchus tshawytscha	S,U	Copper sulfate	211	96 hr	LC50	54		Hamilton and Buhl 1990
Chinook salmon (18-21 weeks), Oncorhynchus tshawytscha	S,U	Copper sulfate	343	96 hr	LC50	60		Hamilton and Buhl 1990
Chinook salmon (5.2 cm), Oncorhynchus tshawytscha	S,U	Copper nitrate	-	5 days	LC50	178	-	Holland et al. 1960
Chinook salmon (eyed embryos) Oncorhynchus tshawytscha	F,M,D	Copper sulfate	44	26 days	93% mortality	41.67	-	Hazel and Meith 1970
Chinook salmon (alevin), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC50	20	-	Chapman 1978
Chinook salmon (alevin), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC10	15	-	Chapman 1978
Chinook salmon (swimup), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC50	19	-	Chapman 1978
Chinook salmon (swimup), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC10	14	-	Chapman 1978
Chinook salmon (parr), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC50	30	-	Chapman 1978
Chinook salmon (parr), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC10	17	-	Chapman 1978
Chinook salmon (smolt), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC50	26	-	Chapman 1978
Chinook salmon (smolt), Oncorhynchus tshawytscha	F,M,T	Copper chloride	23	200 hr	LC10	18	-	Chapman 1978
Chinook salmon (3.9-6.8 cm), Oncorhynchus tshawytscha	F,M,T	Copper sulfate	20-22	96 hr	LC50	32	-	Finiayson and Verrue 1982
Cutthroat trout (3-5 mo), Oncorhynchus clarki	F,M	Copper chloride	50	20 min	avoidance of copper	7.708	-	Woodward et al. 1997

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout, Oncorhynchus mykiss	-	-	320	48 hr	LC50	500	-	Brown 1968
Rainbow trout (9-16 cm), Oncorhynchus mykiss	In situ	-	21-26	48 hr	LC50	70	-	Calamari and Marchetti 1975
Rainbow trout (0.4 g), Oncorhynchus mykiss	S,U	Copper sulfate	-	96 hr	LC50	185	-	Bills et al. 1981
Rainbow trout (larva), Oncorhynchus mykiss	S, U	Copper sulfate	41.3	96 hr	LC50	36		Buhl and Hamilton 1990
Rainbow trout (0.60 g juvenile), Oncorhynchus mykiss	S, U	Copper sulfate	41.3	96 hr	LC50	13.8		Buhl and Hamilton 1990
Rainbow trout (13-15 cm), Oncorhynchus mykiss	S,U	Copper sulfate	250	72 hr	LC50	580	-	Brown et al. 1974
Rainbow trout (13-15 cm), Oncorhynchus mykiss	S,U	Copper sulfate	250	72 hr	LC50	960	-	Brown et al. 1974
Rainbow trout (3.2 cm), Oncorhynchus mykiss	S,U	Copper sulfate	-	24 hr	LC50	140	-	Shaw and Brown 1974
Rainbow trout (3.2 cm), Oncorhynchus mykiss	S,U	Copper sulfate	-	24 hr	LC50	130	-	Shaw and Brown 1974
Rainbow trout (4.0-10.6 cm), Oncorhynchus mykiss	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>0</sup> C)	950	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), Oncorhynchus mykiss	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>0</sup> C)	430	-	Cairns et al. 1978
Rainbow trout (4.0-10.6 cm), Oncorhynchus mykiss	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>0</sup> C)	150	-	Cairns et al. 1978
Rainbow trout (0.52-1.55 g), Oncorhynchus mykiss	S,U	Copper sulfate	-	96 hr	LC50 (Silver Cup diet)	23.9	-	Marking et al. 1984
Rainbow trout (0.41-2.03 g), Oncorhynchus mykiss	S,U	Copper sulfate	-	96 hr	LC50 (purified H440)	11.3	-	Marking et al. 1984
Rainbow trout (0.0.40-1.68 g), Oncorhynchus mykiss	S,U	Copper sulfate	-	96 hr	LC50 (SD-9 diet)	15.9	-	Marking et al. 1984
Rainbow trout (0.0.34-1.52 g), Oncorhynchus mykiss	S,U	Copper sulfate	-	96 hr	LC50 (liver diet)	14.3	-	Marking et al. 1984
Rainbow trout (0.0.38-1.30 g), Oncorhynchus mykiss	S,U	Copper sulfate	-	96 hr	LC50 (brine shrimp diet)	11.3	-	Marking et al. 1984
Rainbow trout (embryo), Oncorhynchus mykiss	S,U	Copper chloride	30	56 hr	LC50	100	-	Rombough 1985
Rainbow trout (6.6 cm), Oncorhynchus mykiss	R,U	Copper sulfate	320	72 hr	LC50	1,100	-	Lloyd 1961
Rainbow trout (6.6 cm), Oncorhynchus mykiss	R,U	Copper sulfate	17.5	7 days	LC50	44	-	Lloyd 1961
Rainbow trout, Oncorhynchus mykiss	R,U	Copper sulfate	320	48 hr	LC50	270	-	Herbert and Vandyke 1964
Rainbow trout (yearling), Oncorhynchus mykiss	R,U	Copper sulfate	240	48 hr	LC50	750	-	Brown and Dalton 1970

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout (13-15 cm), Oncorhynchus mykiss	R,U	Copper sulfate	250	8 days	LC50	500	-	Brown et al. 1974
Rainbow trout (embryo), Oncorhynchus mykiss	R,U	Copper sulfate	104	28 days	LC50	90	-	Birge 1978; Birge et al. 1978
Rainbow trout (embryo), Oncorhynchus mykiss	R,U	Copper sulfate	101	28 days	EC50 (death or deformity)	110	-	Birge et al. 1980; Birge and Black 1979
Rainbow trout (embryo), Oncorhynchus mykiss	R,U	Copper sulfate	101	28 days	EC10 (death or deformity)	16.5	-	Birge et al. 1980
Rainbow trout (eyed embryos), Oncorhynchus mykiss	R,U	Copper sulfate	-	96 hr	LC50	1,150	-	Kazlauskiene et al. 1994
Rainbow trout (larva), Oncorhynchus mykiss	R,U	Copper sulfate	-	96 hr	LC50	430	-	Kazlauskiene et al. 1994
Rainbow trout (16-18 cm), Oncorhynchus mykiss	R,U	Copper sulfate	-	96 hr	LC50	930	-	Kazlauskiene et al. 1994
Rainbow trout (embryo), Oncorhynchus mykiss	R,M,T	Copper sulfate	62.9	7-9 mo	Lesions in olfactory rosettes	22	-	Saucier et al. 1991b
Rainbow trout (embryo), Oncorhynchus mykiss	R,M,T	Copper sulfate	62.9	7-9 mo	31% mortality	22	-	Saucier et al. 1991b
Rainbow trout (eyed embryos), Oncorhynchus mykiss	R,M,T	Copper sulfate	40-48	96 hr	LC50	400	-	Giles and Klaverkamp 1982
Rainbow trout (yearling), Oncorhynchus mykiss	R,M,T	Copper sulfate	36.5	21 days	Elevated plasma cortisol returned to normal	45	-	Munoz et al. 1991
Rainbow trout (embryo), Oncorhynchus mykiss	R,M,T	Copper sulfate	44	96 hr	15-20% post-hatch mortality	80	-	Giles and Klaverkamp 1982
Rainbow trout (embryo), Oncorhynchus mykiss	R,M,T	Copper sulfate	62.9	7-9 mo	Inhibited olfactory discrimination	22	-	Saucier et al. 1991a
Rainbow trout (5.1-7.6 cm), Oncorhynchus mykiss	F,U	Copper nitrate	-	96 hr	LC50	253	-	Hale 1977
Rainbow trout (11 cm), Oncorhynchus mykiss	F,U	-	100	96 hr	LC50	250	-	Goettl et al. 1972
Rainbow trout (5 wk post swimup) <i>Oncorhynchus mykis</i> s	F,U	Copper sulfate	89.5	1 hr	Avoidance	10	-	Folmar 1976
Rainbow trout (18.5-26.5 cm), Oncorhynchus mykiss	F,U	Copper sulfate	90	2 hr	55% depressed olfactory response	50	-	Hara et al. 1976
Rainbow trout (3.2 cm), Oncorhynchus mykiss	F,M,I	Copper sulfate	-	8 days	LC50	500	-	Shaw and Brown 1974
Rainbow trout (12-16 cm), Oncorhynchus mykiss	F,M,T	Copper sulfate	300	14 days	LC50	870	-	Calamari and Marchetti 1973
Rainbow trout (adult), Oncorhynchus mykiss	F,M,T	Copper chloride	42	-	LC50	57	-	Chapman 1975, Chapman and Stevens 1978
Rainbow trout (53.5 g), Oncorhynchus mykiss	F,M,T	Copper sulfate	365	96 hr	LC50	465	-	Lett et al. 1976

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout (53.5 g), Oncorhynchus mykiss	F,M,T	Copper sulfate	365	15 days	Transient decrease in food consumption	100	-	Lett et al. 1976
Rainbow trout (alevin).	F.M.T	Copper	24	200 hr	LC50	20	-	Chapman 1978
Oncorhynchus mykiss	. ,,.	chloride						
Rainbow trout (alevin),	F,M,T	Copper	24	200 hr	LC10	19	-	Chapman 1978
Oncorhynchus mykiss		chloride						
Rainbow trout (swimup),	F,M,T	Copper	24	200 hr	LC50	17	-	Chapman 1978
Oncorhynchus mykiss		chloride						
Rainbow trout (swimup).	F.M.T	Copper	24	200 hr	LC10	9	-	Chapman 1978
Oncorhynchus mykiss	, ,	chloride				-		
Rainbow trout (parr),	F,M,T	Copper	25	200 hr	LC50	15	-	Chapman 1978
Oncorhynchus mykiss		chloride						
Rainbow trout (parr),	F,M,T	Copper	25	200 hr	LC10	8	-	Chapman 1978
Oncorhynchus mykiss		chloride						
Rainbow trout (smolt),	F,M,T	Copper	25	200 hr	LC50	21	-	Chapman 1978
Oncorhynchus mykiss		chloride						
Rainbow trout (smolt),	F,M,T	Copper	25	200 hr	LC10	7	-	Chapman 1978
Oncorhynchus mykiss		chloride						
Rainbow trout,	F,M,T	Copper	112.4	80 min	Avoidance threshold	74	-	Black and Birge 1980
Oncorhynchus mykiss		sulfate						, i i i i i i i i i i i i i i i i i i i
Rainbow trout (>8 g),	F,M,T	Copper	49	15-18 days	LC50	48	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate		-				
Rainbow trout (>8 g),	F,M,T	Copper	51	15-18 days	LC50	46	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate		-				
Rainbow trout (>8 g),	F,M,T	Copper	57	15-18 days	LC50	63	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate						
Rainbow trout (>8 g),	F,M,T	Copper	12	15-18 days	LC50	19	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate						
Rainbow trout (>8 g),	F,M,T	Copper	99	15-18 days	LC50	54	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate						
Rainbow trout (>8 g),	F,M,T	Copper	98	15-18 days	LC50	78	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate						
Rainbow trout (>8 g),	F,M,T	Copper	12	15-18 days	LC50	18	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate						
Rainbow trout (>8 g),	F,M,T	Copper	97	15-18 days	LC50	96	-	Miller and MacKay 1980
Oncorhynchus mykiss		sulfate						
Rainbow trout (200-250 g),	F,M,T	Copper	320	4 mo	Altered liver and blood enzymes and	30	-	Arillo et al. 1984
Oncorhynchus mykiss		sulfate			mitochondrial function			
Rainbow trout (7 cm),	F,M,T	Copper	28.4	20 min	Avoidance	6.4	-	Giattina et al. 1982
Oncorhynchus mykiss		chloride						
Rainbow trout (2.70 g),	F,M,T	Copper	9.2	96 hr	LC50	4.2	-	Cusimano et al. 1986
Oncorhynchus mykiss		chloride						
Rainbow trout (2.88 g),	F,M,T	Copper	9.2	96 hr	LC50	66	-	Cusimano et al. 1986
Oncorhynchus mykiss	1	chloride						

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout (2.88 g), Oncorhynchus mykiss	F,M,T	Copper chloride	9.2	168 hr	LC50	36.7	-	Cusimano et al. 1986
Rainbow trout (2.70 g),	F,M,T	Copper	9.2	168 hr	LC50	3.1	-	Cusimano et al. 1986
Rainbow trout (2.65 g),	F,M,T	Copper	9.2	168 hr	LC50	2.3	-	Cusimano et al. 1986
Rainbow trout (5 day embryo), Oncorhynchus mykiss	F,M,T	Copper sulfate	87.7	48 hr	LC50	8,000	-	Shazili and Pascoe 1986
Rainbow trout (10 day embryo), Oncorhynchus mykiss	F,M,T	Copper sulfate	87.7	48 hr	LC50	2,000	-	Shazili and Pascoe 1986
Rainbow trout (15 day embryo), Oncorhynchus mykiss	F,M,T	Copper sulfate	87.7	48 hr	LC50	400	-	Shazili and Pascoe 1986
Rainbow trout (22 day embryo), Oncorhynchus mykiss	F,M,T	Copper sulfate	87.7	48 hr	LC50	600	-	Shazili and Pascoe 1986
Rainbow trout (29 day embryo), Oncorhynchus mykiss	F,M,T	Copper sulfate	87.7	48 hr	LC50	400	-	Shazili and Pascoe 1986
Rainbow trout (36 day embryo), Oncorhynchus mykiss	F,M,T	Copper sulfate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (2 day larva), Oncorhynchus mykiss	F,M,T	Copper sulfate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (7 day larva), Oncorhynchus mykiss	F,M,T	Copper nitrate	87.7	48 hr	LC50	100	-	Shazili and Pascoe 1986
Rainbow trout (yearling), Oncorhynchus mykiss	F,M,T	Copper sulfate	63	15 days	Olfactory receptor degeneration	20	-	Julliard et al. 1993
Rainbow trout (swimup), Oncorhynchus mykiss	F,M,T	Copper sulfate	60.9	13-40 wk	Inhibited olfactory discrimination	20	-	Saucier and Astic 1995
Rainbow trout (swimup), Oncorhynchus mykiss	F,M,T	Copper sulfate	60.9	40 wk	43% mortality	40	-	Saucier and Astic 1995
Rainbow trout (9.0-11.5 cm, 10.6 g), <i>Oncorhynchus mykiss</i>	F,M,T	Copper sulfate	284	96 hr	LC50	650	-	Svecevicius and Vosyliene 1996
Rainbow trout (3.5 cm), Oncorhynchus mykiss	F,M,T	Copper chloride	24.2	96 hr	LC50	12.7	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), Oncorhynchus mykiss	F,M,T	Copper chloride	24.2	96 hr	LC50	16.6	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), Oncorhynchus mykiss	F,M,T	Copper chloride	24.2	96 hr	LC50	21.4	-	Marr et al. Manuscript
Rainbow trout (3.5 cm), Oncorhynchus mykiss	F,M,T	Copper chloride	24.2	96 hr	LC50	34.2	-	Marr et al. Manuscript
Rainbow trout (10.0 g), Oncorhynchus mykiss	F,M,D	Copper sulfate	362	144 hr	LC50 (extruded diet)	276	-	Dixon and Hilton 1981
Rainbow trout (10.9 g), Oncorhynchus mykiss	F,M,D	Copper sulfate	362	144 hr	LC50 (steam pelleted diet)	350	-	Dixon and Hilton 1981

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Rainbow trout (12.3 g),	F,M,D	Copper	362	144 hr	LC50	408	-	Dixon and Hilton 1981
Oncorhynchus mykiss		sulfate	ļ		(Low carbohydrate diet)	ļ		
Rainbow trout (11.6 g),	F,M,D	Copper	362	144 hr	LC50	246	-	Dixon and Hilton 1981
Oncorhynchus mykiss		sulfate			(high carbohydrate diet)	ļ		
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level	329	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate				<u> </u>		
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level	333	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate						
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level	311	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate						
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level	274	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate				<u> </u>		
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level	371	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate				l		
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level (acclimated to 30	266	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate			ug/L)	l	l	
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level (acclimated to 58	349	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate			ug/L)	l	l	
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level (acclimated to 94	515	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate		-	ug/L)	l		
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level (acclimated to 13	564	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate		-	ug/L)	l		
Rainbow trout (1.7-3.3 g),	F,M,D	Copper	374	21 days	Incipient lethal level (acclimated to 194	708	-	Dixon and Sprague 1981a
Oncorhynchus mykiss		sulfate		-	ug/L)	l		
Rainbow trout (2.9 g),	F,M,D	Copper	30.5	ca. 2 hr	Inhibited avoidance of serine	6.667	-	Rehnberg and Schreck 1986
Oncorhynchus mykiss		chloride				l		_
Rainbow trout (3.2 g),	F,M,T,D	Copper	30	96 hr	LC50	-	19.9	Howarth and Sprague 1978
Oncorhynchus mykiss		sulfate				l		
Rainbow trout (1.4 g),	F,M,T,D	Copper	101	96 hr	LC50	-	176	Howarth and Sprague 1978
Oncorhynchus mykiss		sulfate				l		
Rainbow trout (2.2 g),	F,M,T,D	Copper	370	96 hr	LC50	-	232	Howarth and Sprague 1978
Oncorhynchus mykiss		sulfate				l		
Rainbow trout (smolt),	F,M,T,D	Copper	363	>10 days	LC50	97.92	-	Fogels and Sprague 1977
Oncorhynchus mykiss		sulfate				l		
Rainbow trout (parr),	F,M,T,D,I	-	31.0	62 days	NOEC	90	-	Mudge et al. 1993
Oncorhynchus mykiss					(growth and survival)	l	l	
Atlantic salmon (2-3 yr parr),	S,M,T	-	8-10	96 hr	LC50	125	-	Wilson 1972
Salmo salar						l	l	
Atlantic salmon (6.4-11.7 cm),	F,M,T	Copper	20	7 days	LC50	48	-	Sprague 1964
Salmo salar		sulfate		-		l		
Atlantic salmon (7.2-10.9 cm),	F,M,T	-	14	7 days	LC50	32	-	Sprague and Ramsay 1965
Salmo salar	<i>,</i> .	l		-		l		
Brown trout (3-6 day larva),	S.M,T	Copper	4	30 days	>90% mortality	80	-	Reader et al. 1989
Salmo trutta		chloride						

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Brown trout (larva), Salmo trutta	S,M,T	Copper chloride	4	30 days	>90% mortality	20	-	Sayer et al. 1989
Brown trout (larva), Salmo trutta	S,M,T	Copper chloride	22	30 days	<10% mortality	80	-	Sayer et al. 1989
Brown trout (larva), Salmo trutta	F,M,T	Copper chloride	25	60 days	Inhibited growth	4.6	-	Marr et al. 1996
Brook trout, Salvelinus fontinalis	-	-	-	24 hr	Significant change in cough rate	9	-	Drummond et al. 1973
Brook trout (1 g), Salvelinus fontinalis	S,M,T	Copper chloride	4	80 hr	75% mortality	25.4	-	Sayer et al. 1991 b, c
Brook trout (8 mo), <i>Salvelinus fontinalis</i>	R,M,T	-	20	10 days	IC50 (growth)	187	-	Jop et al. 1995
Brook trout (15-20 cm), Salvelinus fontinalis	F,M,T	Copper sulfate	47	21 days	Altered Blood Hct, RBC, Hb, Cl, PGOT, Osmolarity, protein	38.2	-	McKim et al. 1970
Brook trout (13-20 cm), Salvelinus fontinalis	F,M,T	Copper sulfate	47	337 days	Altered blood PGOT	17.4	-	McKim et al. 1970
Goldfish (3.8-6.3 cm), <i>Carassius auratus</i>	S,U	Copper sulfate	20	96 hr	LC50	36		Pickering and Henderson 1966
Goldfish (10.5 g), <i>Carassius auratus</i>	S,M,T	Copper sulfate	34.2	-	LC50	150	-	Hossain et al. 1995
Goldfish (embryo), <i>Carrassius auratus</i>	R,U	Copper sulfate	195	7 days	EC50 (death or deformity)	5,200	-	Birge 1978; Birge and Black 1979
Goldfish, <i>Carassius auratus</i>	R,U	Copper sulfate	45	24 hr	LC50 (5 <sup>0</sup> C)	2,700	-	Cairns et al. 1978
Goldfish, Carassius auratus	R,U	Copper sulfate	45	24 hr	LC50 (15 <sup>0</sup> C)	2,900	-	Cairns et al. 1978
Goldfish, Carassius auratus	R,U	Copper sulfate	45	24 hr	LC50 (30 <sup>0</sup> C)	1,510	-	Cairns et al. 1978
Common carp (1.8-2.1 cm), Cyprinus carpio	S,U	Copper sulfate	144-188	96 hr	LC50	117.5		Deshmukh and Marathe 1980
Common carp (5.0-6.0 cm), Cyprinus carpio	S,U	Copper sulfate	144-188	96 hr	LC50	530		Deshmukh and Marathe 1980
Common carp (embryo), <i>Cyprinus carpio</i>	S,U	Copper sulfate	360	-	EC50 (hatch and deformity)	4,775	-	Kapur and Yadav 1982
Common carp (embryo), <i>Cyprinus carpio</i>	S,U	Copper acetate	274	96 hr	LC50	140	-	Kaur and Dhawan 1994
Common carp (larva), Cyprinus carpio	S,U	Copper acetate	274	96 hr	LC50	4	-	Kaur and Dhawan 1994
Common carp (fry), <i>Cyprinus carpio</i>	S,U	Copper acetate	274	96 hr	LC50	63	-	Kaur and Dhawan 1994
Common carp, Cyprinus carpio	S,M,T	Copper nitrate	53	-	LC50	110	-	Rehwoldt et al. 1971
Common carp, Cyprinus carpio	S,M,T	Copper nitrate	55	-	LC50	800	-	Rehwoldt et al. 1972

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Common carp (4.7-6.2 cm), Cyprinus carpio	R,U	Copper sulfate	19	96 hr	LC50	63		Khangarot et al. 1983
Common carp (embryo and larva), Cyprinus carpio	R,U	Copper sulfate	50	108 hr	77% deformed	10	-	Wani 1986
Common carp (3.5 cm), Cyprinus carpio	R,U	Copper sulfate	-	96 hr	LC50	300	-	Alam and Maughan 1992
Common carp (6.5 cm), Cyprinus carpio	R,U	Copper sulfate	-	96 hr	LC50	1,000	-	Alam and Maughan 1992
Common carp (embryo), Cyprinus carpio	R,M,T	Copper sulfate	50	72 hr	Prevented hatching	700	-	Hildebrand and Cushman 1978
Common carp (1 mo), Cyprinus carpio	R,M,T	Copper nitrate	84.8	1 wk	Raised critical D.O. and altered ammonia excretion	14.0	-	De Boeck et al. 1995a
Common carp (22.9 cm), Cyprinus carpio	F,M,T	Copper chloride	17	48 hr	LC50	170	-	Harrison and Rice 1981
Common carp (embryo and larva), Cyprinus carpio	F,M,T	Copper chloride	100	168 hr	55% mortality	19	-	Stouthart et al. 1996
Common carp (embryo and larva), Cyprinus carpio	F,M,T	Copper chloride	100	168 hr	18% mortality;	50.8	-	Stouthart et al. 1996
Bonytail (larva), Gila elegans	S, U	Copper sulfate	199	96 hr	LC50	364		Buhl and Hamilton 1996
Bonytail (100-110 days), <i>Gila elegans</i>	S, U	Copper sulfate	199	96 hr	LC50	231		Buhl and Hamilton 1996
Golden shiner (11-13 cm), Notemigonus crysoleucas	S,U	Copper sulfate	221	94 hr	Decreased serum osmolality	2,500	-	Lewis and Lewis 1971
Golden shiner, Notemigonus crysoleucas	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>0</sup> C)	330	-	Cairns et al. 1978
Golden shiner, Notemigonus crysoleucas	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>°</sup> C)	230	-	Cairns et al. 1978
Golden shiner, Notemigonus crysoleucas	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>0</sup> C)	270	-	Cairns et al. 1978
Golden shiner, Notemigonus crysoleucas	F,M,T	Copper chloride	72.2	15 min	EC50 (avoidance)	26	-	Hartwell et al. 1989
Striped shiner, Notropis chrysocephalus	F,M,T,D	Copper sulfate	318	96 hr	LC50	3,400	-	Geckler et al. 1976
Striped shiner (4.7 cm) Notropis chrysocephalus	F,M,T,D	Copper sulfate	316	96 hr	LC50	4,000	-	Geckler et al. 1976
Striped shiner (5.0 cm) Notropis chrysocephalus	F,M,T,D	Copper sulfate	274	96 hr	LC50	5,000	-	Geckler et al. 1976
Striped shiner, Notropis chrysocephalus	F,M,T,D	Copper sulfate	314	96 hr	LC50	8,400	-	Geckler et al. 1976

Appen	dix B.	Other	Data on	Effects of	f Copper on	Freshwater	Organisms

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Striped shiner, Notropis chrysocephalus	F,M,T,D	Copper sulfate	303	96 hr	LC50	16,000	-	Geckler et al. 1976
Bluntnose minnow,	S,U	Copper	208	48 hr	LC50	290	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,U	Copper	132	48 hr	LC50	150	-	Geckler et al. 1976
Pluntnoso minnow	811	Connor	100	10 hr		200		Cooklar at al. 1076
Pimephales notatus	3,0	sulfate	102	40 11	LCSU	200	-	Geckler et al. 1970
Bluntnose minnow	SU	Copper	233	48 hr	1 C 50	180	-	Geckler et al. 1976
Pimephales notatus	0,0	sulfate	200					
Bluntnose minnow.	S.U	Copper	282	48 hr	LC50	260	-	Geckler et al. 1976
Pimephales notatus	-,-	sulfate						
, Bluntnose minnow,	S,U	Copper	337	48 hr	LC50	260	-	Geckler et al. 1976
Pimephales notatus	- / -	sulfate		_				
Bluntnose minnow,	S,U	Copper	322	48 hr	LC50	6,300	-	Geckler et al. 1976
Pimephales notatus	-	sulfate						
Bluntnose minnow,	S,U	Copper	322	48 hr	LC50	11,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,U	Copper	322	48 hr	LC50	25,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,U	Copper	203	48 hr	LC50	160	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,U	Copper	203	48 hr	LC50	1,100	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,U	Copper	203	48 hr	LC50	2,900	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	320	48 hr	LC50	6,300	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	324	48 hr	LC50	9,000	-	Geckler et al. 1976
Pimephales notatus	CMD	sulfate	204	40 hr	1.050	4 700		Cooklan et al. 4070
Biunthose minnow, Bimenhales notatus	5,M,D	copper	324	48 nr	LC50	4,700	-	Geckler et al. 1976
Riuntnose minnow	SMD	Copper	320	48 hr	1 C 50	11,000	_	Geckler et al. 1976
Pimenhales notatus	5,IVI,D	sulfate	520	4011	Less	11,000	-	
Bluntnose minnow	SMD	Copper	318	48 hr	1 C 50	5 700	-	Geckler et al. 1976
Pimephales notatus	0,111,12	sulfate	010	10111	2000	0,100		
Bluntnose minnow.	S.M.D	Copper	318	48 hr	LC50	10.000	-	Geckler et al. 1976
Pimephales notatus	_ ,, <b>_</b>	sulfate				,		
Bluntnose minnow,	S,M,D	Copper	314	48 hr	LC50	8,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	318	48 hr	LC50	11,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	324	48 hr	LC50	9,700	-	Geckler et al. 1976
Pimephales notatus		sulfate						

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Bluntnose minnow, Pimephales notatus	S,M,D	Copper sulfate	339	48 hr	LC50	7,000	-	Geckler et al. 1976
Bluntnose minnow,	S,M,D	Copper	310	48 hr	LC50	12,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	310	48 hr	LC50	21,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	302	48 hr	LC50	19,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	296	48 hr	LC50	8,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	332	48 hr	LC50	11,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	340	48 hr	LC50	6,300	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	296	48 hr	LC50	1,500	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	306	48 hr	LC50	750	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	308	48 hr	LC50	2,500	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	304	48 hr	LC50	1,600	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow,	S,M,D	Copper	315	48 hr	LC50	4,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow (3.9 cm),	F,M,T,D	Copper	314	96 hr	LC50	6,800	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Bluntnose minnow (5.3 cm),	F,M,T,D	Copper	303	96 hr	LC50	13,000	-	Geckler et al. 1976
Pimephales notatus		sulfate						
Fathead minnow (adult),	S,U	Copper	103-104	96 hr	LC50	210		
Pimephales promelas		sulfate						Birge et al. 1983
Fathead minnow (adult),	S,U	Copper	103-104	96 hr	LC50	310		
Pimephales promelas		sulfate						Birge et al. 1983
Fathead minnow (adult),	S,U	Copper	103-104	96 hr	LC50	120		
Pimephales promelas		sulfate						Birge et al. 1983
Fathead minnow (adult),	S,U	Copper	103-104	96 hr	LC50	210		Birge et al. 1983;
Pimephales promelas		sulfate						Benson and Birge 1985
Fathead minnow (adult),	S,U	Copper	254-271	96 hr	LC50	390		Birge et al. 1983;
Pimephales promelas		sulfate						Benson and Birge 1985
Fathead minnow,	S,U	Copper	200	96 hr	LC50	430		Mount 1968
Pimephales promelas		sulfate						
Fathead minnow,	S,U	Copper	31	96 hr	LC50	84		Mount and Stephan 1969
Pimephales promelas	<u> </u>	sulfate	-					
Fathead minnow (3.8-6.3 cm),	S,U	Copper	20	96 hr	LC50	25		Pickering and Henderson 1966
Pimephales promelas		sulfate						

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (3.8-6.3 cm), Pimephales promelas	S,U	Copper sulfate	20	96 hr	LC50	23		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), Pimephales promelas	S,U	Copper sulfate	20	96 hr	LC50	23		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), Pimephales promelas	S,U	Copper sulfate	20	96 hr	LC50	22		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), Pimephales promelas	S,U	Copper sulfate	360	96 hr	LC50	1760		Pickering and Henderson 1966
Fathead minnow (3.8-6.3 cm), Pimephales promelas	S,U	Copper sulfate	360	96 hr	LC50	1140		Pickering and Henderson 1966
Fathead minnow, Pimephales promelas	S,U	Copper sulfate	20	96 hr	LC50	50		Tarzwell and Henderson 1960
Fathead minnow, Pimephales promelas	S,U	Copper sulfate	400	96 hr	LC50	1,400		Tarzwell and Henderson 1960
Fathead minnow (3.2-4.2 cm), <i>Pimephales promelas</i>	S,M	Copper acetate	44	96 hr	LC50	117	-	Curtis et al. 1979; Curtis and Ward 1981
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	294	96 hr	LC50	16,000	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	120	96 hr	LC50	2,200	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	298	96 hr	LC50	16,000	-	Brungs et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	280	96 hr	LC50	3,300	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	244	96 hr	LC50	1,600	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	212	96 hr	LC50	2,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	260	96 hr	LC50	3,500	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	224	96 hr	LC50	9,700	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	228	96 hr	LC50	5,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	150	96 hr	LC50	2,800	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	310	96 hr	LC50	11,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	280	96 hr	LC50	12,000	-	Brungs et al. 1976; Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	280	96 hr	LC50	11,000	-	Brungs et al. 1976; Geckler et al. 1976

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	260	96 hr	LC50	22,200	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	308	96 hr	LC50	4,670	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	206	96 hr	LC50	920	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	262	96 hr	LC50	1,190	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	322	96 hr	LC50	2,830	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	210	96 hr	LC50	1,450	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	260	96 hr	LC50	1,580	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	252	96 hr	LC50	1,000	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	312	96 hr	LC50	5,330	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	276	96 hr	LC50	4,160	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	252	96 hr	LC50	10,550	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), <i>Pimephales promelas</i>	S,M,D	Copper sulfate	298	96 hr	LC50	22,200	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	282	96 hr	LC50	21,800	-	Geckler et al. 1976
Fathead minnow (2.0-6.9 cm), Pimephales promelas	S,M,D	Copper sulfate	284	96 hr	LC50	23,600	-	Geckler et al. 1976
Fathead minnow (<24 h), Pimephales promelas	S,M,T	Copper nitrate	290	96 hr	LC50	>200	-	Schubauer-Berigan et al. 1993
Fathead minnow (<24 h), Pimephales promelas	S,M,T	Copper sulfate	16.8	96 hr	LC50	36.0	-	Welsh et al. 1993
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	19.0	96 hr	LC50	70.3	-	Welsh et al. 1993
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	19.0	96 hr	LC50	85.6	-	Welsh et al. 1993
Fathead minnow (<24 h), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	19.0	96 hr	LC50	182.0	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	17	96 hr	LC50	1.99	-	Welsh et al. 1993

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	20.5	96 hr	LC50	4.86	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	16.5	96 hr	LC50	11.1	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	17.5	96 hr	LC50	9.87	-	Welsh et al. 1993
Fathead minnow (<24 h; 0.68 mg), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	17	96 hr	LC50	15.7	-	Welsh et al. 1993
Fathead minnow (60-90 days), Pimephales promelas	S,M,T	-	110	48 hr	LC50	284	-	Dobbs et al. 1994
Fathead minnow (3 wk), Pimephales promelas	S,M,T	Copper sulfate	101	48 hr	Short-term intolerance of hypoxia (2 mg D.O./L)	186	-	Bennett et al. 1995
Fathead minnow (2-4 day), Pimephales promelas	S,M,T	Copper sulfate	6-10	-	LC50	12.5	-	Suedel et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	9.9	96 hr	LC50	10.7	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	7.1	96 hr	LC50	6.3	-	Welsh et al. 1996
Fathead minnow (<24 hrs), Pimephales promelas	S,M,T	Copper sulfate	8.3	96 hr	LC50	12.2	-	Welsh et al. 1996
Fathead minnow (<24 hrs), Pimephales promelas	S,M,T	Copper sulfate	8.9	96 hr	LC50	9.5	-	Welsh et al. 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	S,M,T	Copper sulfate	16.8	96 hr	LC50	26.8	-	Welsh et al. 1996
Fatnead minnow (<24 nrs), <i>Pimephales promelas</i>	S,M,T	Sulfate	12.2	96 nr	LC50	21.2	-	Weish et al. 1996
Pathead minihow (<24 hrs), Pimephales promelas	5,IVI, I	sulfate	9.4	90 m	LC50	31.0	-	Weish et al. 1996
Pimephales promelas	S,W,T	sulfate	10.0	90 m	LC50	26.1	-	Weish et al. 1996
Pimephales promelas	S,W,T	sulfate	12.4	96 hr	LC50	26.0	-	Welsh et al. 1996
Pimephales promelas	S,IVI, I	sulfate	12.4	90 m	1.050	169.5	-	Welsh et al. 1990
<i>Pimephales promelas</i>	SMTD	sulfate	46	90 m 96 hr	1 C 50	17 15	- 14 87	Frickson et al. 1996a h
Pimephales promelas		sulfate	46	90 m	1.050	21.50	19.72	
Pimephales promelas	3,IVI, I ,D	sulfate	40	90 11	LCOU	21.09	10.72	ETICKSUIT EL AL. 1990A,D

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (<24 hrs), Pimephales promelas	S,M,T,D	Copper sulfate	47	96 hr	LC50	123.19	106.8	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), Pimephales promelas	S,M,T,D	Copper sulfate	45	96 hr	LC50	42.56	36.89	Erickson et al. 1996a,b
Fathead minnow (<24 hrs), Pimephales promelas	S,M,T,D	Copper sulfate	46	96 hr	LC50	83.19	72.13	Erickson et al. 1996a,b
Fathead minnow, Pimephales promelas	S,M,T,D	Copper sulfate	100	96 hr	LC50 (fish from metal-contaminated pond)	360	-	Birge et al. 1983
Fathead minnow, Pimephales promelas	S,M,T,D	Copper sulfate	250	96 hr	LC50 (fish from metal-contaminated pond)	410	-	Birge et al. 1983
Fathead minnow (<24 hr), Pimephales promelas	R,U	-	45	7 days	LC50	70	-	Norberg and Mount 1985
Fathead minnow (<24 hr), Pimephales promelas	R,U	-	45	7 days	LOEC (growth)	26	-	Norberg and Mount 1985
Fathead minnow (<24 hr), Pimephales promelas	R,U	Copper sulfate	345	4 days	RNA threshhold effect	130	-	Parrott and Sprague 1993
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	5 days	LC50	480	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	5 days	LC50	440	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	5 days	EC50 (malformation)	270	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	5 days	EC50 (malformation)	260	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	7 days	LC50	310	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	7 days	LC50	330	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	7 days	EC50 (malformation)	190	-	Fort et al. 1996
Fathead minnow (embryo), <i>Pimephales promelas</i>	R,U	Copper sulfate	106	7 days	EC50 (malformation)	170	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	7 days	LOEC (length)	160	-	Fort et al. 1996
Fathead minnow (embryo), Pimephales promelas	R,U	Copper sulfate	106	7 days	LOEC (length)	180	-	Fort et al. 1996
Fathead minnow (larva), Pimephales promelas	R,M,T	Copper sulfate	180	7 days	LOEC (growth)	25	-	Pickering and Lazorchak 1995
Fathead minnow (larva), <i>Pimephales promelas</i>	R,M,T	Copper sulfate	218	7 days	LOEC (growth)	38	-	Pickering and Lazorchak 1995
Fathead minnow (larva), Pimephales promelas	R,M,T	Copper sulfate	218	7 days	LOEC (growth)	38	-	Pickering and Lazorchak 1995
Fathead minnow (3-7 days), Pimephales promelas	R,M,T	Copper sulfate	74	48 hr	LC50	225	-	Diamond et al. 1997b

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Fathead minnow (larva), Pimephales promelas	R,M,T,D	Copper sulfate	80	48 hr	LC50	35.9	-	Diamond et al. 1997a
Fathead minnow (larva), Pimephales promelas	R,M,T,D	Copper sulfate	80	48 hr	LC50	28.9	-	Diamond et al. 1997a
Fathead minnow (larva), Pimephales promelas	R,M,T,D	Copper sulfate	80	48 hr	LC50	20.7	-	Diamond et al. 1997a
Fathead minnow (larva), Pimephales promelas	R,M,T,D	Copper sulfate	80	48 hr	LC50	80.8	-	Diamond et al. 1997a
Fathead minnow (3-7 days), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	80	48 hr	LC50	297.1	-	Diamond et al. 1997b
Fathead minnow (3-7 days), <i>Pimephales promelas</i>	R,M,T,D	Copper sulfate	72	48 hr	LC50	145.8	-	Diamond et al. 1997b
Fathead minnow (32-38 mm), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	244	9 mo	LOEC (93% lower fecundity)	120	-	Brungs et al. 1976
Fathead minnow (larva), Pimephales promelas	F,M,T	Copper sulfate	202	-	LC50	250	-	Scudder et al. 1988
Fathead minnow (embryo), Pimephales promelas	F,M,T	Copper sulfate	202	34 days	Reduced growth; increased abnormality	61	-	Scudder et al. 1988
Fathead minnow (embryo), Pimephales promelas	F,M,T	Copper sulfate	202	34 days	LC50	123	-	Scudder et al. 1988
Fathead minnow (24-96 hr), Pimephales promelas	F,M,T	Copper sulfate	10.7	21 days	Incipient lethal level	6.2	-	Welsh 1996
Fathead minnow (24-96 hr), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	10.7	21 days	Growth (length) reduced by 8%	5.3	-	Welsh 1996
Fathead minnow (24-96 hr), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	9.3	21 days	Incipient lethal level	17.2	-	Welsh 1996
Fathead minnow (24-96 hr), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	9.3	21 days	Growth (length) reduced by 17%	16.2	-	Welsh 1996
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	46	96 hr	LC50	305	-	Erickson et al. 1996 a,b
Fathead minnow (<24 hrs), <i>Pimephales promelas</i>	F,M,T	Copper sulfate	46	96 hr	LC50	298.6	-	Erickson et al. 1996 a, b
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	30	96 hr	LC50 (TOC=12 mg/L)	436	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	37	96 hr	LC50 (TOC=13 mg/L)	516	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	87	96 hr	LC50 (TOC=36 mg/L)	1,586	-	Lind et al. manuscript
Fathead minnow, Pimephales promelas	F,M,T	-	73	96 hr	LC50 (TOC=28 mg/L)	1,129	-	Lind et al. manuscript
Fathead minnow, <i>Pimephales promelas</i>	F,M,T	-	84	96 hr	LC50 (TOC=15 mg/L)	550	-	Lind et al. manuscript
Fathead minnow, Pimephales promelas	F,M,T	-	66	96 hr	LC50 (TOC=34 mg/L)	1,001	-	Lind et al. manuscript
Species	Method <sup>a</sup> Chemical Hardness (mg/L as CaCO <sub>3</sub> ) Duration Effect Total Concentration (µg/L) <sup>b</sup> (µg/L)		Dissolved Concentration (µg/L)	Reference				
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Fathead minnow,	F,M,T	-	117	96 hr	LC50	2,050	-	Lind et al. manuscript
Pimephales promelas					(TOC=30 mg/L)			
Fathead minnow,	F,M,T	-	121	96 hr	LC50	2,336	-	Lind et al. manuscript
Pimephales promelas					(TOC=30 mg/L)			
Fathead minnow,	F,M,T	Copper	117	96 hr	LC50	2,050	-	Lind et al. manuscript
Pimephales promelas		sulfate						
Fathead minnow,	F,M,T	Copper	121	96 hr	LC50	2,336	-	Lind et al. manuscript
Pimephales promelas		sulfate						
Fathead minnow (4.4 cm),	F,M,T,D	Copper	314	96 hr	LC50	11,000	-	Geckler et al. 1976
Pimephales promelas		sulfate						
Fathead minnow (4.2 cm),	F,M,T,D	Copper	303	96 hr	LC50	15,000	-	Geckler et al. 1976
Pimephales promelas		sulfate						
Fathead minnow (<24 hrs),	F,M,T,D	Copper	45	96 hr	LC50	158.8	138.1	Erickson et al. 1996a,b
Pimephales promelas		sulfate						
Fathead minnow (<24 hrs),	F,M,T,D	Copper	45	96 hr	LC50	80.01	72.01	Erickson et al. 1996a,b
Pimephales promelas		sulfate						
Fathead minnow (<24 hrs),	F,M,T,D	Copper	46	96 hr	LC50	20.96	18.23	Erickson et al. 1996a,b
Pimephales promelas		sulfate						
Fathead minnow (<24 hrs),	F,M,T,D	Copper	44	96 hr	LC50	50.8	39.12	Erickson et al. 1996a,b
Pimephales promelas		sulfate						
Fathead minnow (<24 hrs),	F,M,T,D	Copper	45	96 hr	LC50	65.41	45.78	Erickson et al. 1996a,b
Pimephales promelas		sulfate						
Colorado squawfish (larva),	S,U	Copper	199	96 hr	LC50	363		Buhl and Hamilton 1996
Ptychocheilus lucius		sulfate						
Colorado squawfish (155-186	S.U	Copper	199	96 hr	LC50	663		Buhl and Hamilton 1996
days).	,	sulfate						
Ptychocheilus lucius								
Colorado squawfish (32-40 days	S,U	Copper	144	96 hr	LC50	293		Hamilton and Buhl 1997
posthatch).	- , -	sulfate						
Ptvchocheilus lucius								
Colorado squawfish (32-40 davs	S.U	Copper	144	96 hr	LC50	320		Hamilton and Buhl 1997
posthatch).	,	sulfate						
Ptvchocheilus lucius								
Creek chub.	F.M.T	Copper	316	96 hr	LC50	11.500	-	Geckler et al. 1976
Semotilus atromaculatus	, ,	sulfate				,		
Creek chub.	F.M.T	Copper	274	96 hr	LC50	1,100	-	Geckler et al. 1976
Semotilus atromaculatus	, ,	sulfate				,		
Razorback sucker (larva)	SU	Copper	199	96 hr	1 C50	404		Buhl and Hamilton 1996
Xyrauchen texanus	-,-	sulfate						
Razorback sucker (102-116	S.U	Copper	199	96 hr	LC50	331		Buhl and Hamilton 1996
davs).	-,-	sulfate						
Xvrauchen texanus								
Razorback sucker (13-23 days	รม	Copper	144	96 hr	1 C50	231	1	Hamilton and Buhl 1997
posthatch)	2,0	sulfate						
Xvrauchen texanus								
		1				1	1	

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Razorback sucker (13-23 days posthatch), <i>Xyrauchen texanus</i>	S,U	Copper sulfate	144	96 hr	LC50	314		Hamilton and Buhl 1997
Brown bullhead, Ictallurus nebulosus	F,M,T	Copper sulfate	303	96 hr	LC50	12,000	-	Geckler et al. 1976
Brown bullhead (5.2 cm), Ictalurus nebulosus	F,M,T	Copper sulfate	314	96 hr	LC50	5,200	-	Geckler et al. 1976
Channel catfish (13-14 cm), Ictalurus punctatus	S,U	Copper sulfate	221	94 hr	Decreased serum osmolality	2,500	-	Lewis and Lewis 1971
Channel catfish, Ictalurus punctatus	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>0</sup> C)	3,700	-	Cairns et al. 1978
Channel catfish, <i>Ictalurus punctatus</i>	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>0</sup> C)	2,600	-	Cairns et al. 1978
Channel catfish, Ictalurus punctatus	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>0</sup> C)	3,100	-	Cairns et al. 1978
Channel catfish, Ictalurus punctatus	S,U	Copper sulfate	100	10 days	EC50 (death and deformity)	6,620	-	Birge and Black 1979
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	16	96 hr	LC50	54		Straus and Tucker 1993
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	16	96 hr	LC50	55		Straus and Tucker 1993
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	83	96 hr	LC50	762		Straus and Tucker 1993
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	83	96 hr	LC50	700		Straus and Tucker 1993
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	161	96 hr	LC50	768		Straus and Tucker 1993
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	161	96 hr	LC50	1139		Straus and Tucker 1993
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	287	96 hr	LC50	1041		Straus and Tucker 1993
Channel catfish (fingerlings), Ictalurus punctatus	S,U	Copper sulfate	287	96 hr	LC50	925		Straus and Tucker 1993
Channel catfish (400-600 g), Ictalurus punctatus	F,M,I	Copper sulfate	-	10 wk		354	-	Perkins et al. 1997
Channel catfish (4.1 gm), Ictalurus punctatus	F,M,T,D	Copper sulfate	319	14 days	LC50	1,229	-	Richey and Roseboom 1978
Channel cattisn (5.7 gm), Ictalurus punctatus		Sulfate	315	14 days	LC50	1,073	-	Richey and Roseboom 1978
Fundulus diaphanus	S,M,I	nitrate	53	-		860	-	Renwoldt et al. 1971
Banded Killifish, Fundulus diaphanus	S,M, I	nitrate	55	-		840	-	Renwoldt et al. 1972

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference	
Flagfish (0.1-0.3 g), Jordanella floridae	F,M,T,D	Copper sulfate	363	10 days	LC50	-	680	Fogels and Sprague 1977	
Flagfish (0.1-0.3 g), Jordanella floridae	F,M,T,D	Copper sulfate	363	96 hr	LC50	-	1,270	Fogels and Sprague 1977	
Mosquitofish (3.8-5.1 cm female), Gambusia affinis	S,U	Copper nitrate	27-41	96 hr	LC50	93		Joshi and Rege 1980	
Mosquitofish (3.8-5.1 cm female), Gambusia affinis	S,U	Copper sulfate	27-41	96 hr	LC50	200		Joshi and Rege 1980	
Mosquitofish (2.5 cm male), <i>Gambusia affinis</i>	S,U	-	50	96 hr	LC50	3,500		Kallanagoudar and Patil 1997	
Mosquitofish (2.5 cm male), Gambusia affinis	S,U	-	150	96 hr	LC50	5,000		Kallanagoudar and Patil 1997	
Mosquitofish (2.5 cm male), Gambusia affinis	S,U	-	300	96 hr	LC50	6,000		Kallanagoudar and Patil 1997	
Mosquitofish (3.5 cm female), Gambusia affinis	S,U	-	50	96 hr	LC50	2,500		Kallanagoudar and Patil 1997	
Mosquitofish (3.5 cm female), Gambusia affinis	S,U	-	150	96 hr	LC50	2,900		Kallanagoudar and Patil 1997	
Mosquitofish (3.5 cm female), Gambusia affinis	S,U	-	300	96 hr	LC50	5,000		Kallanagoudar and Patil 1997	
Mosquitofish (0.8 cm fry), Gambusia affinis	S,U	-	50	96 hr	LC50	900		Kallanagoudar and Patil 1997	
Mosquitofish (0.8 cm fry), Gambusia affinis	S,U	-	150	96 hr	LC50	1,400		Kallanagoudar and Patil 1997	
Mosquitofish (0.8 cm fry), <i>Gambusia affinis</i>	S,U	-	300	96 hr	LC50	2,000		Kallanagoudar and Patil 1997	
Mosquito fish, <i>Gambusia affinis</i>	S,U	Copper sulfate	-	96 hr	LC50 (high turbidity)	75,000	-	Wallen et al. 1957	
Mosquito fish, <i>Gambusia affinis</i>	R,M	Copper sulfate	45	48 hr	LC50	180	-	Chagnon and Guttman 1989	
Guppy (1.5 cm), <i>Poecilia reticulata</i>	S,U	Copper sulfate	230	96 hr	LC50	1,230		Khangarot 1981	
Guppy (1.62 cm), <i>Poecilia reticulata</i>	S,U	Copper sulfate	240	96 hr	LC50	764		Khangarot et al. 1981b	
Guppy (1.9-2.5 cm), Poecilia reticulata	S,U	Copper sulfate	20	96 hr	LC50	36		Pickering and Henderson 1966	
Guppy (1.5 cm), Poecilia reticulata	R,U	Copper sulfate	260	96 hr	LC50	2,500		Khangarot et al. 1981a	
Guppy (0.8-1.0 cm), Poecilia reticulata	R,U	Copper sulfate	144-188	96 hr	LC50	160		Deshmukh and Marathe 1980	
Guppy (1.2-2.3 cm; female), Poecilia reticulata	R,U	Copper sulfate	144-188	96 hr	LC50	275		Deshmukh and Marathe 1980	

Appen	dix B.	Other	Data on	Effects of	f Copper on	Freshwater	Organisms

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Guppy (2.3-2.8 cm; male), Poecilia reticulata	R,U	Copper sulfate	144-188	96 hr	LC50	210		Deshmukh and Marathe 1980
Guppy (340 mg; female), Poecilia reticulata	R,U	Copper sulfate	144-188	96 hr	LC50	480		Deshmukh and Marathe 1980
Guppy (1.5 cm), Poecilia reticulata	R,U	Copper sulfate	260	48 hr	LC50	2,500	-	Khangarot et al. 1981a
Guppy (1.5 cm), Poecilia reticulata	R, U	Copper sulfate	181	96 hr	LC50	986	-	Khangarot and Ray 1987b
Guppy (1 mo), Poecilia reticulata	F,U	Copper sulfate	76	24 hr	LC50	1,370	-	Minicucci 1971
Guppy (1 mo), <i>Poecilia reticulata</i>	F,U	Copper sulfate	76	24 hr	LC50	930	-	Minicucci 1971
Guppy (1 mo), <i>Poecilia reticulata</i>	F,U	Copper sulfate	76	24 hr	LC50	1,130	-	Minicucci 1971
White perch, <i>Morone americana</i>	S,M,T	Copper nitrate	53	-	LC50	6,200	-	Rehwoldt et al. 1971
White perch, <i>Morone americana</i>	S,M,T	Copper nitrate	55	-	LC50	6,400	-	Rehwoldt et al. 1972
Striped bass (larva), <i>Morone saxitilis</i>	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (larva), <i>Morone saxitilis</i>	S,U	Copper sulfate	34.6	96 hr	LC50	100		Hughes 1973
Striped bass (3.5-5.1 cm), <i>Morone saxitilis</i>	S,U	Copper chloride	34.6	96 hr	LC50	50		Hughes 1973
Striped bass (3.1-5.1 cm), <i>Morone saxitilis</i>	S,U	Copper sulfate	34.6	96 hr	LC50	150		Hughes 1973
Striped bass (35-80 day), <i>Morone saxitilis</i>	S,U	Copper sulfate	285	96 hr	LC50	270		Palawski et al. 1985
Striped bass (6 cm), <i>Morone saxitilis</i>	S,U	Copper sulfate	35	96 hr	LC50	620		Wellborn 1969
Striped bass, <i>Morone saxitilis</i>	S,M,T	Copper nitrate	53	96 hr	LC50	4,300	-	Rehwoldt et al. 1971
Striped bass, <i>Morone saxitilis</i>	S,M,T	Copper nitrate	55	96 hr	LC50	2,700	-	Rehwoldt et al. 1972
Rock bass, Ambloplites rupestris	F,M,T	-	24	96 hr	LC50 (high TOC)	1,432	-	Lind et al. manuscript
Pumpkinseed (1.2 g), Lepomis gibbosus	S,M,T	Copper nitrate	53	-	LC50	2,400	-	Rehwoldt et al. 1971
Pumpkinseed (1.2 g), Lepomis gibbosus	S,M,T	Copper nitrate	55	-	LC50	2,700	-	Rehwoldt et al. 1972
Pumpkinseed, <i>Lepomis gibbosus</i>	S,M,T	Copper nitrate	53	96 hr	LC50	2,400	-	Rehwoldt et al. 1971
Pumpkinseed, <i>Lepomis gibbosus</i>	S,M,T	Copper nitrate	55	96 hr	LC50	2,700	-	Rehwoldt et al. 1972

Appen	dix B	. Other	Data on	Effects of	f Copper o	n Freshwater	Organisms

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Dissolved Concentration (μg/L) <sup>b</sup> (μg/L)		Reference
Bluegill, Lepomis macrochirus	S,U	Copper chloride	43	96 hr	LC50	770		Academy of Natural Sciences 1960
Bluegill, Lepomis macrochirus	S,U	Copper sulfate	43	96 hr	LC50	1,250		Academy of Natural Sciences 1960 Cairns and Scheier 1968; Patrick e
Bluegill, Lepomis macrochirus	S,U	Copper sulfate	45	24 hr	LC50 (5 <sup>0</sup> C)	2,590	-	Cairns et al. 1978
Bluegill, Lepomis macrochirus	S,U	Copper sulfate	45	24 hr	LC50 (15 <sup>0</sup> C)	2,500	-	Cairns et al. 1978
Bluegill, Lepomis macrochirus	S,U	Copper sulfate	45	24 hr	LC50 (30 <sup>0</sup> C)	3,820	-	Cairns et al. 1978
Bluegill (3-4 cm), Lepomis macrochirus	S,U	-	119	8 days	33% reduction in locomotor activity	40	-	Ellgaard and Guillot 1988
Bluegill (4.2 cm), Lepomis macrochirus	S,U	Copper sulfate	52	96 hr	LC50	254		Inglis and Davis 1972
Bluegill (4.2 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	209	96 hr	LC50	437		Inglis and Davis 1972
Bluegill (4.2 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	365	96 hr	LC50	648		Inglis and Davis 1972
Bluegill (5-15 g), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	35	2-6 days	8% increase in oxygen consumption rates	300	-	O'Hara 1971
Bluegill (3.8-6.3 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	20	96 hr	LC50	660		Pickering and Henderson 1966
Bluegill (3.8-6.3 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	360	96 hr	LC50	10,200		Pickering and Henderson 1966
Bluegill, Lepomis macrochirus	S,U	Copper sulfate	20	96 hr	LC50	200		Tarzwell and Henderson 1960
Bluegill, Lepomis macrochirus	S,U	Copper sulfate	400	96 hr	LC50	10,000		Tarzwell and Henderson 1960
Bluegill (5-11 cm), <i>Lepomis macrochirus</i>	S,U	Copper sulfate	46	48 hr	LC50	3,000	-	Turnbull et al. 1954
Bluegill (5-11 cm), Lepomis macrochirus	S,U	Copper sulfate	101.2	48 hr	LC50	7,000	-	Turnbull et al. 1954
Bluegill (0.51g), Lepomis macrochirus	S,M,T	-	110	48 hr	LC50	4,300	-	Dobbs et al. 1994

Species	Method <sup>a</sup>	Chemical	Hardness (mg/L as CaCO <sub>3</sub> )	Duration	Effect	Total Concentration (μg/L) <sup>b</sup>	Dissolved Concentration (µg/L)	Reference
Bluegill (5-9 cm), Lepomis macrochirus	S,M,T	Copper chloride	45-47	-	LC50	710	-	Trama 1954
Bluegill (5-9 cm), Lepomis macrochirus	S,M,T	Copper sulfate	45-47	-	LC50	770	-	Trama 1954
Bluegill (5-15 g), Lepomis macrochirus	F,M	Copper sulfate	35	-	LC50	2400	-	O'Hara 1971
Bluegill (3.5-6.0 cm), Lepomis macrochirus	F,M,T	Copper sulfate	112.4	80 min	Avoidance threshold	8,480	-	Black and Birge 1980
Bluegill (3.2-6.7 cm), Lepomis macrochirus	F,M,T	Copper chloride	21.2-59.2	96 hr	LC50	1,100	-	Thompson et al. 1980
Bluegill (3.2-6.7 cm), Lepomis macrochirus	F,M,T	Copper chloride	21.2-59.2	96 hr	LC50	900	-	Thompson et al. 1980
Bluegill (35.6-62.3 g), Lepomis macrochirus	F,M,T	Copper sulfate	273.3	24-96 hr	Various behavioral changes	34	-	Henry and Atchison 1986
Bluegill, Lepomis macrochirus	F,M,T	Copper chloride	157	24-96 hr	27% reduction in food consumption	31 -		Sandheinrich and Atchison 1989
Bluegill, Lepomis macrochirus	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	16,000	-	Geckler et al. 1976
Bluegill, Lepomis macrochirus	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	17,000	-	Geckler et al. 1976
Bluegill (0.14-0.93 g), Lepomis macrochirus	F,M,T,D	Copper sulfate	246	14 days	LC50	-	2,500	Richey and Roseboom 1978
Bluegill (1.15-2.42 g), Lepomis macrochirus	F,M,T,D	Copper sulfate	237	14 days	LC50	-	3,700	Richey and Roseboom 1978
Bluegill (48.3 g), Lepomis macrochirus	F,M,T,D	Copper sulfate	40	96 hr	Biochemical changes	2,000	-	Heath 1984
Largemouth bass (embryo), <i>Micropterus salmoides</i>	R,U	Copper sulfate	100	8 days	EC50 (death and deformity)	6,560	-	Birge et al. 1978; Birge and Black 1979
Largemouth bass, <i>Micropterus salmoides</i>	F,U	-	-	24 hr	Affected opercular rhythm	48	-	Morgan 1979
Rainbow darter, <i>Etheostoma caeruleum</i>	F,M,T,D	Copper sulfate	318	96 hr	LC50 (high BOD)	4,500	-	Geckler et al. 1976
Rainbow darter, <i>Etheostoma caeruleum</i>	F,M,T,D	Copper sulfate	316	96 hr	LC50 (high BOD)	8,000	-	Geckler et al. 1976
Rainbow darter, Etheostoma caeruleum	F,M,T,D	Copper sulfate	274	96 hr	LC50 (high BOD)	2,800	-	Geckler et al. 1976
Rainbow darter (4.6 cm), Etheostoma caeruleum	F,M,T,D	Copper sulfate	314	96 hr	LC50 (high BOD)	4,800	-	Geckler et al. 1976
Rainbow darter (4.6 cm), Etheostoma caeruleum	F,M,T,D	Copper sulfate	303	96 hr	LC50 (high BOD)	5,300	-	Geckler et al. 1976
Fantail, Etheostoma flabellare	S,M,T	Copper sulfate	170	96 hr	Lowered critical thermal maximum	43	-	Lydy and Wissing 1988

Appendix C. Estimation of Water Chemistry Parameters for Acute Copper Toxicity Tests

### FINAL REPORT

## ESTIMATION OF WATER CHEMISTRY PARAMETERS FOR ACUTE COPPER TOXICITY TESTS

For:

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#### FOREWORD

This report was developed by the Great Lakes Environmental Center. Some minor revisions were made by the U.S. Environmental Protection Agency (EPA). These revisions were primarily editorial. Additional editorial and formatting revisions were made by the CDM Group, Inc.

The purpose of this report is to provide input water chemistry information for a Biotic Ligand Model (BLM) analysis of the acute copper toxicity data in Table 1a of the U.S. Environmental Protection Agency's (EPA) draft 2003 Update of Ambient Water Quality Criteria for Copper. EPA will use these BLM data to derive adjusted aquatic life criteria for copper. Many of the reported Table 1a acute copper toxicity data lack sufficient information on the chemistry of the dilution water to generate BLM-derived critical accumulation values. This compendium contains data from the primary authors of these articles. It also contains recommendations for the use of these data, additional supporting documentation and/or computations, and recommendations for estimating missing parameters.

#### Estimation of Water Chemistry Parameters for Acute Copper Toxicity Tests

To prepare for the possibility of incorporating the Biotic Ligand Model (BLM) (Di Toro et al. 2001) into an updated copper aquatic life criteria document, the U.S. Environmental Protection Agency (EPA) sought to generate a data table summarizing the acute toxicity of copper to freshwater organisms that included the following parameters: alkalinity, dissolved organic carbon (DOC), pH, and the major anions (Cl and SO<sub>4</sub>) and cations (Ca, Mg, Na, K) of the test water. Published literature was reviewed and appropriate information tabulated, but measurements for many of the aforementioned parameters were not reported. To resolve the overwhelming number of missing test water chemistry values in the database, certain authors were contacted for additional information and to obtain additional measurements in waters where critical information was either not measured or not reported. EPA also attempted to determine appropriate methods for estimating test water chemistry in the absence of reported values. The information received from the authors and recommended procedures for estimating missing parameters are the subject of this report.

#### 1.0 Data Acquisition

The authors of several studies were contacted for additional information on the chemistry of the water or methods used in their studies. If the primary or corresponding authors could not be contacted, an attempt was made to contact secondary authors or personnel from the laboratories where the studies had been conducted. In a few instances, this initial effort failed to produce the desired information, and censored databases (U.S. Geological Survey's [USGS] National Stream Quality Accounting Network [NASQAN] and EPA's STOrage and RETrieval [STORET] data warehouse) were consulted to obtain the missing data. As a last resort, other available sources of water compositional data (e.g., city drinking water treatment officials) were contacted.

The acquired data were scrutinized for representativeness and usefulness in estimating surrogate values to complete the water quality information in the original studies. Summary tables and figures generated from these data are included in the following pages, which serve as the basis for the addition of values in the spreadsheets. Information used for the tabular and graphical summaries of these data is included in separate appendices.

#### 2.0 Technical Issues and Corresponding Recommendations

#### 2.1 Estimating Ion Concentrations

Develop a methodology for estimating Ca, Mg, Na, K, Cl, and  $SO_4$  concentrations in laboratory-reconstituted waters.

**Recommendation:** The best approach for estimating ion concentrations in standard laboratory-reconstituted water involves scaling default ion concentrations based on measured hardness. The default ion concentrations can be computed from the concentrations of the salts added. The use of calculated ion concentrations as input for the BLM applies only to reconstituted water prepared following the standard recipes reported in guidance documents for conducting acute bioassays with aquatic organisms (ASTM 2000; U.S. EPA 1993) (see Table 1). If similar salts are added in different amounts, then the ion concentrations must be calculated using the recipe reported

in the article. Otherwise, specific ion ratios, and more importantly ion concentrations, cannot be calculated.

		Reagent Add	led (mg/L)		Final Water Quality			
Water Type	NaHCO <sub>3</sub>	CaSO <sub>4</sub> •2H <sub>2</sub> O	MgSO <sub>4</sub>	KCl	$pH^{a}$	Hardness <sup>a</sup>	Alkalinity <sup>b</sup>	
Very Soft	12.0	7.5	7.5	0.5	6.4-6.8	10-13	10-13	
Soft	48.0	30.0	30.0	2.0	7.2-7.6	40-48	30-35	
Mod. Hard	96.0	60.0	60.0	4.0	7.4-7.8	80-100	60-70	
Hard	192.0	120.0	120.0	8.0	7.6-8.0	160-180	110-120	
Very Hard	384.0	240.0	240.0	16.0	8.0-8.4	280-320	225-245	

Table 1.	Standard	Reconstituted	Water	Composition	and	Target	Water	Quality
Character	ristics							

<sup>a</sup> Approximate equilibriumpH after 24-hour aeration

<sup>b</sup> Expressed as mg/L CaCO<sub>3</sub>

When standard laboratory-reconstituted water is cited as the dilution water, and no additional measurements are reported, the recommended approach for estimating ion concentrations is to use the ion concentrations calculated from the amount of salts added for the type of reconstituted water reported in the article. For example, if the range of hardness of the reconstituted water is reported as 80-100 mg/L CaCO<sub>3</sub>, then the specific ion concentrations calculated from the standard recipe for moderately hard reconstituted water should be used for BLM input (see Table 2 and example calculation in Appendix D-2). The use of ion concentrations calculated from the standard recipes assumes that salts were stored in a manner to prevent hydration and that technician errors in weighing of salts, measurements of dilution water, and measurement of solution volumes were minimal.

Alternatively, if the authors state that moderately hard water was prepared following one of the standard recipes, and they measured the hardness of the water, then the calculated ion concentrations should be adjusted to account for any difference from the mean of the expected range. For example, if the mean measured hardness in a test water prepared using the recipe for moderately hard reconstituted water was 78 mg/L CaCO<sub>3</sub>, the Ca:Mg ratio would be 0.700 for all reconstituted water types, and the respective Ca and Mg concentrations could be calculated using the following equations:

$Ca = (0.4008 \times \text{measured hardness}) \div [1 + (1 \div Ca:Mg ratio)]$	Equation 1
$Mg = (0.2431 \times measured hardness) \div (1+Ca:Mg ratio)$	Equation 2

The remaining ion concentrations are each multiplied by 0.92 (quotient of 78 and 85 mg/L CaCO<sub>3</sub>, the latter of which is the expected hardness for moderately hard reconstituted water), as in Table 1.

Table 3 provides ion concentrations predicted for a standard reconstituted water mix using the hardness adjustment in accordance with the example above.

Note that this same rationale for scaling the default major anions and cations in reconstituted water also applies to a variety of natural surface and well waters. Analysis of St. Louis River, MN, water and Western Fish Toxicology Station (WFTS) well water indicated that a strong linear relationship also exists between water hardness and the major anion (Cl,  $SO_4$ ) and cation (Ca, Mg, Na) concentrations in these water types (see Sections 2.6, 2.7, and 2.19). The strong relationships are consistent with findings

		S	pecific Io	ons <sup>a</sup> (mg/l	Ĺ)			
Water Type (Nominal Hardness Range)	Ca	Mg	Na	K	Cl	$SO_4$	Ca:Mg <sup>b</sup>	Expected Hardness (mg/L CaCO <sub>3</sub> ) <sup>c</sup>
Very Soft (10-13 mg/L CaCO <sub>3</sub> )	1.75	1.51	3.28	0.262	0.238	10.2	0.700	11
Soft (40-48 mg/L CaCO <sub>3</sub> )	6.99	6.06	13.1	1.05	0.951	40.7	0.700	42
Moderately Hard (80-100 mg/L CaCO <sub>3</sub> )	14.0	12.1	26.3	2.10	1.90	81.4	0.700	85
Hard (160-180 mg/L CaCO <sub>3</sub> )	27.9	24.2	52.5	4.20	3.80	163	0.700	170
Very Hard (280-320 mg/L CaCO <sub>3</sub> )	55.9	48.5	105	8.39	7.61	325	0.700	339

Table 2. Calculated Ion Concentrations Based on the Standard Salts Added

<sup>a</sup> Ion concentrations were calculated from standard salt recipes (refer to Table 1 and example calculation for very soft water in Appendix D-1).

<sup>b</sup> Ratio equals quotient of (Ca÷40.08) and (Mg÷24.31), where 40.08 and 24.31 are the molecular weights of Ca and Mg, respectively, in units of mg/mmol.

<sup>c</sup> Hardness calculated according to the concentrations of Ca and Mg given here and the equation given in Appendix D-1.

#### Table 3. Adjusted Ion Concentrations for a Standard Reconstituted Water Mix Based on Reported Hardness

				Specific Io	ons (mg/L)		
Moderately Hard Reconstituted Water	Hardness (mg/L CaCO <sub>3</sub> )	Ca	Mg	Na	K	Cl	$SO_4$
Nominal	85ª	14.0	12.1	26.3	2.10	1.90	81.4
Adjusted	78	12.9	11.2	24.2	2.10	1.75	74.9

<sup>a</sup> Expected hardness based on the amount of salts added (from Table 1). Calcium and magnesium are calculated using Equations 1 and 2. Other adjusted values (italic and bold) are a result of the product of the ratio of measured hardness (78 mg/L) to expected hardness (85 mg/L) and nominal ion concentrations, e.g., the adjusted sodium ion concentration for a standard laboratory reconstituted water mix based on a reported total hardness of 78 mg/L CaCO<sub>3</sub> is:  $78 \div 85 = 0.92$ ;  $0.92 \times 26.3 = 24.2$ .

presented in an earlier comprehensive report by Erickson (1985). Note, however, that because there is generally poor correlation between K and water hardness in the various ambient surface and ground water types (see Section 2.6), the value calculated for K should not be scaled according to hardness.

#### 2.2 pH Adjustment with HCl

Schubauer-Berigan et al. (1993) adjusted pH using HCl but reported only nominal hardness and alkalinity. The tests were conducted at the EPA Office of Research and Development, Mid-Continent Ecology Division, Duluth, MN, using a standard very hard reconstituted water mix. The authors need to be contacted to obtain any additional water chemistry data they might have.

**Recommendation:** Alkalinity and hardness were not measured in the tests reported in Schubauer-Berigan et al. (1993), and no additional water chemistry data are available from the study (Phil Monson, U.S. EPA-Duluth, personal communication). The HCl required to adjust the pH was assumed to be added in amounts too small to significantly affect any of the other water quality parameters (Gerald Ankley, U.S. EPA-Duluth, personal communication). Based on these remarks, we believe ion concentrations for this particular study should be estimated using methods outlined in Section 2.1.

#### 2.3 Estimation of DOC

How should DOC be estimated if only total organic carbon (TOC) was measured in the study? Can DOC be estimated if no measurements of organic carbon were reported in the study?

**Recommendation:** As a general rule, TOC values can be used directly in place of DOC for dechlorinated and de-ionized city tap water, well water, and oligotrophic lake water (e.g., Lake Superior water). TOC values are not recommended in place of DOC for water from estuaries, wetlands, or higher order streams unless data are included that indicate otherwise. Rather, the proportion of organic carbon expected to be dissolved in surface waters should be estimated and used to scale the measured TOC value. When possible, the DOC:TOC ratio for a surface water should be obtained using the USGS NASQAN dataset. The NASQAN dataset can be reached through the USGS Web site (water.usgs.gov/nasqan/data/finaldata.html). If a representative ratio for a particular body of water cannot be determined, the ratio for the particular water type (lake or stream) should be obtained from the final draft of the Ambient Water Quality Criteria Derivation Methodology Human Health Technical Support Document (U.S. EPA 1998a, Table 2.4.11). A summary of these data, by State, is provided in Appendix D-2. In this appendix, TOC is operationally defined as the sum of DOC and particulate organic carbon (POC). The national mean fraction of organic carbon is 86 percent for streams and 88 percent for lakes. The DOC:TOC ratio can be applied to lakes or streams within a State to obtain an estimate of DOC form values reported for TOC.

#### Example:

Reference	Water Body	TOC (mg/L)	DOC:TOC	Estimated DOC (mg/L)
Lind et al. manuscript	St. Louis R, MN	32	0.87	28

For tests with reconstituted, city tap, or well water, default DOC values can be applied if the author does not report a measured value. The recommended default TOC (DOC) value for laboratory prepared reconstituted water is 0.5 mg carbon/L (note: some newer laboratory water systems can achieve a TOC of less than 0.5 mg/L). For regular city tap and well water, a value of 1.6 mg carbon/L can be assumed. The recommended default value for laboratory-prepared reconstituted water is based on the arithmetic mean of recent measurements of DOC in reconstituted water prepared at two Federal (U.S. EPA Cincinnati, OH, and USGS Yankton, SD) and two consulting (Commonwealth Biomonitoring and GLEC) laboratories (range 0.1 to 1 mg/L). The recommended default value for dechlorinated city tap and well water is based on the arithmetic mean of measurements of DOC in source water from Lake Ontario (Environment Canada, Burlington, ON) and the New River, VA (City of Blacksburg, VA), and well water from Oak Ridge National Laboratory (Oak Ridge, TN) and EPA's WFTS (Corvallis, OR). The DOC values in these waters ranged from 1.1 to 2.5 mg/L.

For tests conducted in surface waters, we do not recommend the use of a default DOC value because of the large variability of DOC observed. Rather, a reliable database such as USGS NASQAN (as described above) should be searched for DOC measurements. If a database such as NASQAN is consulted, only those DOC measurements closest to the time of the study should be considered as surrogate values. In general, these DOC concentrations should not differ by more than a factor of 1.25. If DOC measurements for the surface water cannot be obtained from a reliable source, then the toxicity test should not be included in Table 1 for BLM normalization.

#### 2.4 DOC in Lake Superior Water

Lake Superior water has been used in a number of acute and chronic toxicity studies included in the Aquatic Life Criteria for Copper (U.S. EPA 1998b). Dissolved organic matter (DOM) in Lake Superior is assumed to be anywhere from 1 to 3 mg/L (Russ Erickson, U.S. EPA-Duluth, personal communication; McGeer et al. 2000). This value is expected to be at least 90 percent of TOC (or 2 mg/L) (see Spehar and Fiandt 1986). A default value based on recent measurements is needed for DOC in Lake Superior water.

**Recommendation:** Recent measurements of TOC in Lake Superior dilution water are in Appendix D-3 (Greg Lien, U.S. EPA-Duluth, personal communication). The geometric mean concentration of TOC in Lake Superior dilution water from multiple measurements is 1.27 mg/L. Given the recommendation in Section 2.3, the recommended DOC for Lake Superior dilution water is  $1.1 \text{ mg/L} (1.27 \text{ mg/L} \times 0.88)$ .

#### 2.5 Applying Water Chemistry Data to Lake Superior Water

The ionic composition included in the Table 1 spreadsheet for Lake Superior water is based on concentrations converted from values reported in Erickson et al. (1996b): Ca at 0.68 meq/L = 13.6 mg/L; Mg at 0.24 meq/L = 2.9 mg/L; Na at 0.065 meq/L = 1.5 mg/L; K at 0.015 meq/L = 0.59 mg/L; SO<sub>4</sub> at 0.070 meq/L = 3.4 mg/L; Cl at 0.035 meq/L = 1.2 mg/L; and alkalinity at 0.85 meq/L = 43 mg/L. The concentrations for most of these parameters were also reported in Biesinger and Christensen (1972) and approximate those listed above. Should the Erickson et al. (1996b) data be applied to all Lake Superior studies, or is there a stronger rationale for applying the Biesinger and Christensen (1972) data to the older studies?

**Recommendation:** We recommend applying the mean of the Erickson et al. (1996b) citation and Biesinger and Christensen (1972) water chemistry data to all Lake Superior studies prior to 1987, when the results were initially reported. After 1987, we recommend use of the Erickson et al. (1996b) water chemistry data alone (Table 4). For each test, Ca and Mg concentrations should be estimated using Equations 1 and 2, the Ca:Mg ratios given below, and the measured hardness of the test water (Section 2.1). Ions other than K should be scaled according to the measured test hardness, also discussed in Section 2.1.

					Specific	Ions (mg	g/L)		
Applied to:	Hardness (mg/L CaCO <sub>3</sub> )	Alkalinity (mg/L CaCO <sub>3</sub> )	Ca	Mg	Ca:Mg	Na	К	Cl	$SO_4$
Pre-1987 <sup>a</sup>	46	42	13.6	3.0	2.75	1.3	0.57	1.2	3.4
Post-1987 <sup>b</sup>	46	43	13.6	2.9	2.84	1.5	0.59	1.2	3.4

Table 4.	Recommended S	preadsheet Addition	for Lake Su	perior Dilution	Water
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<sup>a</sup> Mean of the Erickson et al. (1996b) and Biesinger and Christensen (1972) water chemistry data

<sup>b</sup> Erickson et al. (1996b) water chemistry data alone

#### 2.6 Predicting Ionic Composition of WFTS Well Water

The following studies seem were conducted at EPA's WFTS using well water: Andros and Garton (1980), Chapman (1975, 1978), Chapman and Stevens (1978), Lorz and McPherson (1976), Nebeker et al. (1984a, 1986a, b), and Seim et al. (1984). Among these studies, however, there is a wide range of hardness values (20-100 mg/L), and the ionic composition of the water was not always reported.

The large variation in WFTS well water hardness, and consequently, ionic composition, is due to seasonal variability (Samuelson 1976). The TOC content of this water has been reported to be 1.1 mg/L (McCrady and Chapman 1979), of which 100 percent is expected to be dissolved. A general strategy is needed to predict the ionic composition of WFTS well water based on measured water hardness.

**Recommendation:** The well feeding the WFTS is susceptible to influx from ground water during rain events in late fall and winter (November through March or April). During this period the water

hardness can reach measured levels as high as 100 mg/L CaCO<sub>3</sub>. Over the remaining months (particularly from July to November), hardness stabilizes at around 25 to 40 mg/L CaCO<sub>3</sub>, as do other water quality parameters (Al Nebeker, U.S. EPA Corvallis, personal communication; Samuelson 1976). It is important to note that the high hardness reported for WFTS well water is sporadic, even in the winter.

The recommended strategy for filling the existing gaps in data reported from studies using this well water is to estimate the ion concentrations on the basis of their relationship to the total hardness measured during a particular test. The acceptability of tests conducted using WFTS water depends on the range of hardness values reported, i.e., if the hardness varies widely over the course of a particular test, then perhaps the test should not be used. Regression analyses were performed using measured hardness and ion data for the WFTS well water reported in Samuelson (1976), April 1972

to April 1974, and supplemented with additional data from Gary Chapman, personal communication (only those data from May 1974 to April 1978; see Appendix D-4). These relationships and the corresponding regression equations are presented in Figures 1 through 6 (found at the end of this report). Major ion concentrations for WFTS well water were predicted using the regression equations over a wide range of water hardness (10 to 80 mg/L CaCO<sub>3</sub>) to determine the accuracy of the procedure (Table 5). The error between predicted and measured ion concentrations is generally within 10 percent for all ions except K, where a default value of 0.7 mg/L was chosen for all hardness levels (actual range is 0.1 to 1.1 mg/L, with the majority of data falling between 0.5 and 0.9 mg/L). The correlation coefficient (R<sup>2</sup>) for the relationship between K and water hardness in WFTS well water was only 0.124. Note: BLM predictions of copper gill accumulation and toxicity are relatively insensitive to the concentration of K, so errors in its estimation should not appreciably affect model predictions. The following regression equations were used to generate the example data provided in Table 5:

$$\label{eq:massive} \begin{split} & [Ca] = 0.3085 + (measured hardness * 0.2738) \\ & [Mg] = 0.5429 + (measured hardness * 0.0573) \\ & [Na] = 3.3029 + (measured hardness * 0.0713) \\ & [C1] = 2.7842 + (measured hardness * 0.1278) \\ & [SO_4] = -3.043 + (measured hardness * 0.2816) \end{split}$$

Lorz and McPherson (1976) and the Seim et al. (1984) tests were not run in WFTS well water, but in water from different wells along the Willamette River. Water chemistry appears to be less variable for these wells (Harold Lorz and Wayne Seim, personal communication). The following additional water chemistry information for the two well water types used in these studies was provided by the respective authors in January 2001.

Many of the studies conducted by Chapman used reverse osmosis treatment to maintain a blended water supply that was of essentially constant ion content throughout the tests. All the test data from Chapman appear to be acceptable; the only test complicated by fluctuating hardness was the 22-month chronic zinc test with sockeye salmon, and that test produced only a NOEC. **Table 5. Predicted Ion Concentrations in WFTS Well Water Based on Measured Hardness** 

Total Hardness		Predicted Ion Concentrations (mg/L)											
(Mean Measured value) mg/L CaCO <sub>3</sub>	Ca	Mg	Na	Cl	$\mathbf{SO}_4$	Default <sup>a</sup> K							
15.00	4.42	1.40	4.10	4.70	1.18	0.70							
20.00	5.78	1.69	4.46	5.34	2.59	0.70							
25.00	7.15	1.98	4.82	5.98	4.00	0.70							
30.00	8.52	2.26	5.17	6.62	5.41	0.70							
35.00	9.89	2.55	5.53	7.26	6.81	0.70							
40.00	11.26	2.83	5.88	7.90	8.22	0.70							
45.00	12.63	3.12	6.24	8.54	9.63	0.70							
50.00	14.00	3.41	6.60	9.17	11.04	0.70							
55.00	15.37	3.69	6.95	9.81	12.45	0.70							
60.00	16.74	3.98	7.31	10.45	13.85	0.70							
65.00	18.11	4.27	7.67	11.09	15.26	0.70							

70.00	19.47	4.55	8.02	11.73	16.67	0.70
75.00	20.84	4.84	8.38	12.37	18.08	0.70
80.00	22.21	5.13	8.74	13.01	19.49	0.70

<sup>a</sup> Value not corrected. Assume default value of 0.70 mg/L.

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Recommended	Recommended Spreadsheet Addition for Oregon Well Water.										
	Hardness (mg/L	Alkalinity (mg/L					Specific	Ions <sup>a</sup> (1	mg/L)		
Applied to:	CaCO <sub>3</sub> )	CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	Κ	Cl	$SO_4$
Lorz and McPherson 1976	95	66	6.8-7.9	1.6 <sup>B</sup>	19	12	1.0	7.6	1.0	7.0	12
Seimet al. 1984	120	126	7.7	1.6 <sup>B</sup>	34	8.6	2.4	15	0.7	5.0	2.3

\*\*\* \*\* \*\*\*

<sup>a</sup> Specific ion values were obtained through personal communication with the primary authors; hardness, alkalinity, and pH values are as reported in the article. The Ca:Mg ratios were calculated on the basis of data provided by authors, then Ca and Mg values used were back-calculated on the basis of these ratios and the measured test hardness (see Equations 1 and 2).

<sup>b</sup> Suggested default value for untreated well water (see Section 2.3).

#### 2.7 Data for Measurement of Blacksburg/New River Water

A substantial amount of acute copper toxicity data to various freshwater organisms is reported using dechlorinated City of Blacksburg, VA, tap water. These include studies by Belanger et al. (1989), Cairns et al. (1981), Hartwell et al. (1989), and Thompson et al. (1980). Hardness, alkalinity, and pH values are reported for City of Blacksburg water in all of these studies, but the ionic compositional data are not. This information is required to obtain BLM-normalized LC50s for these data.

**Recommendation:** According to Don Cherry (personal communication), tests conducted at Virginia Polytechnic Institute and State University used City of Blacksburg, VA, tap water, which is drawn from the nearby New River. Don Cherry collected a sample of New River water for analysis under Work Assignment 1-20. The results of the analysis are provided in Appendix D-5. The sample was of untreated natural water prior to any treatment by the City of Blacksburg. Values for treated New River water (city) were provided by Jerry Higgins, Water Superintendent, City of Blacksburg. Table 6 summarizes the measured values for New River and City of Blacksburg dechlorinated tap water.

Historically, hardness and alkalinity vary substantially in dechlorinated City of Blacksburg tap water and in raw New River water (Table 6). Some of this difference may be attributed to seasonal effects. For example, strong seasonal influence was observed in both well water (influenced by surface water, i.e., WFTS well water; see Section 2.6) and a natural surface water (St. Louis River, MN; refer ahead to Section 2.19). Previously, we plotted ion concentrations against hardness for each of these two water types (Figures 1 through 6 and Appendix D-6). The relationships were good in almost all cases (positive,  $R^2 = 0.5$  to 0.9), and the resultant regression equations were used to scale ion concentrations according to reported water hardness. Incomplete datasets, however, preclude the use

of the same approach for City of Blacksburg tap and raw New River water. Instead, we recommend using the ion and hardness values from the City of Blacksburg water sample and USGS NASQAN ion data, respectively (Table 6), to generate surrogate ion values for the respective waters that were not reported in the previous studies (indicated by the shaded area in Table 6). The operation is simply to multiply ion concentrations for the "acquired data" by the ratio of hardness values in City of Blacksburg and NASQAN water and the corresponding test waters as was done in Section 2.1. We used the NASQAN ion data as the basis for scaling the raw New River water ion estimates because NASQAN represents data collected over several representative years, including the years in the timeframe in which the studies of interest were initiated and completed. The exception was with DOC. We felt that the DOC value obtained from the sample of New River water collected in August 2000 would be more representative than the few values generated from NASQAN (all pre-1980).

#### 2.8 Cu Concentrations and Alkalinity

The methods sections of both Belanger and Cherry (1990) and Belanger et al. (1989) state that total and dissolved Cu were measured, but it is not clear whether the reported LC50s are based on total or dissolved copper concentration. Also, in Belanger and Cherry (1990), pH was adjusted with sodium hydroxide (NaOH) or nitric acid (HNO<sub>3</sub>), but only nominal pHs were reported. Alkalinity and hardness after pH adjustment were not reported. Can alkalinity be adjusted for these tests?

**Recommendation:** The concentration Cu in algae is reported on a total metal basis in Belanger et al. (1989) and Belanger and Cherry (1990). The Cu in water is reported on an acidsoluble basis. The acid-soluble concentration of Cu in water was used to derive the LC50. For all intents and purposes, acid-soluble Cu can be considered as dissolved Cu because the acidification of the filtrate after filtration is probably sufficient to obtain most of the Cu associated with colloidal material. Normally a digestion procedure is required to convert all Cu to the dissolved form. If the sample had not been filtered, it would not have been acceptable because it could have been elevated by dissolution of particulate copper.

The pH levels achieved in the batch culture pH tests in Belanger and Cherry (1990) were reported as 6.15, 8.02, and 8.95. Given the proximity of these values to the desired target pH values of 6, 8, and 9, respectively, it would appear that the researchers were able to closely approximate the nominal pH levels, including those selected for the acute heavy metal tests (also pH 6, 8, and 9, respectively). Assuming that the target pH values of 6, 8, and 9 were achieved in the acute tests, adjustment with NaOH and HNO<sub>3</sub> would have affected alkalinity, but probably not hardness or the major anion and cation concentrations, except possibly Na. The contribution to Na by the addition of NaOH was probably small, so no further adjustment would be necessary.

			Total	Total			Specif	ic Ions (1	mg/L)				
C.	Water		Hardness	Alkalinity	-	14		17	Cl		NO	Ca:Mg	DOC
Source	Type	рн	$(mg/L CaCO_3)$	$(mg/L CaCO_3)$	Ca	Mg	Na	K	CI	$50_4$	NO <sub>3</sub>	ratio	(mg/L)
				Acquired Data									
City of Blacksburg, VA <sup>a</sup>	City	8.5	44	39	-	-	9.3	-	33	45	-	-	1.5
Cherry 2000 (08/00) <sup>b</sup>	New R.	8.0	-	52	15	0.6	6.6	2.0	6.1	9.8	0.7		2
NASQAN <sup>c</sup>	New R.	-	61	-	15	5.8	3.4	1.6	4.0	13	0.8	1.6	5.4
			Values To Be	Applied to Table 1	Toxicity	v Tests <sup>d</sup>							
Belanger et al. 1989	City	7.7	45	40	11	4.2	9.5	1.6	34	46	-	1.6	1.5
Hartwell et al. 1989	City	7.5	72	43	18	6.8	15	1.6	54	74	-	1.6	1.5
Cairns et al. 1981	City	7.0	26	27	6.4	2.4	5.5	1.6	19	26	-	1.6	1.5
Thompson et al. 1980	City	7.2	40	28	9.9	3.8	8.5	1.6	30	41	-	1.6	1.5
Belanger et al. 1989	New R.	8.2	94	70	23	8.8	5.2	1.6	6.2	20	-	1.6	2
Belanger and Cherry 1990	New R.	6, 8, 9	98	74	24	9.1	5.4	1.6	6.4	21	-	1.6	2

Table 6.	Comparison o	f Values for	Untreated	(Natural) ar	nd Treated	(Dechlorinated	City o	of Blacksburg	. VA) New	River	Water
I dole of	companison o	i varaes ioi	C II II Cuttu	(1 (avaiai) ai	ia ilcutta	(Decimorniacea	City o	n Diacissourg	, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	111,01	

<sup>a</sup> Data provided by Gerard (Jerry) Higgins of Blacksburg-Christianburg VPI Water Authority, Blacksburg, VA. Values presented are from a grab sample collected January 31, 2000. Organic carbon (originally measured and reported as TOC) is assumed to be 100 percent dissolved.

<sup>b</sup> Sample provided by Don Cherry, Virginia Polytechnic Institute and State University, Blacksburg, VA, and analyzed by Environmental Health Laboratories, South Bend, IN. Values presented are from a grab sample collected August 2000. The value for Mg of 0.6 mg/L appears to be a reporting error, and was not used for subsequent calculations of total hardness or scaling of ion values.

<sup>c</sup> Data obtained from USGS NASQAN database. Values presented are means of 213 samples, except for DOC, which is a mean of seven samples, collected and analyzed from January 1973 to August 1995.

<sup>d</sup> Shaded area indicates mean values estimated from previously (NASQAN) or recently measured (Cherry 2000 or City of Blacksburg; nonadjusted) ion values. All values have been rounded to two significant figures. Shaded values were derived according to text above using the approach outlined in Section 2.1. Using a nomograph found in Faust and Aly (1981), alkalinity at pH 6 should be approximately 33 percent of the alkalinity at pH 8, and alkalinity at pH 9 should be 5 percent higher than the alkalinity at pH 8 (Table 7). Therefore, the values for alkalinity in Table 7 should be used for the acute toxicity tests presented in Belanger and Cherry (1990) in this case. For other analyses, different adjustment factors may be appropriate, based on other interpretations from the Faust and Aly nomograph or other methods as well. Appropriate consideration should also be given to the test system equilibration with the atmosphere.

Source Water	Nominal pH	Alkalinity (mg/L CaCO <sub>3</sub> )
New River	6	24.5
	8.1	74.2ª
	9	77.9
Clinch River	6	47.6
	8.3	144 <sup>a</sup>
	9	152
Amy Bayou	6	40.2
	8.3	122ª
	9	128

Table 7.	Estimated	Alkalinity i	n Natural	Surface	Water	Based	on	pН
1 40 10 / 1								

<sup>a</sup> Indicates values reported in text.

#### 2.9 Calculation of DOC and Humic Acid

What was the technical approach used to calculate DOC and percent humic acid (HA) for the Winner (1985) toxicity tests?

**Recommendation:** At a nominal HA concentration of 0.0 mg/L in soft and medium hardness test waters, the DOC is assumed to be that of the ultrapure laboratory water, which is estimated to be 0.3 mg/L (approximately one-half of the recommended default value for DOC in laboratory water; see Section 2.3). At nominal HA concentrations of 0.15, 0.75, and 1.50 mg/L, the DOC is calculated by dividing by a value of 2, based on the assumption in the BLM User's Guide (Di Toro et al. 2000) that the percent carbon in HA is 0.50 (see example below and Table 8). Because the water used to obtain these HA concentrations was ultrapure laboratory water, 0.3 mg carbon/L was added; final rounded values of 0.38, 0.68, and 1.1 are recommended.

Table 8.	Estimates of Dissolved	<b>Organic Carbon</b>	and Percent	Humic Acid	for the Winner
(1985) To	oxicity Tests				

Humic Acid Added (mg/L) <sup>a</sup>	Calculated DOC (mg/L)	Calculated Percent Humic Acid
0	0.3	10
0.15	0.38	28
0.75	0.68	60
1.5	1.1	74

<sup>a</sup> As indicated in Table 3 of Winner (1985).

#### 2.10 Alkalinity of Lake Superior Water

For the Lind et al. (manuscript) tests conducted in Lake Superior water (adjusted with  $CaSO_4$  or  $MgSO_4$ ), is there any way to estimate alkalinity values?

**Recommendation:** For tests conducted in Lake Superior water, assume an alkalinity of 42 mg/L CaCO<sub>3</sub> (see Section 2.5).

#### 2.11 Availability of LC50s

The LC50s reported by Collyard et al. (1994) are shown graphically in publication. The LC50s provided in Table 1 are interpolated from the figure. Are the actual measured LC50s available from the authors?

**Recommendation:** The actual LC50s generated and presented graphically in Collyard et al. (1994) have been archived at U.S. EPA-Duluth, as reported by Gerald Ankley (personal communication, 3 November 2000). These values are not readily available in any other form. The data are acceptable as is on the basis of recommendations in the Guidelines (Stephan et al. 1985). Precedence for the use of values gleaned from graphical data is provided in the 2001 Update of Ambient Water Quality Criteria for Cadmium (U.S. EPA 2001).

#### 2.12 Cl and Na Concentrations

Cl and Na ion concentrations of the tap water used for testing in Rice and Harrison (1983) were derived from the addition of 20 mg/L sodium chloride (NaCl). What are the specific concentrations of the individual ions from the addition of the salt? What concentrations do you suggest using for K and  $SO_4$  in this water?

**Recommendation:** The Cl content of the tap dilution water used in Rice and Harrison (1983) was reported as having been derived from the addition of 20 mg/L of NaCl. Assuming that the initial Na and Cl concentrations in tap water were essentially zero, the concentrations of these ions can be calculated in the following way:

The molecular weight of NaCl is 58.44 g/mol. The atomic weight of Na is 22.98 mg/L and the atomic weight of Cl is 35.453 mg/L.

The concentration of Na is:

20 mg NaCl/L \* 1 mmol NaCl/58.44 mg NaCl = 0.342 mmol NaCl/L. 0.342 mmol NaCl \* 1 mmol Na/1 mmol NaCl \* 22.98 mg Na/1 mmol Na = 7.86 mg Na/L.

The concentration of Cl is:

 $20 \text{ mg NaCl/L} \times 1 \text{ mmol NaCl/58.44 mg NaCl} = 0.342 \text{ mmol NaCl/L}.$ 

 $0.342 \text{ mmol NaCl} \times 1 \text{ mmol Na/1 mmol NaCl} \times 35.453 \text{ mg Cl/1 mmol Cl} = 12.12 \text{ mg Cl/L}.$ 

Given the potentially large dichotomy between the default ion concentrations and measured hardness of the water used in this study, we recommend adjusting the default  $SO_4$  concentration according to measured hardness as in Section 2.1. We do not, however, recommend adjusting the current default value of 1.0 mg/L for K.

#### 2.13 Calculating DOC in Dilution Water

The dilution water used in the acute copper toxicity tests with cutthroat trout in Chakoumakos et al. (1979) was a different mix of spring water and de-ionized water for each test. Ca and Mg concentrations were measured and reported for each of the test waters used, but measurements of the other ions were reported only for the undiluted spring water. Based on a percentage dilution, ions other than Ca and Mg were estimated in the following way: hardness was measured in the spring water and in each of the test waters; the proportion of spring water was calculated for each test using these measured hardness values; this proportion was then multiplied by the concentration of, for example, Na in the spring water to get an estimated Na value for each test. TOC in the spring water was 3.3 mg/L. Should the same approach as that used to estimate the other ions be used to calculate DOC, which was only measured in undiluted spring water?

**Recommendation:** The concentrations of the major cations and anions in the dilution water used by Chakoumakos et al. (1979) were calculated based on the percent dilution of natural spring water with de-ionized water. The same correction can be used to estimate DOC, with the following assumptions. First, the TOC in spring water was 100 percent dissolved. Second, the DOC of de-ionized water was 0.5 mg/L. If these assumptions are acceptable, the DOCs for H/H, M/H, L/H, H/M, M/M, L/M, H/L, M/L, and L/L would be 3.3, 1.5, 0.75, 3.3, 1.7, 0.94, 2.8, 1.5, and 0.87 mg/L, respectively.

#### 2.14 Ionic Composition of Chehalis River Water

The ionic composition of Chehalis River, WA, water is needed to fill in existing data gaps used for BLM analysis of acute toxicity reported in Mudge et al. (1993). The publication states, "Water quality data collected during this bioassay program is similar to historical data for Chehalis River (WPPSS 1982) and other Pacific NW streams (Samuelson 1976)." Are data from Samuelson (1976) acceptable for use in approximating these ion concentrations? Furthermore, are there any dissolved or ionic LC50s available other than those reported in the publication?

**Recommendation:** The following additional water chemistry information for the Chehalis River dilution water used in the studies reported by Mudge et al. (1993) was provided by the author on 20 November 2000. These measurements were made on Chehalis River water at the time of testing. A corresponding value for DOC was obtained from the NASQAN dataset.

Recommended s	preadsheet	addition	for	Chehalis	River	dilution	water

		Specific Ions (mg/L)										
	DOC											
Applied to:	(mg/L)	Ca	Mg	Ca:Mg	Na	Κ	Cl	$SO_4$				

Mudge et al. 1993	3.2ª	7.1	2.4	1.8	5.1	0.65	4.5 (May)	4.0 (May)
							4.2 (Jun)	3.5 (May-Jul)
							3.1 (Sep)	2.3 (Sep)

<sup>a</sup> Value from the USGS NASQAN dataset, 1980-1982, when the tests were conducted.

#### 2.15 Chemistry of Water in Howarth and Sprague (1978)

What is the ionic composition and organic carbon content of test waters used in Howarth and Sprague (1978)? The waters used for testing were various mixes of University of Guelph (Guelph, ON, Canada) well water and de-ionized well water. The de-ionized well water was reported as "having retained its original chloride content (22 mg/l)," but the values for the other major anion and cation concentrations were not reported. Furthermore, the equation provided for calculating alkalinity from pH and hardness (supposedly accounting for 96.7 percent of the variability) appears unreliable. For example, using the equation and a total water hardness of 364 mg/L CaCO<sub>3</sub> at pH 9, one obtains an estimated alkalinity value of 341 mg/L CaCO<sub>3</sub>. In contrast, the measured alkalinity reported in the text for this level of hardness and pH was 263 mg/L CaCO<sub>3</sub>.

**Recommendation:** The equation provided in the text of Howarth and Sprague (1978) for calculating alkalinity appears unreliable. The calculated alkalinity does not approximate measured alkalinity within a reasonable degree of accuracy. Values of hardness, pH, and alkalinity in Dixon and Sprague (1981a), which used the same water source in their toxicity tests, give greater evidence of this; i.e., using the measured value of hardness of 374 mg/L CaCO<sub>3</sub> and a pH of 7.75, the alkalinity calculated with the equation is 98 mg/L CaCO<sub>3</sub>. This compares rather poorly with the measured alkalinity of 223 mg/L CaCO<sub>3</sub>. Instead, alkalinity can be estimated using the nomograph from Faust and Aly (1981) as in Section 2.8.

It is possible to apply the procedure used with the Chakoumakos et al. (1979) data here, i.e., using the ratio of hardness in full-strength well water and de-ionized well water to calculate the dilution of the other major ion concentrations. However, no values are given for Na or K in University of Guelph well water. This study is also complicated by the reverse-osmosis unit used to create the de-ionized well water. In particular, the statement concerning the retention of the original Cl concentration in the de-ionized well water implies an ionic exchange that would also require a cation (to maintain charge balance). The cation involved is unknown. As discussed in a phone conversation with John Sprague on 17 November 2000, and later that day with Scott Howarth (Environment Canada), NaCl may have leached through the RO unit. Assuming that Na and Cl leached through the unit in equivalent proportions, a value of 14 mg/L for Na can be back-calculated from the reported Cl concentration of 22 mg/L.

Default DOC concentrations of 1.6 and 0.5 mg/L were assumed for the well water and deionized water used in the tests, respectively (see Section 2.3). The DOC concentrations were adjusted for each particular test water hardness level based on the proportion of well water and de-ionized water used to achieve the desired test hardness level. In the example provided in Table 9, the dilution factor of 0.27, based on the ratio of the average hardness of well water (366 mg/L CaCO<sub>3</sub>) versus the average hardness of well plus de-ionized well water (100 mg/L CaCO<sub>3</sub>), was applied to the starting DOC concentrations to achieve an estimate of the DOC concentrations at 100 mg/L CaCO<sub>3</sub>). Table 9 shows the results of similar adjustments made for the major anions and cations based on the data reported in Howarth and Sprague (1978).

#### 2.16 Default Values for Analyte Concentrations

What value should be used when a specific analyte is not detected at its designated detection limit?

**Recommendation:** The use of half the detection limit (DL) is most appropriate when the concentration of an analyte is not detected. One-half the DL will closely approximate a replacement value for censored data in a log-normally distributed population that includes several measured values (Berthouex and Brown 1994; Dolan and El-Shaarawi 1991). This way some of the "nondetect" samples will actually be counted as detected.

Parameter			Example Calculations
(units in mg/L)	De-ionized water	Well Water	for Mixture
Hardness	0	366	100 (i.e., 0.27 dilution factor)
Ca	0	77 (fromDixon & Sprague 1981)	21
Mg	0	43 (fromDixon & Sprague 1981)	12
Na	14 (assuming NaCl used for the softening process)	14 (estimated from [Cl])	14
К	0	2.4 (based on personal communication fromDr. Patricia Wright, Univ. of Guelph, Guelph, ON)	0.66
Cl	22 (stated as not having changed from the water softening process)	22	22
$SO_4$	0	129	35
DOC	0.5 (default value for de- ionized waters)	1.6 (default value for well waters)	0.8
<u>Alkalinity</u> (calcul	ated using ratios as in Section 2.8	8):	
at pH 6	0 <sup>a</sup>	81.5	22
at pH 7	0 <sup>a</sup>	205	55
at pH 8	0 <sup>a</sup>	250	N/A
at pH 9	0 <sup>a</sup>	263	70

# Table 9. Example Calculations to Estimate Water Chemistry of Tests Conducted at 100 mg/L CaCO<sub>3</sub> by Howarth and Sprague (1978) Using a Mixture of University of Guelph Well Water and De-ionized Water

<sup>a</sup> Alkalinity in de-ionized well water is assumed to be 0.0 mg/L.

#### 2.17 Organic Carbon Content of Samples

Can any information be obtained on the organic carbon content of the spring water / City of Cincinnati, OH, tap water mixes used in Brungs et al. (1973), Geckler et al. (1976), Horning and Neiheisel (1979), Mount (1968), Mount and Stephan (1969), and Pickering et al. (1977)?

**Recommendation:** The water used for all tests was a mixture of spring-fed pond water (originating at the Newtown Fish Farm) and carbon-filtered, demineralized Cincinnati tap water. The water was mixed to achieve the desired test hardness level and discharged to a large (several thousand gallon) concrete reservoir that fed the test system. The detention time varied anywhere from 30 to 90 days, depending on the study, which was sufficient to allow the growth of phytoplankton and zooplankton in moderate abundance. No additional information regarding the TOC (DOC) concentration or treatment of this water is available at this time. The recommended organic carbon content of spring/city water mix is currently a conservative 1.6 mg/L, but could be as high as 2.5 mg/L, the highest DOC concentration recorded for a natural surface or well water used for studies included in this report (see Section 2.3). Considering the long retention time, and the fact that the natural water was spring-fed pond water, the more conservative DOC value of 2.5 mg/L is recommended for this water.

#### 2.18 Additional Water Chemistry Data Needed

Additional water chemistry data are needed for Bennett et al. (1995) and Richards and Beitinger (1995). In the case of Richards and Beitinger 1995, only the ranges of measured pH, alkalinity, and hardness across all tests were given.

**Recommendation:** Detailed pH, alkalinity, and hardness values were provided by both Bennett et al. (1995) and Richards and Beitinger (1995) (Appendixes D-7 and D-9, respectively). The studies performed by Bennett et al. were conducted using dechlorinated City of Denton, TX, tap water (from Lake Roy Roberts). The author was not able to provide any additional data regarding the ionic composition of this water; however, based on supplementary data, mean values of pH, alkalinity, and temperature were 8.07 and 89.7 mg/L CaCO<sub>3</sub> and 21.4 C, respectively. Richards and Beitinger's studies were conducted using standard reconstituted (hard) water. To estimate the ionic composition of this water, refer to recommendations provided in Section 2.1.

#### 2.19 Estimating Data for Waters

Values for DOC, TSS, Ca, Mg, Na, K, SO<sub>4</sub>, and Cl are needed for the following natural waters:

<u>Water Body</u> American River, California – sand filtered Clinch River – 11µm filtered

Amy Bayou Blaine Creek, Kentucky – 1.6 μm filtered S. Kawishiwi St. Louis River Lake One ReferenceFinlayson and Verrue 1982Belanger et al. 1989Belanger and Cherry 1990Belanger and Cherry 1990Dobbs et al. 1994Lind et al. manuscriptLind et al. manuscriptLind et al. manuscript

Colby Lake	Lind et al. manuscript					
Cloquet Lake	Lind et al. manuscript					
Greenwood Lake	Lind et al. manuscript					
Embarrass River	Lind et al. manuscript					
Green Duwamish River	Buckley 1983					
Chehalis River	Mudge et al. 1993					
Pinto Creek, AZ	Lewis 1978					
Naugatuck River	Carlson et al. 1986					

**Recommendation:** On the following pages are data (current and/or historical, presented as arithmetic means) from selected natural waters that were retrieved from NASQAN, STORET, or a secondary source (as indicated). As mentioned earlier (see Sections 2.6 and 2.7), given the reasonably good correlation between most of the major anion and cations (except K) and water hardness in natural surface and well waters, we recommend using the ion and hardness values retrieved from these various sources to estimate the ion concentrations in the test water used in the previous studies. The operation, again, is simply to multiply the ion concentrations listed below by the ratio of hardness values presented below and the earlier test waters.

Note that additional data were not available for Blaine Creek, KY, or Pinto Creek, AZ, and although additional data were obtained from the City of Sacramento, CA, regarding the American River, the default DOC value (8.2 mg/L) for California streams may be artificially high on the basis of reported values of DOC in the Sacramento River (1.2 mg C/L), of which the American River is a tributary. Therefore, the data from Finlayson and Verrue (1982) have been relegated to "other data." Likewise, Amy Bayou is a highly contaminated and dynamic system (Don Cherry, personal communication), and BLM normalization is not recommended for these data. A large annual variability in water quality also excludes the use of surrogate STORET data for the Embarrass River, MN, for BLM analysis (Lind et al. manuscript).

	Hardness	Alkalinity		<u> </u>			Specific	: Ions (n	ng/L)		
Applied to:	(mg/L CaCO <sub>3</sub> )	(mg/L CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$
Finlayson and Verrue 1982	21	22	7.5	_a	5.6	1.8	2.0	3.0	-	2.6	3.8

|--|

<sup>a</sup> DOC and K data for the American River were not available.

C1:	374 (4	1: D E	). C	Daw Chamer	V/A D - 1-	The st Q Ctat	- II:- D	1 1 1	<b>T</b> 7 A
Ulinch Kiver	. VA (A)	ppendix D-5	): Source: I	Jon Cherry	. VA PON	V. INSL. & MAL	е опіх в	ласк уршту.	VA
ennen ru ver	, , , , (, ,	ppename c	) Doureer 1	e on onen j	, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	i moti ce stat	e e m ; i, z	raenco arg,	

	Hardness	Alkalinity					Specific	: Ions (r	ng/L)		
Applied to:	(mg/L CaCOa)	(mg/L	лЦ	DOC	Ca	Μα	CarMa	Na	ĸ	Cl	50.
Applied to.	CaCO <sub>3</sub> )	CaCO <sub>3</sub> )	рп	DOC	Ca	wig	Ca. Wig	INa	К	U	$30_4$
Belanger et al. 1989, and Belanger and Cherry 1990	150	150	8.3	2.3	42	11	2.3	12	2.4	9.2	19

#### S. Kawishiwi River, MN (Appendix C-10). Source: STORET

	Hardness	Alkalinity					Specific	lons (r	ng/L)		
Applied to:	(mg/L CaCO <sub>3</sub> )	(mg/L CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$
Lind et al. manuscript	24	18	6.6	_ <sup>a</sup>	5.6	2.4	1.5	1.3	0.5	1.0	4.9

<sup>a</sup> DOC data for this river were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.8721) in Minnesota streams (see Section 2.3 and Appendix D-2).

#### Lake One, MN (Appendix C-10). Source: STORET Hardness Alkalinity Specific Ions (mg/L) (mg/L (mg/L Applied to: CaCO<sub>3</sub>) CaCO<sub>3</sub>) pН DOC Ca Mg Ca:Mg Na Κ Cl $SO_4$ \_a Lind et al. 10 15 6.7 2.8 0.7 1.8 0.1 0.3 0.2 4.2 manuscript

<sup>a</sup> DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2).

#### Colby Lake, MN (Appendix C-10). Source: STORET

	Hardness	Alkalinity					Specific	Ions (n	ıg∕L)		
Applied to:	(mg/L CaCO <sub>3</sub> )	(mg/L CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$
Lind et al. manuscript	56	33	7.1	_a	13.3	5.4	1.6	4.0	1.4	7.3	23

<sup>a</sup> DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC: TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2).

	Hardness	Alkalinity					Specifi	c Ions (n	ng/L)		
Applied to:	(mg/L CaCO <sub>3</sub> )	(mg/L CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$
Lind et al. manuscript	27	21	7.2	_a	6.9	2.3	1.4	1.9 <sup>b</sup>	1.4°	1.2	5.6

#### Cloquet Lake, MN (Appendix C-10). Source: STORET

<sup>a</sup> DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be

adjusted based on a mean DOC:TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2). <sup>b</sup> Na data for this lake were not available. The Na value given here is based on data for Colby Lake, MN, and was

scaled on the basis of hardness (see Section 2.1): Na = 4.0 mg Na/L \* (27 mg/L CaCO<sub>3</sub> / 56 mg/L CaCO<sub>3</sub>).

<sup>c</sup> K data for this lake were not available. The K value given here is from data for Colby Lake, MN. This value was not scaled on the basis of hardness (see discussion of K-hardness relationship in Sections 2.1 and 2.7).

	Hardness	Alkalinity					Specifi	c Ions (n	ng/L)		
Applied to:	(mg/L CaCO <sub>3</sub> )	(mg/L CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$
Lind et al. manuscript	17	11	6.4	_a	4	1.8	2.4	0.2 <sup>b</sup>	0.3°	1.7	7.6

#### Greenwood Lake (Appendix C-10), MN. Source: STORET

<sup>a</sup> DOC data for this lake were not available. TOC measurements reported by Lind et al. (manuscript) should be adjusted based on a mean DOC:TOC ratio (0.9677) in Minnesota lakes (see Section 2.3 and Appendix D-2). <sup>b</sup> Na data for this lake were not available. The Na value given here is based on data for Lake One, MN, and was scaled based on hardness:  $Na = 0.1 \text{ mg } Na/L * (17 \text{ mg/L } CaCO_3 / 10 \text{ mg/L } CaCO_3)$ .

<sup>c</sup> K data for this lake were not available. The K value given here is from data for Lake One, MN. This value was not scaled on the basis of hardness (see discussion of K-hardness relationship in Sections 2.1 and 2.7).

St. Louis River, MN (Appendix C-6). Source: NASQAN

Note: for the St. Louis River dataset (1973 to 1993), a question arose as to which data would be most representative for estimating the ion concentrations in St. Louis River water for BLM analysis. In order to determine this, the relationship between hardness and Na ion for all 20 years was plotted. Linear regression was used to fit the data. Most data showed very high coefficient correlation (0.8-0.94). For each of these 20 regression lines, the slope and intercept coefficients were plotted on separate graphs as functions of time (Figures 7 and 8). The following conclusions were derived:

- A significant event occurred in 1976 and perhaps 1977 that affected the water balance of the St. Louis River. A wastewater treatment plant was built, which substantially improved the water quality (Jesse Anderson, Minn. Pollution Control Bd., personal communication).
- For the 1979-1993 period, hardness and ion concentrations did not change significantly as absolute values. • Therefore, general equations (which could be used to extrapolate water chemistry data till year 2000 and before 1979) can be obtained connecting hardness, alkalinity, pH, and the major ion concentrations.
- The exponential growth in the values between 1973 and 1979 shows that averaging values on seasonal and annual basis is not appropriate. The constant values for the slopes and intercepts for 1979-1993 allow mean monthly and annual interpretation of the data.
- The regression equations derived for 1977 alone are recommended to predict ion concentrations based on the water hardness levels measured in the Lind et al. (manuscript). The equations derived for each ion are provided in Appendix D-6 with the corresponding figures.

	Hardness	Alkalinity	Alkalinity Specific Ions (mg/L)								
Applied to:	(mg/L CaCO <sub>3</sub> )	(mg/L CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$
Buckley 1983	33	29	7.2	3.2ª	8.9	2.8	2.0	7.5	1.2	7.0	6.3

<sup>a</sup> Value given as TOC. DOC data for this river were not available. TOC measurements reported by Buckley et al. (1983) should be adjusted on the basis of a mean DOC: TOC ratio (0.7803) in Washington streams (see Section 2.3 and Appendix C-2).

Naugatuck	River.	WA.	Source:	STORET
0	,			

	Hardness	Alkalinity					Specific	lons (r	ng/L)		
Applied to:	(mg/L CaCO <sub>3</sub> )	(mg/L CaCO <sub>3</sub> )	pН	DOC	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$
Carlson et al. 1986	39	20	6.4	3.7ª	9.9	3.3	1.9	9.9	2.3	-	22

<sup>a</sup> Value given as TOC. DOC data for this river were not available. TOC measurements reported by Carlson et al. (1986) should be adjusted on the basis of a mean DOC: TOC ratio (0.8711) in Connecticut streams (see Section 2.3 and Appendix C-2).

Figure 1. Relationship between Ca and hardness in WFTS well water



Total Hardness (mg/L as CaCO3)

Figure 2. Relationship between Mg and hardness in WFTS well water.



Total Hardness (mg/L as CaCO<sub>3</sub>)





Total Hardness (mg/L as CaCO3)





Total Hardness (mg/L as CaCO3)








Total Hardness (mg/L as CaCO<sub>3</sub>)

Figure 7. Slopes of the regression equations derived for Na concentration in St. Louis River, MN, water versus water hardness from 1973 to 1993.



Figure 8. Intercepts of the regression equations derived for Na concentration in St. Louis River, MN water versus water hardness from 1973 to 1993.



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## Appendix C-1. Calculations for Ionic Composition of Standard Laboratory-Reconstituted Water

Molecular Weights	Atomic Weights
NaHCO <sub>3</sub> = 84.03	Na = 22.98
$CaSO_4.2H_2O = 172.12$	Ca = 40.08
$MgSO_4 = 120.37$	Mg = 24.31
KCl = 74.55	K = 39.10
$SO_4 = 96.06$	C1 = 35.45

### Example Calculation

[Na] in very soft water: 12 mg NaHCO<sub>3</sub>/L x 1 mmol NaHCO<sub>3</sub>/84.03 mg NaHCO<sub>3</sub> = 0.143 mmol NaHCO<sub>3</sub>/L. 0.143 mmol NaHCO<sub>3</sub>/L x (1 mmol Na/1 mmol NaHCO<sub>3</sub>) x 22.98 mg Na/1 mmol Na = 3.3 mg Na/L.

[Ca] in very soft water: 7.5 mg CaSO<sub>4</sub>.2H2O/L x 1 mmol CaSO<sub>4</sub>.2H<sub>2</sub>O/172.12 mg CaSO<sub>4</sub>.2H<sub>2</sub>O = 0.044 mmol CaSO<sub>4</sub>.2H<sub>2</sub>O/L. 0.044 mmol CaSO<sub>4</sub>.2H<sub>2</sub>O/L x (1 mmol Ca/1 mmol CaSO<sub>4</sub>.2H<sub>2</sub>O) x 40.08 mg Ca/1 mmol Ca = 1.8 mg Ca/L.

[Mg] in very soft water: 7.5 mg MgSO<sub>4</sub>/L x 1 mmol MgSO<sub>4</sub>/120.37 mg MgSO<sub>4</sub> = 0.062 mmol MgSO<sub>4</sub>/L. 0.062 mmol MgSO<sub>4</sub>/L x (1 mmol Mg/1 mmol MgSO<sub>4</sub>) x 24.31 mg Mg/1 mmol Mg = 1.5 mg Mg/L.

[K] in very soft water:
0.5 mg KCl/L x 1 mmol KCl/74.55 mg KCl = 0.0067 mmol KCl/L.
0.0067 mmol KCl/L x (1 mmol K/1 mmolKCl) x 39.102 mg K/1 mmol K = 0.26 mg K/L.

[Cl] in very soft water: 0.5 mg KCl/L x 1 mmol KCl/74.55 mg KCl = 0.0067 mmol KCl/L. 0.0067 mmol KCl/L x (1 mmol Cl/1 mmolKCl) x 35.453 mg Cl/1 mmol K = 0.24 mg Cl/L.

 $[SO_4] \text{ in very soft water:} \\ 7.5 \text{ mg } CaSO_4.2H_2O/L \text{ x 1 mmol } CaSO_4.2H_2 \text{ O}/172.12 \text{ mg } CaSO_4.2H_2O = 0.044 \text{ mmol } CaSO_4.2H_2O/L. \\ 0.044 \text{ mmol } CaSO_4.2H_2O/L \text{ x (1 mmol } SO_4/1 \text{ mmol } CaSO_4.2H_2O) \text{ x 96.064 mg } Ca/1 \text{ mmol } CaSO_4.2H_2O/L. \\ \end{cases}$ 

 $[SO_4] \text{ in very soft water:}$ 7.5 mg MgSO<sub>4</sub>/L x 1 mmol MgSO<sub>4</sub>/120.37 mg MgSO<sub>4</sub> = 0.062 mmol MgSO<sub>4</sub>/L. 0.062 mmol MgSO<sub>4</sub>/L x (1 mmol SO<sub>4</sub>/1 mmol MgSO<sub>4</sub>) x 96.064 mg Mg/1 mmol Mg = 6.0 mg Mg/L.

Total  $SO_4 = 10.2 \text{ mg/L}$ 

Conversion Factors to calculate water hardness (as CaCO<sub>3</sub>) from [Ca] and [Mg]:

[Ca] x 2.497 [Mg] x 4.116

			Streams				Lakes	
State	POC	DOC	Est. TOC	Est. DOC:TOC	POC	DOC	Est. TOC	Est. DOC:TOC
AK	0.54	4.6	5.14	89.49	0.53	6.4	6.93	92.35
AL	0.72	3.4	4.12	82.52				
AR	0.8	7.2	8	90.00	0.4	2.7	3.1	87.10
AZ	0.71	5.2	5.91	87.99	0.52	4.2	4.72	88.98
CA	1.13	8.2	9.33	87.89	0.32	2.3	2.62	87.79
CO	1.29	8.6	9.89	86.96				
СТ	0.71	4.8	5.51	87.11				
DC								
DE*	0.7	7.1	7.8	91.03				
FL^	0.68	16.1	16.78	95.95	2.9	12.1	15	80.67
GA	0.67	4.3	4.97	86.52				
HI	0.59	4	4.59	87.15				
IA	1.79	11.6	13.39	86.63				
ID	0.6	3.2	3.8	84.21				
IL	1.77	6.8	8.57	79.35	0.12	4.7	4.82	97.51
IN	0.71	9.2	9.91	92.84				
KS	1.75	5.2	6.95	74.82	1.53	4.5	6.03	74.63
KΥ	0.75	3.1	3.85	80.52				
LA	1.52	6.9	8.42	81.95	0.65	5.6	6.25	89.60
MA	0.47	5.9	6.37	92.62				
MD	1.66	3.7	5.36	69.03				
ME	0.46	15.3	15.76	97.08				
MI	0.58	6.3	6.88	91.57	0.32	2.7	3.02	89.40
MN	1.79	12.2	13.99	87.21	0.16	4.8	4.96	96.77
МО	0.56	4.2	4.76	88.24				
MT	0.9	9.4	10.3	91.26	0.91	8.2	9.11	90.01
NC	1.14	11.5	12.64	90.98				
ND	1.14	14.5	15.64	92.71	0.8	14.9	15.7	94.90
NE	1.84	6.8	8.64	78.70				
NH	0.28	4.2	4.48	93.75				
NJ	0.69	5.5	6.19	88.85	1.04	5	6.04	82.78
NM	1.43	6.3	7.73	81.50	0.51	5.2	5.71	91.07
NV	0.82	4.2	5.02	83.67				
NY	1.4	4	5.4	74.07	0.46	2.4	2.86	83.92
OH	0.57	5	5.57	89.77	0.49	2.6	3.09	84.14
OK^	1.27	7.7	8.97	85.84	1.72	15	16.72	89.71
OR*^	1.14	2.1	3.24	64.81	0.64	4.4	5.04	87.30
PA	2.19	5.4	7.59	71.15	0.63	3.2	3.83	83.55
RI*	0.42	8.3	8.72	95.18				
SC	0.7	5.7	6.4	89.06				
SD	1.25	7.6	8.85	85.88				
TN	0.67	2.3	2.97	77.44				
ТΧ	1.33	6.5	7.83	83.01	1.55	10.3	11.85	86.92
$UT^{\wedge}$	1.38	8.9	10.28	86.58	0.5	2.4	2.9	82.76
VA	0.81	4.7	5.51	85.30				
VT	0.31	4.5	4.81	93.56				
WA	1.52	5.4	6.92	78.03	0.61	2.8	3.41	82.11
WI	1.03	9.2	10.23	89.93	0.16	4.1	4.26	96.24
WV	0.63	2.8	3.43	81.63				
WY	1.07	8.2	9.27	88.46				

## Appendix C-2. Dissolved, Particulate, and Estimated Total Organic Carbon for Streams and Lakes by State (as presented in EPA Document #822-B-98-005)

			Streams				Lakes	
State	POC	DOC	Est. TOC	Est. DOC:TOC	POC	DOC	Est. TOC	Est. DOC:TOC
			Mean	85.71			Mean	87.84
			Max	97.08			Max	97.51
			Min	64.81			Min	74.63

\* States where sample size was low for streams. ^ States where sample size was low for lakes.

	Replicate	Ambient (8/29/2000)	pH 7.0 (8/30/2000)	pH 6.2 (8/31/2000)
Filter Blank*		-0.04	0.22	0.38
Pre-gill	а	1.13	1.34	1.26
experiment TOC	b	1.37	1.30	1.36
	Mean	1.25	1.32	1.31
Post-gill	а	1.20	1.24	1.18
experiment TOC	b	1.27	1.46	1.10
	Mean	1.24	1.35	1.14
Pre-gill	а	1.96	1.51	1.34
experiment DOC	b	1.52	1.28	0.99
		1.54	1.40	
	Mean	1.74	1.40	1.17
	а	1 49	1 36	1 44
Post-gill	u 1	1.47	1.50	1.24
experiment DOC	D	1.64	1.58	1.24
	Mean	1.57	1 47	1 34
	1110411	1.07	1.1/	1.0 1

# Appendix C-3. Mean TOC and DOC in Lake Superior Dilution Water (data from Greg Lien, U.S. EPA-Duluth, MN)

\* Filter blank is ultra-pure Duluth-EPA laboratory water.

WOITH	Total Hardness	Ca	Mg	Na	K	$SO_4$	C1
Mar-72							
Apr-72		7.9	2	5	1.1	<10.0	8
May-72	22	5.8	1.4	4.4	0.5	<5.0	7
Jun-72	24	5.8	1.6	4.4	0.5	3	7
Jul-72	23	6.7	1.6	4.6	0.5	<1.0	8.3
Aug-72	23	6.5	1.7	4.7	0.5	<10.0	6.3
Sep-72	22	6	1.6	4.5	0.6	<10.0	4
Oct-72	22	6.7	1.9	4.7	0.6	5	5.5
Nov-72	23	6.2	1.6	4.2	0.6	3.7	5.3
Dec-72	23	6.2	1.5	4.2	0.5	3	4
Jan-73	52	15.3	3.5	7.1	0.7	7.8	12.4
Feb-73	33	7.7	2.1	5	0.5	5	5
Mar-73	30	8	2.1	5.3	0.7	5	6
Apr-73	31	8.9	2.3	5.4	0.7	5.3	8.8
May-73	28	8.3	2.4	5.8	0.7	3	8
Jun-73	28	8.4	2.2	5.8	0.7	4.8	7.5
Jul-73	26	7.4	1.9	5.8	0.8	<5.0	6.8
Aug-73	25	6.5	1.7	5.7	0.7	3.1	5.8
Sep-73	25	6.7	1.7	5.4	0.7	3.1	5.3
Oct-73	27	7	1.8	5.4	0.7	2.9	5.4
Nov-73	28	7.9	2.1	4.8	0.7	10	6.8
Dec-73	62	20.3	4.2	9	0.8	13	14
Jan-74	67	21.3	4.8	7	0.8	17.3	11.3
Feb-74	58	14.3	3.4	6.9	0.9	14.7	6.7
Mar-74	53	20.8	3.8	7.2	0.7	13	7
Apr-74	51	18.2	3.7	6.8	0.6	15.5	8.5
May-74	23	7.5	2.1	4.6	0.6	5	4.8
Jun-74	22	6	1.9	4.8	0.5	3	4.5
Jul-74	23	5.4	1.7	5	0.6	3.3	6.3
Aug-74	23	4.8	1.6	5	0.7	3	6
Sep-74	23	5.8	1.5	5.1	0.7	2.9	4.8
Oct-74	23	11	2	7.1	0.8	3.1	5
Nov-74	23	12	2.6	4.5	0.5	3.8	5.3
Dec-74	24	6.4	2.5	5.2	0.7	3.8	5
Jan-75	41	7.7	2.9	6.7	0.6	8	8
Feb-75	61	11.6	4.2	8.6	0.8	16	11.8
Mar-75	54	9.1	3.1	6.4	0.6	8	8
Apr-75		4.4	1.6	4.4	0.5	3	5
May-75		7.2	2	5	0.5	6	7
Jun-75		4.4	1.6	4.6	0.6	5	6
Jul-75		5.2	1.6	7	0.7	5	7
Aug-75		5.2	1.4	7	0.6	5	5
Sep-75		4.5	1.5	4.5	0.7	5	4
Oct-75		7.1	1.9	4.3	0.5	20	5
Nov-75	18	5.3	1.5	4.2	0.5	5	4
Dec-75							
Jan-76							
Feb-76		9.8	5	5.4	0.4	9	9
Mar-76				4.1	0.1	3	6
Apr-76				5.3	0.1	6	9

## Appendix C-4. Measured Hardness and Major Ion and Cation Concentrations in WFTS Well Water from April 1972 to April 1978. Concentrations Given as Mg/L (data from Samuelson 1976 and Chapman, personal communication)

Month	Total Hardness	Ca	Mg	Na	К	$SO_4$	CID
May-76		7.9	1.8	4.5	0.5	3	6
Jun-76	27	8.1	1.9	3.3	0.6	4	7
Jul-76	26						
Aug-76	23	4.9	1.3	4.8	0.1	3	6
Sep-76	23	6.7	2.6	4.7	0.1		
Oct-76	21	6.7	2.6	4.7	0.1		
Nov-76	22	7.7	3	4.7	0.1	3	
Dec-76	25.5	6.4	1.8	5	0.1	4	7
Jan-77	27.2	7.7	2.6	5.6	0.6	4	8
Feb-77		10.7	4.9	5.9	0.6	3	11
Mar-77						3	8
Apr-77		10.7	2.2	5.5	0.8	3	7
May-77	25	5	1.8	5	0.8	3	5
Jun-77	27	6.6	2	5.2	0.7	3	5
Jul-77	24	6.7	2	7.1	0.8	3	7
Aug-77	25	6.9	1.9	6.9	1		8
Sep-77	27	9.9	2.1	5.9	0.9	3	6
Oct-77						3	
Nov-77		6.6	2.1	5.6	0.9	10	4.6
Dec-77	27	9.7		4.95	0.65	9	4.6
Jan-78		10.9	3.75		0.85	6	12
Feb-78		10.6	3.8	8.6	0.7	5	11
Mar-78		10.2	2.6	4.7	0.6	6	9
Apr-78		8.3	2.4		0.7	5	9.55

Date	рН	Hardness	Alkalinity	Са	Mg	Na	K	C1	$SO_4$	NO <sub>3</sub>	DOCD
19790329	7.6	80	63	19	8	8.4	2.3	7.8	13		
19790430	7.6	37	29	8.7	3.7	2.2	1.3	2.8	8.9		20
19790611	7.2	47	34	11	4.8	3.1	0.8	2.8	9.4	ĺ	ĺ
19790723	7.6	73	55	17	7.3	3.9	0.9	3.7	8.9		30
19790827	7.2										
19791015	8.1	74	54	16	8.2	5	1.1	3.9	13	0.01	12
19791126	7.8	61	52	14	6.3	3.8	0.9	3.6	11	0.37	
19800121	7.6	60	53	14	6	3.8	0.9	3.2	9.9	0.15	ĺ
19800219	7.4	63	51	15	6.2	3.9	0.8	2.9	9.2	0.19	17
19800331	8.4	68	64	16	6.9	4.2	1.1	3.5	9.2	0.3	
19800602	8.3	84	72	19	8.8	6.4	1.2	5	15	0.01	21
19800630	8.3	93	68	21	9.9	7.9	1.4	6.7	24	0.02	
19800804	8.1	130	110	28	14	10	1.9	11	24	0.01	13
19800902	7.8	110	82	24	11	7.2	1.7	7.6	18	0.01	
19800929	7.6	73	54	16	8.1	5.7	1.4	5.8	14	0.12	
19801103	7	82	58	18	8.9	5.6	1.3	6.9	18	0.19	23
19801208		67	50	15	7.2	4.6	1	4.1	11	0.19	
19810105	7.6	70	55	16	7.2	4.2	1.1	4.1	13	0.23	
19810209	7.5	68	58	16	6.9	4.9	1	3.5	8.1	0.27	14
19810309	7.7	61	57	14	6.2	5.2	1.8	5.1	8.6	0.36	
19810504	7.3	42	40	9.6	4.3	3.7	1.2	3.6	9.6	0.18	21
19810706	7.4	51	39	12	5	3.5	1.2	3.2	7.5	0.14	10
19810908	7.9	73	64	16	8	4.2	0.8	4.2	8.3	0.11	
19811020	7.6	51	37	12	5.2	4.3	1.2	4.2	8.9	0.31	
19820113		62	52	14	6.5	4	0.9	3.7	9.3	0.24	
19820309	7.4	66	58	15	7	5.3	1	3.8	11	0.36	
19820420	7.2	32	25	7.5	3.3	2.1	1.3	2.3	6	0.19	
19820621	7.9	61	55	14	6.4	4.3	1.1	4	10	0.1	
19820809	7.4	66	54	15	6.9	3.9	0.6	3.5	9	0.25	
19821004	8	73	63	15	8.7	4.9	1	4.7	13	0.11	
19821207	7.3	55	43	12	6.1	4.2	0.8	3.3	16	0.24	
19830131	6.9	62	50	14	6.5	4.1	0.8	3.5	15	0.36	
19830328	7.5	68	56	15	7.3	4.5	1.2	4.1	15	0.35	
19830523	8.2	68	53	15	7.5	4	1.3	0.8	23	0.12	
19830718	7.6	67	53	15	7.2	3.7	1.3	3.7	22	0.15	
19831031	7.7	64	48	14	7	3.9	1.2	3.5	24	0.12	
19840109	7.4	57	50	13	6	3.6	0.9	3.4	13	0.23	
19840306	7.1	66	57	15	7	4.4	0.9	5.2	8.7	0.31	
19840424	7.2	51	39	11	5.6	3.1	1.4	3.2	14	0.12	
19840619	9.5	52	39	12	5.3	2.9	0.8	3.6	10	0.13	
19840822	6.4	70	58	15	7.9	4.7	1	3.8	17	0.1	
19841009	7.6	73		16	7.9	4.6	1	3.7	15	0.1	
19841120	7.1	64		14	7.1	3.9	0.9	3.7	14	0.24	
19850211	7	69		15	7.7	4.6	1.1	4	11	0.27	
19850325	7.3	61		13	7	5.6	2.5	6.6	16	0.31	
19850506	7.4	55		12	6	3.6	1.7	4.2	14	0.15	
19850730	7.6	62		14	6.6	3.2	0.9	4	9.8	0.1	
19851021	7.5	58		12	6.8	3.7	1.1	0.2	12	0.13	

Date	pН	Hardness	Alkalinity	Са	Mg	Na	К	C1	$SO_4$	NO <sub>3</sub>	DOC
19730222	6.8	68	53	17	6.3	11	1.6	14	14	0.19	
19730503	7.1	58	46	14	5.5	6.6	1.1	9.5	13	0.17	
19730816	6.9	70	51	17	6.6	7.6	1.2	9	20	0.01	
19731128	7	65	48	16	6.1	7.5	1.3	8.8	14		Î
19740221	7	64	48	16	5.8	8.9	1.3	12	14		
19740516	6.9	45	32	11	4.3	3.5	1.2	3.8	11		
19740919		88	60	21	8.6	12	1.8	17	23		
19741030	7.3	83	62	23	6.3	13	1.3	16	23		
19741209	7.4	86	62	22	7.6	12	1.6	15	18		Î
19750121	7.3	74	66	18	7	10	1.1	12	13		
19750303	7.3	74	68	17	7.6	10	1.7	11	12		
19750407	7.2	95	80	22	9.7	11	2	14	16		
19750527	7.5	63	50	15	6.1	8.5	1.5	9.2	12		
19750708	9.2	58	43	14	5.7	3.2	1	3.4	10		Î
19750818	7.2	73	56	18	6.9	12	1.3	16	16		
19750929	7.4	90	72	23	8	12	1.5	13	20		
19751110	7.1	90	63	22	8.4	12	1.7	15	24		
19751216	7.6	87	61	22	7.8	14	1.6	16	28		
19760209	7.5	72	59	18	6.6	13	1.6	13	18		ĺ
19760322	7.7	78	65	19	7.4	12	1.4	11	17		
19760503	7.6	59	43	14	5.8	7.9	1.3	8.6	15		
19760614	7.5	94	75	22	9.4	16	1.9	20	20		
19760726	7.4	93	80	22	9.3	21	1.9	25	24		
19760908	7.5	82	78	18	9.1	17	2.5	9.3	26		
19761019	7.5	83	72	20	8.1	21	1.6	24	21		
19761129	7.4	95	74	22	9.7	25	1.8	32	24		
19770110	7.3	85	88	20	8.4	17	1.5	15	19		
19770214	8.2	82	73	20	7.8	18	1.7	26	17		
19770404	7.3	87	67	21	8.5	20	2.4	28	24		
19770516	7.3	120	98	29	11	30	2.8	26	36		
19770628	7.8	100	75	24	9.9	13	2	16	23		
19770808	7.4	110	90	26	10	27	2.2	32	28		
19770919	7.4	73	44	17	7.3	6.6	1.7	8.9	17		
19771031	7.6	64	47	15	6.5	7.9	1.3	9.7	22		37
19771212	7.5	65	50	15	6.8	6.3	1.2	7.1	16		
19780123	7.3	71	52	17	6.9	12	1.5	9.4	18		
19780306	7.2	67	48	16	6.5	8.8	1.2	17	16		32
19780417	7.5	43	28	10	4.3	4.2	1.8	5.7	15		
19780530	7.9	64	54	15	6.4	5.7	1.5	7.1	14		33
19780710	7.4	53	44	13	5.1	4.3	1.3	5.3	8.9		
19780821	8.4	60	42	15	5.5	5.3	1.5	6.5	12		36
19781002	7.7	71	57	17	6.9	8.2	1.1	9.6	15		24
19781115	7.4	68	52	16	6.8	11	1.1	10	12		
19781218	7.4	68	55	16	6.9	11	1	9.2	14		
19790205	7.4	63	57	15	6.3	334.4	1	3.1	8		12

# Appendix C-6. Water Composition of St. Louis River, MN, from USGS NASQAN and Select Relationships to Water Hardness

Date	рН	Hardness	Alkalinity	Са	Mg	Na	K	C1	$SO_4$	NO <sub>3</sub>	DOCD
19790329	7.6	80	63	19	8	8.4	2.3	7.8	13		
19790430	7.6	37	29	8.7	3.7	2.2	1.3	2.8	8.9		20
19790611	7.2	47	34	11	4.8	3.1	0.8	2.8	9.4	ĺ	ĺ
19790723	7.6	73	55	17	7.3	3.9	0.9	3.7	8.9		30
19790827	7.2										
19791015	8.1	74	54	16	8.2	5	1.1	3.9	13	0.01	12
19791126	7.8	61	52	14	6.3	3.8	0.9	3.6	11	0.37	
19800121	7.6	60	53	14	6	3.8	0.9	3.2	9.9	0.15	ĺ
19800219	7.4	63	51	15	6.2	3.9	0.8	2.9	9.2	0.19	17
19800331	8.4	68	64	16	6.9	4.2	1.1	3.5	9.2	0.3	
19800602	8.3	84	72	19	8.8	6.4	1.2	5	15	0.01	21
19800630	8.3	93	68	21	9.9	7.9	1.4	6.7	24	0.02	
19800804	8.1	130	110	28	14	10	1.9	11	24	0.01	13
19800902	7.8	110	82	24	11	7.2	1.7	7.6	18	0.01	
19800929	7.6	73	54	16	8.1	5.7	1.4	5.8	14	0.12	
19801103	7	82	58	18	8.9	5.6	1.3	6.9	18	0.19	23
19801208		67	50	15	7.2	4.6	1	4.1	11	0.19	
19810105	7.6	70	55	16	7.2	4.2	1.1	4.1	13	0.23	
19810209	7.5	68	58	16	6.9	4.9	1	3.5	8.1	0.27	14
19810309	7.7	61	57	14	6.2	5.2	1.8	5.1	8.6	0.36	
19810504	7.3	42	40	9.6	4.3	3.7	1.2	3.6	9.6	0.18	21
19810706	7.4	51	39	12	5	3.5	1.2	3.2	7.5	0.14	10
19810908	7.9	73	64	16	8	4.2	0.8	4.2	8.3	0.11	
19811020	7.6	51	37	12	5.2	4.3	1.2	4.2	8.9	0.31	
19820113		62	52	14	6.5	4	0.9	3.7	9.3	0.24	
19820309	7.4	66	58	15	7	5.3	1	3.8	11	0.36	
19820420	7.2	32	25	7.5	3.3	2.1	1.3	2.3	6	0.19	
19820621	7.9	61	55	14	6.4	4.3	1.1	4	10	0.1	
19820809	7.4	66	54	15	6.9	3.9	0.6	3.5	9	0.25	
19821004	8	73	63	15	8.7	4.9	1	4.7	13	0.11	
19821207	7.3	55	43	12	6.1	4.2	0.8	3.3	16	0.24	
19830131	6.9	62	50	14	6.5	4.1	0.8	3.5	15	0.36	
19830328	7.5	68	56	15	7.3	4.5	1.2	4.1	15	0.35	
19830523	8.2	68	53	15	7.5	4	1.3	0.8	23	0.12	
19830718	7.6	67	53	15	7.2	3.7	1.3	3.7	22	0.15	
19831031	7.7	64	48	14	7	3.9	1.2	3.5	24	0.12	
19840109	7.4	57	50	13	6	3.6	0.9	3.4	13	0.23	
19840306	7.1	66	57	15	7	4.4	0.9	5.2	8.7	0.31	
19840424	7.2	51	39	11	5.6	3.1	1.4	3.2	14	0.12	
19840619	9.5	52	39	12	5.3	2.9	0.8	3.6	10	0.13	
19840822	6.4	70	58	15	7.9	4.7	1	3.8	17	0.1	
19841009	7.6	73		16	7.9	4.6	1	3.7	15	0.1	
19841120	7.1	64		14	7.1	3.9	0.9	3.7	14	0.24	
19850211	7	69		15	7.7	4.6	1.1	4	11	0.27	
19850325	7.3	61		13	7	5.6	2.5	6.6	16	0.31	
19850506	7.4	55		12	6	3.6	1.7	4.2	14	0.15	
19850730	7.6	62		14	6.6	3.2	0.9	4	9.8	0.1	
19851021	7.5	58		12	6.8	3.7	1.1	0.2	12	0.13	

Date	pН	Hardness	Alkalinity	Са	Mg	Na	K	C1	$SO_4$	NO <sub>3</sub>	DOCD
19851203	7.4	73		16	8	4	1	4.2	18	0.16	
19860303	7.4	66		15	7	4	1	3.4	10	0.24	
19860407	7.3									0.19	
19860602	7.5	58		13	6.3	3.5	1	2.8	15	0.1	
19860818	7.9	74		15	8.9	4.6	1.2	3.7	24	0.1	
19861112	7.5	55		12	6	3.4	1.4	3.8	19	0.27	
19861210	7.3	70	57	13	9	5	1	4.8	21	0.16	
19870218	7	66		15	6.8	3.7	0.9	3.1	12	0.24	
19870518	8	83		18	9.3	5.8	1.2	5	10	0.1	
19870622	7.8	75		16	8.5	6.2	1.1	5.2	19	0.1	
19870721	7.6	51		12	5.2	2.8	1.3	3.1	15	0.1	
19871028	8	82		17	9.6	6.8	1.4	1.3	19	0.1	
19871208	7.9	69		15	7.7	5.3	1.4	4.8	17	0.1	
19880119	7.4	73		16	8	5.1	1	3.6	15	0.15	
19880223	7.4	85		19	9.2	6.5	8.5	5.1	16	0.2	
19880412	7.4	42		9.2	4.7	3	2.8	5	20	0.25	
19880907	7.1	70		15	8	5.3	1.5	6.1	18	0.15	
19881031	7.6	100		21	12	9	1.9	7.8	2.7	0.1	
19881130	7.6	78		17	8.6	5.5	1.3	5.5	19	0.19	
19890221	7.1	77		17	8.4	6.3	1.3	4.4	17	0.25	
19890410	7.2	48		11	5	4.9	1.8	8.1	8	0.37	
19890626	7.4	63		14	6.8	4.6	1.1	5	12	0.15	
19890814	8.1	95		20	11	9.1	1.5	8.9	18	0.1	
19891101	8.1	110		20	15	7.8	1.9	6.3	31	0.1	
19891218	7.5	88		17	11	6.1	1.4	5	22	0.16	
19900123	7.3	100		18	14	7.2	1.7	5.2	28	0.23	
19900416	7.5	62		13	7.2	5.1	1.9	5.4	14	0.2	
19900716	7.7	70		15	8	5.7	1.3	5.4	11	0.2	
19900820	8.1	95		2.0	11	7.8	1.5	7.9	2.0	0.1	
19901009	7.3	81		18	8.7	5.4	1.5	5.7	13	0.1	
19910102	7.4	83		19	8.7	5.3	1.4	5	12	0.2	
19910212	7.1	80		18	8.5	6.8	13	3.9	11	0.2	
19910502	6.7	56		13	5.8	4	1	3.7	7.9	0.1	
19910610	7.3	64		15	6.5	4	0.7	4.1	6.9	0.12	
19910731	7.8	55		13	5.4	2.5	1	2.6	3.8	0.05	
19910801	7.3			10		2.0	-	2.0	210	0100	
19911003	7.8	67		15	7.1	4.4	1	4.4	9.6	0.068	
19911204	7.4	61		13	6.9	4.8	1	3.5	7	0.18	
19920113	7.9	67		15	7.2	4.3	1.1	3.2	9.3	0.21	
19920413	7.7	30		7.8	2.5	2.5	0.3	2.4	4.8	0.16	
19920722	7.6	71		16	7.5	4.8	0.9	2.1	9.6	0.11	
19921026	8.2	86		18	10	5.3	1.2	5.4	14		
19921216	7.6	89		19	10	6	1.2	5.6	13	0.25	
19930201	7.2	83		18	91	73	1.2	73	12	0.28	
19930426	7.7	66		15	6.8	4 1	1.2	4 9	95	0.092	
19930722	7.5	64		15	6.5	4	0.2	3.9	77	0.079	
19931201	77	80		17	9	4.8	1	4	11	0.16	
	1 ' ' '	50		1 /	· ·	1.0	1			0.10	

Date	pН	Hardness	Alkalinity	Са	Mg	Na	K	Cl	$SO_4$	NO <sub>3</sub>	DOCD
19940216	7.3										
19940511	7.7	51		11	5.6	3.7	1.1	3.4	9.4	0.076	
MIN	6.4	30	25	7.5	2.5	2.1	0.2	0.2	3.8	0.01	10
MAX	9.5	130	110	29	15	30	8.5	32	36	0.37	37
MEAN	7.52	71.11	56.94	16.16	7.46	7.09	1.37	7.39	15.04	0.17	22.19













						Alkalinity	Hardness
	Dose	Conductivity		Oxygen	Temp	(as mg	(as mg
Tank	(µg Cu/L)	(µmho/cm)	рН	(mg/L)	(°C)	CaCO <sub>3</sub> /L)	CaCO <sub>3</sub> /L)
<u>0 hours</u> 7/	<u>9/92</u>						
а	897	325	8.62	7.5	21	100	96
b	897	300	8.6	7.6	21	100	96
с	897	320	8.6	7.6	21	80	96
d	607	320	8.62	7.7	21	80	96
e	607	370	8.62	7.6	21	80	96
f	607	328	8.64	7.6	21	80	96
g	93	310	8.64	7.6	21	80	96
h	93	370	8.69	7.5	21	80	96
Ι	93	310	8.6	7.6	21	80	96
j	505	310	8.62	7.7	21	100	96
k	505	310	8.65	7.7	21	80	96
1	505	320	8.69	7.7	21	80	96
m	319	320	8.69	7.7	21	80	96
n	319	330	8.68	7.7	21	80	96
0	319	320	8.67	7.7	21	80	96
р	0	310	8.62	7.5	21	80	96
q	0	320	8.63	7.6	21	80	96
r	0	320	8.6	7.7	21	80	96
<u>24 hours 7</u>	/10/92						
а	897	300	7.78	8.5	21.5	60	104
b	897	305	7.64	8.4	22	80	100
c	897	305	7.68	8.5	22	90	100
d	607	300	7.7	8.4	21.5	90	100
e	607	305	7.65	8.4	21.5	80	100
f	607	305	7.75	8.4	21.5	80	100
g	93	300	7.77	9.1	22	80	100
h	93	295	7.76	9.2	21.5	80	108
Ι	93	295	7.76	9	21.5	85	100
j	505	300	7.73	8.8	22	90	84
k	505	300	7.71	8.8	21.5	80	100
1	505	300	7.73	8.7	21.5	80	100
m	319	300	7.74	9.1	21.5	80	100
n	319	300	7.52	8.5	22	80	100
0	319	310	7.79	8.7	22.5	80	100
р	0	305	7.79	9.1	22	80	100
q	0	305	7.7	9.1	22	80	104
r	0	300	7.71	9.1	22	80	104
<u>48 hours 7</u>	/11/92						
а	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
c	897	320	8.1	7.2	21.5	100	96
d	607	315	7.91	6.9	21.5	100	96
e	607	310	7.84	6.8	21.5	100	100
f	607	315	8	7	21.5	100	104
g	93	300	8.19	7.7	21.5	100	100

# Appendix C-7. Supplementary Data for Bennett et al. (1995)

						Alkalinity	Hardness
	Dose	Conductivity		Oxygen	Temp	(as mg	(as mg
Tank	(µg Cu/L)	(µmho/cm)	рН	(mg/L)	(°C)	CaCO <sub>3</sub> /L)	CaCO <sub>3</sub> /L)D
h	93	300	8.13	7.7	21	100	100
Ι	93	300	8.16	7.6	21	100	104
j	505	310	8.1	7.5	21	80	100
k	505	310	8.12	7.4	21	100	100
1	505	310	8.13	7.4	21	80	100
m	319	310	8.12	7.4	21	100	100
n	319	310	7.8	6.4#	21.5	100	100
0	319	310	8.18	7.3	22	100	96
р	0	300	8.16	8	21.5	80	100
q	0	300	8.1	7.9	21.5	80	104
r	0	300	8.21	8	21.5	100	100
<u>72 hours 7</u>	/12/92						
а	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
с	897	*	*	*	*	*	*
d	607	310	8.02	8.9	21.5	100	100
e	607	315	8.04	8.8	21.5	100	100
f	607	315	8.02	8.7	21.5	80	100
g	93	310	7.92	9.1	21.5	100	104
h	93	305	7.91	9.1	21	100	100
Ι	93	310	7.91	9	21	80	106
j	505	315	7.97	8.9	21.5	100	104
k	505	310	7.96	8.9	21	100	100
1	505	310	7.96	9	21	80	104
m	319	310	7.91	9	21	100	100
n	319	310	7.97	9	21	80	100
0	319	320	7.99	8.8	22	100	104
р	0	300	7.86	9.3	21.5	100	104
q	0	300	7.81	9.1	21.5	80	100
r	0	305	7.93	9.3	21.5	80	100
<u>96 hours 7</u>	//13/92						
а	897	*	*	*	*	*	*
b	897	*	*	*	*	*	*
с	897	*	*	*	*	*	*
d	607	320	8.03	7.3	21.5	100	104
e	607	320	8.07	7.3	21.5	100	100
f	607	325	8.02	7.2	21.5	100	104
g	93	325	7.95	7.1	21.5	120	104
h	93	315	8.03	7.5	21	100	100
Ι	93	310	8.02	7.4	21	100	100
j	505	320	8.06	7.4	21.5	80	100
k	505	320	8.05	7.4	21	120	100
1	505	320	8.03	7.3	21	100	104
m	319	315	8.05	7.5	21	100	104
n	319	320	8.06	7.4	21	100	100
0	319	330	8.08	7.3	2.2	100	104

Tank	Dose (µg Cu/L)	Conductivity (µmho/cm)	рН	Oxygen (mg/L)	Temp (°C)	Alkalinity (as mg CaCO <sub>3</sub> /L)	Hardness (as mg CaCO <sub>3</sub> /L)D
р	0	330	7.78	8.1	21.5	80	96
q	0	325	7.75	7.9	21.5	80	104
r	0	330	7.86	8.1	21.5	80	100

\* All fish dead, no water quality measured. # Air stone had fallen out of tank.

Acclimation Temperature	5	°C	12	°C	22	°C	32°C		
Replicate	1	2	1	2	1	2	1	2	
Sample size	30	36	30	36	36	30	33	29	
pН	8.2-8.3	7.8-8.2	8.4-8.5	8.2-8.4	8.3-8.4	8.1-8.5	8.4-8.5	8.4-8.5	
Hardness (mg/l CaCO <sub>3</sub> )	164-180	152-166	152-168	148-170	164-174	162-172	164-168	162-172	
Alkalinity (mg/l CaCO <sub>3</sub> )	125-140	130-140	130-140	130-140	140-145	140-145	135-140	135-145	
Weights of minnows (g)	0.62- 3.23	0.42-2.64	0.56-2.38	0.30-1.93	0.66- 1.15	0.13- 1.55	0.26- 1.36	0.23-1.32	
Lengths of minnows (cm)	3.3-5.5	3.2-5.2	3.2-4.9	2.8-5.1	1.9-4.3	2.4-4.6	3.0-4.8	3.3-4.8	

Appendix C-8. Supplementary Data for Richards and Beitinger (1995)

Date	pН	Hardness	Alkalinity	Ca	Mg	Ca:Mg	Na	C1	$SO_4$
Jul-78	7.6	20	22	5.2	1.7	3.06	3.2	2.6	4
Aug-78	7.6	20	22	4.9	1.9	2.58	3.4	2.8	5
Sep-78	7.5	20	22	5.2	1.7	3.06	3.5	2.6	4
Oct-78	7.3	20	22	5	1.8	2.78	3.6	3	4
Nov-78	7.2	20		4.9	1.9	2.58	3.9		5
Dec-78									
Jan-79	7.4	23	24	5.1	2.1	2.43	3.2	2.9	4
Feb-79	7.5	24	25	6.5	1.9	3.42	3	3	5
Mar-79	7.6	26	27	7.4	1.8	4.11	3.3	2.7	6
Apr-79	7.7	27	27	7.5	2	3.75	3.6	2.7	7
May-79	7.6	25	26	5.7	2.6	2.19	3.4	2.4	6
Jun-79	7.7	22	24	5.7	1.9	3.00	3.1	2.5	4
Jul-79	7.6	21	22	5.3	1.9	2.79	3	2.7	4
Aug-79	7.5	21	22	5.6	1.7	3.29	3.2	2.4	5
Sep-79	7.3	20	21	5.7	1.4	4.07	3.5	2.5	3
Oct-79	7.2	19	20	5.5	1.3	4.23	3.1	2.8	3
Nov-79									
Dec-79									
Jan-80	7.5	23	23	6.1	1.9	3.21	2.4	2.6	4
Feb-80	7.4	23	23	6.1	1.9	3.21	2.7	2.3	2
Mar-80	7.5	24	26	5.8	2.3	2.52	2	2.3	2
Apr-80	7.7	25	25	6.4	2.2	2.91	1.9	2.5	3
May-80	7.5	22	21	6.1	1.6	3.81	2.4	2.4	3
Jun-80	7.3	19	21	5.1	1.5	3.40	2.3	2.4	2
Jul-80	7.4	18	20	4.6	1.6	2.88	2.6	2.1	3
Aug-80	7.5	18	21	5.2	1.2	4.33	3	2.7	2
Sep-80	7.3	18	20	4.9	1.4	3.50	2.9	2.4	4
Oct-80	7.3	18	20	5	1.3	3.85	3	2.7	2
Mean	7.5	21.4	22.8	5.6	1.8	3.2	3.0	2.6	3.8
max	7.7	27.0	27.0	7.5	2.6	4.3	3.9	3.0	7.0
min	7.2	18.0	20.0	4.6	1.2	2.2	1.9	2.1	2.0

Appendix C-9. Data for the American River, CA, for July 1978 Through December 1980 (data from the City of Sacramento, CA, Water Quality Laboratory; personal communication). Units Are mg/L.

Imbarraws River, MN           3/22/76         7         103         27         16         6         2.5         2         1         3.4         0.04         16         0.25         2         1         3.4         0.04         16         0.6           5/28/76         6.5         5.5         5         3.5         12           6.8         7.5.8         66.8.3         14.2         9         2.1         3.8         0.6           Mass         7         133         100         10         2.1         1.8         1.8         0.4         0.4         0.6           Mass         7         133         1.0         1.0         0.4         0.4         0.4         0.6           Mass         1.1         0.1 <th 0"<="" colspan="6" th="" th<=""><th>Date</th><th>pН</th><th>Hardness</th><th>Alkalinity</th><th>Ca</th><th>Mg</th><th>Ca:Mg</th><th>Na</th><th>K</th><th>Cl</th><th><math>SO_4</math></th><th>NO<sub>3</sub></th><th>TOC</th><th>DOC</th><th>Sulfide</th></th>	<th>Date</th> <th>pН</th> <th>Hardness</th> <th>Alkalinity</th> <th>Ca</th> <th>Mg</th> <th>Ca:Mg</th> <th>Na</th> <th>K</th> <th>Cl</th> <th><math>SO_4</math></th> <th>NO<sub>3</sub></th> <th>TOC</th> <th>DOC</th> <th>Sulfide</th>						Date	pН	Hardness	Alkalinity	Ca	Mg	Ca:Mg	Na	K	Cl	$SO_4$	NO <sub>3</sub>	TOC	DOC	Sulfide
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Embarrass	Rive	r, MN																		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	3/22/76	7	133	103	27	16	1.69	2.5	2	11	34										
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	4/29/76	6.7	25.3	23	5.2	3	1.73	2.8	0.7	2.9	8.4	0.04	16		0.6						
	5/28/76	6.5		53						3.5	12										
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	6/28/76	6.9	44	36	9.9	4.6	2.15	3.9	0.3	5	13	0.04	37								
8/26/76       6.9       100       110       24       9.9       2.42       9       1       8.4       5.6       21       0.6         Means       6.8       75.58       66.83       14.26       8.38       2.00       4.55       1.00       5.93       13.42       0.04       24.67       0.60         max.       7       133       110       27       16       2.42       9       2       11       34       0.04       37       0.6         S. Kawishiw: River, MN       10/1675       6.4       21       14       4.9       2.1       2.33       1.3       0.4       0.5       4.4       0.01       12       0.2         10/1675       6.9       24       19       5.5       2.5       2.00       1.2       0.4       0.6       4.1       1.2       0.2         10/1675       6.9       23       24       5.2       2.7       1.93       1.7       0.6       0.9       6.3       0.16       16       0       0.2       5/25/76       6.6       1.1       4       1.5       2.67       0.9       0.4       0.7       4.8       0.2       5/25/76       6.6       1.6       1.1	7/28/76	6.6		76	5.2					4.8	7.5										
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	8/26/76	6.9	100	110	24	9.9	2.42	9	1	8.4	5.6		21		0.6						
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Means	6.8	75.58	66.83	14.26	8.38	2.00	4.55	1.00	5.93	13.42	0.04	24.67		0.60						
min.       6.5       25.3       23       5.2       3       1.69       2.5       0.3       2.9       5.6       0.04       16       0.6         S. Kawishiwi River, MN       10/16/75       6.4       21       1.4       4.9       2.1       2.33       1.3       0.4       0.5       4.4       0.01       12       0.2         11/6/75       6.9       24       19       5.5       2.5       2.00       1.2       0.4       0.6       4.1       0.01       12       0.2         12/11/75       6.9       24       20       5.2       2.7       1.93       1.7       0.6       0.9       6.3       0.16       16       0         3/976       6.6       14       8       3.4       1.3       2.62       0.9       0.4       0.7       4.8       0.2         5/25/76       6.8       16       11       4       1.5       2.67       0.9       0.4       0.7       4.8       0.2         6/25/76       6.6       16       1.2       4.4       0.5       3.3       0.01       12       0         Cystrof       6.7       19       3.4       2.36       1.7       0.8	max.	7	133	110	27	16	2.42	9	2	11	34	0.04	37		0.6						
S. Kawishiwi River, MN 10/16/75 6.4 21 14 4.9 2.1 2.33 1.3 0.4 0.5 4.4 0.01 12 0.2 11/6/75 6.9 24 19 5.5 2.5 2.0 1.2 0.4 0.6 4.1 12/11/75 39 23 10 3.4 2.94 1.4 0.4 1.5 2/4/76 6.3 24 20 5.2 2.7 1.93 1.7 0.6 0.9 6.3 0.16 16 0 3/9/76 6.9 23 23 5.7 2.2 2.59 1.5 0.5 0.9 4.9 1/2/2/76 6.6 14 8 3.4 1.3 2.62 0.9 0.4 0.7 4.8 1/2/3/76 6.6 16 11 4 1.5 2.67 0.9 0.4 0.7 4.8 1.2 4.4 1.2 0.5 Means 6.6 23.75 17.70 5.61 2.36 2.40 1.31 0.49 1.04 4.89 0.09 14.00 0.56 max. 6.9 39 24 10 3.4 2.94 1.7 0.8 2.3 7 0.16 16 1.8 min. 6.3 14 8 3.4 1.3 1.93 0.9 0.4 0.5 3.3 0.01 12 0 Colby Lake, MN LCY2 6/17/96 8.5 56 33 13 5.7 2.28 4.3 1.5 6.3 22 0.25 17 6/17/96 6.8 54 33 12 5.8 2.07 3.9 1.4 6.6 26 0.3 16 6/17/96 6.5 41 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 17 6/17/96 6.5 41 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 17 6/17/96 6.5 41 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 18 10 Colby Lake, MN LCY1 6/17/96 6.5 41 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 18 min. 6.5 41 31 17 7 3.44 4.3 1.5 9.4 26 0.33 18 10 Means 7.1 55.50 33.25 13.25 5.43 2.55 4.03 1.40 7.28 23.00 0.28 16.83 max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 26 0.33 18 min. 6.5 41 34 11 3.2 3.00 1.3 6.8 22 0.33 18 min. 6.5 41 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 18 min. 6.5 41 34 11 3.2 3.44 3.15 9.4 26 0.33 18 min. 6.5 41 34 11 3.2 3.00 1.3 6.8 22 0.33 18 min. 6.5 41 34 11 3.2 3.00 1.3 6.8 32 0.01 28 16.83 max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 26 0.33 18 min. 6.5 41 34 11 3.2 3.00 3.6 1.3 6.8 22 0.33 18 min. 6.5 41 34 11 3.2 3.00 3.6 1.3 6.8 22 0.33 18 min. 6.5 41 34 11 3.2 3.00 3.2 1.6 0.3 18 min. 6.5 41 34 11 3.2 3.00 3.2 1.6 0.3 18 min. 6.5 41 34 11 3.2 3.00 3.2 1.2 5.6 0.02 22 Means 7.1 55.50 33.25 13.25 5.43 2.55 4.03 1.40 7.28 2.00 3.8 Lake One, MN 1.016/75 7.2 27 21 6.9 2.3 3.00 1.2 5.6 0.02 22 Greenwod Lake, MN 1.016/75 7.2 07 21 6.9 2.3 3.00 1.2 5.6 0.02 22	min.	6.5	25.3	23	5.2	3	1.69	2.5	0.3	2.9	5.6	0.04	16		0.6						
S. Kawishiwi River, MN 10/16/75 6.4 21 14 4.9 2.1 2.33 1.3 0.4 0.5 4.4 0.01 12 0.2 11/6/75 6.9 24 19 5.5 2.2 2.2 0.12 0.4 0.6 4.1 12/11/75 39 23 10 3.4 2.94 1.4 0.8 2.3 7 12/176 6.6 29 24 6.2 3.2 1.94 1.6 0.8 2.3 7 1/9/76 6.9 2.3 2.3 5.7 2.2 2.59 1.5 0.5 0.9 4.9 1/2/3/76 6.6 14 8 3.4 1.3 2.62 0.9 0.4 0.7 4.8 1.2 4.4 0.2 5/25/76 6.6 16 11 4 1.5 $$ 0.2 1/2/76 6.6 14 8 3.4 1.3 2.62 0.9 0.4 0.7 4.8 1.1 3.3 1.8 1/23/76 6.7 19 1.2 4.4 0.5 Means 6.6 23.75 17.70 5.61 2.36 2.40 1.31 0.49 1.04 4.89 0.09 14.00 0.56 max. 6.9 39 24 10 3.4 2.94 1.7 0.8 2.3 7 0.16 16 1.8 min. 6.3 14 8 3.4 1.3 1.93 0.9 0.4 0.5 3.3 0.01 12 0 Colby Lake, MN LCY2 6/17/96 6.8 56 33 1.3 5.7 2.28 4.3 1.5 6.3 22 0.25 17 6/17/96 6.9 71 33 1.7 7 2.43 4.3 1.4 9.4 22 18 LCY1 6/17/96 6.8 54 3.3 1.2 5.8 2.07 3.9 1.4 6.6 26 0.3 16 6/17/96 6.8 14 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 17 6/17/96 6.8 14 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 17 6/17/96 6.8 14 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 17 6/17/96 6.8 14 3.4 1.7 7 3.44 4.3 1.5 9.4 2.0 18 Means 7.1 55.50 33.25 13.25 5.43 2.55 4.03 1.40 7.28 2.3.00 0.28 16.83 max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 22 18 LCY1 6/17/96 6.8 14 33 11 3.2 3.74 4.3 1.5 9.4 2.0 1.8 Means 7.1 55.50 33.25 13.25 5.43 2.55 4.03 1.40 7.28 2.00 0.28 16.83 max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 20 0.33 18 min. 6.5 41 33 11 3.2 2.55 4.03 1.40 7.28 2.00 0.28 16.83 max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 20 0.33 18 min. 6.5 41 33 11 3.2 2.55 4.03 1.40 7.28 2.00 0.28 16.83 max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 20 0.33 18 min. 6.5 41 33 11 3.2 2.55 4.03 1.40 7.28 2.00 0.38 18 Lake One, MN 10/16/7 7.2 27 2.1 6.9 2.3 3.00 1.2 5.6 0.02 22 Greenwod Lake, MN 7/6/76 6.7 10 15 2.8 0.7 4.00 0.1 0.3 0.2 4.2 0 11																					
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	S. Kawish	iwi Ri	iver, MN																		
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	10/16/75	6.4	21	14	4.9	2.1	2.33	1.3	0.4	0.5	4.4	0.01	12		0.2						
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	11/6/75	6.9	24	19	5.5	2.5	2.20	1.2	0.4	0.6	4.1										
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	12/11/75		39	23	10	3.4	2.94	1.4	0.4	1.5					0.2						
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	1/9/76	6.6	29	24	6.2	3.2	1.94	1.6	0.8	2.3	7										
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	2/4/76	6.3	24	20	5.2	2.7	1.93	1.7	0.6	0.9	6.3	0.16	16		0						
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	3/9/76	6.9	23	23	5.7	2.2	2.59	1.5	0.5	0.9	4.9				1						
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	4/23/76	6.6	14	8	3.4	1.3	2.62	0.9	0.4	0.7	4.8				0.2						
	5/25/76	6.8	16	11	4	1.5	2.67	0.9	0.4	0.7	4.8										
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	6/25/76	6.6		16						1.1	3.3				1.8						
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	7/23/76	6.7		19						1.2	4.4				0.5						
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$																					
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Means	6.6	23.75	17.70	5.61	2.36	2.40	1.31	0.49	1.04	4.89	0.09	14.00		0.56						
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	max.	6.9	39	24	10	3.4	2.94	1.7	0.8	2.3	7	0.16	16		1.8						
Colby Lake, MN LCY2 6/17/96 8.5 56 33 13 5.7 2.28 4.3 1.5 6.3 22 0.25 17 0.25 17 6/17/96 6.8 54 33 17 7 2.43 4.3 1.4 9.4 22 18 LCY1 6/17/96 6.8 54 33 12 5.8 2.07 3.9 1.4 6.6 26 0.3 16 6/17/96 6.5 41 34 11 3.2 3.44 3.6 1.3 6.8 22 0.33 17 6/17/96 7.4 83 39 21 7.3 2.88 7.8 52 0.18 Means 7.1 55.50 33.25 13.25 5.43 2.55 4.03 1.40 7.28 23.00 0.28 16.83 max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 26 0.33 18 min. 6.5 41 33 11 3.2 2.07 3.6 1.3 6.3 22 0.25 16 Cloquet Lake, MN 7/13/76 6.4 17 11 4 1.8 2.22 1.7 7.6 0 38 Lake One, MN 10/16/75 7.2 27 21 6.9 2.3 3.00 1.2 5.6 0.02 22 Greenwood Lake, MN 7/6/76 6.7 10 15 2.8 0.7 4.00 0.1 0.3 0.2 4.2 0 11	min.	6.3	14	8	3.4	1.3	1.93	0.9	0.4	0.5	3.3	0.01	12		0						
Colby Lake, MN LCY2 6/17/96 8.5 56 33 13 5.7 2.28 4.3 1.5 6.3 22 0.25 17 $6/17/96 6.8 54 33 17 7 2.43 4.3 1.4 9.4 22 18LCY16/17/96 6.8 54 33 12 5.8 2.07 3.9 1.4 6.6 26 0.3 16 6/17/96 6.8 54 33 9 21 7.3 2.88 7.8 52 0.18Means 7.1 55.50 33.25 13.25 5.43 2.55 4.03 1.40 7.28 23.00 0.28 16.83max. 8.5 71 34 17 7 3.44 4.3 1.5 9.4 26 0.33 18min. 6.5 41 33 11 3.2 2.07 3.6 1.3 6.3 22 0.25 16Cloquet Lake, MN7/13/76 6.4 17 11 4 1.8 2.22 1.7 7.6 0 38Lake One, MN10/16/75 7.2 27 21 6.9 2.3 3.00 1.2 5.6 0.02 22Greenwood Lake, MN7/6/76 6.7 10 15 2.8 0.7 4.00 0.1 0.3 0.2 4.2 0 11$																					
LCY2 $6/17/96$ 8.5       56       33       13       5.7       2.28       4.3       1.5       6.3       22       0.25       17 $6/17/96$ 6.8       6.8       0.25       17       0.25       17 $6/17/96$ 6.8       71       33       17       7       2.43       4.3       1.4       9.4       22       18         LCY1       6/17/96       6.8       54       33       12       5.8       2.07       3.9       1.4       6.6       26       0.3       16 $6/17/96$ 6.8       54       33       12       5.8       2.07       3.9       1.4       6.6       26       0.3       16 $6/17/96$ 6.5       41       34       11       3.2       3.44       3.6       1.3       6.8       22       0.33       17 $6/17/96$ 6.5       41       34       11       3.2       3.6       1.3       6.8       22       0.33       17 $6/17/96$ 7.4       83       39       21       7.3       2.88       7.8       52       0.18         Means	Colby Lak	e, MN	1																		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	LCY2																				
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	6/17/96	8.5	56	33	13	5.7	2.28	4.3	1.5	6.3	22	0.25	17								
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	6/17/96	6.8				_						0.25	17								
LCY1 $6/17/96$ $6.8$ $54$ $33$ $12$ $5.8$ $2.07$ $3.9$ $1.4$ $6.6$ $26$ $0.3$ $16$ $6/17/96$ $6.8$ $41$ $34$ $11$ $3.2$ $3.44$ $3.6$ $1.3$ $6.8$ $22$ $0.33$ $17$ $6/17/96$ $6.5$ $41$ $34$ $11$ $3.2$ $3.44$ $3.6$ $1.3$ $6.8$ $22$ $0.33$ $17$ $6/17/96$ $7.4$ $83$ $39$ $21$ $7.3$ $2.88$ $7.8$ $52$ $0.18$ Means $7.1$ $55.50$ $33.25$ $13.25$ $5.43$ $2.55$ $4.03$ $1.40$ $7.28$ $23.00$ $0.28$ $16.83$ max. $8.5$ $71$ $34$ $17$ $7$ $3.44$ $4.3$ $1.5$ $9.4$ $26$ $0.33$ $18$ min. $6.5$ $41$ $33$ $11$ $3.2$ $2.07$ $3.6$ $1.3$ $6.3$ $22$ $0.25$ $16.83$	6/17/96	6.9	71	33	17	7	2.43	4.3	1.4	9.4	22		18								
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	LCYI						• • -	•			•										
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	6/17/96	6.8	54	33	12	5.8	2.07	3.9	1.4	6.6	26	0.3	16								
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	6/17/96	6.8						•					16								
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	6/17/96	6.5	41	34	11	3.2	3.44	3.6	1.3	6.8	22	0.33	17								
Means $7.1$ $55.50$ $33.25$ $13.25$ $5.43$ $2.55$ $4.03$ $1.40$ $7.28$ $23.00$ $0.28$ $16.83$ max. $8.5$ $71$ $34$ $17$ $7$ $3.44$ $4.3$ $1.5$ $9.4$ $26$ $0.33$ $18$ min. $6.5$ $41$ $33$ $11$ $3.2$ $2.07$ $3.6$ $1.3$ $6.3$ $22$ $0.25$ $16$ Cloquet Lake, MN $7/13/76$ $6.4$ $17$ $11$ $4$ $1.8$ $2.22$ $1.7$ $7.6$ $0$ $38$ Lake One, MN $10/16/75$ $7.2$ $27$ $21$ $6.9$ $2.3$ $3.00$ $1.2$ $5.6$ $0.02$ $22$ Greenwood Lake, MN $7/6/76$ $6.7$ $10$ $15$ $2.8$ $0.7$ $4.00$ $0.1$ $0.3$ $0.2$ $4.2$ $0$ $11$	6/17/96	7.4	83	39	21	7.3	2.88			7.8	52	0.18									
Means $7.1$ $55.30$ $55.25$ $15.25$ $2.35$ $4.05$ $1.40$ $7.28$ $23.00$ $0.28$ $16.85$ max. $8.5$ $71$ $34$ $17$ $7$ $3.44$ $4.3$ $1.5$ $9.4$ $26$ $0.33$ $18$ min. $6.5$ $41$ $33$ $11$ $3.2$ $2.07$ $3.6$ $1.3$ $6.3$ $22$ $0.25$ $16$ Cloquet Lake, MN $7/13/76$ $6.4$ $17$ $11$ $4$ $1.8$ $2.22$ $1.7$ $7.6$ $0$ $38$ Lake One, MN $10/16/75$ $7.2$ $27$ $21$ $6.9$ $2.3$ $3.00$ $1.2$ $5.6$ $0.02$ $22$ Greenwood Lake, MN $7/6/76$ $6.7$ $10$ $15$ $2.8$ $0.7$ $4.00$ $0.1$ $0.3$ $0.2$ $4.2$ $0$ $11$	Maana	71	55 50	22.75	12.25	5 12	2 5 5	1 02	1 40	7 70	22 00	0.20	16.92								
Imax. $6.5$ $71$ $54$ $17$ $7$ $5.44$ $4.5$ $1.3$ $9.4$ $20$ $0.53$ $18$ min. $6.5$ $41$ $33$ $11$ $3.2$ $2.07$ $3.6$ $1.3$ $6.3$ $22$ $0.25$ $16$ Cloquet Lake, MN $7/13/76$ $6.4$ $17$ $11$ $4$ $1.8$ $2.22$ $1.7$ $7.6$ $0$ $38$ Lake One, MN $10/16/75$ $7.2$ $27$ $21$ $6.9$ $2.3$ $3.00$ $1.2$ $5.6$ $0.02$ $22$ Greenwood Lake, MN $15$ $2.8$ $0.7$ $4.00$ $0.1$ $0.3$ $0.2$ $4.2$ $0$ $11$	means	/.1 05	55.50 71	33.23	13.23	3.43 7	2.33	4.05	1.40	0.4	25.00	0.28	10.85								
Inni.       0.5       41       55       11       5.2       2.07       5.6       1.3       0.5       22       0.25       10         Cloquet Lake, MN       7/13/76       6.4       17       11       4       1.8       2.22       1.7       7.6       0       38         Lake One, MN       10/16/75       7.2       27       21       6.9       2.3       3.00       1.2       5.6       0.02       22         Greenwood Lake, MN       15       2.8       0.7       4.00       0.1       0.3       0.2       4.2       0       11	min	6.5	/1	34	17	3.2	2.07	4.5	1.3	9.4 6.3	20	0.33	16								
Cloquet Lake, MN         7/13/76       6.4       17       11       4       1.8       2.22       1.7       7.6       0       38         Lake One, MN       10/16/75       7.2       27       21       6.9       2.3       3.00       1.2       5.6       0.02       22         Greenwood Lake, MN       15       2.8       0.7       4.00       0.1       0.3       0.2       4.2       0       11	111111.	0.5	41	33	11	3.2	2.07	5.0	1.5	0.5	22	0.25	10								
7/13/76       6.4       17       11       4       1.8       2.22       1.7       7.6       0       38         Lake One, MN       10/16/75       7.2       27       21       6.9       2.3       3.00       1.2       5.6       0.02       22         Greenwood Lake, MN       15       2.8       0.7       4.00       0.1       0.3       0.2       4.2       0       11	Cloquet I	ake M	IN																		
Image: Milling and Mill	7/13/76	6 A	17	11	4	18	2 22			17	7.6	0	38								
Lake One, MN 10/16/75 7.2 27 21 6.9 2.3 3.00 1.2 5.6 0.02 22 Greenwood Lake, MN 7/6/76 6.7 10 15 2.8 0.7 4.00 0.1 0.3 0.2 4.2 0 11	1113110	<b>U.T</b>	1/	11	-7	1.0	2.22			1./	7.0	0	50								
10/16/75       7.2       27       21       6.9       2.3       3.00       1.2       5.6       0.02       22         Greenwood Lake, MN	Lake One	MN																			
Greenwood Lake, MN <u>7/6/76 6.7 10 15 2.8 0.7 4.00 0.1 0.3 0.2 4.2 0 11</u>	10/16/75	7.2	27	21	6.9	2.3	3.00			1.2	5.6	0.02	22								
Greenwood Lake, MN 7/6/76 6.7 10 15 2.8 0.7 4.00 0.1 0.3 0.2 4.2 0 11							2.00														
7/6/76 6.7 10 15 2.8 0.7 4.00 0.1 0.3 0.2 4.2 0 11	Greenwoo	d Lak	e, MN																		
	7/6/76	6.7	<u>1</u> 0	<u>1</u> 5	2.8	0.7	4.00	0.1	0.3	0.2	4.2	0	11								

Appendix C-10. STORET Data for Minnesota Lakes and Rivers

Appendix D. Saltwater Conversion Factors for Dissolved Values

## Appendix D Saltwater Conversion Factors for Dissolved Values

February 14, 2007

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

## ACKNOWLEDGMENTS

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### Saltwater Conversion Factors for Converting Nominal or Total Copper Concentrations to Dissolved Copper Concentrations

The U.S. EPA changed its policy in 1993 of basing water quality criteria for metals from a total metal criteria to a dissolved metal criteria. The policy states "the use of dissolved metal to set and measure compliance with water quality standards is the recommended approach, because dissolved metal more closely approximates the bioavailable fraction of metal in the water column than does total recoverable metal" (Prothro 1993). All of the criteria for metals to this date were based upon total metal and very few data were available with dissolved concentrations of the metals. A problem was created by the new policy of how to derive dissolved metal concentrations for studies in which this form of the metal was not measured. The U.S. EPA attempted to develop correction factors for each metal for which criteria exist for both fresh- and saltwater (Lussier et al. 1995; Stephan 1995). In the case of saltwater, a correction for copper was not derived.

Several saltwater studies are available that report nominal, total, and dissolved concentrations of copper in laboratory water (Table 1) from site-specific water effect ratio (WER) studies. These studies show relatively consistent ratios for the nominal-to-dissolved concentrations and for the total-to-dissolved concentrations. Calculation of a mean ratio (conversion factor) to convert nominal and total copper concentrations to dissolved copper permits the use of the results for critical studies without dissolved copper measurements.

Three studies, each with multiple tests per study, were useful for deriving the conversion factors. One study was conducted for the lower Hudson River in the New York/New Jersey Harbor (SAIC 1993). The tests were conducted with harbor site water and with EPA Environmental Research Laboratory -Narragansett water from Narragansett Bay, Massachusetts. Only the tests with laboratory water were used for this exercise. Three series of 48-hour static tests were conducted with various animals. Salinity ranged from 28 to 32 ppt during all the tests. Series 1 tests were not used to calculate ratios for dissolvedto-total or dissolved-to-nominal copper concentrations, because in many instances, concentrations of measured copper did not increase as nominal concentrations increased. Of the series 2 tests, only the coot clam (Mulinia lateralis) tests were successful and used to calculate ratios. Three replicate tests without ultraviolet (UV) light present and one test with UV light present were reported with total and dissolved copper measurements made at 0 hr and 48 hr (end) of the tests. Dissolved-to-total and dissolved-tonominal ratios were calculated for the four tests each with two time intervals. The mean ratio for the dissolved-to-total measurements is 0.943 and the mean ratio for the dissolved-to-nominal is 0.917. A third series of static tests was conducted by SAIC and the mussel (Mytilus sp.) test was the only successful test. Again the tests were conducted as three replicate tests without UV light and a fourth with UV light. The mean test ratio for dissolved-to-total copper was 0.863 and the dissolved-to-nominal mean test ratio was 0.906.

The summer flounder (*Paralichthys dentatus*) was exposed to copper in laboratory water for 96 hours in a static test (CH2MHill 1999a). The water was collected from Narragansett Bay and diluted with laboratory reverse osmosis water to dilute the solution to 22 ppt salinity. Three tests were run with copper concentrations measured at the start of the tests as total recoverable and dissolved copper. Five exposure concentrations were used to conduct the tests. Only the two lowest concentrations were used to derive ratios for dissolved-to-total and dissolved-to-nominal copper mean ratios. These concentrations were at the approximate 500  $\mu$ g/L or lower concentrations, and are in the range of most copper concentrations routinely tested in the laboratory. The mean dissolved-to-total and dissolved-to-nominal ratios were 0.947 and 0.836, respectively.

Three 48-hour static tests were conducted with the blue mussel (Mytilus edulis) in water from the

same source and treated in the same manner as the summer flounder tests (CH2MHill 1999b). Salinity was diluted to 20 ppt. Exposures were made at eight concentrations of copper and total and dissolved copper concentrations were measured only at the start of the tests. Mean ratios for the dissolved-to-total and dissolved-to-nominal copper were calculated by combining the ratios calculated for each of the test concentrations. The mean dissolved-to-total and dissolved-to-nominal ratios were 0.979 and 0.879, respectively.

A study was conducted by the City of San Jose, CA to develop a WER for San Francisco Bay in which copper was used as a toxicant and the concentrations used in the laboratory exposures were measured as total and dissolved copper (Environ. Serv. Dept., City of San Jose 1998). Mussels and the purple sea urchin (*Strongylocentrotus purpuratus*) were used as the test organisms. Tests were conducted in filtered natural sea water from San Francisco Bay that was diluted to a salinity of 28 ppt. The mussel test was of 48-hour duration and the purple sea urchin test was of 96-hour duration. Five concentrations of copper were used in the toxicity tests with the concentrations measured at the start of each test. (During each test, a single concentration of copper was measured at the termination of the test and this value was not used in the calculations.) Twenty-two tests were conducted during a 13-month period with the mussel and two tests were conducted with the purple sea urchin. The mean dissolved-to-total and dissolved-to-nominal ratios for the purple sea urchin were 0.883 and 0.702, respectively.

For some of the tests, control concentrations had measured concentrations of total and dissolved copper. These values were not used to calculate ratios for dissolved-to-total and dissolved-to-nominal copper concentrations. All mean ratios were calculated as the arithmetic mean and not as a geometric mean of the available ratios. When the data are normally distributed, the arithmetic mean is the appropriate measure of central tendency (Parkhurst 1998) and is a better estimator than the geometric mean. All concentrations of copper used to calculate ratios should be time-weighted averages (Stephan 1995). In all instances of data used to calculate ratios, the concentrations were identical to time-weighted values because either only one value was available or if two were available they were of equal weight.

Based on the information presented above the overall ratio for correcting total copper concentrations to dissolved copper concentrations is 0.909 based upon the results of six sets of studies. This is comparable to its equivalent factor in freshwater, which is  $0.960 \pm 0.037$  (Stephan 1995). When it is necessary to convert nominal copper concentrations to dissolved copper concentrations the conversion factor is 0.838 based upon the same studies. The means of both conversion factors have standard deviations of less than ten percent of the means (Table 1).

# Table D-1. Summary of Saltwater Copper Ratios

Species	Mean Dissolved-to- Total Ratio	Mean Dissolved-to- Nominal Ratio	Reference
Coot clam, Mulinia lateralis	0.943	0.917	SAIC 1993
Summer flounder, Paralichthys dentatus	0.947	0.836	CH2MHill 1999a
Blue mussel, <i>Mytilus sp</i>	0.863	0.906	SAIC 1993
Blue mussel, <i>Mytilus edulis</i>	0.979	0.879	CH2MHill 1999b
Blue mussel, <i>Mytilus sp</i>	0.836	0.785	Environ. Serv. Dept., City of San Jose 1998
Purple sea urchin, Strongylocentrotus purpuratus	0.883	0.702	Environ. Serv. Dept., City of San Jose 1998
Arithmetic Mean	0.909	0.838	
Standard Deviation	$\pm 0.056$	$\pm 0.082$	

### References

CH2MHill. 1999a. Bioassay report: Acute toxicity of copper to summer flounder (*Paralichthys dentatus*). Final report prepared for U.S. Navy. November 1999. CH2MHill, Norfolk, Virginia. 26 p.

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Appendix E. BLM Input Data and Notes

	Model Output							N	lodel Input							
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
LUVA01S	1.1869	290	25	6.57	124.8	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
LUVA02S	2.1707	290	25	7.29	259.2	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
LUVA03S	2.0991	290	25	8.25	480	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
CADE01F	27.6903	44.9	15	7.7	1920	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
CADE02F	26.6895	44.9	15	7.7	1344	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
JUPL01F	0.1537	21	15	7.20	14.4	1.1	10	6.0583	1.7462	4.5302	0.7	2.8706	5.468	26	0.0003	1,3,6,7,9,10
LIVI01F	0.0570	21	15	7.2	7.68	1.1	10	6.0583	1.7462	4.5302	0.7	2.8706	5.468	26	0.0003	1,3,6,7,9,10
PHIN01F	0.4378	44.9	15	7.7	39.36	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
PHIN02F	0.3410	44.9	15	7.7	35.52	1.1	10	13.1965	2.911001	1.27	0.56	3.32	1.2	42.7	0.0003	1,2,3,6,7,8
ACPE01S	0.1147	96	25	8.35	25.92	0.5	10	15.8434	13.728	29.734	2.3762	92.159	2.1544	102	0.0003	1,2,3,4,6,7,20
ACPE02S	0.1556	68	25	8.35	27.84	0.5	10	11.2224	9.724	21.061	1.6831	65.279	1.526	108	0.0003	1,2,3,4,6,7,20
UTIM01S	8.2925	39	23	7.4	82.56	0.5	10	6.43638	5.577	12.079	0.9653	37.439	0.8752	32.5	0.0003	1,2,3,4,6,11
UTIM02S	8.0633	90	23	7.6	191.04	0.5	10	13.9716	12.11764	26.253	2.098	81.372	1.9022	65	0.0003	1,2,3,4,12
UTIM03S	1.3555	92	25	8.1	72.96	0.5	10	29.0614	4.73839	30.798	1.6408	46.006	32.716	77	0.0003	1,2,3,4,6,7,53
UTIM04S	1.4793	86	25	8.2	81.6	0.5	10	27.1661	4.429364	28.79	1.5338	43.005	30.583	78	0.0003	1,2,3,4,6,7,53
UTIM05S	0.5289	90	25	8	39.36	0.5	10	28.4296	4.635381	30.129	1.6052	45.006	32.005	78	0.0003	1,2,3,4,6,7,53
UTIM06S	1.2514	90	24	8.2	75.84	0.5	10	14.8532	12.87	13.938	1.1138	43.199	1.0099	99	0.0003	1,2,3,4,5,6,7
UTIM07S	1.3009	90	25	7.9	69.12	0.5	10	28.4296	4.635381	30.129	1.6052	45.006	32.005	99	0.0003	1,2,3,4,6,7,53
UTIM08S	0.7111	86	25	7.9	36.48	0.5	10	14.193	12.298	13.318	1.0643	41.279	0.965	59	0.0003	1,2,3,4,5,6,7
CEDU01S	0.1132	52	24.5	7.5	18.24	1.1	10	15.2833	3.371316	1.5	0.57	3.8	1.4	55	0.0003	1,2,3,6,7,8
CEDU02S	0.0941	52	24.5	7.5	16.32	1.1	10	15.2833	3.371316	1.5	0.57	3.8	1.4	55	0.0003	1,2,3,6,7,8
CEDU03S	0.0751	45	25	7.72	25	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU04S	0.0400	45	25	7.72	17	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU05S	0.1046	45	25	7.72	30	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU06S	0.0700	45	25	7.72	24	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU07S	0.0920	45	25	7.72	28	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU08S	0.1184	45	25	7.72	32	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU09S	0.0651	45	25	7.72	23	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU10S	0.0517	45	25	7.72	20	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU11S	0.0476	45	25	7.72	19	1.5	10	11.0991	4.2075	9.5	1.6	46	34	39.7	0.0003	1,2,6,7,16
CEDU12S	0.0194	94.1	25	8.15	26	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU13S	0.0144	94.1	25	8.15	21	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU14S	0.0206	94.1	25	8.15	27	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17

	Model Output	Hand	Model Input													
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
CEDU15S	0.0338	94.1	25	8.15	37	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU16S	0.0294	94.1	25	8.15	34	2	10	23.2094	8.79835	5.2449	1.6	20.054	6.1705	69.6	0.0003	1,2,6,7,17
CEDU17S	0.0428	179	25	8.31	67	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU18S	0.0164	179	25	8.31	38	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU19S	0.0579	179	25	8.31	78	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU20S	0.0627	179	25	8.31	81	2.3	10	50.1069	13.12323	14.32	2.4	22.673	10.979	140.1	0.0003	1,2,6,7,18
CEDU21S	0.0283	97.6	25	8	28	2	10	24.0727	9.1256	5.44	1.6	20.8	6.4	74.2	0.0003	1,2,6,7,17
CEDU22S	0.1218	182	25	8	84	2.3	10	50.9467	13.34317	14.56	2.4	23.053	11.163	144.3	0.0003	1,2,6,7,18
CEDU23S	0.0510	57.1	25	8.18	12.864	0.5	10	9.42352	8.1653	17.685	1.4133	54.815	1.2814	81	0.0003	1,2,3,4,6,7,20
CEDU24R	0.0377	80	20	7.6	5.5396825	0.5	10	13.2028	11.44	24.778	1.9801	76.799	1.7953	53	0.0003	1,2,6,7,20,21
DAMA01S	0.0221	39	20	7.8	8.736	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	51	0.0003	1,2,3,6,7,9,10
DAMA02S	0.0315	39	20	7.8	11.232	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	51	0.0003	1,2,3,6,7,9,10
DAMA03S	0.0147	38	20	7.79	6.336	1.1	10	10.7129	2.7203	5.7423	0.7	7.6578	7.6406	50	0.0003	1,2,3,6,7,9,10
DAMA04S	0.0253	38	20	7.79	9.504	1.1	10	10.7129	2.7203	5.7423	0.7	7.6578	7.6406	50	0.0003	1,2,3,6,7,9,10
DAMA05S	0.1799	39	20	6.9	11.232	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	30	0.0003	1,2,3,6,7,9,10
DAMA06S	0.0786	39	20	6.9	6.432	1.1	10	10.9867	2.7776	5.8136	0.7	7.9394	7.7684	30	0.0003	1,2,3,6,7,9,10
DAMA07S	0.0312	26	20	7.6	8.736	1.1	10	7.4273	2.0327	4.8867	0.7	4.2786	6.107	24	0.0003	1,2,3,6,7,9,10
DAMA08S	0.0123	27	20	7.7	4.992	1.1	10	7.7011	2.09	4.958	0.7	4.5602	6.2348	24	0.0003	1,2,3,6,7,9,10
DAMA09S	0.4278	170	20	7.8	39.552	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA10S	0.0443	170	20	7.8	10.08	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA11S	0.1330	170	20	7.8	19.776	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA12S	0.0990	170	20	7.8	16.608	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA13S	0.9670	170	20	7.8	67.872	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA14S	0.2716	170	20	7.8	30.048	0.5	10	27.9433	24.23527	52.507	4.1961	162.74	3.8045	115	0.0003	3,4,22,23
DAMA15S	0.0160	109.9	21	6.93	6.816	2.4	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA16S	0.0298	109.9	21	6.93	15.744	3.4	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA17S	0.0393	109.9	21	7.43	38.304	3.4	10	40.0	2.43	85.1	1.23	10	106	13.875	0.0003	1,2,3,6,7,19,24
DAMA18S	0.0219	109.9	21	7.43	17.952	2.4	10	40.0	2.43	85.1	1.23	10	106	13.875	0.0003	1,2,3,6,7,19,24
DAMA19S	0.0111	109.9	21	7.82	18.144	2.4	10	40.0	2.43	85.1	1.23	10	106	14.5	0.0003	1,2,3,6,7,19,24
DAMA20S	0.0189	109.9	21	7.82	38.112	3.4	10	40.0	2.43	85.1	1.23	10	106	14.5	0.0003	1,2,3,6,7,19,24
DAMA21S	0.0898	109.9	21	6.93	44.16	4.4	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA22S	0.1076	109.9	21	6.93	69.024	6.1	10	40.0	2.43	85.1	1.23	10	106	12.5	0.0003	1,2,3,6,7,24
DAMA23S	0.0458	109.9	21	7.43	54.912	4.4	10	40.0	2.43	85.1	1.23	10	106	13.875	0.0003	1,2,3,6,7,19,24
DAMA24S	0.0288	109.9	21	7.82	65.088	4.4	10	40.0	2.43	85.1	1.23	10	106	14.5	0.0003	1,2,3,6,7,19,24

	Model Output		Model Input													
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
DAMA25S	0.1143	52	18.2	7.8	24.96	1.1	10	14	3.5	12	2.9	23	11	45	0.0003	1,2,3,6,7,9,25
DAMA26S	0.0917	105	20.3	7.9	28.8	1.1	10	29	6.8	29	5.3	57	21	79	0.0003	1,2,3,6,7,9,25
DAMA27S	0.1053	106	19.7	8.1	36.48	1.1	10	29	6.8	29	5.3	57	21	82	0.0003	1,2,3,6,7,9,25
DAMA28S	0.1538	207	19.9	8.3	66.24	1.1	10	58	13	62	8.2	127	40	166	0.0003	1,2,3,6,7,9,25
DAMA29S	0.0062	7.1	24	8.55	4.608	0.5	10	1.15182	1.027387	3.5102	2.8052	6.8159	2.5434	56	0.0003	1,2,3,4,6,7,56
DAMA30S	0.2536	20.6	24	6.97	7.104	0.5	10	3.39973	2.9458	2.5478	2.1356	19.776	1.9363	60	0.0003	1,2,3,4,6,7,56
DAMA31S	0.0119	23	24	8.52	6.24	0.5	10	3.79581	3.289	2.8446	2.3845	22.08	2.1619	64	0.0003	1,2,3,4,6,7,56
DAPC01S	0.0087	48	18	8.03	10.944	2.288	10	14.1077	3.111984	1.36	0.57	3.55	1.25	42	0.0003	1,2,3,6,7,15,26
DAPC02S	0.0052	48	18	8.03	8.6976	2.816	10	14.1077	3.111984	1.36	0.57	3.55	1.25	42	0.0003	1,2,3,6,7,15,26
DAPC03S	0.0043	48	18	8.01	6.9504	2.728	10	14.1077	3.111984	1.36	0.57	3.55	1.25	44	0.0003	1,2,3,6,7,15,26
DAPC04S	0.0057	44	18	8.04	10.368	3.08	10	12.932	2.852652	1.24	0.57	3.25	1.15	42	0.0003	1,2,3,6,7,15,26
DAPC05S	0.0879	31	18	6.66	53.184	12.2094	10	7.37407	3.063455	1.6792	0.5	6.3292	1.2917	27	0.0003	1,2,3,6,7,27,28
DAPC06S	0.0490	29	18	6.97	53.088	11.3373	10	6.89832	2.865813	1.5708	0.5	5.9208	1.2083	27	0.0003	1,2,3,6,7,27,28
DAPC07S	0.0285	28	18	7.2	51.168	11.3373	10	6.66045	2.766992	1.5167	0.5	5.7167	1.1667	22	0.0003	1,2,3,6,7,27,28
DAPC08S	0.0268	88	18	7.01	93.312	24.4188	10	20.9464	8.5194	16.466	1.8787	22.629	18.986	20	0.0003	1,2,3,6,7,27,29
DAPC09S	0.0187	100	18	7.55	191.04	29.6514	10	23.9296	9.4686	21.207	2.1631	25.98	23.28	20	0.0003	1,2,3,6,7,27,29
DAPC10S	0.0701	82	18	6.99	204.48	27.9072	10	19.4548	8.0448	14.095	1.7365	20.953	16.84	18	0.0003	1,2,3,6,7,27,29
DAPC11S	0.0460	84	18	7.01	158.4	27.9072	10	19.952	8.203	14.885	1.7839	21.512	17.555	17	0.0003	1,2,3,6,7,27,29
DAPC12S	0.0100	16	18	7.39	34.08	11.6124	10	4.13844	1.379481	0.16	0.3	6.72	0.32	11	0.0003	1,2,3,6,7,27,28
DAPC13S	0.0137	151	18	7.76	75.648	12.5801	10	36.7872	14.39533	10.786	1.4	62.018	19.684	44	0.0003	1,2,3,6,7,27,28
DAPC14S	0.0053	96	18	8.1	108.48	27.0956	10	22.0888	9.939946	6.8571	1.4	19.911	4.2667	91	0.0003	1,2,3,6,7,27,28
DAPC15S	0.0137	26	18	7.24	73.344	24.1925	10	7.37925	1.844812	0.26	0.3	11.624	2.6	4	0.0003	1,2,3,6,7,27,28
DAPC16S	0.0564	84	18	7.08	81.312	12.5801	10	20.4644	8.008	6	1.4	34.5	10.95	13	0.0003	1,2,3,6,7,27,28
DAPC17S	0.0633	92	18	7.22	176.64	20.3217	10	22.4134	8.770667	6.5714	1.4	37.786	11.993	19	0.0003	1,2,3,6,7,27,28
DAPC18S	0.0056	47	18	8.03	8.928	2.728	10	13.8137	3.047151	1.33	0.57	3.47	1.23	42.5	0.0003	1,2,3,6,7,15,26
DAPC19S	0.0119	97	18	8.03	17.088	2.728	10	34	2.9	1.3	0.57	51.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC20S	0.0160	147	18	8.03	22.752	2.728	10	54	2.9	1.3	0.57	99.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC21S	0.0168	247	18	8.03	26.208	2.728	10	94	2.9	1.3	0.57	147.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC22S	0.0171	97	18	8.03	24.192	2.728	10	13.6	15.2	1.3	0.57	51.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC23S	0.0155	147	18	8.03	24.096	2.728	10	13.6	27.5	1.3	0.57	99.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
DAPC24S	0.0133	247	18	8.03	24.096	2.728	10	13.6	51.9	1.3	0.57	147.3	1.2	42.5	0.0003	1,2,3,6,7,15,30
SCSP01S	0.1034	52	24.5	7.5	17.28	1.1	10	15.2833	3.371316	1.47	0.57	3.84	1.36	55	0.0003	1,2,3,6,7,8
GAPS01F	0.1153	44.9	15	7.7	21.12	1.1	10	13.1965	2.911001	1.27	0.57	3.32	1.17	42.7	0.0003	1,2,3,6,7,8
GAPS02F	0.0888	44.9	15	7.7	18.24	1.1	10	13.1965	2.911001	1.27	0.57	3.32	1.17	42.7	0.0003	1,2,3,6,7,8
	Model Output							N	lodel Input							
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BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
HYAZ01S	0.1511	290	25	6.23	16.32	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5,13
HYAZ02S	0.1074	290	25	7.51	23.04	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5,13
HYAZ03S	0.2392	290	25	8.38	83.52	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5,13
HYAZ04S	0.0794	20.5	21	7.15	23.328	2.8	10	5.1	1.9	5.3	0.8	9.3	10.0	6.7	0.0003	3,31
HYAZ05S	0.0768	20.5	21	7.15	22.848	2.8	10	5.1	1.9	5.3	0.8	9.3	10.0	6.7	0.0003	3,31
HYAZ06S	0.2314	20.6	21	7.14	7.872	0.5	10	5.3	1.8	5.5	0.8	7.0	9.7	11.0	0.0003	3,31
HYAZ07S	0.3312	20.6	21	7.14	9.6	0.5	10	5.3	1.8	5.5	0.8	7.0	9.7	11.0	0.0003	3,31
ACLY01S	29.5658	42	18.5	7.0	7968	1.1	10	12.3442	2.722986	1.3	0.57	3.4	1.2	47	0.0003	1,2,3,6,7,8
CHDE01S	25.2731	44	20	7.40	709.44	0.5	10	6.99	6.06	13.1	1.05	40.7	0.951	32.5	0.0003	1,2,3,4,32,33
SCPL01S	2.9865	167	22	7.6	153.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
ONAP01S	0.9139	169	12	8	67.2	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONCL01S	1.0007	169	12	8.1	76.8	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONCL02S	0.5538	169	12	8.25	57.6	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONCL03F	2.8512	205	13.7	7.73	367	3.3	10	49.8	19.6	4	0.64	10	0.44	178	0.0003	1,2,6,7,34
ONCL04F	1.5731	69.9	13.7	8.54	186	1.5	10	18.4	5.8	1.405	0.2248	3.5126	0.1546	174	0.0003	1,2,6,7,35
ONCL05F	0.4400	18	13.7	8.07	36.8	0.75	10	4.8	1.5	0.3618	0.0579	0.9045	0.0398	183	0.0003	1,2,6,7,35
ONCL06F	1.9714	204	13.7	7.61	232	3.3	10	64.7	10.3	4.1005	0.6561	10.251	0.4511	77.9	0.0003	1,2,6,7,35
ONCL07F	5.2514	83	13.7	7.4	162	1.7	10	20.4	7.8	1.6683	0.2669	4.1709	0.1835	70	0.0003	1,2,6,7,35
ONCL08F	1.2778	31.4	13.7	8.32	73.6	0.94	10	7.9	2.7	0.6312	0.101	1.5779	0.0694	78.3	0.0003	1,2,6,7,35
ONCL09F	0.3591	160	13.7	7.53	91	2.8	10	57.5	4.0	3.2161	0.5146	8.0402	0.3538	26.0	0.0003	1,2,6,7,35
ONCL10F	0.3318	74.3	13.7	7.57	44.4	1.5	10	24.7	3.1	1.4935	0.239	3.7337	0.1643	22.7	0.0003	1,2,6,7,35
ONCL11F	0.1192	26.4	13.7	7.64	15.7	0.87	10	6.0	2.8	0.5307	0.0849	1.3266	0.0584	20.1	0.0003	1,2,6,7,35
ONGO01F	1.3932	83.1	7.15	7.63	137.28	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONGO02F	0.3615	83.1	7.15	7.63	83.52	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONGO03F	3.5018	83.1	7.15	7.63	191.04	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONKI01R	4.9807	33	13.5	7.29	157.44	2.496	10	8.77741	2.698479	7.3188	1.15	6.1426	6.8124	29	0.0003	1,2,3,6,7,27,36
ONKI02F	0.4054	25	12	7.30	31.68	1.3	10	6.8	1.8	5.0	0.6	4.2	6	24	0.0003	3,37
ONKI03F	0.9203	20	9.4	7.29	44.16	1.3	10	5.7845	1.6889	4.4589	0.7	2.589	5.3402	22	0.0003	1,2,3,6,7,10,38
ONKI04F	0.1617	31.1	13.3	7.30	49	3.2	10	8.01999	2.695987	5.12	0.653	4	4.5	29.6	0.0003	1,2,6,7,39
ONKI05F	0.1736	31.1	13.3	7.30	51	3.2	10	8.01999	2.695987	5.12	0.653	4	4.5	29.6	0.0003	1,2,6,7,39
ONKI06F	0.1461	31.6	15.7	7.50	58	3.2	10	8.14893	2.739331	5.12	0.653	3.5	4.2	30.4	0.0003	1,2,6,7,39
ONKI07F	0.4829	31	15.3	7.20	78	3.2	10	7.99421	2.687318	5.12	0.653	2.3	3.1	29.7	0.0003	1,2,6,7,39
ONMY01S	1.3925	169	12	8.2	105.6	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONMY02S	0.5765	169	12	7.95	48	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20

	Model Output			Model Input												
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
ONMY03S	0.7648	169	12	7.95	57.6	0.5	10	27.891	24.167	52.344	4.183	162.24	3.7927	117	0.0003	1,2,3,4,6,7,20
ONMY04R	0.1249	44.1	11.5	7.7	40	2	10	9.07	4.1	4.75	1.02	3.3	1.56	49.7	0.0003	40
ONMY05R	0.0917	44.6	11.5	7.8	19	0.99	10	7.37	6.1	6.24	0.8	1.31	3.82	53.1	0.0003	40
ONMY06R	0.0376	38.7	12	7.62	3.4	0.33	10	2.37	8.65	13.7	0.15	0.36	20.3	40	0.0003	51
ONMY07R	0.1465	39.3	12	7.61	8.1	0.36	10	14.1	1.8	13.2	0.1	0.36	19.9	41.7	0.0003	51
ONMY08R	0.1881	89.5	12	8.21	17.2	0.345	10	15	11.85	10.05	1	0.36	6.73	97.5	0.0003	51
ONMY09R	0.5172	89.67	12	8.15	32	0.345	10	28.9	3.15	32.5	0.5	0.36	45.2	97.25	0.0003	51
ONMY10F	0.3824	23	12.2	7.1	26.88	1.4	10	6.1	1.8	4.4	0.4	5.8	6	22	0.0003	3,37
ONMY11F	0.1589	23	12.2	7.1	16.32	1.4	10	6.1	1.8	4.4	0.4	5.8	6	22	0.0003	3,37
ONMY12F	0.1059	23	12.2	7.4	17.28	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONMY13F	0.4633	23	12.2	7.1	27.84	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONMY14F	0.4998	194	12.8	7.84	169	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY15F	0.1118	194	12.8	7.84	85.3	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY16F	0.1069	194	12.8	7.84	83.3	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY17F	0.1627	194	12.8	7.84	103	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY18F	1.5525	194	12.8	7.84	274	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY19F	0.2605	194	12.8	7.84	128	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY20F	0.9538	194	12.8	7.84	221	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY21F	0.4717	194	12.8	7.84	165	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY22F	0.7244	194	12.8	7.84	197	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY23F	4.6605	194	12.8	7.84	514	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY24F	1.1894	194	12.8	7.84	243	3.3	10	55.1	13.7	4	0.64	10	0.44	174	0.0003	1,2,6,7,34
ONMY25F	0.0613	9.2	15.5	6.96	2.688	0.5	10	2.3	0.7	2	0.2	4.6	2.1	11	0.0003	3,41
ONMY26F	0.3626	31	15.3	7.2	68	3.2	10	7.99421	2.687318	5.12	0.653	2.3	3.1	29.7	0.0003	1,2,6,7,39
ONMY27F	0.0770	36.1	11.4	7.6	18	1.31	10	4.03	7.13	1.56	0.26	1.49	0.88	36.6	0.0003	40
ONMY28F	0.8944	36.2	11.5	6.1	12	1.36	10	3.93	7.27	1.57	0.28	1.47	0.87	8.5	0.0003	40
ONMY29F	0.5568	20.4	11.7	7.5	5.7	0.15	10	3.13	2.77	2.62	0.25	0.36	1.48	23	0.0003	40
ONMY30F	0.2504	45.2	11.7	7.7	35	1.23	10	9.7	4.43	5.33	0.97	3.41	1.47	50	0.0003	40
ONMY31F	1.1775	45.4	11.8	6.3	18	1.22	10	9.7	4.43	5.02	0.98	3.37	1.37	10.9	0.0003	40
ONMY32F	0.5318	41.9	12.3	7.9	17	0.33	10	6.6	5.97	5.89	0.63	1.11	3.37	48.3	0.0003	40
ONMY33F	1.2884	214	7.64	7.94	96.96	0.27	10	49.4	24.1	10.3	1.75	18.9	5.28	198	0.0003	1,2,3,6,7,54,55
ONMY34F	3.8957	220	7.74	7.92	295.68	0.36	10	51.2	25.5	8.36	2.1	24	4.64	197	0.0003	1,2,3,6,7,54,55
ONMY35F	4.4437	105	7.77	7.82	89.28	0.1	10	23.1	11.8	3.54	3.22	17.1	2.91	94.1	0.0003	1,2,3,6,7,54,55
ONMY36F	1.9096	98.2	8.49	7.89	34.464	0.045	10	22.3	11.2	3.58	0.9	11.5	2.85	87.9	0.0003	1,2,3,6,7,54,55

	Model Output							N	lodel Input							
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
ONMY37F	1.7297	104	16.3	7.83	52.224	0.28	10	22.4	11.4	3.76	2.72	12.4	3.01	97.6	0.0003	1,2,3,6,7,54,55
ONNE01F	3.1060	83.1	7.15	7.63	182.4	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE02F	3.5466	83.1	7.15	7.63	192	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE03F	0.5132	83.1	7.15	7.63	96	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE04F	0.6617	83.1	7.15	7.63	105.6	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE05F	1.0574	83.1	7.15	7.63	124.8	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE06F	1.6007	83.1	7.15	7.63	144	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE07F	4.0021	83.1	7.15	7.63	201.6	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE08F	2.2920	83.1	7.15	7.63	163.2	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE09F	3.1060	83.1	7.15	7.63	182.4	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONNE10F	5.4103	83.1	7.15	7.63	230.4	2.58	10	22.3428	6.313221	10.259	7.5024	25.1	9.994	62.5	0.0003	1,2,3,6,7,52
ONTS01F	0.2050	23	12.2	7.4	24.96	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONTS02F	0.1161	23	12.2	7.4	18.24	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONTS03F	0.7109	23	12.2	7.1	36.48	1.4	10	6.1	1.8	4.4	0.4	5.8	6	22	0.0003	3,37
ONTS04F	0.3750	23	12.2	7.1	24.96	1.3	10	6.8	1.8	5.0	0.6	4.2	6	22	0.0003	3,37
ONTS05F	0.3517	13	12	7.15	9.792	0.5	10	2.14546	1.859	4.0264	0.3218	12.48	0.2917	12	0.0003	1,2,3,4,6,7,20
ONTS06F	0.8340	46	12	7.55	23.136	0.5	10	7.59162	6.578	14.247	1.1386	44.159	1.0323	35	0.0003	1,2,3,4,6,7,20
ONTS07F	0.9241	182	12	8.12	79.2	0.5	10	30.0364	26.026	56.37	4.5048	174.72	4.0844	125	0.0003	1,2,3,4,6,7,20
ONTS08F	0.3954	359	12	8.49	123.264	0.5	10	59.2477	51.337	111.19	8.8858	344.64	8.0566	243	0.0003	1,2,3,4,6,7,20
ONTS09F	1.1161	36.6	12	7.71	7.4	0.055	10	6.36	4.73	4.84	0.22	0.94	2.79	40.8	0.0003	51
ONTS10F	0.8313	34.6	12	7.79	12.5	0.19	10	7.82	3.17	9.98	0.11	0.73	8.34	40.6	0.0003	51
ONTS11F	0.8622	38.3	12	7.71	14.3	0.24	10	6.33	5.1	5.27	0.6	0.99	2.96	43.6	0.0003	51
ONTS12F	1.7785	35.7	12	7.74	18.3	0.17	10	8.15	3.38	10	0.37	0.76	9.1	43.3	0.0003	51
SACO01F	2.9901	214	7.64	7.94	218.88	0.27	10	49.4	24.1	10.3	1.75	18.9	5.28	198	0.0003	1,2,3,6,7,54,55
SACO02F	2.6420	220	7.74	7.92	198.72	0.36	10	51.2	25.5	8.36	2.1	24	4.64	197	0.0003	1,2,3,6,7,54,55
SACO03F	3.2456	105	7.77	7.82	63.936	0.1	10	23.1	11.8	3.54	3.22	17.1	2.91	94.1	0.0003	1,2,3,6,7,54,55
SACO04F	2.6405	98.2	8.49	7.89	48	0.045	10	22.3	11.2	3.58	0.9	11.5	2.85	87.9	0.0003	1,2,3,6,7,54,55
SACO05F	3.0680	104	16.3	7.83	85.44	0.28	10	22.4	11.4	3.76	2.72	12.4	3.01	97.6	0.0003	1,2,3,6,7,54,55
ACAL01F	9.7513	54	10.5	7.3	137.28	1.1	10	15.0937	3.6371	6.8831	0.7	12.163	9.6854	43	0.0003	1,2,3,6,7,9,10
GIEL01S	2.6186	173	22	8.05	192	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,6,7,20
NOCR01F	29.9790	72.2	25	7.50	81216	1.5	10	17.8079	6.7507	15.26	1.6	73.841	54.15	42.5	0.0003	2,3,6,7,16,42
PIPR01S	11.3981	103	22	7.4	297.6	0.5	10	28.4667	7.773195	27.778	2.6358	29.602	53.021	65	0.0003	1,2,3,4,6,48
PIPR02S	4.9570	103	22	7.4	115.2	0.5	10	28.4667	7.773195	27.778	2.6358	29.602	53.021	65	0.0003	1,2,3,4,6,48
PIPR03S	9.4256	263	22	7.4	374.4	0.5	10	72.6868	19.84806	36.487	3.4623	77.901	130.77	65	0.0003	1,2,3,4,6,48

	Model Output							N	lodel Input							
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
PIPR04S	1.2005	52	24.5	7.4	52.8	1.1	10	15.2833	3.371316	1.47	0.57	3.84	1.36	55	0.0003	1,2,3,6,7,8
PIPR05S	3.0479	52	24.5	7.4	81.6	1.1	10	15.2833	3.371316	1.47	0.57	3.84	1.36	55	0.0003	1,2,3,6,7,8
PIPR06S	0.1314	290	25	6.27	14.4	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
PIPR07S	0.3064	290	25	7.14	42.24	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
PIPR08S	0.5392	290	25	8.6	192	0.5	10	47.8602	41.47	89.821	7.178	278.4	6.5081	235	0.0003	1,2,3,4,5
PIPR09S	0.0890	19	22	7.06	4.6272	0.6	10	4.9	1.64	3.7	0.78	9.6	5.8	11.17	0.0003	3,49
PIPR10S	0.2665	19.5	22	7.25	7.872	0.4	10	5.2	1.64	5.36	0.79	2.45	8.6	12.7	0.0003	3,49
PIPR11S	0.5716	16.5	22	6.36	30.3072	3.3	10	4.1	1.54	2.82	0.76	9.4	4.7	8.46	0.0003	3,49
PIPR12S	0.2950	17	22	6.42	20.2176	3.1	10	4.2	1.56	2.74	0.74	7.4	4.6	3.4	0.0003	3,49
PIPR13S	0.4162	19	22	6.38	34.5312	4.3	10	5	1.62	7.04	0.72	10.2	12.2	7.83	0.0003	3,49
PIPR14S	0.2640	17	22	7.15	57.4368	3.4	10	4.2	1.54	2.9	1	7.4	4.7	8.74	0.0003	3,49
PIPR15S	0.0477	17	22	7.16	4.6368	0.8	10	4.5	1.46	2.68	0.78	10.9	3.8	9.3	0.0003	3,49
PIPR16S	0.1770	17.5	22	7.13	67.4688	5.1	10	4.6	1.48	2.62	0.77	10.5	3.5	8.95	0.0003	3,49
PIPR17S	0.0787	18.5	22	7.06	80.2464	10.5	10	5	1.54	2.64	0.8	10.7	3.5	8.29	0.0003	3,49
PIPR18S	0.1907	18.5	22	6.90	174.72	15.6	10	4.9	1.5	3.54	0.99	7	5.2	9.52	0.0003	3,49
PIPR19S	3.2305	173	22	8.25	278.4	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR20S	7.4512	173	22	8.1	604.8	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR21S	4.8297	173	22	8.15	384	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR22S	7.6122	173	22	7.3	374.4	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PIPR23S	7.2327	166	5	8.05	432	0.5	10	27.3959	23.738	51.415	4.1088	159.36	3.7253	132.5	0.0003	1,2,3,4,6,7,20
PIPR24S	3.4469	159	12	8.35	285.12	0.5	10	26.2406	22.737	49.247	3.9355	152.64	3.5682	135	0.0003	1,2,3,4,6,7,20
PIPR25S	2.8678	168	22	8.3	298.56	0.5	10	27.7259	24.024	52.034	4.1583	161.28	3.7702	142.5	0.0003	1,2,3,4,6,7,20
PIPR26S	3.3686	167	32	8.45	492.48	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	140	0.0003	1,2,3,4,6,7,20
PIPR27S	0.5950	45.54059	22	7.93	53.958366	1.1	10	13.4911	2.888065	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,44
PIPR28S	4.0104	45.54059	22	7.93	165.17867	1.1	10	13.4911	2.888065	91.27	0.391	3.362	143.23	42.037464	0.0003	43,44
PIPR29S	0.7241	44.53969	22	7.98	59.464322	1.1	10	13.1946	2.824591	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,44
PIPR30S	4.0805	44.53969	22	7.98	146.45842	1.1	10	13.1946	2.824591	45.98	0.391	3.362	72.324	44.039248	0.0003	43,44
PIPR31S	1.8188	44.53969	22	7.99	82.038741	1.1	10	13.1946	2.824591	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44
PIPR32S	4.9213	45.54059	22	7.96	124.4346	1.1	10	13.4911	2.888065	1.6093	0.391	3.362	36.871	43.038356	0.0003	43,44
PIPR33S	3.9367	45.04014	22	7.79	103.759	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	46.041032	0.0003	43,44
PIPR34S	5.7875	45.04014	22	7.81	167.3225	1.1	10	13.3428	2.856328	47.589	0.391	99.42	1.4181	46.041032	0.0003	43,44
PIPR35S	3.2914	138.1231	22	7.785	120.015	1.1	10	12.892	25.75825	1.6093	0.391	3.362	72.324	43.038356	0.0003	43,44
PIPR36S	5.7959	151.1347	22	7.78	169.418	1.1	10	14.1065	28.18476	1.6093	0.391	99.42	1.4181	43.038356	0.0003	43,44
PIPR37S	3.4870	138.1231	22	8.02	268.224	1.1	10	12.892	25.75825	1.6093	0.391	3.362	1.4181	149.13291	0.0003	43,44

	Model Output	Hand	Model Input														
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)		Notes
PIPR38S	9.2068	139.124	22	7.775	242.443	1.1	10	51.1778	2.779812	1.6093	0.391	99.42	1.4181	43.038356	0.0003	43,44	
PIPR39S	4.7038	47.04192	22	7.78	113.3475	1.1	10	13.4268	4.010325	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44	
PIPR40S	3.1754	37.033	22	7.785	77.8764	0.88	10	11.022	3.281175	2.9887	0.391	3.362	1.4181	43.038356	0.0003	43,45	
PIPR41S	5.3335	60.05352	22	7.795	128.016	1.1	10	15.2304	5.954725	1.6093	0.391	17.771	1.4181	43.038356	0.0003	43,44	
PIPR42S	6.4718	76.06779	22	7.8	151.13	1.1	10	18.8376	7.413025	1.6093	0.391	32.179	1.7727	42.037464	0.0003	43,44	
PIPR43S	6.4642	103.0919	22	7.805	166.624	1.1	10	25.05	10.2081	2.0691	0.391	60.036	1.7727	43.038356	0.0003	43,44	
PIPR44S	7.0015	103.0919	22	7.78	163.83	1.1	10	32.064	4.010325	1.8392	0.391	58.115	1.7727	40.03568	0.0003	43,44	
PIPR45S	5.9820	107.0954	22	7.79	157.48	1.1	10	18.2364	15.43368	1.6093	0.391	61.957	1.7727	43.038356	0.0003	43,44	
PIPR46S	7.4331	134.1195	22	7.8	199.7075	1.1	10	32.2644	13.00318	1.6093	0.391	88.854	1.7727	43.038356	0.0003	43,44	
PIPR47S	6.0725	45.04014	22	7.815	128.524	1.1	10	14.028	2.18745	1.3794	0.391	3.362	1.0636	41.036572	0.0003	43,44	
PIPR48S	7.2713	46.04103	22	7.82	150.876	1.1	10	14.028	2.18745	6.2072	1.5639	5.7635	7.0906	42.037464	0.0003	43,44	
PIPR49S	5.4175	45.04014	22	7.82	131.064	1.1	10	14.028	2.18745	15.173	1.5639	10.566	15.245	41.036572	0.0003	43,44	
PIPR50S	6.2395	45.04014	22	7.81	160.2105	1.1	10	14.2284	2.18745	35.174	1.5639	21.613	36.162	41.036572	0.0003	43,44	
PIPR51S	6.2194	44.03925	22	7.82	182.88	1.1	10	15.03	2.18745	62.992	1.5639	40.825	70.906	40.03568	0.0003	43,44	
PIPR52S	4.9667	45.04014	22	7.81	180.848	1.1	10	14.4288	2.18745	101.39	1.9549	59.076	107.78	41.036572	0.0003	43,44	
PIPR53S	6.1183	46.04103	22	7.81	176.784	1.1	10	14.2284	2.18745	57.015	19.158	40.825	71.97	42.037464	0.0003	43,44	
PIPR54S	5.7931	189.1686	22	7.82	188.9125	1.1	10	55.11	15.79825	1.6093	0.782	152.25	1.0636	42.037464	0.0003	43,44	
PIPR55S	5.2814	46.04103	22	7.865	125.603	1.1	10	14.6292	3.15965	1.3794	0.391	3.362	1.0636	42.037464	0.0003	43,44	
PIPR56S	3.8765	75.0669	22	7.87	117.348	1.1	10	24.4488	5.954725	1.3794	0.391	30.739	1.0636	41.036572	0.0003	43,44	
PIPR57S	3.7460	46.04103	22	7.865	114.554	1.1	10	14.4288	3.15965	19.771	0.391	12.488	18.436	41.036572	0.0003	43,44	
PIPR58S	3.8963	74.06601	22	7.85	126.492	1.1	10	24.4488	6.07625	18.392	0.391	38.903	18.436	42.037464	0.0003	43,44	
PIPR59S	5.1820	133.1186	22	7.85	172.72	1.1	10	41.082	11.6664	18.392	0.391	98.94	18.436	42.037464	0.0003	43,44	
PIPR60S	5.0050	76.06779	22	7.85	167.3225	1.1	10	24.048	6.07625	47.589	0.782	58.115	52.116	43.038356	0.0003	43,44	
PIPR61S	6.3379	134.1195	22	7.84	226.695	1.1	10	40.8816	11.6664	49.198	0.782	118.63	51.052	43.038356	0.0003	43,44	
PIPR62S	6.5522	52.04638	22	7.96	84.201	0.3	10	12.024	4.13185	1.6093	0.391	10.566	1.7727	42.037464	0.0003	43,46	
PIPR63S	7.7846	51.04549	22	7.96	97.79	0.3	10	11.2224	3.8888	2.7588	0.782	10.566	3.5453	41.036572	0.0003	43,46	
PIPR64S	5.4254	50.0446	22	7.945	70.0786	0.3	10	11.022	3.767275	5.9773	1.5639	12.007	8.1542	41.036572	0.0003	43,46	
PIPR65S	5.7632	51.04549	22	7.965	81.5848	0.3	10	11.2224	3.8888	11.955	2.3459	15.369	15.245	42.037464	0.0003	43,46	
PIPR66S	5.0152	51.04549	22	7.96	77.4319	0.3	10	11.2224	3.767275	23.22	3.1279	21.613	30.135	41.036572	0.0003	43,46	
PIPR67S	5.9195	53.04728	22	7.97	110.871	0.3	10	11.2224	3.767275	46.899	4.6918	33.62	59.207	41.537018	0.0003	43,46	
PIPR68S	5.4017	53.04728	22	7.96	151.892	0.3	10	11.6232	3.8888	117.94	7.0377	68.201	141.81	42.037464	0.0003	43,46	
PIPR69S	4.1225	52.04638	22	7.94	175.26	0.3	10	11.4228	3.767275	236.79	10.948	128.24	279.72	43.038356	0.0003	43,46	
PIPR70S	6.6575	47.04192	25	7.82	145.288	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44	
PIPR71S	4.6725	47.04192	20	7.82	111.76	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44	

	Model Output	Hand	Model Input														
BLM Data Label	Critical Accumulation	ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)		Notes
PIPR72S	2.3613	47.04192	15	7.82	79.1845	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44	
PIPR73S	1.1782	47.04192	10	7.82	60.0075	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44	
PIPR74S	7.6860	140.1249	22	8.03	370.078	0.3	10	29.058	12.03098	25.059	4.3008	60.036	25.881	98.087416	0.0003	43,46	
PIPR75S	10.9585	88.0785	22	7.965	292.1	0.3	10	19.038	7.04845	14.943	2.7369	37.943	17.017	63.056196	0.0003	43,46	
PIPR76S	7.9470	59.05263	22	7.89	101.473	0.3	10	12.024	4.61795	9.1959	0.782	23.054	9.9268	39.034788	0.0003	43,46	
PIPR77S	6.9448	41.03657	22	7.825	62.5094	0.3	10	8.2164	3.038125	7.5866	2.7369	13.928	6.3815	29.025868	0.0003	43,46	
PIPR78S	5.9976	27.02408	22	7.745	42.0624	0.3	10	5.6112	1.822875	4.598	2.3459	8.6452	4.2544	23.020516	0.0003	43,46	
PIPR79S	9.0570	43.03836	22	7.885	172.466	1.1	10	10.4208	2.67355	1.6093	0.782	2.8817	1.4181	42.037464	0.0003	43,44	
PIPR80S	0.7034	25.0223	22	7.565	12.4333	0.3	10	6.68596	2.02764	3.4485	1.1729	4.3226	4.9634	16.014272	0.0003	43,46	
PIPR81S	7.0672	107.0954	22	8.105	271.272	0.3	10	28.6924	8.631893	14.254	1.9549	19.212	16.308	80.07136	0.0003	43,46	
PIPR82S	4.9660	87.0776	22	7.055	71.12	0.3	10	23.3293	7.018455	13.564	1.9549	19.212	15.954	58.051736	0.0003	43,46	
PIPR83S	5.1028	85.07582	22	7.33	79.629	0.3	10	22.793	6.857111	13.794	1.9549	19.212	15.954	58.051736	0.0003	43,46	
PIPR84S	5.4229	88.0785	22	7.605	99.53625	0.3	10	23.5975	7.099127	13.564	1.9549	19.212	15.954	59.052628	0.0003	43,46	
PIPR85S	6.5439	87.0776	22	7.745	132.715	0.3	10	23.3293	7.018455	14.484	1.9549	18.731	15.954	59.052628	0.0003	43,46	
PIPR86S	5.4310	87.0776	22	8.07	137.16	0.3	10	23.3293	7.018455	12.644	1.9549	18.731	15.954	59.052628	0.0003	43,46	
PIPR87S	5.4306	87.0776	22	8.375	182.245	0.3	10	23.3293	7.018455	13.334	1.9549	18.731	15.954	59.052628	0.0003	43,46	
PIPR88S	5.7955	87.0776	22	8.73	268.9225	0.3	10	23.3293	7.018455	14.254	1.9549	18.731	14.89	59.052628	0.0003	43,46	
PIPR89S	6.9862	87.0776	22	8.115	188.976	0.3	10	23.3293	7.018455	12.874	1.9549	18.731	15.954	59.052628	0.0003	43,46	
PIPR90S	8.5781	251.2239	22	7.2	662.559	0.3	10	67.127	20.35751	57.475	4.6918	72.524	62.397	150.1338	0.0003	43,46	
PIPR91S	9.0461	252.2248	22	7.575	904.875	0.3	10	67.3945	20.43861	57.475	4.6918	70.603	62.043	164.14629	0.0003	43,46	
PIPR92S	8.7054	252.2248	22	7.915	995.68	0.3	10	67.3945	20.43861	57.475	4.6918	73.484	62.043	150.1338	0.0003	43,46	
PIPR93S	6.4404	251.2239	22	8.275	891.54	0.3	10	67.127	20.35751	57.475	4.6918	73.484	62.043	143.12756	0.0003	43,46	
PIPR94S	8.4348	200.1784	22	8.05	757.6185	0.3	10	53.5426	16.18781	37.243	3.5188	49.47	46.798	128.11418	0.0003	43,46	
PIPR95S	8.0730	140.1249	22	7.95	404.8125	0.3	10	37.4414	11.35479	22.99	2.3459	28.817	25.172	99.088308	0.0003	43,46	
PIPR96S	8.8271	90.08028	22	8.045	262.128	0.3	10	24.1338	7.260471	14.254	1.9549	18.731	15.599	65.05798	0.0003	43,46	
PIPR97S	2.3840	19.01695	22	7.525	20.447	0.3	10	5.08133	1.541007	3.4485	0.782	0.9606	4.9634	19.016948	0.0003	43,46	
PIPR98S	2.6680	34.03033	22	7.53	23.1648	0.3	10	9.0929	2.757591	3.4485	0.782	9.6058	4.6089	20.01784	0.0003	43,46	
PIPR99S	4.5268	51.04549	22	7.54	34.9885	0.3	10	13.6394	4.136386	3.4485	0.782	16.81	4.6089	21.018732	0.0003	43,46	
PIPR100S	3.5167	29.02587	22	7.585	27.94	0.3	10	7.75571	2.352063	3.4485	0.782	5.2832	4.6089	22.019624	0.0003	43,46	
PIPR101S	3.1703	30.02676	22	7.605	26.67	0.3	10	8.02315	2.433168	1.3794	0.782	4.3226	2.4817	23.020516	0.0003	43,46	
PIPR102S	1.9033	27.02408	22	7.55	20.32	0.3	10	7.22084	2.189852	10.345	1.1729	5.2832	13.118	20.01784	0.0003	43,46	
PIPR103S	2.9068	27.02408	22	7.525	26.67	0.3	10	7.22084	2.189852	20.691	1.5639	10.566	26.59	20.01784	0.0003	43,46	
PIPR104S	6.9464	90.08028	22	7.995	182.88	0.3	10	24.1338	7.260471	14.254	1.9549	19.212	15.954	63.056196	0.0003	43,46	
PIPR105S	4.3303	60.05352	22	8.11	96.6724	0.3	10	16.0463	4.866337	11.955	1.5639	3.8423	17.372	58.051736	0.0003	43,46	

	Model Output	Hand						N	lodel Input							
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	CI (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
PIPR106S	6.1231	120.107	22	8.09	182.88	0.3	10	32.0926	9.732674	11.955	1.5639	33.62	17.372	59.052628	0.0003	43,46
PIPR107S	5.3380	180.1606	22	8.09	190.6905	0.3	10	48.1389	14.59901	11.955	1.5639	62.438	17.017	58.051736	0.0003	43,46
PIPR108S	4.7175	91.08117	22	8.125	127.0635	0.3	10	24.3369	7.380611	11.955	1.5639	19.212	15.954	59.052628	0.0003	43,46
PIPR109S	5.7327	90.08028	22	8.155	148.59	0.3	10	24.0695	7.299505	2.299	6.2557	15.85	6.027	60.05352	0.0003	43,46
PIPR110S	6.5363	93.08296	22	8.135	223.52	0.3	10	24.8718	7.542822	35.864	3.9098	27.377	49.989	62.055304	0.0003	43,46
PIPR111S	6.7795	92.08206	22	8.145	283.1465	0.3	10	24.6043	7.461717	71.728	7.4287	41.305	102.81	61.054412	0.0003	43,46
PIPR112S	5.0174	91.08117	22	8.19	150.241	0.3	10	24.402	7.341142	14.484	15.248	18.731	17.372	62.055304	0.0003	43,46
PIPR113S	6.2630	144.1284	22	8.38	644.525	0.3	10	38.5111	11.67921	34.485	3.1279	12.488	42.189	138.1231	0.0003	43,46
PIPR114S	5.5141	292.2605	22	8.27	697.5475	0.3	10	78.092	23.68284	34.485	3.1279	87.893	57.079	137.1222	0.0003	43,46
PIPR115S	5.1749	440.3925	22	8.225	752.475	0.3	10	117.673	35.68647	34.485	3.1279	175.31	41.125	133.11864	0.0003	43,46
PIPR116S	5.8459	217.1936	22	8.31	653.415	0.3	10	58.0341	17.59992	34.485	3.1279	46.588	43.253	133.11864	0.0003	43,46
PIPR117S	6.1591	218.1945	22	8.305	646.3665	0.3	10	58.3016	17.68102	6.8969	1.5639	38.903	9.5723	140.12488	0.0003	43,46
PIPR118S	5.9250	212.1891	22	8.345	939.8	0.3	10	56.6969	17.19439	103.45	7.8197	65.319	124.79	143.12756	0.0003	43,46
PIPR119S	8.2172	92.08206	22	8.125	253.365	0.3	10	24.6701	7.421814	14.254	1.9549	19.212	16.663	63.056196	0.0003	43,46
PIPR120F	0.3052	48	25	8.03	109.44	2.64	10	14.1077	3.111984	1.35	0.57	3.54	1.25	44	0.0003	1,2,3,6,7,15,26
PIPR121F	0.3617	45	25	8.04	116.16	2.64	10	13.2259	2.917485	1.27	0.57	3.33	1.17	44	0.0003	1,2,3,6,7,15,26
PIPR122F	0.1755	46	25	7.98	84.96	2.64	10	13.5198	2.982318	1.3	0.57	3.4	1.2	41	0.0003	1,2,3,6,7,15,26
PIPR123F	3.4889	30	25	6.82	418.56	10.4652	10	7.1362	2.964634	1.625	0.5	6.125	1.25	21	0.0003	1,2,3,6,7,27,28
PIPR124F	1.8656	37	25	7.28	495.36	11.3373	10	8.80131	3.656382	2.0042	0.5	7.5542	1.5417	21	0.0003	1,2,3,6,7,27,28
PIPR125F	2.8066	87	25	7.11	1522.56	31.3956	10	20.6978	8.4403	16.071	1.855	22.35	18.629	20	0.0003	1,2,3,6,7,27,29
PIPR126F	3.1774	73	25	6.94	1083.84	24.4188	10	17.2174	7.3329	10.539	1.5232	18.439	13.619	18	0.0003	1,2,3,6,7,27,29
PIPR127F	1.4538	84	25	7.07	528	14.5155	10	20.4644	8.008	6	1.4	34.5	10.95	12	0.0003	1,2,3,6,7,27,28
PIPR128F	1.0075	66	25	6.97	960.96	32.9018	10	16.0792	6.292	4.7143	1.4	27.107	8.6036	12	0.0003	1,2,3,6,7,27,28
PIPR129F	1.2809	43.9	25	7.4	88.32	2	10	12.9026	2.846168	1.24	0.57	3.24	1.14	42.4	0.0003	1,2,6,7,8,14,15
PIPR130F	0.0860	47.04192	22	8.1	27.94	1.1	10	13.9359	2.983276	1.6093	0.391	3.362	1.4181	42.53791	0.0003	43,44
PIPR131F	1.1899	243.2168	22	8.01	105.7275	1.1	10	92.7261	2.884195	47.129	0.391	3.362	143.23	43.038356	0.0003	43,44
PIPR132F	0.1230	255.7279	22	8.01	40.0558	1.1	10	14.1661	53.5752	1.6093	0.391	3.362	143.23	43.538802	0.0003	43,44
PIPR133F	0.4522	47.04192	22	8.1	64.262	1.1	10	13.9359	2.983276	47.589	0.391	3.362	72.324	43.538802	0.0003	43,44
PIPR134F	0.3833	45.04014	22	8.02	49.01565	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44
PIPR135F	0.3216	45.04014	22	8.65	67.7164	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	47.041924	0.0003	43,44
PIPR136F	0.1834	45.54059	22	7.3	18.669	1.1	10	13.4911	2.888065	1.6093	0.391	3.362	1.4181	44.039248	0.0003	43,44
PIPR137F	0.1256	49.04371	22	6.63	6.1468	1.1	10	14.5289	3.110224	1.6093	0.391	3.362	1.4181	49.043708	0.0003	43,44
PIPR138F	0.2961	45.04014	22	7.16	20.447	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	15.599	26.023192	0.0003	43,44
PIPR139F	2.8408	43.03836	22	7.93	93.36405	1.1	10	12.7498	2.72938	1.6093	0.391	3.362	1.4181	41.036572	0.0003	43,44

	Model Output							Ν	Iodel Input							
BLM Data Label	Critical Accumulation	Hard- ness (mg/L)	Temp (⁰C)	рН	Dissolved LC50 (µg/L)	DOC (mg/L)	Humic Acid (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	Notes
PIPR140F	0.0373	45.54059	22	7.91	245.364	6.1	83.7705	13.4911	2.888065	1.6093	0.391	3.362	1.4181	44.039248	0.0003	43,47
PIPR141F	1.3667	45.04014	22	7.94	72.3392	1.1	10	13.3428	2.856328	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,44
PIPR142F	0.0310	45.04014	22	7.95	229.8065	6.1	83.7705	13.3428	2.856328	1.6093	0.391	3.362	1.4181	43.038356	0.0003	43,47
PIPR143F	0.1023	45.54059	22	7.94	195.453	3.6	72.5	13.4911	2.888065	1.6093	0.391	3.362	1.4181	44.039248	0.0003	43,47
PIPR144F	0.1038	45.04014	22	7.91	109.347	2.35	57.8723	13.3428	2.856328	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,47
PIPR145F	1.9076	44.03925	22	7.87	78.0034	1.1	10	13.0463	2.792854	1.6093	0.391	3.362	1.4181	42.037464	0.0003	43,44
PIPR146F	0.4905	44.03925	22	7.84	45.52315	1.1	10	13.0463	2.792854	1.6093	0.391	3.362	19.145	17.015164	0.0003	43,44
PIPR147F	1.3078	22.52007	22	6.01	4.3815	0.3	10	6.01736	1.824876	3.4485	0.391	3.362	4.2544	15.01338	0.0003	43,46
PIPR148F	1.5995	24.02141	22	7.02	12.4333	0.3	10	6.41852	1.946535	3.6784	0.391	3.362	4.9634	17.015164	0.0003	43,46
PIPR149F	2.4015	23.02052	22	8	26.8605	0.3	10	6.15108	1.865429	4.1382	0.782	3.362	4.9634	17.51561	0.0003	43,46
PIPR150F	2.3670	21.51918	22	9.01	51.3334	0.3	10	5.74992	1.743771	4.598	1.5639	3.362	4.9634	19.016948	0.0003	43,46
PTLU01S	4.0390	173	22	8.3	364.8	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PTLU02S	9.0637	173	22	7.25	460.8	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
PTOR01F	0.2752	25	7.8	7.3	22.08	1.1	10	7.1535	1.9754	4.8154	0.7	3.997	5.9792	25	0.0003	1,2,3,6,7,9,10
PTOR02F	0.1587	54	11.5	7.3	17.28	1.1	10	15.0937	3.6371	6.8831	0.7	12.163	9.6854	43	0.0003	1,2,3,6,7,9,10
XYTE01S	2.6511	173	22	8.15	211.2	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
XYTE02S	4.5011	173	22	8.05	326.4	0.5	10	28.5511	24.739	53.583	4.282	166.08	3.8824	117	0.0003	1,2,3,4,6,7,20
POAC01S	2.2126	167	22	8	153.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
LEMA01R	25.6628	85	20.2	7.3	2200	1.1	10	23.9	6.5	0.64	0.46	4.32	1.5	82	0.0003	50
LEMA02F	25.8381	45	20	7.5	1056	1.1	10	13.2259	2.917485	1.3	0.57	3.4	1.2	43	0.0003	1,2,3,6,7,8
LEMA03F	27.6113	25.9	19	7.03	960	1.5	10	6.38814	2.42165	5.4743	1.6	26.489	19.425	27.1	0.0003	1,2,3,6,7,16
LEMA04F	22.5658	85	21.85	7.45	1300	1.1	10	23.9	6.5	0.64	0.46	4.32	1.5	82	0.0003	50
ETFL01S	5.5744	170	20	7.8	316.8	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETFL02S	5.7421	170	20	7.8	327.36	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETFL03S	5.8278	170	20	7.9	358.08	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETFL04S	6.4920	170	20	7.8	376.32	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETLE01S	3.7314	167	22	8	249.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
ETNI01S	7.8536	170	20	7.8	473.28	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETNI02S	7.7256	170	20	7.8	463.68	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETNI03S	9.1617	170	20	7.8	577.92	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETNI04S	8.5329	170	20	7.8	526.08	0.5	10	27.9	24.2	52.5	4.2	163	3.80	115	0.0003	1,3,4,22
ETRU01S	0.4735	167	22	8.2	57.6	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20
BUBO01S	1.7185	167	22	7.9	115.2	0.5	10	27.5609	23.881	51.724	4.1335	160.32	3.7478	115	0.0003	1,2,3,4,6,7,20

Appendix F. Regression Plots

#### Appendix F. Analyses of Chronic Data

The following pages contain figures and other information related to the regression and probability distribution analyses that were performed to calculate chronic EC20s. The initial parameter estimates are shown in the tables below. In the figures that follow, circles denote measured responses and solid lines denote estimated regression lines.

Species	Study	Test	Endpoint		Final Estimates			
				Control Value	EC50	Standard Deviation	EC20	EC10
Snail, Campeloma decisum (Test 1)	Arthur and Leonard 1970	LC	Survival	0.925	14.50	0.192	8.73	7.01
Snail, Campeloma decisum (Test 2)	Arthur and Leonard 1970	LC	Survival	0.875	11.80	0.339	10.94	9.16
Cladoceran, Daphnia pulex	Winner 1985	LC	Survival	1.00	4.57	0.260	2.83	2.24
Cladoceran, Daphnia pulex	Winner 1985	LC	Survival	0.900	11.3	0.111	9.16	8.28
Caddisfly, Clistoronia magnifica	Nebeker et al. 1984b	LC	Emergence (adult 1st gen)	0.750	20.0	0.300	7.67	5.63
Bluegill (larval), Lepomis macrochirus	Benoit 1975	ELS	Survival	0.880	39.8	0.250	27.15	21.60

#### **Probability Distribution Analysis**

#### Logistic Regression Analysis

Species	Study	Test	Endpoint		Final Estimates			
				Control Value	EC50	Slope	EC20	EC10
Cladoceran,	Carlson et al. 1986	LC	Reproduction	13.10	14.6	1.36	9.17	7.28
Ceriodaphnia dubia								
Cladoceran,	Chapman et al. Manuscript	LC	Reproduction	171.5	16.6	1.40	12.58	10.63
Daphnia magna								
Cladoceran,	Chapman et al. Manuscript	LC	Reproduction	192.1	28.4	1.59	19.89	16.34
Daphnia magna								
Cladoceran,	Chapman et al. Manuscript	LC	Reproduction	88.0	15.8	1.00	6.06	3.64
Daphnia magna								
Rainbow trout,	Seim et al. 1984	ELS	Biomass	137.6	40.7	1.69	27.77	22.16
Oncorhynchus mykiss								
Rainbow trout,	Besser et al. 2001	ELS	Biomass	1224	29.2	1.99	20.32	16.74
Oncorhynchus mykiss								
Chinook salmon,	Chapman 1975, 1982	ELS	Biomass	0.901	9.55	1.27	5.92	4.47
Oncorhynchus tshawytscha								
Fathead minnow,	Lind et al. manuscript	ELS	Biomass	108.4	11.4	4.00	9.38	8.67
Pimephales promelas								

#### Evaluation of the Chronic Data Available for Freshwater Species

Following is a species-by-species discussion of each chronic test on copper evaluated for this document. Also presented are the results of regression analysis and probability distribution analysis of each dataset that was from an acceptable chronic test and contained sufficient acceptable data. For each such dataset, this appendix contains a figure that presents the data and regression/probability distribution line.

Brachionus calyciflorus. The chronic toxicity of copper was ascertained in 4-day renewal tests conducted at regular intervals throughout the life of the freshwater rotifer, *B. calyciflorus* (Janssen et al. 1994). The goal of this study was to develop and examine the use of this rotifer as a viable test organism. The effect of copper on the age-specific survivorship and fertility of *B. calyciflorus* was determined, but no individual replicate data were provided and only three copper concentrations were tested, which precludes these data from further regression analysis. Chronic limits based on the intrinsic rate of natural increase were 2.5  $\mu$ g/L total copper (NOAEC) and 5.0  $\mu$ g/L total copper (LOAEC). The chronic value determined via traditional hypothesis testing is 3.54  $\mu$ g/L total copper (Table 2a).

Campeloma decisum. Adult C. campeloma were exposed to five concentrations of total copper and a control (Lake Superior water) under flow-through conditions in two 6-week studies conducted by Arthur and Leonard (1970). Adult survival in the two separate chronic copper toxicity test trials was markedly reduced in the two highest copper concentrations, 14.8 and 28.0  $\mu$ g/L, respectively. The authors reported that growth, as determined from cast exoskeleton, was not measurable for this test species, although the authors did observe that the adult snails would not consume food at the two highest copper concentrations. Control survival was 80 percent or greater. Chronic values of 10.88  $\mu$ g/L total copper were obtained for survival based on the geometric mean of the NOAEC and LOAEC of 8.0 and 14.8  $\mu$ g/L, respectively, in both tests. The corresponding EC20s were 8.73 and 10.94  $\mu$ g/L (Table 2a).

*Ceriodaphnia dubia.* The chronic toxicity of copper to *C. dubia* was determined in ambient river water collected upstream of known point-source discharges of domestic and industrial wastes as part of a water effect ratio study (Carlson et al. 1986). In this study, survival and young production of *C. dubia* were assessed using a 7-day life-cycle test. Organisms were not affected at total copper concentrations ranging from 3 to 12  $\mu$ g/L (5 to 10  $\mu$ g/L dissolved copper). There was a 62.7 percent reduction in survival and 97 percent reduction in the mean number of young produced per female at 32  $\mu$ g/L total copper (27  $\mu$ g/L dissolved copper). No daphnids survived to produce young at 91  $\mu$ g/L total copper. Control survival during the study was 80 percent, which included one male. The chronic value EC20 selected for *C. dubia* in this study, 9.17  $\mu$ g/L derived from a nonlinear regression evaluation, was based on mean number of young produced (reproduction).

The effects of water hardness on the chronic toxicity of copper to *C. dubia* were assessed by Belanger et al. (1989) using 7-day life-cycle tests. *C. dubia* 2 to 8 hours old were exposed to copper in ambient surface water from the New and Clinch Rivers, Virginia. Mean water hardness levels were 179 and 94 mg/L as CaCO<sub>3</sub>, respectively. Test water was renewed on days 3 and 5. The corresponding chronic values for reproduction based on the NOAEC and LOAEC approach were 7.9 and <19.3  $\mu$ g/L dissolved copper, respectively. The EC20 value for number of young (neonates) produced in Clinch River water (water hardness of 94 mg/L as CaCO<sub>3</sub>) was 19.36  $\mu$ g/L dissolved copper. The EC20 for young produced in New River water was not calculated. The chronic values were converted to total copper using the freshwater conversion factor for copper 0.96 (e.g., 7.897/0.96). The resulting total chronic values for the New and Clinch rivers are 8.23 and 20.17  $\mu$ g/L, respectively.

Copper was one of 12 toxicants examined by Oris et al. (1991) in their comparisons between a 4day survival and reproduction toxicity test utilizing *C. dubia* and a standard 7-day life-cycle test for the species. The reported 7-day chronic values for survival and reproduction (mean total young per living female) in two tests based on the traditional hypothesis testing techniques were 24.5 and 34.6  $\mu$ g/L total copper. Comparable point estimates for these 7-day tests could not be calculated using regression analysis.

Daphnia magna. Blaylock et al. (1985) reported the average numbers of young produced for six broods of *D. magna* in a 14-day chronic exposure to copper. A significant reduction was observed in the mean number of young per female at a concentration of 30  $\mu$ g/L total copper, the highest copper concentration tested. At this concentration, young were not produced at brood intervals 5 and 6. Reproduction was not affected at 10  $\mu$ g/L total copper. The chronic value determined for this study (17.32  $\mu$ g/L total copper) was based on the geometric mean of the NOAEC, 10  $\mu$ g/L, and LOAEC, 30  $\mu$ g/L.

Van Leeuwen et al. (1988) conducted a standard 21-day life-cycle test with *D. magna*. The water hardness was 225 mg/L as CaCO<sub>3</sub>. Carapace length was significantly reduced at 36.8  $\mu$ g/L total copper, although survival was 100 percent at this concentration. Carapace length was not affected at 12.6  $\mu$ g/L total copper. No daphnids survived at 110  $\mu$ g/L concentration. The highest concentration not significantly different from the control for survival was 36.8  $\mu$ g/L. The lowest concentration significantly different from the control based on survival was 110  $\mu$ g/L, resulting in a chronic value of 63.6  $\mu$ g/L for survival. The chronic value based on carapace length was 21.50  $\mu$ g/L. The 21-day EC10 as reported by the author was 5.9  $\mu$ g/L total copper.

Chronic (21-day) renewal toxicity tests were conducted using *D. magna* to determine the relationship between water hardness (nominal values of 50, 100, and 200 mg/L as CaCO<sub>3</sub>, respectively) and the toxicity of total copper (Chapman et al. unpublished manuscript). All test daphnids were <1 day old at the start of the tests. The dilution water was well water from the Western Fish Toxicology Station (WFTS), Corvallis, Oregon. Test endpoints were reproduction (total and live young produced per female) and adult survival. The survival of control animals was 100 percent at nominal water hardness levels of 50 and 200 mg/L as CaCO<sub>3</sub>, and 80 percent at a hardness of 100 mg/L as CaCO<sub>3</sub>. The chronic values for total young produced per female (fecundity) based on the geometric mean of the NOAEC and LOAEC were 13.63, 29.33, and 9.53 µg/L at the nominal hardness levels of 50, 100, and 200 mg/L as CaCO<sub>3</sub>, respectively. The corresponding EC20 values for reproduction calculated using nonlinear regression analysis were 12.58, 19.89, and 6.06 µg/L total copper. The chronic toxicity of copper to *D. magna* was somewhat ameliorated from an increase in water hardness from 50 to 100 mg/L as CaCO<sub>3</sub>, but slightly increased from 100 to 200 mg/L as CaCO<sub>3</sub>.

Daphnia pulex. Winner (1985) evaluated the effects of water hardness and humic acid on the chronic toxicity (42-day) of copper to *D. pulex*. Contrary to the expectation that sublethal endpoints are more sensitive indicators of chronic toxicity, reproduction was not a sensitive indicator of copper stress in this species. Water hardness also had little effect on the chronic toxicity of copper (similar to *D. magna* trends), but humic acid significantly reduced chronic toxicity of copper when added to the varying water types. The survival chronic values based on the NOAEC and LOAEC values for the three low to no humic acid studies were 4.90, 7.07, and 12.25  $\mu$ g/L total copper at hardnesses of 57.5, 115, and 230 (0.15 mg/L HA)  $\mu$ g/L as CaCO<sub>3</sub>, respectively. The EC20 values calculated for the low and high hardness studies using nonlinear regression techniques were 2.83 and 9.16  $\mu$ g/L at hardness values of 57.5 and 230 (0.15 mg/L HA)  $\mu$ g/L as CaCO<sub>3</sub>, respectively.

Clistoronia magnifica. The effects of copper on the lifecycle of the caddisfly, C. magnifica, were examined in Nebeker et al. (1984b). The test included continuous exposure of first-generation aquatic larvae and pupae through to a third generation of larvae. A significant reduction in adult emergence occurred at 13.0  $\mu$ g/L total copper from first-generation larvae. No observed adverse effect to adult emergence occurred at 8.3  $\mu$ g/L total copper. Percent larval survival was close to the control value of 80 percent. The chronic value based on hypothesis testing was 10.39  $\mu$ g/L total copper. The corresponding EC20 value for adult emergence was 7.67  $\mu$ g/L total copper.

Oncorhynchus mykiss. The growth and survival of developing O. mykiss embryos continuously and intermittently exposed to copper for up to 85 days post-fertilization was examined by Seim et al. (1984). Results only from the continuous exposure study are considered here for deriving a chronic value. A flow-through apparatus was used to deliver six concentrations and a control (untreated well water; average of 3 µg/L copper) to a single incubation chamber. Continuous copper exposure of steelhead embryos in the incubation chambers was begun 6 days post-fertilization. At 7 weeks postfertilization, when all control fish had hatched and reached swim-up stage, subsamples of approximately 100 alevins were transferred to aquaria and the same exposure pattern continued. Dissolved oxygen remained near saturation throughout the study. Water hardness averaged 120 mg/L as CaCO<sub>3</sub>. Survival of steelhead embryos and alevins exposed continuously to total copper concentrations in the range of 3 (controls) to 30 µg/L was greater than 90 percent or greater. Survival was reduced at 57 µg/L and completely inhibited at 121 µg/L. A similar effect on survival was observed for embryos and alevins exposed to a mean of 51 (peak 263) and 109 (peak 465) µg/L of copper in the intermittent exposure, respectively. The adverse effect of continuous copper exposure on growth (measured on a dry weight basis) was observed at concentrations as low as 30 µg/L. (There was a 30 percent reduction in growth during the intermittent exposure at 16 µg/L.) The chronic limits for survival of embryos and alevin steelhead trout exposed continuously to copper were 16 and 31  $\mu$ g/L, respectively (geometric mean = 22.27  $\mu$ g/L). The EC20 for biomass for the continuous exposure was 27.77  $\mu$ g/L.

Besser et al. (2001) conducted an ELS toxicity test with copper and the rainbow trout, *O. mykiss*, starting with eyed embryos and continuing for 30 days after the fish reached the swim-up stage. The total test period was 58 days. The test was conducted in ASTM moderately hard reconstituted water with a hardness of approximately 160 to 180 mg/L as  $CaCO_3$ . Twenty-five eyed embryos were held in each of four replicate egg cups at each concentration. Survival was monitored daily. At the end of the test, surviving fish in each replicate chamber were weighed (dry weight). Dry weights were used to determine growth and biomass of surviving fish. The no observed effect concentrations (NOECs) for survival and biomass were both 12 µg/L and the lowest observed effect concentrations (LOECs) for survival and biomass was also the same for both endpoints, 22 µg/L. The chronic values for biomass and survival based on the geometric mean of the NOEC and LOEC were 16.25 µg/L. The corresponding EC20 for biomass was  $20.32 \mu g/L$ .

Oncorhynchus tshawytscha. The draft manuscript prepared by Chapman (1975/1982) provides the results from a 4-month egg through fry partial chronic test conducted to determine the effects of copper on survival and growth of *O. tshawytscha*. Continuous exposure occurred from several hours post-fertilization through hatch, swim-up, and feeding fry stages. The test was terminated after 14 weeks post-hatch. The dilution water was WFTS well water. Because of the influence of the nearby Willamette River on the hardness of this well water, reverse osmosis water was mixed periodically with ambient well water to attain a consistent hardness. The typical hardness of this well water was approximately 23 mg/L as CaCO<sub>3</sub>. Control survival exceeded 90 percent for the test. The measured total copper concentrations during the test were 1.2 (control), 7.4, 9.4, 11.7, 15.5, and 20.2  $\mu$ g/L, respectively. Copper adversely affected survival at 11.7  $\mu$ g/L copper and higher, and growth was reduced at all copper concentrations tested compared with the growth of control fish. The chronic limits for copper in this study were estimated to be less than 7.4  $\mu$ g/L. The EC20 value estimated for biomass is 5.92  $\mu$ g/L total copper based on a logistic nonlinear regression model.

Salmo trutta. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile brown trout to copper. The most sensitive exposure was with embryos exposed for 72 days. The NOAEC and LOAEC, as obtained from the figure, were 20.8 and 43.8  $\mu$ g/L total copper, respectively. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value selected for this species was 29.91  $\mu$ g/L total copper (geometric mean of 20.8 and 43.8  $\mu$ g/L total copper).

Salvelinus fontinalis. Sauter et al. (1976) examined the effects of copper on selected freshwater fish species at different hardness levels (softwater at 37.5 mg/L as CaCO<sub>3</sub>; hardwater at 187 mg/L as CaCO<sub>3</sub>) during a series of partial life-cycle (PLC) tests. The species tested were brook trout (*Salvelinus fontinalis*), channel catfish (*Ictalurus punctatus*), and walleye (*Stizostedion vitreum*). Because of the poor embryo and larval survival of control animals (in all cases less than 70 percent), results from tests with channel catfish and walleye were not included in Table 2a. One of the replicate control chambers from the PLC tests conducted with brook trout in hard water also exhibited poor hatchability (48 percent) and survival (58 percent) between 31 and 60 days of exposure. Therefore, the data for brook trout in hard water were not included in the subsequent EC20 (regression) analysis either.

The softwater test with brook trout was conducted using untreated well water with an average water hardness of 35 mg/L as CaCO<sub>3</sub>. This PLC exposure consisted of six copper concentrations and a control. Hatchability was determined by examining randomly selected groups of 100 eggs from each replicate exposure tank. Growth and survival of fry were determined by impartially reducing the total sample size to 50 fry per tank and assessing their progress over 30 day intervals up to 60 days post-hatch. The chronic limits based on the growth (wet weight and total length) of larval brook trout after 60 days of exposure to copper in soft water were <5 and 5  $\mu$ g/L. The resultant chronic value for soft water based on hypothesis testing was <5  $\mu$ g/L. The corresponding EC20 values based on total length, wet weight, and biomass (the product of wet weight and survival) for brook trout in the soft-water exposures after 60 days were not amenable to nonlinear regression analysis.

McKim et al. (1978) examined survival and growth (expressed as standing crop) of embryolarval and early juvenile brook trout exposed to copper. The embryo exposure was for 16 days, and the larval-early-juveniles exposure lasted 60 days. The NOAEC and LOAEC were 22.3 and 43.5  $\mu$ g/L total copper, respectively. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value for this species was 31.15  $\mu$ g/L total copper (geometric mean of 22.3 and 43.5  $\mu$ g/L total copper).

Salvelinus namaycush. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile lake trout exposed to copper. The embryo exposure was for 27 days, and the larval-early-juveniles exposure lasted 66 days. The NOAEC and LOAEC were 22.0 and 43.5  $\mu$ g/L total copper, respectively. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value for this species was 30.94  $\mu$ g/L total copper (geometric mean of 22.0 and 43.5  $\mu$ g/L total copper).

*Esox lucius*. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile northern pike exposed to copper. The embryo exposure was for 6 days, and the larval-early-juveniles exposure lasted 34 days. The NOAEC and LOAEC were 34.9 and 104.4  $\mu$ g/L total copper, respectively. The authors attributed the higher tolerance of *E. lucius* to copper to the very short embryonic exposure period compared with salmonids and white sucker, *Catostomus* 

*commersoni*. Data were not available to calculate point estimates at the 20 percent effect level using regression analysis. The chronic value for this species was 60.36  $\mu$ g/L total copper (geometric mean of 34.9 and 104.4  $\mu$ g/L total copper).

Pimephales notatus. An experimental design similar to that described by Mount and Stephan (1967) and Mount (1968) was used to examine the chronic effect of copper on the bluntnose minnow, P. notatus (Horning and Neiheisel 1979). Measured total copper concentrations were 4.3 (control), 18.0, 29.9, 44.1, 71.8, and 119.4 µg/L, respectively. The experimental dilution water was a mixture of spring water and demineralized City of Cincinnati tap water. Dissolved oxygen was kept at 5.9 mg/L or greater throughout the test. Total water hardness ranged from 172 to 230 mg/L as CaCO<sub>3</sub>. The test was initiated with 22 6-week-old fry. The fish were later separated according to sex and thinned to a sex ratio of 5 males and 10 females per duplicated test chamber. Growth (total length) was significantly reduced in parental and first (F<sub>1</sub>) generation *P. notatus* after 60 days of exposure to the highest concentration of copper tested (119.4 µg/L). Survival of parental P. notatus exposed to this same high test concentration was also lower (87 percent) at the end of the test compared with the other concentrations (range of 93 to 100 percent). Copper at concentrations of 18  $\mu$ g/L and greater significantly reduced the number of eggs produced per female. The number of females available to reproduce was generally the same up to about 29.9 µg/L of copper. The chronic limits were based on an NOAEC and LOAEC of <18 and 18 µg/L for number of eggs produced per female. An EC20 was not estimated by nonlinear regression; nevertheless, in this case an EC20 is likely to be substantially below  $18 \mu g/L$ .

*Pimephales promelas.* The results from a 30-day ELS toxicity test to determine the chronic toxicity of copper to *P. promelas* using dilution water from Lake Superior (hardness ranging from 40 to 50 mg/L as CaCO<sub>3</sub>) was included in Table 2a from a manuscript prepared by Lind et al. in 1978. In this experiment, five test concentrations and a control were supplied by a continuous-flow diluter. The exposure began with embryos 1 day post-fertilization. Pooled results from fish dosed in replicate exposure chambers were given for mean percentage embryo survival to hatch, mean percentage fish survival after hatch, and mean fish wet weight after 30 days. The percentage of embryo survival to hatch, however, was compromised at 26.2  $\mu$ g/L, and mean wet weight of juvenile fathead minnows was significantly reduced at 13.1  $\mu$ g/L of copper. The estimated EC20 value for biomass was 9.376  $\mu$ g/L total copper.

*Catastomus commersoni*. McKim et al. (1978) examined the survival and growth (expressed as standing crop) of embryo-larval and early juvenile white sucker exposed to copper. The embryo exposure was for 13 days, and the larval-early-juvenile exposure lasted 27 days. The NOAEC and LOAEC were 12.9 and 33.8  $\mu$ g/L total copper, respectively. The resulting chronic value based on hypothesis testing for this species was 20.88  $\mu$ g/L total copper (geometric mean of 12.9 and 33.8  $\mu$ g/L total copper).

Lepomis macrochirus. Results from a 22-month copper life-cycle toxicity test with bluegill (*L. macrochirus*) were reported by Benoit (1975). The study included a 90-day embryo-larval survival and growth component. The tests were conducted at the U.S. EPA National Water Quality Laboratory in Duluth, Minnesota, using Lake Superior water as the dilution water (average water hardness = 45 mg/L as CaCO<sub>3</sub>). The test was initiated in December 1969 with 2-year-old juvenile *L. macrochirus*. In May 1971, the fish were sexed and randomly reduced to three males and seven females per tank. Spawning commenced on 10 June 1971. The 90-day embryo-larval exposure was initiated when 12 lots of 50 newly hatched larvae from one of the two control groups were randomly selected and transferred to duplicate grow-out chambers at 1 of 6 total copper concentrations: 3 (control), 12, 21, 40, 77, and 162  $\mu$ g/L, respectively. In the 22-month juvenile through adult exposure, survival, growth, and reproduction were unaffected at 77  $\mu$ g/L of copper and below. No spawning occurred at 162  $\mu$ g/L. Embryo hatchability and

survival of 4-day-old larvae at 77  $\mu$ g/L did not differ significantly from those of controls. However, after 90 days of exposure, survival of larval *L. macrochirus* at 40 and 77  $\mu$ g/L was significantly lower than for controls, and no larvae survived at 162  $\mu$ g/L. Growth remained unaffected at 77  $\mu$ g/L. Based on the 90-day survival of bluegill larvae, the chronic limits were estimated to be 21 and 40  $\mu$ g/L (geometric mean = 28.98  $\mu$ g/L). The corresponding EC20 for embryo-larval survival was 27.15  $\mu$ g/L.



Campeloma decisum (Test 2), Life-cycle, Arthur and Leonard 1970



Ceriodaphnia dubia (Clinch River), Life-cycle, Belanger et al. 1989



Lepomis macrochirus, Early Life-stage, Benoit 1975



Oncorhynchus mykiss, Early Life-Stage, Besser et al. 2001



Ceriodaphnia dubia, Life-cycle, Carlson et al. 1986





Daphnia magna (Hardness 211), Life-cycle, Chapman et al. Manuscript



Daphnia magna (Hardness 51), Life-cycle, Chapman et al. Manuscript





Pimephales promelas, Early Life-stage, Lind et al. 1978



Clistoronia magnifica, Life-cycle, Nebeker et al. 1984a





Daphnia pulex (Hardness 230 HA 0.15), Life-cycle, Winner 1985



Daphnia pulex (Hardness 57), Life-cycle, Winner 1985



Appendix G. Example Water Quality Criteria Values Using the BLM and the Hardness Equation

Appendix G: Representative water quality criteria values using the BLM and the Hardness equation approaches for waters with a range in pH, Hardness, and DOC concentrations. The BLM calculation assumed that alkalinity was correlated with pH, and that other major ions were correlated with hardness based on observed correlations in EPA synthetic water recipes.

			Hardness	
			Equation Based	BLM Based
			Water Quality	Instantaneous
			Criterion for	Water Quality
рΗ	Hardness	DOC	Cu <sup>[1]</sup>	Criterion for Cu
P	mg/L CaCO <sub>3</sub>	mg / L	μg / L	μg / L
6.5	40	2	5.9	1.6
		4	5.9	3.3
		8	5.9	6.8
		16	5.9	14.3
	80	2	11.3	1.9
		4	11.3	3.8
		8	11.3	7.7
		16	11.3	16.0
	159	2	21.7	2.3
		4	21.7	4.5
		8	21.7	9.2
		16	21.7	18.9
	317	2	41.5	2.8
		4	41.5	5.6
		8	41.5	11.4
		16	41.5	23.1
7.0	40	2	5.9	3.9
		4	5.9	8.0
		8	5.9	16.4
		16	5.9	34.3
	80	2	11.3	4.4
		4	11.3	8.8
		8	11.3	18.0
		16	11.3	37.0
	159	2	21.7	5.1
		4	21.7	10.3
		8	21.7	20.7
		16	21.7	42.4
	317	2	41.5	6.2
		4	41.5	12.4
		8	41.5	24.9
		16	41.5	50.6

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рН	Hardness	DOC	Hardness Equation Based Water Quality Criterion for Cu <sup>[1]</sup>	BLM Based Instantaneous Water Quality Criterion for Cu
	mg/L CaCO <sub>3</sub>	mg / L	μg / L	μg / L
7.5	40	2	5.9	7.9
		4	5.9	15.8
		8	5.9	32.4
		16	5.9	67.3
	80	2	11.3	8.7
		4	11.3	17.4
		8	11.3	35.3
		16	11.3	72.5
	159	2	21.7	10.1
		4	21.7	20.1
		8	21.7	40.5
		16	21.7	82.4
	317	2	41.5	12.0
		4	41.5	23.9
		8	41.5	47.8
		16	41.5	96.8
8.0	40	2	5.9	13.8
		4	5.9	27.6
		8	5.9	55.8
		16	5.9	115.0
	80	2	11.3	15.5
		4	11.3	30.6
		8	11.3	61.4
	450	10	11.3	125.1
	159	<u> </u>	21.7	10.0
		4	21.7	35.3
		0	21.7	142.0
	217	10	<u> </u>	142.0
	317		41.3	C1.5
		4	41.3	41.0
		0	41.3	02.3
	1	10	41.5	105.1

			Hardness Equation Based Water Quality Criterion for	BLM Based Instantaneous Water Quality
рН	Hardness	DOC	Cu <sup>rr</sup>	Criterion for Cu
	mg/L CaCO $_3$	mg / L	μg / L	μg / L
8.5	40	2	5.9	22.5
		4	5.9	43.3
		8	5.9	85.6
		16	5.9	172.9
	80	2	11.3	26.0
		4	11.3	49.1
		8	11.3	96.0
		16	11.3	191.6
	159	2	21.7	31.4
		4	21.7	58.0
		8	21.7	111.7
		16	21.7	220.6
	317	2	41.5	39.1
		4	41.5	70.3
		8	41.5	132.8
		16	41.5	259.6

Notes:

[1] : Hardness Equation:  $CMC = e^{(0.9422 [ln(H)] - 1.7)}$ 

where:

H = water hardness (mg/L CaCO<sub>3</sub>)

\* Appendix updated as of March 2, 2007

Appendix H. Unused Data

#### APPENDIX H. UNUSED DATA

Based on the requirements set forth in the guidelines (Stephan et al. 1985), the following studies are not acceptable for the following reasons and are classified as unused data.

#### Studies Were Conducted with Species That Are Not Resident in North America

Kadioglu and Ozbay (1995)	Raj and Hameed (1991)
Karbe (1972)	Rajkumar and Das (1991)
Knauer et al. (1997)	Reeve et al. (1977)
Kulkarni (1983)	Ruiz et al. (1994, 1996)
Kumar et al. (1985)	Saward et al. (1975)
Lan and Chen (1991)	Schafer et al. (1993)
Lee and Xu (1984)	Smith et al. (1993)
Luderitz and Nicklisch (1989)	Solbe and Cooper (1976)
Majori and Petronio (1973)	Steeman-Nielsen and Bruun-Laursen
Masuda and Boyd (1993)	(1976)
Mathew and Fernandez (1992)	Stephenson (1983)
Maund et al. (1992)	Takamura et al. (1989)
Migliore and Giudici (1988)	Taylor et al. (1991, 1994)
Mishra and Srivastava (1980)	Timmermans (1992)
Negilski et al. (1981)	Timmermans et al. (1992)
Nell and Chvojka (1992)	Vardia et al. (1988)
Neuhoff (1983)	Verriopoulos and Moraitou-
Nias et al. (1993)	Apostolopoulou (1982)
Nonnotte et al. (1993)	Visviki and Rachlin (1991)
Pant et al. (1980)	Weeks and Rainbow (1991)
Paulij et al. (1990)	White and Rainbow (1982)
Peterson et al. (1996)	Wong and Chang (1991)
Pistocchi et al. (1997)	Wong et al. (1993)
Pynnonen (1995)	
	Kadioglu and Ozbay (1995) Karbe (1972) Knauer et al. (1997) Kulkarni (1983) Kumar et al. (1985) Lan and Chen (1991) Lee and Xu (1984) Luderitz and Nicklisch (1989) Majori and Petronio (1973) Masuda and Boyd (1993) Mathew and Fernandez (1992) Maund et al. (1992) Migliore and Giudici (1988) Mishra and Srivastava (1980) Negilski et al. (1981) Nell and Chvojka (1992) Neuhoff (1983) Nias et al. (1993) Nonnotte et al. (1993) Pant et al. (1990) Peterson et al. (1997) Pynnonen (1995)

#### Copper Was a Component of a Drilling Mud, Effluent, Mixture, Sediment, or Sludge

Buckler et al. (1987) Buckley (1994) Clements et al. (1988) de March (1988) Hollis et al. (1996) Horne and Dunson (1995) Hutchinson and Sprague (1987) Kraak et al. (1993 and 1994a,b) Lowe (1988) McNaught (1989) Munkittrick and Dixon (1987) Pellegrini et al. (1993) Roch and McCarter (1984a,b) Roch et al. (1986) Sayer et al. (1991b) Weis and Weis (1993) Widdows and Johnson (1988) Wong et al. (1982)

#### These Reviews Only Contain Data That Have Been Published Elsewhere

- Ankley et al. (1993) Borgmann and Ralph (1984) Chapman et al. (1968) Chen et al. (1997) Christensen et al. (1983) Dierickx and Brendael-Rozen (1996) DiToro et al. (1991) Eisler (1981) Eisler et al. (1979) Enserink et al. (1991)
- Felts and Heath (1984) Gledhill et al. (1997) Handy (1996) Hickey et al. (1991) Janssen et al. (1994) LeBlanc (1984) Lilius et al. (1984) Meyer et al. (1987) Ozoh (1992c)
- Peterson et al. (1996) Phillips and Russo (1978) Phipps et al. (1995) Spear and Pierce (1979b) Starodub et al. (1987b) Taylor et al. (1996) Thompson et al. (1972) Toussaint et al. (1995)

#### No Interpretable Concentration, Time, Response Data, or Examined Only a Single Concentration

Asztalos et al. (1990)	Koltes (1985)	Sayer (1991)
Beaumont et al. (1995a,b)	Kosalwat and Knight (1987)	Sayer et al. (1991a,b)
Beckman and Zaugg (1988)	Kuwabara (1986)	Schleuter et al. (1995, 1997)
Bjerselius et al. (1993)	Lauren and McDonald (1985)	Starcevic and Zielinski (1997)
Carballo et al. (1995)	Leland (1983)	Steele (1989)
Daoust et al. (1984)	Lett et al. (1976)	Taylor and Wilson (1994)
De Boeck et al. (1995b, 1997)	Miller and McKay (1982)	Viale and Calamari (1984)
Dick and Dixon (1985)	Mis and Bigaj (1997)	Visviki and Rachlin (1994b)
Felts and Heath (1984)	Nalewajko et al. (1997)	Waiwood (1980)
Ferreira (1978)	Nemcsok et al. (1991)	Webster and Gadd (1996)
Ferreira et al. (1979)	Ozoh (1990)	Wilson and Taylor (1993a,b)
Hansen et al. (1993, 1996)	Ozoh and Jacobson (1979)	Winberg et al. (1992)
Heath (1987, 1991)	Parrott and Sprague (1993)	Wundram et al. (1996)
Hughes and Nemcsok (1988)	Pyatt and Dodd (1986)	Wurts and Perschbacher (1994)
Julliard et al. (1996)	Riches et al. (1996)	

#### No Useable Data on Copper Toxicity or Bioconcentration

Cowgill et al. (1986) de March (1979) Lehman and Mills (1994) Lustigman (1986) Lustigman et al. (1985) MacFarlane et al. (1986) van Hoof et al. (1994) Weeks and Rainbow (1992) Wong et al. (1977) Wren and McCarroll (1990) Zamuda et al. (1985)

#### **Results Not Interpretable as Total or Dissolved Copper**

Brand et al. (1986) MacFie et al. (1994) Riedel (1983) Sanders and Jenkins (1984) Sanders and Martin (1994) Sanders et al. (1995) Stearns and Sharp (1994) Stoecker et al. (1986) Sunda et al. (1987) Winberg et al. (1992)

Some of these studies would be valuable if copper criteria were developed on the basis of cupric ion activity.

#### Organisms Were Selected, Adapted or Acclimated for Increased Resistance to Copper

- Fisher (1981) Fisher and Fabris (1982) Hall (1980) Hall et al. (1989) Harrison and Lam (1983) Harrison et al. (1983) Lumoa et al. (1983) Lumsden and Florence (1983)
- Munkittrick and Dixon (1989) Myint and Tyler (1982) Neuhoff (1983) Parker (1984) Phelps et al. (1983) Ray et al. (1981) Sander (1982) Scarfe et al. (1982)
- Schmidt (1978a,b) Sheffrin et al. (1984) Steele (1983b) Takamura et al. (1989) Viarengo et al. (1981a,b) Wood (1983)

#### Either the Materials, Methods, Measurements or Results Were Insufficiently Described

Abbe (1982) Alam and Maughan (1995) Balasubrahmanyam et al. (1987) Baudouin and Scoppa (1974) Belanager et al. (1991) Benedeczky et al. (1991) Benedetti et al. (1989) Benhra et al. (1997) Bouquegneau and Martoja (1982) Burton and Stemmer (1990) Burton et al. (1992) Cabejszek and Stasiak (1960) Cain and Luoma (1990) Chapman (1975, 1982) Cochrane et al. (1991) Devi et al. (1991) Dirilgen and Inel (1994) Dodge and Theis (1979) Doucet and Maly (1990) Dunbar et al. (1993) Durkina and Evtushenko (1991) Enesco et al. (1989) Erickson et al. (1997) Evans (1980) Ferrando and Andreu (1993) Finlayson and Ashuckian (1979) Furmanska (1979)

Gibbs et al. (1981) Gordon et al. (1980) Gould et al. (1986) Govindarajan et al. (1993) Hayes et al. (1996) Howard and Brown (1983) Janssen et al. (1993) Janssen and Persoone (1993) Kean et al. (1985) Kentouri et al. (1993) Kessler (1986) Khangarot et al. (1987) Kobayashi (1996) Kulkarni (1983) Labat et al. (1977) Lakatos et al. (1993) LeBlanc (1985) Leland et al. (1988) Mackey (1983) Magni (1994) Martin et al. (1984) Martincic et al. (1984) McIntosh and Kevern (1974) McKnight (1980) Moore and Winner (1989) Muramoto (1980, 1982) Nyholm and Damgaard (1990) Peterson et al. (1996) Pophan and D'Auria (1981) Reed-Judkins et al. (1997) Rehwoldt et al. (1973) Riches et al. (1996) Sakaguchi et al. (1977) Sanders et al. (1995) Sayer (1991) Schultheis et al. (1997) See et al. (1974) Shcherban (1977) Smith et al. (1981) Sorvari and Sillanpaa (1996) Stearns and Sharp (1994) Strong and Luoma (1981) Sullivan and Ritacco (1988) Taylor (1978) Taylor et al. (1994) Thompson (1997) Trucco et al. (1991) Verma et al. (1980) Visviki and Rachlin (1994a) Watling (1983) Winner et al. (1990) Young and Harvey (1988, 1989) Zhokhov (1986)

#### **Questionable Effect Levels Due to Graphical Presentation of Results**

- Alliot and Frenet-Piron (1990) Andrew (1976) Arsenault et al. (1993) Balasubrahmanyam et al. (1987) Bjerselius et al. (1993) Bodar et al. (1989) Chen (1994) Cowgill and Milazzo (1991b) Cvetkovic et al. (1991) Dodoo et al. (1992) Francisco et al. (1996)
- Gupta et al. (1985) Hansen et al. (1996) Hoare and Davenport (1994) Lauren and McDonald (1985) Llanten and Greppin (1993) Metaxas and Lewis (1991) Michnowicz and Weeks (1984) Miersch et al. (1997) Nasu et al. (1988) Pearlmutter and Lembi (1986)

Pekkala and Koopman (1987) Peterson et al. (1984) Romanenko and Yevtushenko (1985) Sanders et al. (1994) Smith and Heath (1979) Stokes and Hutchinson (1976) Winner and Gauss (1986) Wong (1989) Young and Lisk (1972)

#### Studies of Copper Complexation With No Useable Toxicology Data for Surface Waters

Borgmann (1981) Filbin and Hough (1979) Frey et al. (1978) Gillespie and Vaccaro (1978) Guy and Kean (1980) Jennett et al. (1982) Maloney and Palmer (1956) Nakajima et al. (1979) Stauber and Florence (1987) Sunda and Lewis (1978) Swallow et al. (1978) van den Berg et al. (1979) Wagemann and Barica (1979)

#### Questionable Treatment of Test Organisms or Inappropriate Test Conditions or Methodology

Arambasic et al. (1995)	Hockett and Mount (1996)
Benhra et al. (1997)	Huebert et al. (1993)
Billard and Roubaud (1985)	Huilsom (1983)
Bitton et al. (1995)	Jezierska and Slominska (1997)
Brand et al. (1986)	Kapu and Schaeffer (1991)
Bringmann and Kuhn (1982)	Kessler (1986)
Brkovic-Popovic and Popovic	Khangarot and Ray (1987a)
(1977a,b)	Khangarot et al. (1987)
Dirilgen and Inel (1994)	Lee and Xu (1984)
Folsom et al. (1986)	Marek et al. (1991)
Foster et al. (1994)	McLeese (1974)
Gavis et al. (1981)	Mis et al. (1995)
Guanzon et al. (1994)	Moore and Winner (1989)
Hawkins and Griffith (1982)	Nasu et al. (1988)
Ho and Zubkoff (1982)	

Ozoh and Jones (1990b) Reed and Moffat (1983) Rueter et al. (1981) Sayer et al. (1989) Schenck (1984) Shaner and Knight (1985) Sullivan et al. (1983) Tomasik et al. (1995) Watling (1981, 1982, 1983) Wikfors and Ukeles (1982) Wilson (1972) Wong and Chang (1991) Wong (1992)

High control mortalities occurred in all except one test reported by Sauter et al. (1976). Control mortality exceeded 10% in one test by Mount and Norberg (1984). Pilgaard et al. (1994) studied interactions of copper and hypoxia, but failed to run a hypoxic control. Beaumont et al. (1995a,b) studied interactions of temperature, acid pH and copper, but never separated pH and copper effects. The 96-hour values reported by Buikema et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema et al. 1977).

### Bioconcentration Studies Not Conducted Long Enough, Not Steady-State, Not Flow-through, or Water Concentrations Not Adequately Characterized or Measured

Anderson and Spear (1980a) Felton et al. (1994) Griffin et al. (1997) Harrison et al. (1988) Krantzberg (1989) Martincic et al. (1992) McConnell and Harrel (1995) Miller et al. (1992) Ozoh (1994) Wright and Zamuda (1987) Xiaorong et al. (1997) Yan et al. (1989) Young and Harvey (1988, 1989) Zia and Alikhan (1989)

Anderson (1994), Anderson et al. (1994), Viarengo et al. (1993), and Zaroogian et al. (1992) reported on *in vitro* exposure effects. Benedeczky et al. (1991) studied only effects of injected copper. Ferrando et al. (1993b) studied population effects of copper and cladoceran predator on the rotifer prey, but the data are difficult to interpret. A similar problem complicated use of the cladoceran competition study of LeBlanc (1985).



United States Environmental Protection Agency Office of Water 4304T

# Metals Cooperative Research and Development Agreement (CRADA) Phase I Report:

## Development of an Overarching Bioavailability Modeling Approach to Support US EPA's Aquatic Life Water Quality Criteria for Metals

**March 2022** 

Developed by the US Environmental Protection Agency in collaboration with the Metals CRADA Partners

## Acknowledgements

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- B. Explanation of How Toxicity Modifying Factors (TMFs) Affect Individual Metals developed by CRADA Partners
- C. Table 1: Bioavailability Model Comparisons, Table 2: Supporting Information, and References developed by CRADA Partners. See supplemental materials section at https://www.epa.gov/wqc/metals-crada-phase-1-report.
- D. Aluminum and Copper model comparisons: Brix et al. 2020b peer reviewed internal report. The copper portion of this analyses has been published and is available at <u>https://setac.onlinelibrary.wiley.com/doi/10.1002/etc.5012</u>. The publication for the aluminum MLR portion of this analyses has been published and is available at <u>https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/etc.4796</u>. Any subsequent publications will be listed when available in the supplemental materials section at <u>https://www.epa.gov/wqc/metals-crada-phase-1-report</u>.

- E. Lead model comparison: DeForest et al. 2020b peer reviewed internal report. The publication for the lead analyses is in preparation and will be listed when available in the supplemental materials section at <a href="https://www.epa.gov/wqc/metals-crada-phase-1-report">https://www.epa.gov/wqc/metals-crada-phase-1-report</a> .
- F. Nickel model comparison: Santore et al. 2020 peer reviewed internal summary report. Santore et al. 2021 and Croteau et al. 2021 have been published and are available at <u>https://setac.onlinelibrary.wiley.com/doi/10.1002/etc.5109</u> and <u>https://setac.onlinelibrary.wiley.com/doi/abs/10.1002/etc.5063</u>, respectively.
- G. Biotic Ligand Models and Multiple Linear Regression models provided by the CRADA Partners for comparison with artificial and natural waters (internal appendix containing proprietary modeling information which includes the software needed to run the models for aluminum, copper, lead, and nickel and databases with sample water quality parameters and answer keys).
- Addendum: Summary of How Toxicity Modifying Factors (TMFs) Affect Metals Listed in Table 1. Information provided through the peer review by Christopher A. Mebane (USGS).

#### I. Overview of the Metals CRADA Project

In December 2017, the U.S. Environmental Protection Agency (EPA) signed a Cooperative Research and Development Agreement (CRADA) with eight metals associations (Aluminum Association, Aluminum REACH Consortium, Cobalt Institute, International Copper Association, Copper Development Association, International Lead Association, International Zinc Association, NiPERA Inc.) in order to leverage the knowledge and resources of scientists inside and outside of the agency to better protect aquatic life. EPA's Office of Science and Technology within the Office of Water (OW) is the Agency's technical lead on this CRADA which supports EPA's FY 2018-2022 Strategic Plan Goal: Provide for Clean and Safe Water: Protect and Restore Water Quality. EPA is using a two-phased approach to address the CRADA. In the first phase, EPA has worked with external technical experts from the metals associations to develop a proposed modeling approach to predict the bioavailability and toxicity of metals under the range of water chemistry conditions found in aquatic environments common in freshwaters of the United States. Subsequently, in the second phase, EPA will work with the metals associations to develop bioavailability models for individual metals using the overarching modeling approach. Using the resulting peer-reviewed models, EPA plans to develop updated, externally-peer reviewed Aquatic Life Ambient Water Quality Criteria for metals to better support states, territories and tribes with criteria that reflect the latest science and are easier to implement than more complex, previous approaches using metals bioavailability modeling for criteria development.

#### a. Brief overview of metals bioavailability

As summarized in Adams et al. (2020), metal toxicity to aquatic organisms is variable depending on the physicochemical characteristics of the water in which they reside. Adverse effects occur when the metal binds to or accumulates on biotic ligands (surface binding sites leading to internalization and effect, for example, on the gill surface) and reaches a critical toxic threshold. Common water chemistry parameters that are known to affect the toxicity of one or more metals include pH, alkalinity, hardness, temperature, sodium, chloride, suspended solids, and colloidal or dissolved organic carbon (DOC). The bioavailability of metals to aquatic organisms is influenced by these parameters as they control the rate and extent to which the metal reaches the site of action by affecting the solubility, sorption, or partitioning of the metal. The variability in the toxicity of metals as a result of different water chemistries was recognized as early as the 1930s. Since then, research has led to the development of models to describe and predict the toxicity of metals and the response of aquatic organisms at differing water chemistries. Current bioavailability-based models often used to predict metal toxicity include: 1) empirically-based linear regression equations based on single parameters, like hardness, 2) the mechanisticallybased Biotic Ligand Model (BLM), and 3) empirically-based multiple linear regression (MLR) models.
b. Overview of EPA's metals criteria and historic use of bioavailability-based approaches

EPA develops Aquatic Life Ambient Water Quality Criteria (AWQC) for metals pursuant to Clean Water Act Section 304(a)(1). AWQC are intended to protect aquatic organisms from the toxic effects of metals in the aquatic environment and thereby the aquatic life designated use. For most metals, the AWQC is not a single number to be applied uniformly across all surface waters. Early AWQC for metals published in the 1980's were developed to take into account the effects of ambient water hardness on toxicity. Hardness-based criteria are based on simple linear regression models where the numeric magnitude of the AWQC is normalized to be protective at a given site-specific hardness. Currently, EPA has developed recommended AWQC for 9 metals (aluminum, cadmium, chromium (III and IV), copper, iron, lead, nickel, silver, and zinc). Most of these metals criteria were developed in the 1980's and 1990's (https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteriatable). Recent updated criteria efforts address bioavailability using different modeling approaches. For example, in 2007, EPA revised the AWQC for Copper (US EPA 2007) to incorporate an acute BLM to account for bioavailability as a function of water chemistry. In 2016, EPA updated the acute and chronic hardness slopes for cadmium with data for several new species in the AWQC for Cadmium (US EPA 2016a) and determined that a more complex modeling approach was not necessary for the criteria update. Lastly, in 2018, EPA revised the Final AWQC for Aluminum (US EPA 2018) which uses MLR models to incorporate three parameters (pH, total hardness, and DOC) to normalize acute and chronic toxicity data to water quality conditions. EPA is now working to update the older metals criteria to reflect the latest

scientific knowledge on bioavailability using modeling approaches to incorporate water chemistry parameters in addition to hardness, that can modify the bioavailability and toxicity of metals.

c. Goal of project

The goal of the CRADA project is to develop a simplified, overarching modeling framework to predict the bioavailability of metals considering a common model parameter set, modeling approach and platform to update the remaining metals AWQC. This report provides a review of models that are available to predict the toxicity of metals with respect to the factors that modify toxicity as a function of water chemistry. The report focuses on the performance of BLMs and MLR models for existing data sets for aluminum, copper, lead, and nickel. These datasets were developed to meet the criteria established in the 1985 Guidelines (US EPA 1985) for AWQC development and the models were evaluated using the criteria established in the Society of Environmental Toxicology and Chemistry (SETAC) Technical Workshop, *Bioavailability-Based Aquatic Toxicity Models for Metals*, December 2017 (SETAC 2017). The workshop resulted in a series of articles on "Metal Bioavailability Modeling" that evaluated the performance of models and recommend best practices in the development and use of bioavailability-based values for protection of aquatic life (Adams et al. 2020; Brix et al. 2020; see **Appendix A** for references).

## II. Metal Toxicity Modifying Factors (TMFs) and their relative importance

In the aquatic environment, the toxicity of metals is dependent on many factors including the individual metal and its chemical speciation, and the duration, magnitude, and route of exposure. The effect of a number of metals on aquatic organisms is not well predicted by the total metal concentration (except for aluminum). Metal bioavailability is a function of many modifying factors that affect the speciation, bioavailability, and toxicity of metals. These factors include pH, water hardness (primarily Ca and Mg ions), alkalinity, temperature, sodium, chloride, fluoride, suspended solids, and DOC. However, the toxicity modifying factors (TMFs) that have received the most attention in terms of bioavailability models are pH, hardness, and DOC (Adams et al. 2020).

Meyer et al. (2007) described two ways in which these modifying factors can affect whether metals result in bioavailable concentrations that can cause toxicity by affecting the physiological responses of aquatic organisms. The first is by complexing or sorbing to metal ions (e.g., DOC, carbonates, chloride, and hydroxide) which decreases the concentration of the free metal ion and negatively affects the interaction with binding sites on the organism. The second way is by competing with metal ions for binding sites on organisms (e.g., competition from  $H^+$ ,  $Ca^{2+}$ , and  $Mg^{2+}$ ).

Specifically, the effects of the most commonly studied TMFs are described below (see Meyer et al. 2007 for more information and **Appendix B** for more detailed information on how TMFs affect aluminum, copper, lead, nickel and zinc:

## a. pH

There are several mechanisms by which changes in H<sup>+</sup> ion concentrations (reflected by changes in pH) can affect metal bioavailability, including speciation, solubility, and competitive interactions between the metal and biotic ligands. The relative effect of H<sup>+</sup> ions depends on the binding strength of the metal to carbonate, bicarbonate and hydroxide ions. Generally, metals dissociate at low pH (less than pH 6 to 7) which increases their solubility and thus bioavailability and toxicity. However, as pH increases above pH 6 to 7, alkalinity often increases as well and many metals become less bioavailable and less toxic because they form complexes with carbonates and hydroxides, and subsequently may precipitate as oxides and hydroxides. Complexation and precipitation reactions, mediated by changes in pH, can therefore affect the concentration of the free metal ions available to bind to the biotic ligand (Meyer et al. 2007).

b. Hardness

In freshwater, hardness is dominated by  $Ca^{2+}$  and  $Mg^{2+}$  ions which compete with divalent metal ions for binding to the biotic ligand. As a result, increased water hardness generally leads to less metal accumulation by aquatic organisms and lower toxicity. There are differences in the protective effects of  $Ca^{2+}$  and  $Mg^{2+}$  ions: generally,  $Ca^{2+}$  is more protective in fish than  $Mg^{2+}$ (Meyer et al. 2007).

## c. Dissolved Organic Carbon [DOC]

Dissolved organic matter, typically quantified as DOC, is a heterogeneous mix of organic matter of natural and anthropogenic origin that is impermeable to biological membranes. Generally, an increase in DOC decreases metal bioavailability and toxicity by complexing with free metal ions, thereby reducing metal binding at the biotic ligand. The protective effects of DOC depend on its concentration, composition, and the binding affinity of the metal (Meyer et al. 2007, Wood et al. 2011).

### d. Other

Although the TMFs pH, hardness, and DOC have been studied the most, other factors are known also to modify the bioavailability and toxicity of metals. Temperature is potentially an important TMF for some metals, but this is dependent on the species as well as the metal in the exposure scenario. For example, the kinetics underlying aluminum bioavailability has a strong dependency on temperature (Santore et al. 2018). Existing data for other metals such as nickel, copper, and zinc do not show the same magnitude of correlations between temperature and chronic toxicity (Pereira et al. 2017), but more information is needed. Ultimately, this factor has not received enough attention in toxicity testing (Brix et al. 2020a; Mebane et al. 2020) to incorporate this parameter into many models. Another parameter that is potentially important is total suspended solid (TSS). Generally, toxicity decreases as TSS concentration increases because the free metal ion binds to or sorbs to particles. Another parameter that has been investigated is sodium (Na<sup>+</sup>). An increase in Na<sup>+</sup> cations generally decreases toxicity by competition at metal binding sites; however, based on the few comparative studies for Cu and Zn toxicity to freshwater invertebrate and algal species, Na<sup>+</sup> appears to provide less protection than Ca<sup>2+</sup> and Mg<sup>2+</sup> (Meyer et al. 2007).

As mentioned above, metals respond differently to the effects of various TMFs which, in part, is dependent on the type and strength of bonds (ionic or covalent) formed with the binding sites (Meyer et al. 2007). **Table 1** illustrates the relative importance of the most studied TMFs for several metals within a given metal (not across metals). This table is a general guideline as these trends may be variable depending on the species, life stage, test duration, and other factors that are considered within bioavailability models.

Motal	Type	Most Important Parameters <sup>1</sup>					
Wietai	турс	Hardness	pН	DOC	Other		
Aluminum	Freshwater	+	+++	++	temperature		
Cadmium	Freshwater	+++	+	+			
Cobalt	Freshwater	++	+	+			
Copper	Freshwater	+	++	+++	sodium		
Copper	Marine		+	+	salinity		
Lead	Freshwater	+	+	+++			
Nickel	Freshwater	+		+			
Silver	Freshwater			+	chromium reducible sulfur, sodium, chloride		
Zinc	Freshwater	+++	++	+			

**Table 1**. Toxicity modifying factors that have been demonstrated to be important in various BLM and MLR published models and their relative importance within each metal.

<sup>1</sup>Since it is difficult to separate the effects of alkalinity and pH, alkalinity is not listed as a separate factor but is considered as a contribution to the overall effects of pH.

See **Appendix B** for a detailed summary of the how TMFs affect some of the metals (aluminum, copper, lead, nickel and zinc) listed in Table 1. See also **Appendix H** for a high-level summary of how TMFs affect the metals listed in Table 1.

It is important that high quality TMF data be collected for the use in bioavailability model development or as input parameters into the model. Data should be collected using good sampling and measurement practices, particularly in regard to pH and DOC collection (e.g., Balistrieri et al. 2012, Nimick et al. 2011, and Yoro et al. 1999).

### III. Discussion of bioavailability modeling approaches examined

Bioavailability-based models have been developed to take the influence of water chemistry into account when evaluating aqueous metal toxicity to aquatic organisms. Diet is another route of metal exposure that is generally not considered within bioavailability models because of a lack of available data and mechanistic complexity. Currently, for most metals, data indicate that respiratory organs are more sensitive to cationic metals via water exposure than exposure through the gut. Furthermore, these models have been validated with long-term mesocosm studies in which the dietary route of exposure is an operational pathway (Roussel et al. 2007; Schlekat et al. 2010; Versteeg et al. 1999). Additionally, in a dietary zinc toxicity study, De Schamphelaere et al. (2004) concluded that "the zinc BLM predicts chronic reproductive zinc bioavailability and toxicity in synthetic and field surface waters with reasonable accuracy even without explicitly directly considering the dietary toxicity pathway." For many metals, toxicity

stemming from the waterborne pathway has been shown to occur at similar or lower concentrations than the dietary route (e.g., Evens et al. 2009 for nickel, De Schamphelaere et al. 2007 for copper, Nys et al. 2013 and Alsop et al. 2016 for lead),indicating that AWQC which are protective of aqueous metal exposure are also protective of dietary exposures. Mebane et al. (2020) also suggested there is currently "insufficient evidence to conclude that bioavailability models would be under-protective if based on waterborne-only exposures" and recommended that researchers conduct concurrent exposures to strengthen the literature surrounding dietary exposure and support the development of a biodynamic modeling framework that is able to incorporate the dietary exposure route (Mebane et al. 2020). Lastly, when it is well-established that the diet is an important exposure route, EPA has considered this information in their criteria development. For example, the freshwater selenium water quality criteria (US EPA 2016b) are based on fish tissue concentrations since diet is the primary route of exposure.

The approaches used to develop bioavailability-based models fall within a continuum between empirical (e.g., hardness equations) and mainly mechanistic (e.g., biokinetic BLM) (see Textbox 3 in Adams et al. 2020 and Figure 1 in Brix et al. 2020a). In the middle of the continuum are the empirically-based MLR and mechanistically-based BLM. Adams et al. (2020) and Mebane et al. (2020) provide overviews of the history of the science resulting in the development of the BLM and later MLR models, as well as other bioavailability models not under consideration as an overarching approach at this time as they are either not as scientifically robust and/or practical as the BLM and MLR models (e.g., hardness-based equations, WER, generalized bioavailability models [gBAMs] and biodynamic models). In addition, after reviewing bioavailability-based toxicity models in terms of use, refinement, and application to protection values, Mebane et al. (2020) lays out a series of recommendations for developing mechanistically-based models. Similarly, Brix et al. (2020a) describe best practices for the development and evaluation of empirical models.

In this section, we describe the BLM and MLR approaches and discuss the advantages and disadvantages of each, which can depend on the complexity of the environmental chemistry, data availability and intended use or policy decisions for a given metal. Table 2 highlights the different models in this category that are currently available or in development for the six metals represented by the CRADA (Al, Co, Cu, Pb, Ni and Zn). Bioavailability models encompassed in this table span across fresh- and marine waters and, in total, include 17 BLMs and 13 MLR models developed across different global jurisdictions. Simplified bioavailability look-up tools (e.g., Bio-Met, M-BAT), which have been designed for regulatory ease-of-use, are also included in this comparison framework. More information is provided in **Appendix C** where the comparative metrics have been divided into two tables. The "Primary" comparison table, similar to Table 2, summarizes major details of each model including the user-interface, primary toxicity modifying factors and chemistry inputs required for each model, the output value generated and the source/references from which the model can be obtained. The "Supplemental" comparison table describes specific details surrounding the development of the models such as applicable chemistry ranges, validation datasets, and the use in regulatory frameworks. The "References" table contains full references for all information included in the primary and supplemental tables.

**Table 2**: Comparisons of bioavailability models currently available or in development for the six metals represented by the CRADA. More information is provided in **Appendix C** which also summarizes other major details of each model including the user-interface, the output value generated and the source/references from which the model can be obtained. An additional table describes specific details surrounding the development of the models such as applicable chemistry ranges, validation datasets, and the use in regulatory frameworks. Reference list provided in **Appendix C**.

Metal	Model	Туре	Primary toxicity modifying factors	Taxa model is applicable to	Chemistry Inputs needed
Aluminum	BLM v3.18.2.42         Full BLM         DOC, Hardness, pH, Temperature		A, I, F	Temperature, pH, DOC, Al, Ca, Mg, Na, K, SO4, Cl, Alkalinity	
	MLR	MLR	DOC, Hardness, pH	A, I, F	pH, DOC, Hardness
	BLM v3.15.2.41	Full BLM	DOC, Hardness, pH	A, I, F	Temperature, pH, Co, DOC, Humic acid %, Ca, Mg, Na, K, SO4, Cl, Alkalinity, S
Cobalt	MLR	MLR	DOC, Hardness, pH	A, I, F	pH, DOC, Hardness (Ca, Mg)
	Bio-met v5.1	Bio-met Simplified BLM v5.1 Lookup Tool DOC, Ca, pH		A, I, F	pH, DOC, Ca, Co
	USEPA BLM	Full BLM	Alkalinity, DOC, Hardness, pH	I, F	Temperature, pH, Cu, DOC, Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
Copper	ECCC BLM v1.10	Full BLM	Alkalinity, DOC, Hardness, pH	A, P, I, F	Required: Temperature, pH, Cu, DOC, Hardness; Optional: Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
	BC BLM v1.11	Full BLM	Alkalinity, DOC, Hardness, pH	A, P, I, F, Am	Required: Temperature, pH, Cu, DOC, Hardness; Optional: Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
	Windward BLM v3.41.2.45	Full BLM	Alkalinity, DOC, Hardness, pH	I, F	Required: Temperature, pH, Cu, DOC, Hardness; Optional: Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S

Metal	Model	Туре	Primary toxicity modifying factors	Taxa model is applicable to	Chemistry Inputs needed
Copper	BLM/gBAM	Mixed regression + speciation model	Alkalinity, DOC, Hardness, pH	I, F	Temperature, pH, Cu, DOC, Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
	Bio-met v5.0	Simplified BLM Lookup Tool	DOC, Ca, pH	A, I, F	pH, DOC, Ca, Cu
	M-BAT v30.0	Simplified BLM Lookup Tool	DOC, Ca, pH	A, I, F	pH, DOC, Ca, Cu
	PNEC-Pro v6.0	[M]LR	DOC	A, I, F	Required: DOC; Optional: pH, Mg, Ca, Na, Cu
	WHAM-F <sub>TOX</sub>	HAM-FTOXToxicity model linked to speciationNot specified		Р	Temperature, pH, Cu, DOM (fulvic and humic acids), Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, metals
	MLR	MLR	DOC, Hardness, pH	I, F	pH, Hardness, DOC
	Windward Marine BLM v3.41.2.45	Full BLM	DOC, pH, salinity	I, F	Required: Temperature, pH, Cu, DOC, Salinity; Optional: Ca, Mg, Na, K, SO4, Cl, PO4, DIC
	Marine MLR	[M]LR	DOC	I (Mytilus sp.)	DOC
	Unified/North America BLM	Full BLM	DOC, Hardness, pH	I, F	Temperature, pH, Pb, DOC, Humic acid %, Ca, Mg, Na, K, SO4, Cl, Alkalinity, S
Lead	EU Risk Assessment BLM/gBAM	Full BLM	DOC, Hardness, pH	A, I, F	Temperature, pH, Pb, DOC, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, CO3
	EU Risk Assessment Lead EQS Screening Tool v1.0	DOC Equation	DOC	A, I, F	DOC, Pb

Metal	Model	Туре	Primary toxicity modifying factors	Taxa model is applicable to	Chemistry Inputs needed
	Bio-met v5.0	Simplified BLM Lookup Tool	pH, DOC, Ca	A, I, F	pH, DOC, Ca, Pb
Laad	PNEC Pro v6.0	[M]LR	DOC	A, I, F	Required: DOC; Optional: pH, Mg, Ca, Na, Pb
Leau	Canadian WQG MLR	MLR	DOC, Hardness, pH	A, I, F	pH, DOC, Hardness
	MLR	MLR	DOC, Hardness, pH	A, I, F	pH, DOC, Hardness
	EU Risk Assessment BLM	Full BLM	DOC, Hardness, pH	A, I, F	Temperature, pH, Ni, DOC, Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
	Bio-met v5.0Simplified BLM Lookup ToolpH, I		pH, DOC, Ca	A, I, F	pH, DOC, Ca, Ni
Nickel	M-BAT 20150206	Simplified BLM Lookup Tool	pH, DOC, Ca	A, I, F	pH, DOC, Ca, Ni
	Best Overall Pooled	Full BLM	DOC, Hardness, pH	A, I, F	Temperature, pH, Ni, DOC, Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
	North American C. dubia BLM	Full BLM	DOC, Hardness, pH, Alkalinity	Ι	Temperature, pH, Ni, DOC, Humic acid %, Ca, Mg, Na, K, SO4, Cl, Alkalinity, S
	PNEC Pro v6.0	ro [M]LR DOC, Hardness, pH		A, I, F	Required: DOC; Optional: pH, Mg, Ca, Na, Ni
	MLR	MLR	DOC, Hardness	A, I, F	Hardness (Ca/Mg), DOC, pH, Ni
	Marine BLM	Full BLM	DOC	Ι	Temperature, pH, Ni, DOC, Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
Zinc	Unified/North America BLM	Full BLM	DOC, Hardness, pH	I, F	Temperature, pH, Zn, DOC, Humic acid %, Ca, Mg, Na, K, SO <sub>4</sub> , Cl, Alkalinity, S
	EU Risk Assessment BLM/gBAM	Full BLM	DOC, Hardness, pH	A, I, F	Temperature, pH, Zn, DOC, Humic acid %, Ca, Mg, Na, K, SO4, Cl, Alkalinity, S

Metal	Model	Туре	Primary toxicity modifying factors	Taxa model is applicable to	Chemistry Inputs needed
	M-BAT v30.0 - 20150206	Simplified BLM Lookup Tool	plified BLM pH, DOC, Ca		pH, DOC, Ca, Zn
	Bio-met v5.0	Simplified BLM Lookup Tool	BLM Fool pH, DOC, Ca		pH, DOC, Ca, Zn
Zinc	PNEC Pro v6.0	[M]LR	DOC	A, I, F	Required: DOC; Optional: pH, Mg, Ca, Na, Zn
	Canadian WQG MLR	MLR	DOC, Hardness, pH	A, I, F	pH, DOC, Hardness
	MLR	MLR	DOC, Hardness, pH	A, I, F	pH, DOC, Hardness
	Marine BLM	Full BLM	DOC, pH, salinity	I, F	Required: Temperature, pH, Zn, DOC, Salinity; Optional: Ca, Mg, Na, K, , Cl, PO <sub>4</sub> , DIC

Model name, Version/Identification, and Type abbreviations: BC - British Columbia; BLM - Biotic ligand model; ECCC - Environment and Climate Change Canada; EU - European Union; gBAM - Generalized bioavailability model; M-BAT - Metal bioavailability assessment tool; MLR - Multiple linear regression; [M]LR - Multiple linear regression and/or simple linear regression; PNEC - Predicted no effect concentration; USEPA - United States Environmental Protection Agency; WHAM - Windermere humic aqueous model; WQG - Water quality guideline.

Taxa model applicable to abbreviations: A - algae; I - invertebrates; F - fish; P - plants; Am - amphibians

Chemistry inputs needed abbreviations: DIC - Dissolved inorganic carbon; DOC - Dissolved organic carbon

## a. Biotic Ligand Models

Biotic Ligand Models are mechanistically-based and the most complex of the models considered. As summarized in Adams et al. (2020), the BLM uses sub-models to account for 1) chemical speciation, 2) the competition of metal and non-metal ions and complexes for binding to the biotic ligand (which is assumed to be the gill or respiratory mechanism) and 3) the metal accumulation and toxicity. BLMs require several inputs of water parameters for chemical speciation calculations including: temperature, pH, DOC, major ions (Ca, Mg, Na, K, Cl, SO4), and alkalinity. Once the water parameters are entered into the model, the BLM predicts the concentration of the different metal species (complexes and free metal ion) associated with a critical accumulation (i.e., an accumulation level at the biotic ligand that corresponds to a certain effect level). BLMs assume that equilibrium is reached immediately and there are no changes in reaction rates over time.

Acute and/or chronic BLMs have been developed for several metals, including all six of the metals represented by the CRADA (see Table 2, Appendix C, and Table 2 in Mebane et al. 2020). However, currently only four regulatory jurisdictions have adopted the BLM approach to develop aquatic life protective values (EPA's Cu AWQC [US EPA 2007], British Columbia's Cu Water Quality Guideline for Protection of Freshwater Aquatic Life [B.C. Ministry of Environment and Climate Change Strategy 2019], Environment and Climate Change Canada's draft Cu Federal Environmental Quality Guidelines [ECCC 2019], and European Commission's Ni Environmental Quality Standard [EQS; European Commission 2010]). BLMs are also under consideration by others (Canada and Australia/New Zealand) (Adams et al. 2020). One of the primary advantages of the BLM approach is that it is based on the premise that bioavailability is linked to chemical speciation, which supports its application to a wide range of conditions and media. However, a barrier to adoption and implementation is the complexity of the approach which can be technically demanding, transparency of the algorithms, and the large number of water chemistry parameters required, some of which are costly and not routinely collected. For example, in 2007, EPA finalized its recommended Cu AWQC, however only five states (Delaware, Idaho, Iowa, Kansas, and Oregon) and the Commonwealth of the Northern Mariana Islands have adopted the Cu BLM statewide and nine states (California, Colorado, Georgia, Maryland, Massachusetts, New Hampshire, North Carolina, South Carolina, and Texas) have the ability to develop site-specific Water Quality Standards to be submitted to EPAfor review and approval.

## b. Simplified Biotic Ligand Models

To address the issues of complexity, transparency, and water chemistry requirements which have hindered the adoption and implementation of the BLM, several simplified or abbreviated tools have been developed based on the full BLM. Most of these "user-friendly" tools have been developed under the European Union's Water Framework Directive (Adams et al. 2020). Compared to the full BLM, these tools require fewer water chemistry input parameters (but typically still require DOC, pH, and hardness [or Ca as an estimator of hardness]) by restricting

input parameters or relying on default values and require less training. Examples of simplified BLMs include Bio-met (an Excel-based "look-up" table with EQS values for thousands of combinations of water chemistries that have been calculated using the full BLM), PNEC-pro and MBAT (both "algorithm"-based tools). Adams et al. (2020) provides an overview of these simplified tools and how they perform compared to the BLM. In addition, **Appendix C** provides a summary of the comparison of these tools (e.g., inputs, outputs) to developed BLMs for the six metals represented in the CRADA.

### c. Multiple Linear Regressions Models

Multiple linear regression models have more recently been developed (e.g., Brix et al. 2017, DeForest et al. 2018 and 2020a, Brix et al. 2020a) partially in response to the complexity and high water quality data input requirements of the BLM. As summarized in Adams et al. (2020), MLR models are empirically-based, statistically-derived approaches to incorporating TMFs to predict metal toxicity across a range of water chemistries where there are direct measurements of the influence of water chemistry on metal toxicity. This approach is similar to the simple linear regression hardness-based models, but MLRs take into account multiple TMFs like hardness, pH, and DOC (and their interactions, if necessary) and rely on large empirical toxicity data sets covering wide ranges of water chemistry parameters and ecotoxicology endpoints. Unlike the BLM, MLR models often use hardness as a parameter rather than the concentrations of specific ions (e.g., Ca and Mg). One of the main reasons MLR models use hardness is because most endusers monitor hardness rather than Ca and Mg. One line of evidence that validates the use of hardness instead of Ca and/or Mg concentrations in MLR models is the consistency in the result from cross-validation exercises comparing the BLM and MLR predictions (see Appendices D, E and F). In addition, models may be fitted to acute or chronic toxicity data and for single species or pooled into a single model for multiple species.

Brix et al. (2020a) recommend a pooled MLR modeling approach, if feasible, because the pooled version may increase the confidence of applying the model to different species as it is based on more data and it often includes a wider range of TMFs than species-specific models. In a pooled MLR modeling approach, species-specific intercepts account for the variances in species sensitivity. However, determining whether to use a species-specific or pooled model depends on the available data for the metal, metal-specific characteristics and interactions<sup>1</sup> with TMFs, and performance over a broad range of water chemistries. For example, EPA decided to use the individual fish and invertebrate models in the final recommended Al AWQC (US EPA 2018) rather than a pooled model because the chronic toxicity of Al differed considerably between species depending on water chemistry conditions.

Acute and/or chronic MLR models have been developed for several metals, including all six of the metals represented by the CRADA (see **Table 2**, **Appendix C**, and Table 2 in Brix et al. [2020a]). As noted, EPA adopted vertebrate and invertebrate (unpooled) MLRs for the chronic Al AWQC (US EPA 2018). The MLR approach has also been adopted or is under consideration

<sup>&</sup>lt;sup>1</sup>MLR models can explicitly evaluate the interactive effects of how TMFs influence each other. For example, pH may influence the speciation of a metal, while the influence of hardness on the bioavailability of the metal varies depending on the pH-dependent speciation of the metal.

by others for water quality standards (Canada and Australia/New Zealand) (Adams et al. 2020, ECCC 2020). Some advantages of the MLR approach are the relative simplicity and transparency of the model, decreased number of input parameters (in comparison to the BLM) resulting in easier data collection, and ease of use while maintaining comparable output (see **Section IV**). The primary disadvantage of the MLR is that it does not explicitly address the effects of metals speciation and the binding affinity of the metal for the biotic ligand receptor within the model, but instead these effects are taken into account in the models based on empirical observations. MLRs can be informed by mechanistic analyses by evaluating MLR models against existing BLMs.

### **IV.** Case Studies of Modeling Approach Comparisons

This section provides a comparative evaluation of BLM and MLR models for several metals. While there are many variations of these models available (see **Table 2** and **Appendix C**), the current analyses start with the same underlying toxicity data sets to facilitate model comparisons. **Table 3** reports the model performance scores which form the basis for the evaluation of the model comparisons from methods developed in the 2017 SETAC Metals Bioavailability Modelling workshop (see publications in **Appendix A**; specifically, Garman et al. 2020) and modified by Brix et al. (2020b; see **Appendix D**). Most MLR models include DOC, hardness, and pH as TMFs with the exception of Ni (that only considers DOC and hardness). In addition, these case studies followed EPA guidelines (US EPA 1985) to generate estimated AWQC based on the output of the differing modeling approaches to assess how the criteria respond to changing water quality characteristics.

**Table 3**: Acute and chronic performance scores for each metal based on the recommended MLR models and BLMs in the cases studies (**Appendices D, E and F**). Performance score is the arithmetic mean of individual scores for adjusted  $R^2$  (for MLR) or  $R^2$  (for BLM),  $RF_{x,2.0}$ , and residuals (see Garman et al. 2020 and Brix et al. 2020b for details). NA – no model available.

Metal	Acute Score		Chronic Score		Defenence	
	MLR	BLM	MLR	BLM	Kelerence	
Aluminum	NA	NA	0.91	0.75	Brix et al. 2020b	
Copper	0.71	0.71	0.87	0.55	Brix et al. 2020b	
Lead	0.79	0.76	0.81	0.62	DeForest et al. 2020b	
Nickel	0.90	0.93	0.89	0.88	Croteau et al. 2021	

### a. Aluminum

Aluminum is the metal that EPA has most recently updated (US EPA 2018) and the only metal for which EPA used the MLR approach to develop the AWQC. Compared to some other metals (e.g., Cu), Al has a relatively small toxicity data set as well as complex environmental chemistry that can strongly influence bioavailability and toxicity (Brix et al. 2020b). A full analysis of the comparison of the chronic Al MLR and BLM is provided in **Appendix D** (Brix et al. 2020b) and

describes the toxicity dataset used for the models. This dataset was an update from the dataset used by Santore et al. (2018) and DeForest et al. (2018 and 2020a; which formed the basis of the MLR used in the EPA Al AWQC). Briefly, chronic MLR models were developed for a representative invertebrate (*Ceriodaphnia dubia*) and fish (*Pimephales promelas*) which both included interactions among TMFs (the *C. dubia* model included a term for interactions between pH and hardness and the *P. promelas* model included terms for interactions between pH and hardness and between pH and DOC. The data used to develop the two species-specific models were pooled to develop a pooled MLR model for the comparison to the BLM. The analysis indicates that the MLR model performs considerably better than the BLM across a range of performance metrics (**Table 3**) and resulted in differences in estimated AWQC as a function of water chemistry.

#### b. Copper

Copper is the only metal for which the EPA has adopted the BLM approach to develop AWQC (US EPA 2007). Copper has a large toxicity data set over a range of water quality conditions and the environmental chemistry is comparatively simpler than some other metals. A full analysis of the comparison of the acute and chronic Cu MLR and BLM is provided in Appendix D (Brix et al. 2020b)<sup>2</sup>. Briefly, six acute species-specific MLR models (four daphnid and two fish) and two chronic models (a daphnid and a fish) were developed and then pooled without interactions for comparison to the BLM. The BLM is the same for both acute and chronic with only the sensitivity adjusted; the MLR models are separate for acute and chronic effects. The analysis indicates that the acute Cu MLR and BLM performance is comparable (Table 3), however there are differences in performance on a species-specific basis. In contrast, the chronic Cu MLR performs better than the BLM (Table 3). It is important to note that the Cu BLM is optimized for measured Cu accumulations on the biotic ligand and not for toxicity observations (neither chronic nor acute). In contrast, the chronic Cu MLR is based explicitly on chronic Cu toxicity data and so it is not surprising that it performs better than the Cu BLM. For both the acute and chronic modeling approaches, there are differences in the estimated AWQC as a function of water chemistry.

c. Lead

The existing EPA AWQC for Pb are based on a hardness equation (US EPA 1984). A full analysis of the comparison of the acute and chronic Pb MLR models and the BLM is provided in **Appendix E** (DeForest et al. 2020b). Briefly, two acute species-specific MLR models (a daphnid and a fish) and three chronic models (two invertebrates and a fish) were developed and then pooled (separate acute and chronic pooled models were developed) for comparison to the BLM (MLR models without TMF interaction terms were recommended because MLR models with interaction terms resulted in toxicity predictions under some water chemistry conditions that were not mechanistically supported). DeForest et al. (2020b) explains that only the pooled MLR models were compared to the BLM as this approach is most similar where model parameters are

<sup>&</sup>lt;sup>2</sup> The copper portion of this analysis has been published and is <u>available via open access</u> at: <u>https://setac.onlinelibrary.wiley.com/doi/10.1002/etc.5012</u>

applied to all species. To account for species-specific sensitivity, the sensitivity term varies in the BLM which is similar to the intercept of the pooled MLR model. The analysis indicates that the acute Pb MLR and BLM performance were similar, however the chronic Pb MLR model performs considerably better than the chronic Pb BLM (**Table 3**).

## d. Nickel

The existing EPA AWQC for Ni is based on a hardness equation (US EPA 1995). The BLM approach for Ni, described by Santore et al. (2021) in **Appendix F**, provides a critical review of the importance of TMFs (including hardness cations, DOC, and pH) on acute and chronic toxicity to aquatic organisms. The authors also propose a refined BLM that incorporates the conclusions of the critical review of TMFs. The analysis of the "Best Overall Pooled" model clearly shows the broad importance of hardness cations and DOC across all taxonomic groups. A second nickel BLM was developed following the observation that *C. dubia* exhibit poor reproduction at pH > 8, in which the authors propose that these organisms are experiencing combined effects of nickel and bicarbonate toxicities under these circumstances. To address this observation, Santore et al. (2021) developed a species-specific *C. dubia* model which considers both Ni and bicarbonate toxicities. Although this model has only been calibrated and validated with *C. dubia* data, there is preliminary evidence that these effects may be present in other organisms. The refined BLM software contained both the "Best Overall Pooled" BLM and the "North American *C. dubia* BLM".

The MLR approach, described by Croteau et al. (2021) in **Appendix F**, empirically seeks to explain the influence of TMFs on acute and chronic Ni toxicity. The MLRs account for a similar set of TMFs as the BLMs. Croteau et al. (2021) compares the performance of the BLMs versus the MLRs using a recently published approach for quantifying model performance (Garman et al. 2020; **Appendix A**) and a Ni toxicity and chemistry database consisting of 1498 toxicity observations in 64 studies. The outcome of this comparison is that both models perform similarly, and that both can serve as the basis for normalizing Ni ecotoxicity data for the purpose of developing bioavailability-based AWQC for Ni.

### V. Conclusions: Discussion and recommendations of modeling approach

There are now several approaches for modeling metals bioavailability in freshwater. The SETAC Technical Workshop, *Bioavailability-Based Aquatic Toxicity Models for Metals* held in December 2017 sought to assess and provide recommendations on approaches for model development, evaluation, selection, and use. Schlekat et al. (2020) summarized the main recommendations from the workshop and resulting publications: 1) the mechanistic understanding of metal toxicity and speciation should inform all bioavailability models, 2) it is possible to develop simplified tools (including MLR models) that are mechanistically-informed, 3) models should be validated with qualitative and quantitative methods and appropriately applied within a range of water chemistries, and 4) communication regarding the choice of appropriate models, which may be different depending on the situation, needs to be clear. For example, Brix et al (2020b) describe that the selection of the most appropriate model for a given situation requires consideration of several factors including data needs and availability, proposed

model use, model performance, and practical and policy decisions.

In this report, we explored and compared performance of the BLM and MLR approaches for several metals by applying procedures developed as part of the Technical Workshop. Model performance evaluations were conducted for four of the six metals represented by the CRADA. For each metal case study, the BLM and MLR approaches were applied to the same toxicity dataset. In most cases, the empirically-based MLR models performed as well as or better than the mechanistically-based BLM (see Table 3 and Appendices D, E, and F). While there may be metal-specific advantages and disadvantages of using the BLM or MLR approach, it is advantageous, if feasible, for EPA to choose one overarching approach for updating AWQC for all metals. Given the similarities in performance between the BLM and MLR approaches for several metals, with the MLR generally showing somewhat to significantly better performance scores across the acute and chronic metals models examined, and as a practical and policy decision, EPA intends to use MLR models as the overarching metals bioavailability-modeling approach with pH, hardness, and DOC as the core set of TMFs to consider in model development. Additional reasons to recommend the MLR modeling approach are its relative simplicity, transparency, decreased number of input parameters and data collection requirements, ease of use, and reduced need for ongoing maintenance of the models compared to the BLM. However, EPA agrees with Mebane et al. (2020) and Brix et al (2020b) that the development of empirical models like MLR can be informed by mechanistic models like the BLM by helping to identify the key TMFs and expected mechanistic patterns and by evaluating MLR models against existing BLMs.

While MLR models may require lower maintenance than BLMs (Mebane et al. 2020), as EPA moves forward with updating the metals AWQC, it is desirable to have a single software platform. This user-friendly platform would incorporate the updated bioavailability modeling information for all metals so that the user could enter the core set of TMFs once and receive output information on multiple metal criteria values.

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# **Appendix B**

# Explanation of How Toxicity Modifying Factors (TMFs) Affect Individual Metals

## Aluminum, Copper, Lead, Nickel and Zinc

Developed by CRADA Partners

#### A. Aluminum

#### Hardness, pH and DOC

To evaluate how water chemistry affects toxicity, aluminum (Al) HC5 values (hazard concentrations affecting 5% of the population) were calculated by varying DOC, pH, and hardness concentrations. HC5 values were calculated as a function of one parameter being varied and the other 2 held constant. In these examples, HC5s were calculated using the MLR EC20 models and following the USEPA approach. The most noticeable observations are that the HC5 values consistently increase with increasing DOC (Figure 1A–C) and with increasing pH (Figure 1D–F). The influence of hardness on HC5 values is variable depending on pH. Overall, HC5 values increase with increasing hardness at pH 6, remain essentially constant at pH 7, and show a variable pattern at pH 8 (Figure 1G–I). These trends generally follow the empirical data, where available, which is not unexpected given that the MLR models were derived solely from those data. However, fewer empirical toxicity data are available to evaluate the HC5 trends at pH 8. For example, the observation that HC5 values at pH 8 decrease with increasing hardness appears to be consistent with data for *P. subcapitata* but less clearly so for *C. dubia* based on more limited data and insufficient data are available for *P. promelas*. See DeForest et al. 2018 and 2020 for more details.



Figure 1: Total Al 5% hazardous concentrations as a function of dissolved organic carbon (DOC) concentration (A–C), pH (D–F), and hardness (G–I). (A–C) Hardness of 10, 50, and 125 mg/L (blue, red, and green symbols, respectively). (D–F) Dissolved organic carbon of 1, 3, and 5 mg/L (blue, red, and green symbols, respectively). (G–I) pH of 6, 7, and 8 (blue, red, and green symbols, respectively). H = hardness; HC5 = 5% hazardous concentration.

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## **B.** Copper

## Hardness

Many studies have reported a protective effect of water hardness on Cu toxicity in acute and chronic exposures to fish and invertebrates (e.g., Waiwood and Beamish 1978; Miller and Mackay 1980; Birge et al. 1983; Winner 1985; Erickson et al. 1996, 1997; Collyard 2002; De Schamphelaere and Janssen 2002; Gensemer et al. 2002; Meyer et al. 2002; Long et al. 2004; Sciera et al. 2004; Van Genderen et al. 2005; Ryan et al. 2009). However, inconsistent results or no protection have been reported in some other studies (e.g., Chapman et al. 1980, Richards and Playle 1999, De Schamphelaere and Janssen 2004b, Hyne et al. 2005, Markich et al. 2005, Wang et al. 2009). Details are provided in Meyer et al. (2007). In terms of the Cu BLM, the hardness effect is characterized by competitive interactions between Cu and hardness cations (i.e., Ca and Mg) at the biotic ligand. For example, log<sub>10</sub> values of the biotic ligand binding constants (i.e., log K values) for both Ca and Mg are 3.60 in the Windward (formerly HydroQual) acute Cu BLM, which is the basis for the U.S. EPA's current acute Cu water quality criteria; and they are 4.40 in the chronic Cu BLMs for fish and invertebrates that were recently proposed by Environment and Climate Change Canada (ECCC) and by the Province of British Columbia (BC). As a complementary approach to the BLM for calculating acute and chronic water quality criteria for Cu, Brix et al. (2017) recently recommended multiple linear regression (MLR) models that included the protective effect of hardness (i.e., represented by a positive regression coefficient for hardness). In the update of these models described in Brix et al. (2020), hardness was also identified as a TMF in all of the MLRs developed.

### DOC

In freshwaters, dissolved organic matter (DOM) – quantified as dissolved organic carbon (DOC) – decreases Cu bioavailability and toxicity (e.g., Brown et al. 1974; Lind et al. 1978; Buckley 1983; Winner 1984, 1985; Flickinger 1984; Meador 1991; Oikari et al. 1992; Welsh et al. 1993; Erickson et al. 1996; Hollis et al. 1997; Kim et al. 1999; Ma et al. 1999; De Schamphelaere et al. 2002, 2004, 2006; McGeer et al. 2002; De Schamphelaere and Janssen 2004a, 2004b; Kramer et al. 2004; Schwartz et al. 2004; Sciera et al. 2004; Tusseau-Vuillemin et al. 2004; Van Genderen et al. 2005; Rogevich et al. 2008; Ryan et al. 2009). Details are provided in Meyer et al. (2007). As with other metals, DOC effects are characterized in the Windward, ECCC, and BC Cu BLMs by using a set of discrete binding sites and reactions calibrated in the Windermere Humic Aqueous Model (WHAM; Tipping 1994) in which Cu competes with other metals and cations for binding, thereby decreasing the ability of Cu to bind at the biotic ligand. As a complementary approach to the BLM for calculating acute and chronic water quality criteria for Cu, Brix et al.

(2017) recently recommended multiple linear regression (MLR) models that included the protective effect of DOC (i.e., represented by a positive regression coefficient for DOC). In the update of these models described in Brix et al. (2020), DOC was also identified as a TMF in all of the MLRs developed.

## pН

There are several mechanisms by which pH can affect Cu bioavailability, including via speciation, solubility, and competitive interactions between Cu and biotic ligands. Additionally, pH and alkalinity (another water chemistry parameter that can protect against Cu toxicity; Fulton and Meyer 2014, and review in Meyer et al. 2007) usually are positively correlated at pH values exceeding approximately 6.0. Thus, in some experiments with some species, the toxicity of dissolved or total Cu increased as pH was increased; but in other experiments with some species, the toxicity of dissolved or total Cu decreased as pH was increased (e.g., see details in Meyer et al. 2007). However, Cu toxicity to fish and invertebrates, expressed on the basis of  $Cu^{2+}$ , increases with increasing pH (e.g., Howarth and Sprague 1978; Meador 1991; Erickson et al. 1996; Collyard 2002; De Schamphelaere and Janssen 2002; De Schamphelaere et al. 2002; Meyer et al. 2002; Ryan et al. 2004, 2009), suggesting the importance of competition between protons and Cu at the biotic ligand. All Cu BLMs incorporate Cu<sup>2+</sup> speciation in the exposure water (usually via WHAM calculations) and competition with protons at the biotic ligand when predicting Cu toxicity, thus reconciling the otherwise apparently contradictory toxicity results if only dissolved or total Cu concentrations is used to predict toxicity. A generalized bioavailability model (gBAM) can incorporate both the fundamental pH-related speciation effects and the positive relationship between  $Cu^{2+}$  toxicity and pH (e.g., Van Regenmortel et al. 2015; Nys et al. 2020). As a complementary approach to the BLM for calculating acute and chronic water quality criteria for Cu, Brix et al. (2017) recently recommended multiple linear regression (MLR) models that included the protective effect of pH [i.e., represented by a positive regression coefficient for pH when calculating dissolved Cu (not Cu<sup>2+</sup>) criteria]. In the update of these models described in Brix et al. (2020), pH was also identified as a TMF in all of the MLRs developed, with the only exceptions being the species-specific acute D. pulex and O. mykiss MLRs.

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## C. Lead

## Hardness

The effect of hardness on Pb toxicity is variable among species and depending on whether acute or chronic exposures were evaluated. In acute Pb exposures, Mager et al. (2011a) observed that hardness (calcium specifically) was protective against Pb toxicity to the fathead minnow (*Pimephales promelas*) but not the cladoceran *Ceriodaphnia dubia*. In contrast, Nys and De Schamphelaere (2013) observed that hardness (calcium specifically) did protect against acute Pb toxicity to *C. dubia*. Despite the conflicting data for *C. dubia*, hardness was retained by the Akaike information criterion (AIC) and Bayesian information criterion (BIC) in the MLR models for both *C. dubia* and *P. promelas*, with the hardness slope for *P. promelas* being about two-fold greater than for *C. dubia* (Table 1).<sup>3</sup> Hardness was likewise retained by AIC and BIC in the final pooled MLR model for these two species (Table 1).

For chronic Pb exposures, hardness did not have an influence on Pb toxicity to the rotifer *Brachionus calyciflorus* (Nys et al. 2016) nor *C. dubia* (Mager et al. 2011b; Nys et al. 2014). For the snail *L. stagnalis*, *P. promelas*, and the alga *Raphidocelis subcapitata*, the influence of hardness on chronic Pb toxicity was less clear. For *L. stagnalis* and *P. promelas*, series of chronic toxicity tests with only hardness varied were not available for these two species, while for *R. subcapitata* the influence of hardness was equivocal (De Schamphelaere et al. 2014). Hardness was retained in the pooled chronic MLR model for invertebrates and fish and in the pooled chronic MLR model for the two most sensitive invertebrates, *C. dubia* and *L. stagnalis* (Table 1).<sup>4</sup> Ultimately, the final recommended pooled model for chronic toxicity did include hardness, but the influence of hardness was relatively minor compared to dissolved organic carbon (DOC).

## DOC

Increasing DOC concentrations consistently reduced both the acute and chronic toxicity of lead (De Schamphelaere et al. 2014; Esbaugh et al. 2011, 2012; Mager et al. 2011a,b; Nys et al. 2016; Parametrix 2010). The consistent and, in many cases, strong influence of DOC as a TMF for algal and animal species has led to the development and adoption of a DOC-based bioavailable EQS for Pb in the EU (EC 2010). DOC was retained by AIC and BIC in all MLR models, including the acute individual *C. dubia* and *P. promelas* models and the pooled acute model, as well as in the chronic individual *B. calyciflorus*, *C. dubia*, *L. stagnalis*, *P. promelas*, and *R. subcapitata* models and the pooled chronic model (Table 1).

<sup>3</sup> The MLR models referred to in this summary are those that considered hardness, DOC, and pH as individual TMFs, but not interactions of these TMFs, as the final recommended MLR models for lead did not consider interactions.

<sup>4</sup> For the pooled C. dubia and L. stagnalis model, AIC retained hardness but BIC did not.

## pН

As for hardness, the effects of pH on lead toxicity is variable among species. For acute exposures, increasing pH tends to have a protective effect on lead toxicity to *P. promelas* and a lesser effect on lead toxicity to *C. dubia* (Mager et al. 2011a; Nys and De Schamphelaere 2013). Nevertheless, pH was retained by AIC and BIC in the acute individual species MLR models for *C. dubia* and *P. promelas*, as well as in the pooled acute model (Table 1).

For chronic exposures, from series of tests where only pH was varied, there is evidence that chronic toxicity is reduced with increasing pH for *B. calyciflorus* and *C. dubia* (Nys et al. 2014, 2016). However, pH was not retained by AIC nor BIC in either the individual species MLR models nor in the pooled MLR model (Table 1). Regardless, in selection of the final chronic MLR model, the "full" model with pH included (along with DOC and hardness) was selected based on (1) the empirical data for *B. calyciflorus* and *C. dubia*; and (2) mechanistic support from the biotic ligand model (BLM).<sup>5</sup> For the alga *R. subcapitata*, the influence of pH is the opposite, with Pb toxicity increasing as pH increases (De Schamphelaere et al. 2014). This is why a pooled MLR model that included both animals and algae was not considered.

Exposure	Model	DOC	Hardness	pН
	C. dubia	X	Х	Х
Acute	P. promelas	Х	Х	Х
	Pooled Acute	X	Х	X
	B. calyciflorus	X		
	C. dubia	Х		
Chronic	L. stagnalis	X	Х	
	P. promelas	X	Х	
	Pooled Chronic <sup>1</sup>	X	Х	X
	R. subcapitata	X	Х	X

Table 1.	Summary	of TMFs	identified	in lead	MLR	models
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<sup>1</sup> The pooled model was based on toxicity data for animals (*C. dubia* and *L. stagnalis*, specifically) because TMFs influence Pb toxicity to algae differently. DOC was retained in the pooled model by both AIC and BIC; hardness was retained by AIC; and pH was included based on considerations from empirical data and mechanisms supported by the BLM.

<sup>5</sup> As noted in Brix et al. (2020), selection of the final model should not be based solely on strict adherence to statistical methods for model selection, but should also consider mechanistic and other information on how TMFs influence toxicity and validity for other datasets.

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## D. Nickel

## Hardness

There is a consistent hardness effect on nickel toxicity in acute and chronic exposures to fish and invertebrates (Deleebeeck et al., 2008; Kozlova et al., 2009). In terms of the nickel BLM, this effect is quantified through binding constants (Log K values) of Ca and Mg with the biotic ligand. In the nickel BLM, final Log K values for BL-Ca and BL-Mg were 4.25 and 3.60, respectively. Hardness was identified as a TMF in all available nickel MLR models, with the only exception being the species-specific acute *C. dubia* MLR.

## DOC

Increased concentrations of dissolved organic carbon (DOC) consistently shows mitigation of the toxic effects of nickel (Doig & Liber, 2006; Kozlova et al., 2009). DOC effects are simulated in the nickel BLM by using a set of discrete binding sites and reactions calibrated in the WHAM model (Tipping, 1994) in which nickel and other cations in the system can bind to DOC, thereby reducing the ability of the metal to bind at the biotic ligand. DOC was identified as a TMF in all three of the "Pooled" MLRs developed for nickel, in every chronic-species-specific MLR spanning across fish, invertebrates and algae, and identified in both *D. pulex* and *D. pulicaria* acute-species-specific MLRs.

## pН

pH effects on nickel toxicity have been observed to be highly species-dependent. While some studies (Deleebeeck et al., 2008; Kozlova et al., 2009; Pyle et al., 2002; Schubauer-Berigan et al., 1993) have shown essentially no change in nickel toxicity to *D. pulex*, *D. magna*, and *P. promelas* in acute exposures ranging from pHs around 5.5 through 8.7, Schubauer-Berigan et al (1993) reported a 10-fold decrease in nickel EC50s between pH 7.3-8.7 in acute exposures to C. dubia. The results of this study could be indicative of species-specific differences in pH mechanisms of nickel bioavailability. For the pooled MLR models developed for nickel, only the chronic model identified pH as a TMF. However, pH was identified as a TMF in 7 out of the 10 species-specific nickel MLR models.

	Model	Duration	Endpoint	Measure	DOC	Hardness	pН
	C. dubia	48h	Survival	LC50			Х
	D. magna	48h	Survival	LC50		Х	Х
A outo	D. pulex	48h	Survival	LC50	Х	Х	
Acute	D. pulicaria	48h	Survival	LC50	Х	Х	Х
	P. promelas	96h	Survival	LC50		Х	Х
	<b>Pooled Acute</b>	-	-	-	Χ	Χ	
	C. dubia	7d	Survival + Reproduction	IC25	Х	Х	X
	D. magna	21d	Reproduction	EC50	Х	Х	
	D. magna	21d	Survival	LC50	Х	Х	Х
Chronic	O. mykiss	17-26d	Survival	LC50	Х	Х	Х
	<i>P</i> .	72h	Growth	EC50	v	v	
	subcapitata				Λ	Λ	
	Pooled	-	-	-	v	v	v
	Chronic				Λ	Λ	Λ
Acute +	Pooled All		_	_	v	v	
Chronic	I UUICU AII	-	-	-	Λ	Λ	

**Table 1.** Summary of TMFs identified in nickel MLR models (adapted from Croteau et al, 2021)

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## E. Zinc

## Hardness

There is a consistent effect of hardness on Zn toxicity in acute and chronic exposures to fish and invertebrates (e.g., Hyne et al. 2005; Clifford and McGeer 2009; De Schamphelaere and Janssen 2004; Heijerick et al. 2005). Similar ameliorative effects of hardness have been demonstrated in tests with natural waters where pH was allowed to covary (Mebane et al. 2012). In terms of the Zn BLM, the hardness effect is characterized by competitive interactions between Zn and hardness cations (i.e., Ca and Mg) at the biotic ligand. The biotic ligand binding constants for Ca and Mg for several Zn BLMs, representing multiple organisms and acute and chronic exposures, are summarized in DeForest and Van Genderen (2012). The recently updated MLR-based Canadian water quality guideline (WQG) for Zn, includes hardness as a toxicity modifying factor (TMF) in both the short-term Zn benchmark and the long-term Zn WQG (CCME 2018).

## DOC

In freshwaters, dissolved organic matter (DOM) – quantified as dissolved organic carbon (DOC) – generally decreases Zn bioavailability (e.g., Clifford and McGeer 2009; Heijerick et al. 2003), though the effect is not as strong as observed for copper (e.g., Hyne et al. 2005), and mainly at high DOC concentrations (e.g., above 10 mg/L mg/L; Clifford and McGeer 2009; Bringolf et al. 2006). As with other metals, DOC effects are characterized in the Zn BLM by using a set of discrete binding sites and reactions calibrated in the Windermere Humic Aqueous Model (WHAM; Tipping 1994) in which Zn competes with other metals and cations for binding. In the recently updated Canadian WQG, DOC was identified as a TMF for Zn and included as a term in both the short-term benchmark and long-term WQG equations (CCME 2018).

## pН

There are several mechanisms by which pH can affect Zn bioavailability, including via speciation, solubility, and competitive interactions between Zn and biotic ligands. Generally, Zn toxicity to fish and invertebrates, expressed on the basis of  $Zn^{2+}$ , increases with increasing pH (e.g., De Schamphelaere and Janssen 2004; Van Regenmortel et al. 2017), suggesting the importance of competition between protons and Zn at the biotic ligand. On the basis of dissolved Zn, toxicity generally increases marginally with increasing pH in acute exposures, but the effect is inconsistent in chronic exposures (see summary in CCME 2018), potentially due to differences in bulk solution chemistry characteristics. Santore et al. (2002) describes how differences in bulk chemistry characteristics can influence the relative importance of competitive interactions and speciation on Zn toxicity across a pH gradient. In the recently updated Canadian WQG, pH is included as a TMF in the short-term benchmark, but not the long-term WQG (CCME 2018).

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# Addendum

# Summary of How Toxicity Modifying Factors (TMFs) Affect Metals Listed in Table 1

Information provided through the peer review by Christopher A. Mebane Water Quality Specialist, U.S. Geological Survey

Aluminum: Hardness has a moderate role in modifying Al toxicity; pH has a strong role with the greatest toxicity expressed at both low (pH 5) and elevated (pH >8.5) pH, and DOC consistently reduced Al toxicity (DeForest et al. 2018).

**Cadmium:** Hardness regressions predict acute and chronic toxicity well in natural waters (Mebane 2006; USEPA 2016). pH effects appear weak and ambiguous (Niyogi et al. 2008; Clifford and McGeer 2010). The threshold for a DOC effect appears to be >5 mg/L (Niyogi et al. 2008).

**Cobalt:** Hardness is clearly important (Diamond et al. 1992; Borgmann et al. 2005). pH at least affected gill uptake, with uptake increasing with increasing pH up to 8.7. DOM reduced Co gill binding, but Co-DOM affinity was much lower than that of Cd, Cu, or Ag (Richards and Playle 1998).

**Copper, freshwater:** DOC has a strong binding affinity to Cu and predictably reduces Cu toxicity, even at low concentrations (Erickson et al. 1996; Welsh et al. 2008). pH has a strong effect on Cu toxicity, with toxicity tending to decrease with increasing pH in alkaline conditions, but toxicity decreasing with decreasing pH in acidic conditions (Cusimano et al. 1986; Erickson et al. 1996). Hardness is a comparatively minor factor in natural waters (Markich et al. 2005).

**Copper, marine:** DOC and salinity tend to reduce Cu toxicity in marine and estuarine waters (Grosell et al. 2007; Hall et al. 2008).

**Lead:** Similar to Cu, DOC and pH have strong effects on the bioavailability and toxicity of Pb (DeForest et al. 2017) Hardness may be an important factor in natural waters, especially when DOC is low (Mebane et al. 2012).

**Nickel:** Ni toxicity tends to decrease as hardness increased and decrease with increasing DOC. pH has inconsistent influence on toxicity (Croteau et al. 2021; Santore et al. 2021).

Silver: DOC reduces toxicity but pH and hardness influences may be inconsistent (Naddy et al. 2018).

Addendum-1
**Zinc:** Similar to Cd, hardness has a strong influence on Zn toxicity, with decreasing toxicity with increasing hardness (Clifford and McGeer 2009; Mebane et al. 2012; CCME 2018); with fish, toxicity generally increases with increasing pH but relations may be inconsistent in other taxa (De Schamphelaere and Janssen 2004). DOC reduces Zn toxicity but some studies suggest influences may be nonlinear, with a threshold of  $\geq 10 \text{ mg/L}$  DOC required to substantially reduce toxicity (Hyne et al. 2005; Bringolf et al. 2006; Ivey et al. 2019).

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Figure 1. Electronically posted rulemaking information, public notice and rules on WQCC Webpage.



Figure 2. Post Rulemaking Info and Public Notice to the New Mexico Sunshine Portal

WQCC 24-31 NMED Provide to the Public Documentation



Figure 3. Photos of Public Notice posted at the Albuquerque District Office and Las Cruces District Office.

## WQCC 24-31 NMED Provide to the Public Documentation



Figure 4. Photos of Public Notice posted at the Los Alamos Field Office, Las Cruces District Office and the Runnels Building in Santa Fe.

### WQCC 24-31 NMED Provide to the Public Documentation

From:	Baca, Michael, ENV
To:	lcs@nmlegis.gov
Cc:	Guevara, Lynette, ENV; Chai, Lisa, ENV
Subject:	RE: WQCC 24-31 - Public Notice of Rulemaking
Date:	Wednesday, October 16, 2024 12:57:00 PM
Attachments:	Notice of Public Hearing - Eng-C 10.4.24.pdf
	Notice of Public Hearing - Span-C 10.4.24.pdf
	2024-05-23-WQCC-24-31-Triad-Newport-News-and-DOE-Petition-for-Rulemaking-pj (4).pdf
	2024-07-16-WQCC-24-31-Supplement-to-Petition-for-Rulemakingpj.pdf
Importance:	High

Good afternoon,

The hearing in this matter has been rescheduled for January 14, 2025. For more information, please see the attached public notice, petition with technical rulemaking information, and the proposed amendments to 20.6.4 NMAC. Additional rulemaking and participation information may be found on NMED's Water Quality Standards website at <u>Proposed Copper Criteria for Pajarito Plateau Surface Waters (nm.gov)</u> and the Water Quality Control Commission's <u>Docketed Matters (nm.gov)</u> website.

Please let me know if you have any questions or concerns regarding this matter.

Respectfully,

Michael Baca | WQS Coordinator NMED SWQB | <u>www.env.nm.gov/surface-water-quality/</u> <u>michael.baca1@env.nm.gov</u> | (505) 470-1652

### Science | Innovation | Collaboration | Compliance

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Figure 5. Email to Legislative Council Services providing public notice and how to access rulemaking information.

### Surface Water Quality Bureau



Our mission is to preserve, protect, and improve New Mexico's surface water quality for present and future generations.

### Oficina de Calidad de Aguas Superficiales

Nuestra misión es preservar, proteger y mejorar la calidad de las aguas superficiales de Nuevo México para las generaciones presentes y futuras.

# Rescheduled Public Hearing for Proposed Site-Specific Copper Criteria on the Pajarito Plateau

The Water Quality Control Commission ("WQCC") has cancelled the public hearing scheduled for this matter for October 8, 2024. The WQCC has rescheduled the public hearing for this matter to begin on **January 14, 2025,** immediately following the WQCC's regularly scheduled meeting, which starts at 9:00 am and continuing thereafter as necessary. The hearing shall be conducted in-person in Room 321 at the New Mexico State Capitol, 411 S. Capitol Street, in Santa Fe, New Mexico and remotely via the WebEx video conferencing platform. The hearing will last as long as required to hear all testimony, evidence, and public comment. Detailed information concerning the time and location and the WebEx link can be found on the New Mexico Environment Department's ("NMED's") Event Calendar at https://www.env.nm.gov/events-calendar/. Please visit the WQCC website prior to the

https://www.env.nm.gov/events-calendar/. Please visit the WQCC website prior to the hearing for any updates at https://www.env.nm.gov/opf/water-quality-controlcommission/. The WQCC may make a decision on the proposed regulatory change at the conclusion of the hearing.

The purpose of the public hearing is to consider Triad National Security, LLC's, Newport News Nuclear BWXT-Los Alamos, LLC's, and the United States Department Of Energy, Office Of Environmental Management, Los Alamos Field Office's Petition For Rulemaking To Amend 20.6.4.900.I & J NMAC to add site-specific water quality criteria for copper for stream segments on the Pajarito Plateau, in accordance with 20.6.4.10.F NMAC. The proposed amendments may be reviewed online at https://www.env.nm.gov/opf/water-quality-control-commission/. Technical information that served as a basis for the proposed rule was filed in docket number WQCC 24-31 (R) as exhibits to the Petition and may be viewed online at https://www.env.nm.gov/opf/docketed-matters/ and may also be obtained from the Petitioners upon request to <u>N3Boutreach@em-la.doe.gov</u>. Persons who wish to review a physical copy of the proposed amendments should contact the WQCC Administrator at the address provided below.

All interested persons will be given reasonable opportunity at the hearing to submit relevant evidence, data, views, and arguments, orally or in writing; to introduce exhibits; and to examine witnesses.

The WQCC appointed Hearing Officer has issued a revised filing schedule to reflect the new hearing date. Pursuant to 20.1.6.202 NMAC and the Second Pre-Hearing Order issued by the Hearing Officer on September 11, 2024, those wishing to present direct technical testimony must file a written notice of intent to present technical testimony with the WQCC Administrator **on or before 5:00 p.m. Mountain Standard Time on December 20, 2024**. Those wishing to present rebuttal technical testimony must file a written notice of intent to present rebuttal technical testimony with the WQCC Administrator **on or before 5:00 p.m. Mountain Standard Time on December 20, 2024**. Those wishing to present rebuttal technical testimony must file a written notice of intent to present rebuttal technical testimony with the WQCC Administrator **on or before 5:00 p.m. Mountain Standard Time on January 3, 2025.** 

Notices of intent to present technical testimony shall conform to 20.1.6.104 NMAC and reference the docket number, **WQCC 24-31(R)**.

The form and content of the notice of intent to present technical testimony shall:

- Identify the person for whom the witness(es) will testify;
- Identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their education and work background;
- Include a copy of the full written direct or rebuttal testimony of each technical witness in narrative form;
- Include the text of any recommended modifications to the proposed regulatory change; and
- List and attach all exhibits anticipated to be offered by that person at the hearing, including any proposed statement of reasons for adoption of rules.

Notices of intent to present direct and rebuttal technical testimony shall be filed with:

Pamela Jones, WQCC Administrator New Mexico Environment Department Harold Runnels Building P.O. Box 5469 Santa Fe, NM 87502 Telephone: (505) 660-4305 Email: <u>pamela.jones@env.nm.gov</u>

Those wishing to do so may offer non-technical public comment at the hearing in person or remotely via the WebEx platform. The Hearing Officer will hold a **public comment session at 1pm and 5pm on January 14, 2025**. Non-technical written statements may be submitted in lieu of oral testimony at or before the hearing. Written comments regarding the proposed rule may be addressed to Pamela Jones, WQCC Administrator, at the above address, or by entering your comments in the public comment portal at: https://nmed.commentinput.com?id=MerTf7Zj4 or via email to: pamela.jones@env.nm.gov and should reference docket number **WQCC 24-31(R)**. Pursuant to 20.1.6.203 NMAC, any person may file an entry of appearance as a party. The entry of appearance shall be filed with the WQCC Administrator, at the above address, no later than **December 20, 2024**.

The hearing will be conducted in accordance with the WQCC Rulemaking Procedures (20.1.6 NMAC); the Water Quality Act, Sections 74-6-1 to -17 NMSA 1978 (1967 as amended through 2019); the State Rules Act, Section 14-4-5.3 NMSA 1978, other applicable procedures and any Procedural Order or Scheduling Order issued by the WQCC or Hearing Officer. These documents are available online at <a href="https://www.env.nm.gov/opf/docketed-matters/">https://www.env.nm.gov/opf/docketed-matters/</a> or by contacting the WQCC Administrator at <a href="mailto:pamela.jones@env.nm.gov">pamela.jones@env.nm.gov</a>.

If any person requires assistance, an interpreter or auxiliary aid to participate in this process, please contact Pamela Jones, WQCC Administrator, at the above address, at least 14 days prior to the hearing date. (TDD or TTY users please access the number via the New Mexico Relay Network, 1-800-659-1779 (voice); TTY users: 1-800-659-8331).

NMED does not discriminate on the basis of race, color, national origin, disability, age or sex in the administration of its programs or activities, as required by applicable laws and regulations. NMED is responsible for coordination of compliance efforts and receipt of inquiries concerning non-discrimination requirements implemented by 40 C.F.R. Parts 5 and 7, including Title VI of the Civil Rights Act of 1964, as amended; Section 504 of the Rehabilitation Act of 1973; the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, and Section 13 of the Federal Water Pollution Control Act Amendments of 1972. If you have any questions about this notice or any of NMED's non-discrimination programs, policies or procedures, you may contact:

Kate Cardenas, Non-Discrimination Coordinator New Mexico Environment Department 1190 St. Francis Dr., Suite N4050 P.O. Box 5469 Santa Fe, NM 87502 (505) 827-2855 nd.coordinator@env.nm.gov https://www.env.nm.gov/general/environmental-justice-in-new-mexico/

If you believe that you have been discriminated against with respect to a NMED program or activity, you may contact the Non-Discrimination Coordinator identified above.

# Audiencia Pública Reprogramada para la Propuesta de Criterios Específicos del Sitio par el Cobre en la Meseta de Pajarito

La Comisión de Control de Calidad del Agua ("WQCC", por sus siglas en inglés) ha cancelado la audiencia pública programada para este asunto para el 8 de octubre de 2024. La WQCC ha reprogramado la audiencia pública para este asunto para que comience el 14 de enero de 2025, inmediatamente después de la reunión programada regularmente de la WQCC, que comienza a las 9:00 a. m. y continúa después según sea necesario. La audiencia se llevará a cabo en persona en la Sala 321 del Capitolio del Estado de Nuevo México, 411 S. Capitol Street, en Santa Fe, Nuevo México y de forma remota a través de la plataforma de videoconferencia WebEx. La audiencia durará el tiempo que sea necesario para escuchar todos los testimonios, pruebas y comentarios públicos. Puede encontrar información detallada sobre la hora, la ubicación y el enlace de WebEx en el Calendario de eventos del Departamento de Medio Ambiente de Nuevo México ("NMED", por sus siglas en inglés) en https://www.env.nm.gov/events-calendar/. Visite el sitio web de WQCC antes de la audiencia para obtener actualizaciones en https://www.env.nm.gov/opf/water-quality-control-commission/. La WQCC puede tomar una decisión sobre el cambio regulatorio propuesto al finalizar la audiencia.

El propósito de la audiencia pública es considerar la Petición de Reglamentación para modificar 20.6.4.900.I y J NMAC de Triad National Security, LLC, Newport News Nuclear BWXT-Los Alamos, LLC y la Oficina de Gestión Ambiental del Departamento de Energía de los Estados Unidos, oficina local de Los Alamos, para agregar criterios de calidad del agua específicos del sitio para el cobre en los segmentos de arroyos en la meseta de Pajarito, de acuerdo con 20.6.4.10.F del NMAC. Las enmiendas propuestas se pueden revisar en línea en <u>https://www.env.nm.gov/opf/water-qualitycontrol-commission/</u>. La información técnica que sirvió de base para la norma propuesta se presentó en el expediente número WQCC 24-31 (R) como pruebas instrumentales a la petición y se puede consultar en línea en

<u>https://www.env.nm.gov/opf/docketed-matters/</u> y también se puede obtener de los Peticionarios mediante solicitud a <u>N3Boutreach@em-la.doe.gov</u>. Las personas que deseen revisar una copia impresa de las enmiendas propuestas deben comunicarse con la administradora de la WQCC a la dirección que se proporciona más abajo.

A todas las personas interesadas se les dará una oportunidad razonable en la audiencia para presentar evidencia, datos, puntos de vista y argumentos relevantes, oralmente o por escrito; para presentar pruebas instrumentales; y para interrogar a los testigos.

El funcionario de audiencias designado por la WQCC ha emitido un calendario de presentación revisado para reflejar la nueva fecha de audiencia. De conformidad con 20.1.6.202 NMAC y la Segunda Orden Previa a la Audiencia emitida por el funcionario de audiencias el 11 de septiembre de 2024, aquellos que deseen presentar un testimonio técnico directo deben presentar un aviso por escrito de intención de presentar un testimonio técnico ante la administradora de la WQCC **a más tardar hasta las 5:00 p. m., hora estándar de la montaña, del 20 de diciembre de 2024**. Aquellos que deseen presentar un testimonio técnico de presentar un testimonio técnico de refutación deben presentar un testimonio técnico de refutación deben presentar un aviso por escrito de intención de la MQCC **a más tardar hasta las 5:00 p. m., hora estándar de la montaña, del 20 de diciembre de 2024**. Aquellos que deseen presentar un testimonio técnico de refutación deben presentar un aviso por escrito de intención de presentar un testimonio técnico de refutación deben presentar un aviso por escrito de intención de presentar un testimonio técnico de refutación de la MQCC **a más tardar hasta las 5:00 p. m., hora estándar de la montaña, del 3 de enero de 2025**.

Los avisos de intención de presentar un testimonio técnico deberán cumplir con 20.1.6.104 NMAC y hacer referencia al número de expediente, **WQCC 24-31(R)**.

La forma y contenido del aviso de intención de presentar un testimonio técnico deberá:

- Identificar a la persona(s) para la cual testificarán los testigos;
- Identificar a cada testigo técnico que la persona pretende presentar y establecer las calificaciones de ese testigo, incluida una descripción de su formación y experiencia laboral;
- Incluir una copia del testimonio escrito completo, directo o de refutación, de cada testigo técnico en forma narrativa;
- Incluir el texto de cualquier modificación recomendada al cambio regulatorio propuesto; y
- Enumerar y adjuntar todas las pruebas instrumentales que se prevé que esa persona presente en la audiencia,

Los avisos de intención de presentar un testimonio técnico directo y de refutación se presentarán ante:

Pamela Jones, administradora de WQCC Departamento de Medio Ambiente de Nuevo México Harold Runnels Building P.O. Box 5469 Santa Fe, NM 87502 Teléfono: (505) 660-4305 Correo electrónico: <u>pamela.jones@env.nm.gov</u>

Quienes deseen hacerlo pueden ofrecer comentarios públicos no técnicos en la audiencia en persona o de forma remota a través de la plataforma WebEx. El funcionario de audiencias llevará a cabo una **sesión de comentarios públicos a la 1:00 p. m. y a las 5:00 p. m. el 14 de enero de 2025**. Se pueden presentar declaraciones no técnicas por escrito en lugar de testimonio oral en la audiencia o antes de ella. Los comentarios por escrito sobre la norma propuesta se pueden dirigir a Pamela Jones, administradora de WQCC, a la dirección indicada anteriormente, o ingresando sus comentarios en el portal de comentarios públicos en: https://nmed.commentinput.com?id=MerTf7Zj4 o por correo electrónico a: pamela.jones@env.nm.gov y deben hacer referencia al número de expediente **WQCC 24-31(R).** De conformidad con 20.1.6.203 NMAC, cualquier persona puede presentar un registro de comparecencia como parte. El registro de comparecencia deberá

presentarse ante la administradora de la WQCC, en la dirección antes mencionada, a más tardar el **20 de diciembre de 2024**.

La audiencia se llevará a cabo de conformidad con los Procedimientos de Reglamentación de la WQCC (20.1.6 NMAC); la Ley de calidad del agua, Secciones 74-6-1 a -17 NMSA 1978 (1967 con sus enmiendas hasta 2019, inclusive); la Ley de Normas Estatales, Sección 14-4-5.3 NMSA 1978, otros procedimientos aplicables y cualquier Orden de Procedimiento u Orden de Programación emitida por la WQCC o el funcionario de audiencias. Estos documentos están disponibles en línea en https://www.env.nm.gov/opf/docketed-matters/ o comunicándose con la administradora de la WQCC en pamela.jones@env.nm.gov.

Si alguna persona requiere asistencia, un intérprete o un dispositivo auxiliar para participar en este proceso, comuníquese con Pamela Jones, administradora de la WQCC, a la dirección indicada anteriormente, al menos 14 días antes de la fecha de la audiencia. (Los usuarios de TDD o TTY pueden acceder al número a través de la red de retransmisión de Nuevo México, 1-800-659-1779 (voz); usuarios de TTY: 1-800-659-8331).

NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, según lo exigen las leyes y regulaciones aplicables. NMED es responsable de la coordinación de los esfuerzos de cumplimiento y la recepción de consultas sobre los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluido el Título VI de la Ley de Derechos Civiles de 1964, según enmendada; Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas de Educación de 1972 y la Sección 13 de las Enmiendas de la Ley de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o alguno de los programas, políticas o procedimientos de no discriminación de NMED o si cree que ha sido discriminado con respecto a un programa o actividad de NMED, puede comunicarse con:

Kate Cardenas, coordinadora de no discriminación, NMED 1190 St. Francis Dr. Suite N4050, P.O. Box 5469 Santa Fe, NM 87502 teléfono (505) 827-2855 correo electrónico <u>nd.coordinator@env.nm.gov</u>

También puede visitar nuestro sitio web en <u>https://www.env.nm.gov/general/environmental-justice-in-new-mexico/</u> para saber cómo y dónde presentar una queja de discriminación.

Stay Connected with New Mexico Environment Department



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This email was sent to <u>michael.baca1@env.nm.gov</u> using GovDelivery Communications Cloud on behalf of: New Mexico Environment Department · Harold L. Runnels Building · 1190 St. Francis Drive · Suite N4050 · Santa Fe, New Mexico 87505

Figure 6. ListServ Email notifying SWQB Main Subscribers of the public rulemaking hearing.



Figure 1. Electronically post link to public notice and proposed rules on SWQB Webpage



Figure 2. Electronically post public notice, proposed rules, PIP/LEP and other rulemaking info on SWQB Webpage



Figure 3. Post Public Notice and Hearing Information on NMED's Events Calendar.



Figure 4. NMED Calendar Event for Public Hearing.

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Figure 5. NMED Public Comment Portal for WQCC 24-31 (R).



Figure 6. NMED Public Notice Website.

# Affidavit of Publication

STATE OF NEW MEXICO } SS COUNTY OF BERNALILLO }

Ad Cost:\$920.51Ad Number:120110Account Number:1032471Classification:NON-GOVERNMENT LEGALS

I, Bernadette Gonzales, the undersigned, Legal Representative of the Albuquerque Journal, on oath, state that this newspaper is duly qualified to publish legal notices or advertisements within the meaning of Section 3, chapter 167, Session Laws of 1937, and payment of fees has been made of assessed and a copy of which is hereto attached, was published in said publication in the daily edition, 1 times(s) on the following date(s):

October 9, 2024

That said newspaper was regularly issued and circulated on those dates. SIGNED:

Legal Representative

Subscribed to and sworn to me this 9<sup>th</sup> day of October 2024.

Notary Public County

ID#: 1110229 My commission expires: 04-26-202



MONTGOMERY & ANDREWS ATTN ACCOUNTS PAYABLE PO BOX 2307 SANTA FE, NM 87504 WATER QUALITY CONTROL COMMISSION PUBLIC NOTICE: NOTICE OF RESCHEDULED PUBLIC HEARING FOR PRO-POSED SITE SPECIFIC

COPPER CRITERIA FOR STREAM SEGMENTS ON THE PAJARITO PLATEAU

POSED SITE SPECIFIC COPPER CRITERIA FOR STREAM SEGMENTS ON THE PAJARITO PLATEAU The Water Quality Control Commission ('WQCC') has cancelled the public hearing scheduled for this matter for October 8, 2024. The WQCC has rescheduled the public hearing for this matter to begin on January 14, 2025, immediately following the WQCC's regularly scheduled meeting, which starts at 9:00 am and continuing thereafter as necessary. The hearing shall be con-ducted in-person in Room 321 at the New Mexico State Capitol, 411 S. Capitol Street, in Santa Fe, New Mexico and remotely via the WebEx video conferencing platform. The hearing will last as long as required to hear all testimony, evidence, and public comment. Detailed information concerning the time and location and the WebEx link can be found on the New Mexico Environment Department's ('NMED's') Event Calendar at https://www.env.nm. gov/events-calendar/. Please visit the WQCC website prior to the hearing for any updates at https://www.env.nm.gov/op//water-quality-control-commission/. The WQCC may make a decision on the proposed regulatory change at the conclusion of the hearing. The purpose of the public hearing is to consider Triad National Security, LLC's, Newport News Nuclear BWXT-Los Alamos, LLC's, and the United States Department Of Energy, Office Of Envi-ronmental Management, Los Alamos Field Office's Petition For Rulemaking To Amend 20.64.900.1 & J NMAC to add site-specific water quality criteria for copper for stream segments on the Pajanto Plateau, in accordance with 20.64.10.F. NMAC. The proposed amendments may be reviewed online at https://www. env.nm.gov/opl/water-quality-control-commission/. Technical in-formation that served as a basis for the proposed rule was filed in docket number WQCC 24-31 (R) as exhibits to the Petitioners upon request to N3Boutreach@em-la.doe.gov. Persons who wish to review a physical copy of the proposed amendments should contact the WQCC Administrator at the address provide below. All interested persons will be given reasonable

All interested persons will be given reasonable opportunity at the hearing to submit relevant evidence, data, views, and arguments, orally or in writing; to introduce exhibits; and to examine witnesses.

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The form and content of the notice of intent to present technical

Identify the person for whom the witness(es) will testify: Identify the person for whom the witness(es) will testify: Identify each technical witness the person intends to present and state the qualifications of that witness, including a description of their education and work background; Include a copy of the full written direct or rebuttal testimony of each technical witness in narrative form; Include the text of any concentration of their education.

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The hearing will be conducted in accordance with the WQCC Rulemaking Procedures (20.1.6. NMAC); the Water Quality Act, Sections 74-6-1 to -17 NMSA 1978 (1967 as amended through 2019); the State Rules Act, Section 14-4-5.3 NMSA 1978, other applicable procedures and any Procedural Order or Scheduling Order issued by the WQCC or Hearing Officer. These documents are available online at https://www.env.nm.gov/opf/docketed-matters/ or by contacting the WQCC Administrator at pamela. iones@env.nm.gov. jones@env.nm.gov.

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#### STATEMENT OF NON-DISCRIMINATION

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AVISO PÚBLICO DE LA COMISIÓN DE CONTROL DE CALIDAD DEL AGUA: AVISO DE AUDIENCIA PÚBLICA REPROGRAMADA PARA LA PROPUESTA DE CRITERIOS ESPECÍFICOS DEL SITIO PARA EL COBRE EN LOS SEGMENTOS DE ARROYOS EN LA MESETA DE PAJARITO

La Comisión de Control de Calidad del Agua ("WQCC", por sus siglas en inglés) ha cancelado la audiencia pública programada para este asunto para el 8 de octubre de 2024. La WQCC ha para este asunto para el 8 de octubre de 2024. La WUCC ha reprogramado la audiencia pública para este asunto para que comience el 14 de enero de 2025, inmediatamente después de la reunión programada regularmente de la WQCC, que comienza a las 9:00 a. m. y continúa después según sea necesario. La audiencia se llevará a cabo en persona en la Sala 321 del Capitolio del Estado de Nuevo México. 411 S Capitol Street, en Santa Fe. Nuevo México. y de forma transfe de la parte de la de forma transfe de la seguira sea regués de la seguira sea seguira sea de seguira sea seguira sea seguira sea seguira sea seguira seguira seguira sea de la seguira sea de la seguira segui Santa Fe, Nuevo México y de forma remota a través de la plataforma de videoconferencia WebEx. La audiencia durará el platariorma de videoconterencia webez. La audiencia durara el tiempo que sea necesario para escuchar todos los testimonios, pruebas y comentarios públicos. Puede encontrar información detallada sobre la hora, la ubicación y el enlace de WebEx en el Calendario de eventos del Departamento de Medio Ambiente de Calendano de eventos del Departamento de Medio Ambiente de Nuevo México ("NMED", por sus siglas en inglés) en https://www. env.nm.gov/events-calendar/. Visite el sitio web de WQCC antes de la audiencia para obtener actualizaciones en https://www.env. nm.gov/opf/water-quality-control-commission/. La WQCC puede tomar una decisión sobre el cambio regulatorio propuesto al foalisar la cutalencia. finalizar la audiencia.

El propósito de la audiencia pública es considerar la Petición de El propósito de la audiencia pública es considerar la Petición de Reglamentación para modificar 20.6.4.900.1 y J NMAC de Triad National Security, LLC, Newport News Nuclear BWXT-Los Alamos, LLC y la Oficina de Gestión Ambiental del Departamento de Energía de los Estados Unidos, oficina local de Los Alamos, para agregar criterios de calidad del agua específicos del sitio para el cobre en los segmentos de arroyos en la meseta de Pajanto, de acuerdo con 20.6.4.10.F del NMAC. Las enmiendas propuestas se pueden revisar en línea en https://www.env.mn.gov/ oot/water-quality-control-commission/. La información técnica que opt/water-quality-control-commission/. La información técnica que optivater-quality-control-commission/. La informacion tecnica que sirvió de base para la norma propuesta se presentó en el expediente número WQCC 24-31 (R) como pruebas instrumen-tales a la petición y se puede consultar en línea en https://www. env.mn.gov/opt/docketed-matters/ y también se puede obtener de los Peticionarios mediante solicitud a N3Boutreach@em-la.doe. gov. Las personas que deseen revisar una copia impresa de las comunicarse con la administradora gov. Las personas que ceseen revisar una copia impresa de las enmiendas propuestas deben comunicarse con la administradora de la WOCC a la dirección que se proporciona más abajo. A todas las personas interesadas se les dará una oportunidad razonable en la audiencia para presentar evidencia, datos, puntos

razonable en la audiencia para presentar evidencia, datos, puntos de vista y argumentos relevantes, oralmente o por escrito; para presentar pruebas instrumentales; y para interrogar a los testigos. El funcionario de audiencias designado por la WOCC ha emitido un calendario de presentación revisado para reflejar la nueva fecha de audiencia. De conformidad con 20.1.6.202 NMAC y la Segunda Orden Previa a la Audiencia emitida por el funcionario de audiencias el 11 de septiembre de 2024, aquellos que deseen presentar un testimonio técnico ante la administradora de la WOCC a más tardar hasta las 5:00 p.m., hora estándar de la montaña, del 20 de diciembre de 2024. Aquellos que deseen presentar un estimonio técnico de refutación deben presentar un aviso por escrito de intención de presentar un deben presentar un aviso por escrito de intención de presentar un testimonio técnico de retutación ante la administradora de la

WQCC a más tardar hasta las 5:00 p. m., hora estándar de la

montaña, del 3 de enero de 2025. Los avisos de intención de presentar un testimonio técnico deberán cumplir con 20.1.6.104 NMAC y hacer referencia al número de expediente, WQCC 24-31(R).

La forma y contenido del aviso de intención de presentar un testimonio técnico deberá:

testimonio tecnico depera: Identificar a la persona(s) para la cual testificarán los testigos; Identificar a cada testigo técnico que la persona pretende presentar y establecer las calificaciones de ese testigo, incluida una descripción de su formación y experiencia laboral; Incluir una copia del testimonio escrito completo, directo o de

refutación, de cada testigo técnico en forma narrativa; Incluir el texto de cualquier modificación recomendada al

cambio regulatorio propuesto; y Enumerar y adjuntar todas las pruebas instrumentales que se prevé que esa persona presente en la audiencia,

Los avisos de intención de presentar un testimonio técnico directo y de refutación se presentarán ante:

Pamela Jones, administradora de WQCC Departamento de Medio Ambiente de Nuevo México Harold Runnels Building P.O. Box 5469 Santa Fe, NM 87502 Teléfono: (505) 660-4305 Correo electrónico: pamela.jones@env.nm.gov

Quienes deseen hacerlo pueden ofrecer comentarios públicos no técnicos en la audiencia en persona o de forma remota a través de la plataforma WebEX. El funcionario de audiencias llevará a cabo una sesión de comentarios públicos a la 1:00 p. m. y a las 5:00 p. m. el 14 de enero de 2025. Se pueden presentar declaraciones no técnicas por escrito en lugar de testimonio oral en la audiencia o antes de ella. Los comentarios por secrito sobre la norma propuesta se pueden dirigir a Pamela Jones, administradora de WQCC, a la dirección indicada anteriormente, o ingresando sus comentarios en el portal de comentarios públicos en thest/inmed.commentingut.com/ide.MerTif72j4 o por correo electrónico a: pamela.iones@env.nm.gov y deben hacer referencia en: https://nmed.commentinput.com?id=MerTi7Zj4 o por correo electrónico a: pamela\_iones@env.nm.gov y deben hacer referencia al número de expediente WQCC 24-31(R). De conformidad con 20.1.6.203 NMAC, cualquier persona puede presentar un registro de comparecencia como parte. El registro de comparecencia deberá presentarse ante la administradora de la WQCC, en la dirección antes mencionada, a más tardar el 20 de diciembre de 2024. 2024.

2024. La audiencia se llevará a cabo de conformidad con los Procedimientos de Reglamentación de la WQCC (20.1.6 NMAC): la Ley de calidad del agua, Secciones 74-6-1 a -17 NMSA 1978 (1967 con sus enmiendas hasta 2019, inclusive): la Ley de Normas Estatales, Sección 14-4-5.3 NMSA 1978, otros procedimientos aplicables y cualquier Orden de Procedimiento u Orden de Programación emitida por la WQCC o el funcionario de audiencias. Estos documentos están disponibles en línea en thtps://www.env.mm.gov/opf/dockted-matters/ o comunicándose con la administradora de la WQCC en pamela.iones@env.nm.gov. https://www.env.mm.gov/opt/docketed-matters/ o comunicándose con la administradora de la WQCC en pamela\_jones@env.mg.gov. Si alguna persona requiere asistencia, un intérprete o un dispositivo auxiliar para participar en este proceso, comuniquese con Pamela Jones, administradora de la WQCC, a la dirección indicada anteriormente, al menos 14 días antes de la fecha de la audiencia. (Los usuarios de TDD o TTY pueden acceder al número a través de la red de retransmisión de Nuevo México, 1.800.650.1726 (urg.): usuarios de TTY 1.800.650.853.01 1-800-659-1779 (voz); usuarios de TTY: 1-800-659-8331).

### DECLARACIÓN DE NO DISCRIMINACIÓN

DECLARACIÓN DE NO DISCRIMINACIÓN El NMED no discrimina por motivos de raza, color, origen nacional, discapacidad, edad o sexo en la administración de sus programas o actividades, tal como lo exigen las leyes y reglamentaciones aplicables. El NMED es responsable de coordinar los esfuerzos de cumplimiento y recibir consultas sobre los requisitos de no discriminación implementados por 40 C.F.R. Partes 5 y 7, incluído el Título VI de la Ley de Derechos Civiles de 1964, en su forma enmendada; la Sección 504 de la Ley de Rehabilitación de 1973; la Ley de Discriminación por Edad de 1975, el Título IX de las Enmiendas de Educación de 1972 y la Sección 13 de las Enmiendas de Ley Federal de Control de la Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o sobre cualquiera de los programas, políticas o Contaminación del Agua de 1972. Si tiene alguna pregunta sobre este aviso o sobre cualquiera de los programas, políticas o procedimientos de no discriminación de NMED, puede comunicarse con: Kate Cardenas, coordinadora de no discriminación, NMED, 1190 St. Francis Dr., Suite N4050, P.O. Box 5469, Santa Fe, NM 87502 o (505) 827-2855 o nd. coordinator@env.nm.gov. Si cree que ha sido discriminado con respecto a un programa o actividad de NMED, puede comunicarse con la coordinadora de no discriminación de NMED identificada anteriormente. anteriormente.

Journal: October 9, 2024



### Affidavit of Publication in New Mexico Register

I, Matthew Ortiz, certify that the agency noted on Invoice # 7841 has published legal notice of rulemaking or rules in the NEW MEXICO REGISTER, VOLUME XXXV, that payment has been assessed for said legal notice of rulemaking or rules, which appears on the publication date and in the issue number noted on Invoice # 7841, and that Invoice # 7841 has been sent electronically to the person(s) listed on the *Billing Information Sheet* provided by the agency.

Affiant:

Matthew Ortiz 3

Subscribed, sworn and acknowledged before me this 2 day of October, 2024.

Notary Public: My Commission Expires:

PAMELA ANNE LUJAN Y VIGIL
Notary Public
State of New Mexico
Comm. # 2001927
My Comm. Exp. Jan 22, 2028

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